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Ideal Data to Determine Accurate Fajr Time

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Abstrak. Penelitian awal waktu fajar banyak dilakukan oleh berbagai pihak dengan beragam teknik, salah satunya menggunakan alat fotometri sky quality meter (SQM). Data pengamatan dari berbagai daerah yang memiliki level malam bervariasi menghasilkan awal waktu fajar yang bervariasi juga. Dengan memperhatikan pengaruh kualitas langit yang direpresentasikan level malam pada lokasi pengamatan, penelitian ini ingin menjawab apakah batas level malam 20mpsas sebagai data ideal dengan melihat koefisien korelasi antara level malam dengan solusi titik belok. Dari 1068 data dengan level malam bervariasi menunjukkan koefisien korelasi (R^2) antara level malam dengan solusi titik beloknya adalah 0,42 yang berarti ada pengaruh, sedangkan untuk data-data dengan level malam minimal 20mpsas koefisien korelasinya sebesar 0,07 yang berarti tidak ada pengaruh. Berdasarkan hasil analisis, level malam 20 mpsas bisa menjadi batas minimal untuk melakukan penelitian awal waktu fajar yang ideal. Dari 241 data pengamatan yang ideal dari 6 stasiun pengamatan LAPAN, awal waktu fajar hadir saat sudut elevasi Matahari -16,51°. Awal waktu fajar juga merupakan awal waktu subuh, dengan standar waktu subuh yang digunakan di Indonesia yaitu -20° atau berbeda 3,49° dengan hasil analisis, jika dikonversi ada perbedaan 13 menit 57 detik.

Abstract. Early fajr time research was carried out by various parties with various techniques, one of which was using a sky quality meter (SQM) photometric tool. Observational data from various regions that have varying night levels result in a varying early fajr time as well. By paying attention to the effect of sky quality represented by the night level at the observation location, this research wants to answer whether the 20 mpsas night level limit is ideal data by looking at the correlation coefficient between night level and the turning point solution. From 1068 data with varying night levels, the correlation coefficient (R^2) between the night level and the turning point solution is 0,42 which means there is an effect, while for data with a minimum night level of 20mpsas the correlation coefficient is 0,07 which means there is no influence. Based on the results of the analysis, the night level of 20mpsas can be the minimum limit for conducting an ideal early fajr time research. From 241 ideal observation data from 6 LAPAN observation stations, early fajr time presents when the Sun's elevation angle is -16,51°. Early fajr time is also the beginning of subuh prayer time, with its standard used in Indonesia, which is -20° or 3,49° different from the analysis results, if it converted there is a difference of 13 minutes 57 seconds.

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1. Introduction

The beginning of the presence of the dawn light on the western horizon in addition to marking the end of the night, it is also for Muslims as a sign of the entry of the subuh prayer time. When the Sun is below the horizon with a certain altitude, sunlight interacts with the upper atmosphere so that the Earth's surface will appear slightly reddish [1]. In practice, the presence of dawn is represented by the elevation angle of the Sun or the position of the Sun below the horizon. The sun's elevation angle below the horizon, which indicates the presence of dawn, also indicates the beginning of subuh prayer time. In Indonesia, the elevation angle of the Sun used for the beginning of subuh prayer time is -20° or zenith=110° [2], lately this standard has been questioned because it is assumed that when the Sun is in that position, the dawn light on the western horizon has not yet appeared. Dawn light research has been carried out with various approaches, some using the naked eye [3], using a digital camera [4][5], and some using simple photometric tools, namely Sky Quality Meter (SQM) [2], [6]–[8].

SQM is a simple photometric tool that can quantify the quality of sky darkness in units of magnitude per arc second square (mpsas) [9]–[12]. Research of the beginning of subuh prayer time using SQM was carried out by looking for turning points from SQM data which indicate the presence of dawn due to changes in sky conditions from dark to bright due to the presence of dawn light. Then the obtained brightness level also indicates the level of light pollution, the higher the brightness in the mpsas, the lower the level of light pollution [13]–[15] . Light pollution has an impact on the emergence of dawn light in the form of pseudo-night which is caused by the absorption between sunlight and pollutant particles in the atmosphere, to overcome this, it is necessary to select observational data from the night which has a night level of at least 20 mpsas which corresponds to grade 4 on the Bortle scale [16], [17] or Bright category [18].

There are several techniques used to determine inflection points, including using polynomial functions as has been done by [8], with this method, the determination of the inflection point uses a degree of polynomial that varies from polynomial of degree 3, polynomial of degree 4, polynomial degree 5, to polynomial degree 6, depending on the SQM data itself, even several times have to reduce unnecessary data. In addition, in the research conducted by Saksono, et al. used less ideal data because the data used came from a location have sky quality below 20mpsas or fall into category 5 and above on the bortle scale [16], [17] .

In this study, determining the turning point of SQM data uses the solver method, which is a method that uses the exponential function but to determine the variables used as parameters for its function using the solver menu [19]–[21], besides the data used for determining the elevation angle of the Sun that indicates the presence of dawn light is only data that has been selected with the condition that it comes from data that has a minimum night level of 20mpsas or category 4 on the bortle scale in order to reduce the effects of air pollution that can interfere with SQM signal capture. By considering light pollution which can cause interference during observation [15],[16] the data selected with the main criteria must come from data that has a night level of at least 20 mpsas or class 4 on the bortle scale [16], [17] or bright class [18]. By connecting the night level and the turning point solution using a regression function to obtain a correlation coefficient (R^2), this research tries to answer whether the minimum 20mpsas night level limit show no effect between the night level and the turning point solution or still shows a significant effect. The correlation level will be consulted with the Guilford Empirical Rules correlation table [22]. If the night level of at least 20mpsas shows no effect between the night level and the turning point solution, then the ideal data to determine the beginning of fajr time is data from observations with a night level of at least 20mpsas, and what the elevation angle of the sun as a marker of the beginning of fajr time based on the ideal data.

2.   Material and Method

2.1 Sky Quality Meter

Sky Quality Meter (SQM) is a simple and very easy to use photometric tool for measuring sky brightness levels. SQM is produced by Unihedron, and has been widely used for sky quality mapping research [23], [24] determine astronomical site [25], [26], light pollution research [25], [27]–[29] research in the health sector [28], behavioural research birds [30], [31], to research on determining the time prayer [2], [8], [13], [15] . SQM uses a light frequency sensor TSL237, SQM in this study is set to quantify in mpsas every 1 minute with the direction of the sensor to the zenith [32]. Observations were made throughout the day in 2019. The data generated from SQM is in the form of ANSI data which contains information on sky brightness levels, time and date data in Universal Time (UT) as well as local time, solar elevation angle data, temperature data and count data. Sky brightness level is expressed in magnitude per square arc second (mpsas), where SQM has a precision level of 0.1 mpsas [14]. This will be used for this study only data on sky brightness, time and date data, as well as data on the elevation angle of the Sun.

2.2 Location and Data Selection

SQM data is taken from the observation data from 6 LAPAN Observation Stations, namely in Agam, Garut, Kupang, Pasuruan, Pontianak and Sumedang. All data that can be analyzed are 1,068 data. Even though observations are made throughout the year, not all data can be processed for several reasons, including because of interference at critical moments such as from the moonlight, the data is disturbed due to the presence of clouds, to disturbances due to rain. As shown in Table 1, the data to be used in determining the early dawn of time must fulfill the requirements, namely that the night level is at least 20 mpsas. The night level is obtained by averaging the mpsas from 00.00 AM until the height of the Sun reaches -20° (z=110°). To determine the dawn time in this study only selected data were used.

Table 1. Location of Observation

Location	Latitude	Longitude	Number of Data
Agam, West Sumatera	-0.204430	100.320057	118
Garut, West Java	-7.650062	107.692214	65
Kupang, East Nusa Tenggar	-10.142009	123.731231	224
Pasuruan, East Java	-7.567506	112.673702	239
Pontianak, West Borneo	-0.007800	109.365000	221
Sumedang, West Java	-6.913079	107.837213	201

2.3 Method of Analysis

To determine the turning point on the graph, two data are used, namely the solar elevation angle data and the mpsas value, then the mpsas data is approached with the exponential function obtained using formula (1) of normal distribution [33], [34]. To simplify the calculation, the solver menu is used, so that the prediction function gets an optimal minimum difference from the original data.

$$f(x) = C - N \times \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{x-\mu}{2\sigma}\right)^2} \tag{1}$$

Where C is a constant level, N is normalized, μ is mean, and σ is the standard deviation. The values for C, N, μ, and σ will be obtained using the menu solver, respectively, with the variables C, N, μ, and σ being used as boundary variables, or chi-square being selected as the objective variable. Meanwhile, to determine the inflection point, it is obtained from the Formula (2):

$$Solution = \mu - 3\sigma \tag{2}$$

The result of the calculation using turning point formula is the final result that shows the elevation angle of the Sun at dawn. For example, for analysis on 10 January 2019 for the Pontianak location, the model is obtained as shown in figure 1.
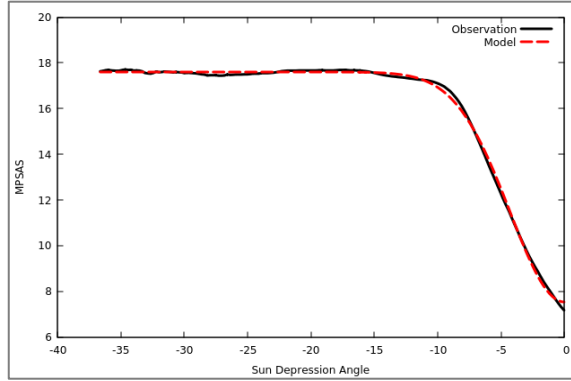

Figure 1. Plot of solver analysis

After the turning point of each data is known, the next step is to look at the correlation or effect between the solution or the turning point which represents the presence of dawn light with the night level which represents the quality of the sky. Correlation is represented by the correlation coefficient or R^2, the smaller the value of R^2 shows that the correlation is getting smaller. To obtain the correlation coefficient (R^2) with the formula:

$$R^2 = \frac{SSR}{SSR+SSE} \tag{3}$$

Where R^2 is coefficient correlation, SSR is a total regression sum of squares, SSE is an Error sum of squares. Plotting and calculating correlation coefficients using the GNU Plot [35]. Furthermore, to determine the level of correlation, R^2 is compared with the Guilford Empirical Rules correlation table as shown in table 2 below.

Table 2. Table Guilford Empirical Rules

R^2	Interpretation
$0,00 < 0,20$	Very weak relationship (ignored, presumed non-existent)
$0,20 < 0,40$	Low relationship
$0,40 < 0,70$	Medium or moderate relationship
$0,70 < 0,90$	Strong or high relationship
$0,90 \leq 1,00$	Very strong or very high relationship

3. Result and Discussion

From 1,068 data with various night level conditions, it shows $R^2 = 0,42$ as shown in Figure 2(a) while for a minimum night level of 20mpsas, 241 data is obtained and shows $R^2 = 0,07$ as shown in Figure 2(b).
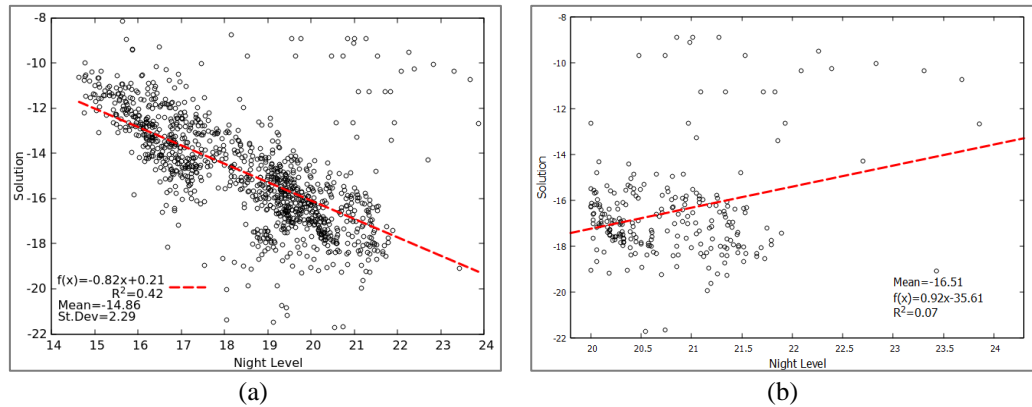
Figure 2. (a) plotting all data, (b) plotting for minimum night level 20 mpsas

Based on observations of sky brightness using the Sky Quality Meter at 6 LAPAN observation station as shown in table 1, obtained 1.068 daily data with the lowest night level of 14,64mpsas and the highest 23,86 mpsas and an average of 18,49 mpsas. From the 1.068 data, the solution for the lowest turning point is obtained with the sun's elevation angle of -21,71°, the highest sun's elevation angle of -8,16°, and an average of -14,86°. The correlation coefficient (R^2) between the turning point solution and the night level is 0,42 which indicates that there is still a significant effect of the night level on the turning point solution.

As for the data with a minimum night level of 20mpsas, there are only 241 data, with the lowest turning point solution with a sun's elevation angle of -21,71° and the highest turning point solution with a sun's elevation angle of -8,91° with an average of -16,51 ° with a correlation coefficient of 0,07. With a night level of at least 20mpsas or at grade 4 on the bortle scale, it shows the agreement with R^2 between the turning point solution and the night level is small, which is 0,07. This shows that the effect of night level on the turning point solution is very small or can be ignored.

4. Conclusions

Data with a night level of at least 20 mpsas or grade 4 on the Bortle scale shows a correlation coefficient (R^2) of 0,07 which is based on the Guilford Empirical Rules table showing the correlation between night levels which represent night quality and the solution of the turning point or elevation angle of the Sun which indicates the fajr time is very weak and can be ignored or considered non-existent. And from 241 data with a night level of at least 20mpsas, it shows that on average the fajr time is present when the Sun's elevation is at -16,51° or 3,49° different from official standard and if it is converted into a time of about 13 minutes 57 seconds. If rounded, -16,51° becomes -17° and differs by about 3° or if converted to about 12 minutes later than the beginning of the official early subuh prayer time.

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