Establishing Dawn: Challenges and Opportunities for Muslims in Northern Latitudes

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1. Abstract

Three of the five daily prayers are established by geometrically-derived times when the Sun is above the horizon and can be directly observed. However, the times of the two remaining prayers are determined not by simple geometrical rules, but by illumination conditions, related to the angular position of the Sun below the horizon, and the clarity of the atmosphere on a particular day. Many factors contribute to how much illumination (twilight) can be observed, and variations in these conditions lead to significant changes in the brightness of the sky. Since twilight conditions last longer at high latitude locations such as the UK, than they do near the equator, the variations in brightness have a disproportionate effect on those living at these latitudes.

Muslims living at higher latitudes therefore face considerable challenges in establishing dawn times appropriate to the locality and around the summer months when twilight persists. A number of rules have been devised in order to establish meaningful prayer times for Muslims in this situation. We will consider these rules and the natural processes which determine lighting conditions. We propose a project, involving a wide cross-section of the UK Muslim community, in which observations are made that might help to inform further discussion of the subject, and potentially establish a truer observed dawn time and reduce the hardship experienced by Muslims in the UK during the summer months.

2. Introduction

As the position of the Sun is used to establish the end of Fajr (sunrise), Zawaal, Zuhr, Asr and Maghrib (sunset), it is understandable that many have extended this principle to the calculation of the start of Fajr (dawn) and Isha. However, unlike the daylight prayers (Zuhr, Asr and Maghrib), Fajr and Isha are established on the basis of illumination conditions (twilight) rather than the position of the Sun, which is below the horizon during these two prayers. Science allows us to accurately predict the position of the Sun when it is below the horizon, but any timeless and universal Islamic definition of dawn must be based on the level of twilight, rather than the position of the Sun below the horizon. It is because the daylight prayers (Zuhr, Asr and Maghrib) can be consistently established by the position of the Sun, that many Muslims have incorrectly applied the same principle when the Sun is below the horizon believing there is a consistent and direct correction with the depression angle of the Sun and illumination for all locations.

Many of the issues that have arisen surrounding the timing of Fajr and Isha are due to this purely geometrical approach being promoted to establish when dawn will occur, without the associated observations required to establish if twilight can be observed by the human eye at the calculated time in all locations, every day. The same approach has been adopted by Saudi Arabia when establishing the start of the Islamic month using the fixed Umm al-Qura calendar system; a system widely criticised because it ignores the Islamic principle of observation and cannot be universally applied to all locations.

Any true formula for establishing the times of when dusk ends (Isha) and when dawn begins (Fajr) would need to be supported by science without compromising Islamic principles of observation, and be applicable to all locations. The current approach based purely on the depression angle of the Sun does not fulfil this requirement, because other factors, rarely if ever discussed by the community, affect the visibility of twilight. These factors can lead to significant differences in the visibility of twilight for a given solar depression angle.

To frame the discussion, three reference locations will be used in this work:

- Leicester, United Kingdom (1° 08' W, 52° 38' N)
  Broadly situation in the centre of England, it serves to show the current challenges in higher latitude locations.

- Makka, Saudi Arabia (39° 49' E, 21° 26' N)
  The centre of Islam and the direction to which all Muslim turn when performing Salaah (prayer).

- Bareilly, India (79° 26' E, 28° 24' N)
  The birthplace of *Ala'Hazrat* Ahmed Raza Khan (May God be pleased with him) who through his genius provided the Muslim world with insights and literature on numerous subjects including the prayer times.

Although both the time of Fajr and Isha are a result of the measure of illumination (twilight), we will focus the specific issue around establishing the dawn time for Fajr.

This paper will outline the Islamic definition of dawn and explore the scientific considerations that are relevant when trying to establish the time of dawn for Muslims living at higher latitudes. We will illustrate why much of the Islamic world can use the depression angle of 18° as a proxy for dawn but why, in reality, the onset of dawn can begin later than the 18° rule would predict. We propose a scientifically supported observation project to explore this effect. The results of this project would provide important information to inform further discussion within the Muslim community about improving the accuracy of the rules for establishing dawn, with the potential to reduce the hardship suffered by Muslims living at higher latitudes.

3. Islamic Definition of Dawn

The Quran describes the motion of the Sun, Moon and the stars in their orbits:

"And He has made the Sun and the moon, constant in their courses, to be of service to you, and He has made the night and the day (to be of service to you)" (14:33).

"And He it is Who created the night and the day, and the Sun and the moon. They float, each in an orbit" (21:33).

" It is not for the Sun to overtake the moon, nor does the night outstrip the day. They all float, each in an orbit" (36:40).

The development of astronomy owes much to the work of the early Muslim astronomers, and this history of scholarship has allowed Muslims from the birth of Islam to use scientific principles to establish prayer times and measure the passing of the months.

For the dawn which marks the start of Fajr and the end of dusk which marks the beginning of Isha, Muslims are required to observe the limits of illumination (twilight) from the Sun, which is below the horizon; a largely qualitative endeavour which is open to many external factors.

In this paper, we concentrate on Fajr or dawn prayer. The Holy Quran prescribes the point at which fasting begins and hence this prayer can be offered, in terms of illumination levels thus:

"...and eat and drink until the white thread of dawn appears ***to you*** *distinctly from the black thread" (2:187).*

The perfection of Quran is again illustrated from this verse. The establishment of dawn is subjective and open to many factors and hence the Quran states "appears to you". Any attempt to establish a formula for the time of dawn, whether it be a depression angle or another method, without observation by the human eye, would go against the teachings of the Quran.

In describing the times of the five daily prayers, the Prophet Muhammad (peace be upon him) used terminology and methods which were understandable, visible and accessible for all; the movement of the Sun and the shadow it casts. For the three geometrically-determined prayers of Zuhr, Asr and Maghrib this has resulted in astronomical formulas which are universally accepted and used.

Prophet Muhammad (peace be upon him) clarified what constitutes dawn in many sayings:

"*Fajr is not what appears in the sky like this (and the Messenger, peace be upon him, raised his hands upward) until like this (and the Messenger peace be upon him made his fingers widespread)* "(Sahih al-Bukhari).

Prophet Muhammad (peace be upon him) said: *"There are two dawns, the dawn when food becomes haram and Salah becomes permissible, and the dawn when prayer is haram and food is permitted"* – (Narrated by al-Hakim and al-Bayhaqi from the Hadith of Ibn Abbas).

Prophet Muhammad (peace be upon him) *said: "There are two dawns. With regard to the dawn which is like the tail of a wolf, this does not make it permissible to pray and haram to eat. With regard to the dawn which appears horizontally in the sky, this makes it permissible to pray and forbidden to eat" (Narrated* by al-Hakim and al-Bayhaqi from the Hadith of Jabir).

Also, Prophet Muhammad (peace be upon him) *said*: *"Do not let the Adhaan of Bilal stop you from eating Suhoor, or the vertical dawn, but the dawn which appears along the horizon"* (Narrated by Abu Dawud and al-Tirmidhi).

The description of this "wolf's tail" or false dawn, matches the appearance of an effect known as the *zodiacal light*, and it is clear from these sayings and from many others that this false dawn does not meet the Islamic definition of dawn; hence any calculation for dawn cannot be based solely on the earliest point at which light levels begin to change.

4. Scientific Considerations

4.1 Twilight

The source of the light of dawn and dusk is the Sun. Even when the Sun is below the horizon, it is possible for sunlight to reach an observer, because of the Earth's atmosphere: particles high up in the atmosphere can scatter and reflect sunlight to an observer on the ground, so that natural light levels are related to the angular position of the Sun below the horizon for a particular observer. Thus, the times of twilight are formally defined in terms of the Sun's depression angle (angular distance below the horizon). Three commonly used definitions of twilight exist (US Naval Observatory, 2015), as described below and illustrated in Figure 1.

- *Civil twilight* is defined to begin in the morning, and to end in the evening, when the centre of the Sun is 6° below the horizon[1]. At the onset of civil twilight, artificial lighting is usually required to conduct outdoor activities (e.g. lighting up time for drivers).
- *Nautical twilight* begins in the morning, and ends in the evening, when the centre of the Sun is 12° below the horizon. At the start/end of this period, the outlines of objects on the ground may be distinguished, and the horizon is visible even on a moonless night (hence the origin of the term "nautical twilight", since mariners can measure the positions of stars with respect to the horizon, for navigation purposes).
- *Astronomical twilight* begins in the morning, and ends in the evening, when the centre of the Sun is 18° below the horizon. Below this angle, sunlight reaching an observer (by being scattered off particles in the atmosphere) is fainter than the levels produced by starlight and other sources, so that greater Sun depression angles do not lead to further darkening.

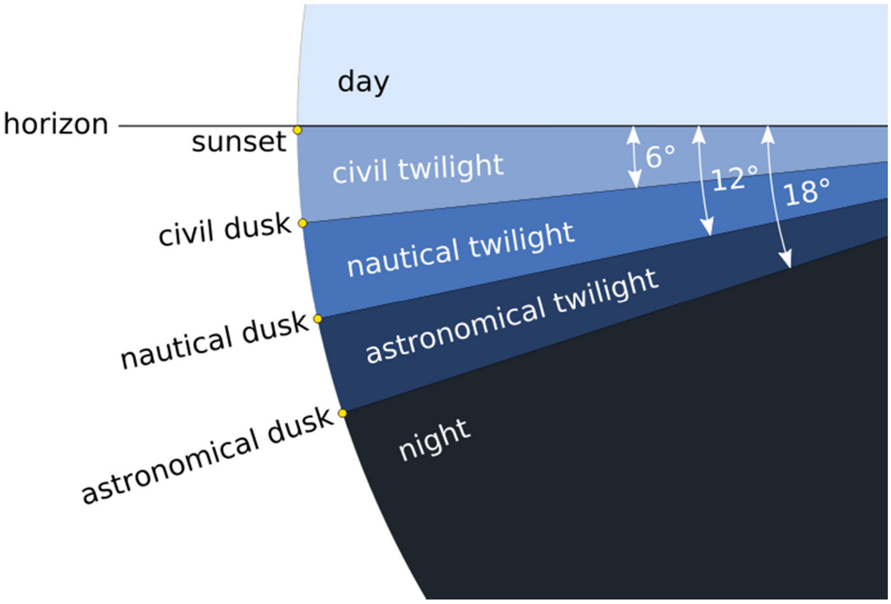

Figure 1. The angular ranges corresponding to the three definitions of twilight (see text for details). Image from http://astrobob.areavoices.com/tag/sunset/#sthash.5lf719wR.dpuf

Nowhere in the scientific definition of astronomical, nautical or civil twilight is the term "dawn" used or defined. But for Muslims at low latitudes such as Makka and Bareilly, these definitions have been used to frame when dawn should occur. For example, the definition of astronomical twilight

[1] The disk of the Sun, as seen from our position on the Earth, is approximately half of a degree in diameter.

provides a threshold: when the Sun's depression angle reaches 18° in the morning hours, scattered sunlight *could* reach an observer if the atmospheric conditions were favourable, and from this point in time onwards, brightening of the sky could, in principle, be detected and used to describe dawn. Although 18° is the upper limit of astronomical twilight, the illuminating conditions attributed with dawn could be seen theoretically up to the depression angle of 12°.

Astronomers B D Yallop and C Y Hohenkerk explored the definition of dawn in work released by HM Nautical Almanac Office in 1996[2]. The authors state:

"There is no general agreement on a precise definition of "dawn"; it is sometimes even identified with sunrise itself. If, however, it is interpreted as the time of "first light", dawn corresponds to a depression between 18° and 12° but it is not possible to be more precise."

The 18° solar depression threshold is a limit, but not necessarily the point at which an unaided observer would begin to detect changes in sky brightness, because solar depression angle is not the only factor that determines sky brightness. Indeed, in their definition of astronomical twilight, the US Naval Observatory state that:

"[f]or a considerable interval after the beginning of morning twilight and before the end of evening twilight, sky illumination is so faint that it is practically imperceptible."

The threshold of 18° and many other astronomical principles were understood by the great Islamic scholars such as Ibn al-Shatir, who studied astronomy over six centuries ago, and established angular rules during that time (Goldstein, 1985). The studies of *Ala'Hazrat* Ahmed Raza Khan (may God be pleased with him) concluded that twilight from a Sun at a depression angle greater than 18° could not be observed long before the advent of modern astronomy and computer modelling. Today this upper value of 18° has been misinterpreted as an absolute value for dawn for a number of reasons, some of which are explored in this paper.

4.2 Particulate Effects

The gases in Earth's atmosphere scatter light (and are the reason that clear sky is blue during daylight). But the transparency of the air is affected by the presence of small particles in the atmosphere, and these can have a large effect on the way that light travels through the atmosphere, affecting the appearance of twilight. Small (often microscopic) solid or liquid particles can be produced through natural processes (like ash from volcanoes) or from human activities (such as pollutants from vehicles). Clouds, haze, and dust all contribute to the transparency of the atmosphere. These particulates can affect the transmission of light from the Sun when it is below the horizon, towards an observer, even if the source of the particulates is not in the locality. Under such conditions the observed twilight could differ significantly from normal conditions. Figure 2 shows the effect of particulates on twilight and potential sources.

The variable transparency of the atmosphere is the principal reason that the 18° rule is not a reliable indicator for dawn – even when it is theoretically possible for light from the Sun to reach an observer, atmospheric conditions can prevent this from happening, so that an observer may not detect the brightening of dawn at the instant when the Sun reaches 18°.

[2] ASTRONOMICAL INFORMATION SHEET No. 7 – 'A note on sunrise, sunset and twilight times and on the illumination conditions during twilight'. Published 1996 and available HM Nautical Almanac Office website.

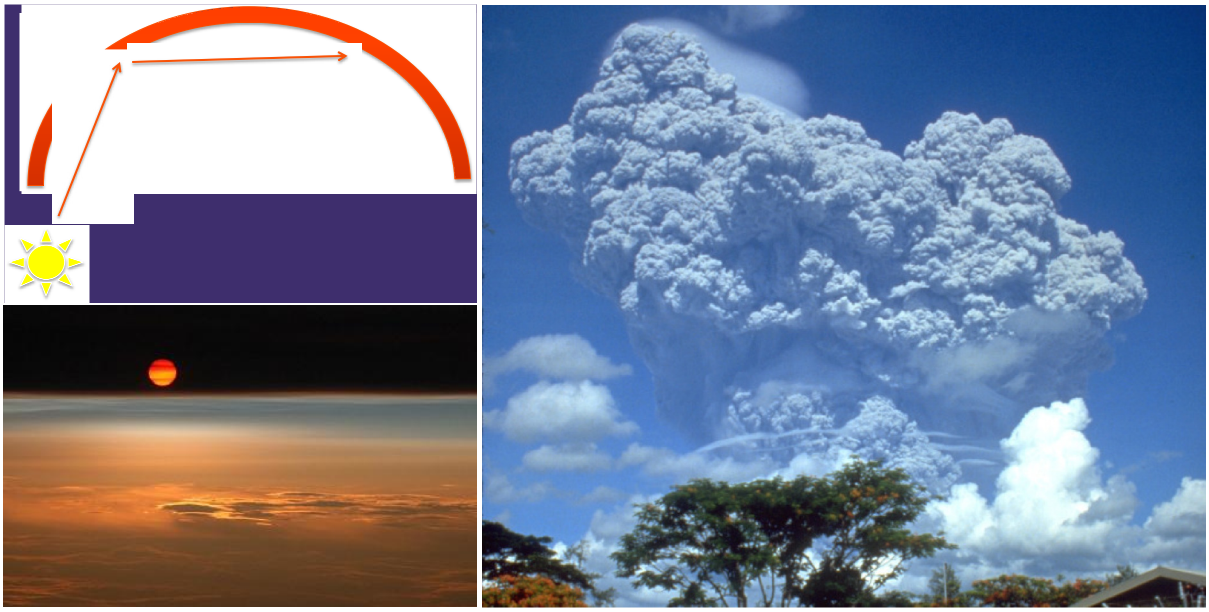

Figure 2. Effects of particulates in the atmosphere. Top left: sunlight can be reflected from particles (represented by the orange arc), enabling the light to reach an observer even when the Sun is below the horizon. Right: the levels of particles in the atmosphere can vary with, e.g., weather and geological events. Volcanic eruptions (like the Pinatubo eruption – Photo by Rick Hoblitt / USGS) can eject huge quantities of gas and ash into the atmosphere. Bottom left: a haze layer produced by volcanic ash obscures the Sun and scatters light in the atmosphere (image by Brian Whittaker: http://www.brianwhittaker.com/volcano/).

4.3 Azimuth

When exploring the scientific principles relating to dawn, the relationship between twilight and the depression angle of the Sun are always considered, but the importance of azimuth is often ignored.

An azimuth (from the Arabic al- *al-sumūt*, meaning "the directions") is an angular measurement in a spherical coordination system. In the context of establishing dawn, it can be used to determine the compass position of the Sun when it is below the horizon. The azimuth is usually measured in degrees, and in navigation it is sometimes referred to as a bearing. The azimuth is nearly always measured from the north, and maps to compass positions as summarised in Figure 3.

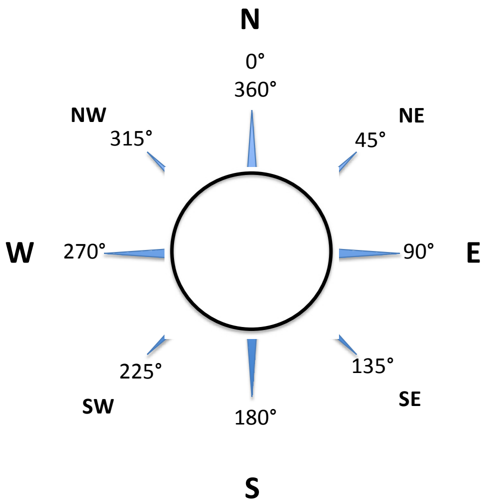

Figure 3. A simple compass rose, showing the relationship between the cardinal points (N, E, S, W), intercardinal points (NE, SE, SW, NW), and the azimuth or compass bearing (numbers, in degrees).

When Prophet Muhammad (peace be upon him) described the false dawn 'pyramid' of light and the spread of light associated with true dawn there was no reference to the eastern sky; however, the compass bearing of the Sun, for a given depression angle, changes over the course of the year, and the precise direction of the "centre" of the brightening dawn, changes with it. To illustrate this effect, consider Figure 4, which shows how the compass bearing of the Sun when at a fixed depression angle of 10° in the morning sky, varies across the year. The range of variation is significant, and any precise and directional measurement of the brightness of the sky around the time of Fajr needs to take this variation into account.

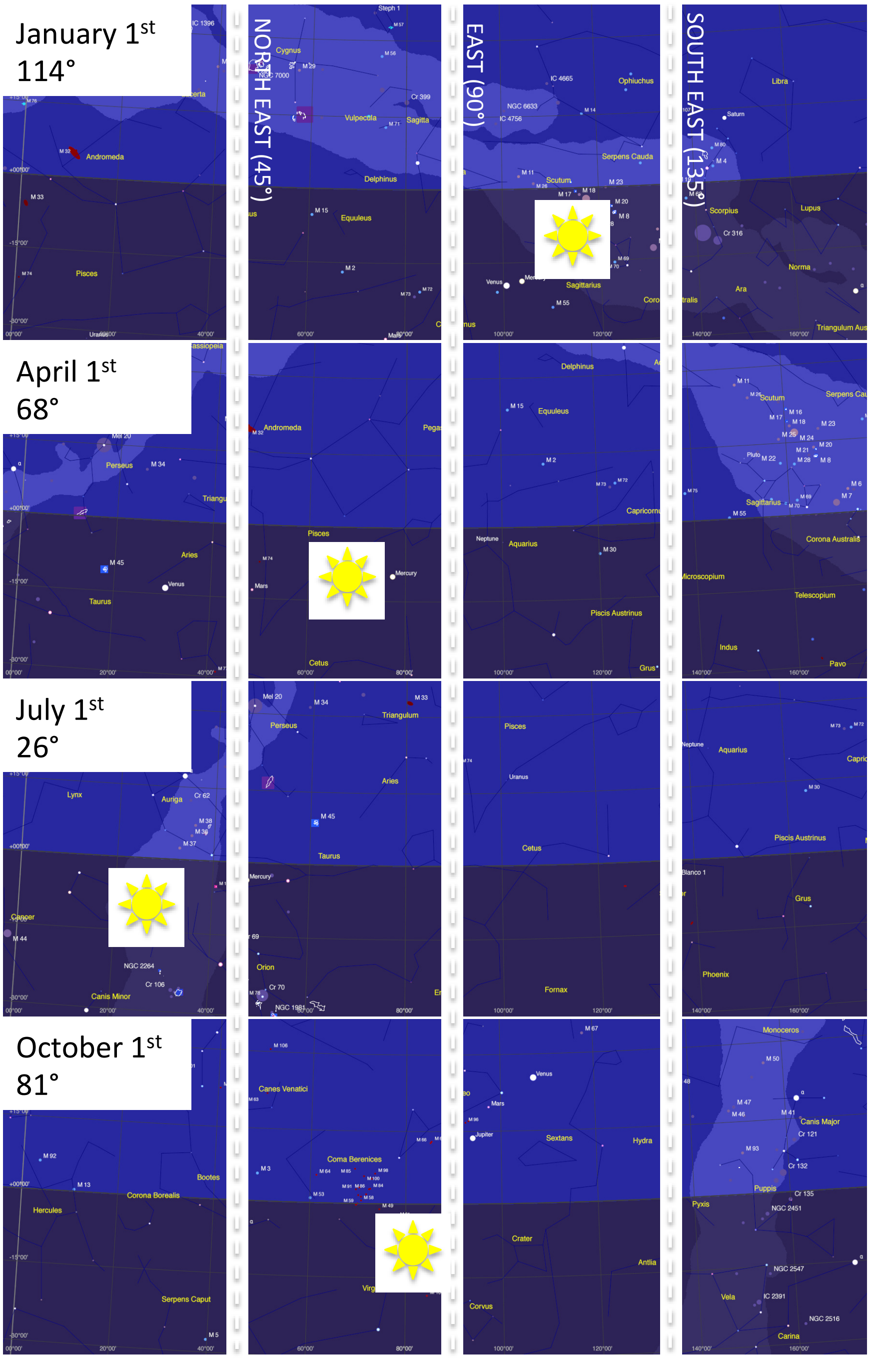

Figure 4. The azimuth (compass bearing) of the Sun when at a depression angle of 10° as observed from Leicester, on the morning of the first day of January, April, July and October. The dark blue area is indicates the area of sky below the horizon. Plots generated using the software package *SkyChart*, (Chevalley, http://www.ap-i.net/skychart/en/start)

4.4 Speed of Light

In addition to the presence of particles in the atmosphere through which sunlight travels, the temperature of the atmosphere also has a role to play in determining the appearance of dawn. The speed of light in a perfect vacuum is a constant, and one of the fundamental parameters in science. When light travels through something that has mass, such as air or glass, the speed of light in that material is slower than it is in vacuum. If we divide the speed of light in vacuum by the speed of light in the material, we have a number which is greater than one. This number is known as the *refractive index* of the material – and the higher the refractive index, the slower light travels through the material. For example: the speed of light in air is only very slightly slower than it is in vacuum, and the refractive index of air is 1.0. But the speed of light in water is significantly slower than in vacuum, and the refractive index of water is 1.3.

Figure 5. The effect of the speed of light. Because light travels slower in water than it does in air, rays of light bend (change direction) when they pass from air into water, or from water into air. In this case, light reflected from the spoon travels at a different angle through water than it does through air, making the spoon appear to be "broken" at the point where the water meets the air. (Image from WiseGeek: http://www.wisegeek.org/what-is-refraction.htm)

Because the density of materials such as glass and air changes with temperature, the speed of light in that material, and hence the refractive index, will also change with temperate, and with it, the way that the material bends light also changes. This effect can be seen as "heat waves" coming off an object that is hot. Hot air has a lower density than cold air, so light travels faster in hot air than in cold air. As the hot air mixes with the surrounding cold air, the light goes slightly faster in the hot regions, than it does in the cold, and this causes a distortion in the light, similar to the distortion seen in Figure 5.

This relationship between the temperature of the air and the angle at which rays of light travel through the air, has an effect on the way light travels from the Sun towards an observer at twilight, affecting the appearance of the dawn or dusk sky. So the observation of twilight from hot locations like Makka and Bareilly will be different to the colder climate of Leicester. However, the effect is more subtle than that produced by the particulates, and because the temperature of the air can change significantly along the path of the ray, it is complex and difficult to predict. Nevertheless, it is included in detailed and complex mathematical models that aim to describe the sky light levels around twilight (e.g. Blättner et al., 1974).

5. Why the Islamic World uses 18° for Dawn

Every Islamic country[3] lies at a latitude below 48.5° north and so the Sun always reaches a depression angle beyond 18°. Kazakhstan is not an Islamic country by definition but is the northern-most Muslim majority[4] country in the world with the capital Astana at the latitude of 51.10° north.

By this very fact, the Muslim world has been able to apply the depression angle of 18° as the definition of dawn even though *observed* dawn may be occurring later. This conservative position is the result of a number of factors, identified below.

5.1 Length of Day

At the equator the length of the day and night remains approximately the same throughout the year. As one travels to more northerly or southerly latitudes, the length of the day will change between the summer and winter solstice. The variation for the three reference locations is summarised in Table 1.

	Summer Solstice (Longest Day)			Winter Solstice (Shortest Day)		
	Sunrise	Sunset	**Night Length**	Sunrise	Sunset	**Night Length**
Leicester (52°38' N)	4:41	21:32	**7 hr 9 min**	8:15	15:52	**16 hr 23 min**
Makka (21°26' N)	5:40	19:05	**10 hr 35 min**	6:55	17:44	**13 hr 11 min**
Bareilly (28°24' N)	4:46	18:42	**10 h 4 min**	6:31	16:51	**13 hr 40 min**

Table 1. Length of night comparison (2015, times shown as local time)

The difference between the length of the shortest and longest nights in Makka and Bareilly is approximately 2.5 and 3.5 hours respectively, but in the UK it is over 9 hours as summarised in Table 2.

Location	Night Length Difference
Leicester	9 hr 14 min
Makka	2 hr 36 min
Bareilly	3 hr 36 min

Table 2. The difference between the length of the longest and shortest nights of the year, for the three reference locations

Even on the shortest night of the year, both Makka and Bareilly have over nine hours of darkness. With this length of night, Muslims would be able wait until Shafaq Abyad[5] to establish Isha, rest for a significant number of hours before dawn even if that dawn was calculated at the depression angle of 18°.

During the summer, the UK experiences daylight periods in excess of sixteen hours; this leaves a very short period in which to establish Maghrib, Isha and the dawn of Fajr.

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[3] Countries where Sharia law applies in full or in part in the judicial system
[4] 56.4 % Muslim percentage of total country population 2010 Pew report
[5] According to Imam Abu Hanifah RA the beginning time of Isha is when there is no trace of light left in the sky

5.2 Rate of Change of the Solar Depression Angle

The latitude of an observing site has a direct bearing on how much time passes as the depression angle of the Sun changes. As illustrated in Table 3 below, in both Makka and Bareilly, on the summer solstice where the night is the shortest, there is no more than six minutes between a 1° change in the depression angle (e.g between 18° and 17°), with half hour between the start and end of astronomical twilight (18° and 12°). For observers in Leicester, the situation is very different. At the summer solstice, the Sun does not set beyond the depression angle of 13.94° in Leicester, and the time taken for the Sun to travel between the depression angles of 12° and 13° shows a marked difference to Makka or Bareilly, with the Sun taking 24 minutes to pass through this 1° change in depression angle.

	Makka Sunrise 5:40	Bareilly Sunrise 4:46	Leicester Sunrise 4:41
Depression Angle	Time		
12°	4:44	3:46	2:25
13°	4:39	3:40	2:01
14°	4:34	3:35	-
15°	4:29	3:29	-
16°	4:24	3:23	-
17°	4:18	3:17	-
18°	4:13	3:11	-

Table 3. Rate of depression angle change measured in time (2015)

The situation is shown graphically in Figure 6, for sunrise at the summer solstice. The plot shows the significantly slower angular rate (i.e. time taken for the Sun's depression angle to change by one degree) for observers in Leicester, compared to those at lower latitudes such as Makka and Bareilly. It is this very low angular rate for observers at higher latitudes which is critical to the argument made in this paper – because even very small changes in the solar depression angle at which dawn becomes observable, make significant differences to the time of Fajr at higher latitudes, while the effect is much less at sites closer to the equator.

Hence if, as suggested earlier, the *observed* dawn could differ from day to day and be mapped to a depression angle between 18° and 12°, for an observer in Makka and Bareilly the difference between the time of true dawn and that predicted by the 18° rule would be very short – but for an observer at higher latitudes, the effect would be more substantial.

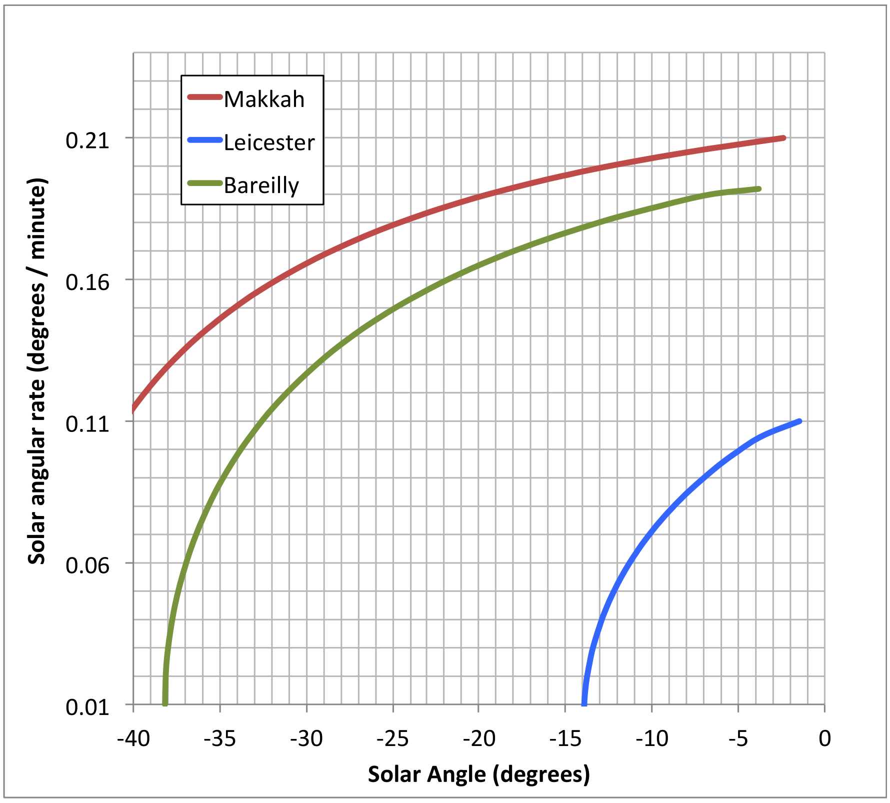

Figure 6. The rate at which solar depression angle changes (in degrees per minute) as a function of depression angle, for the three locations considered in this work, for the time leading up to sunrise on the summer solstice. Note that the Sun does not fall below a depression angle of -15° from Leicester.

6. Alternative to using the Depression Angle of the Sun

The position or depression angle of the Sun at any given time is not in dispute, the Quran makes it clear they are deterministic properties. However, as described earlier, the level of illumination or twilight does not have a direct correlation with the position of the Sun; while the depression angle is the dominant effect, the appearance of twilight is affected by latitude, season, temperature and atmospheric conditions, and these effects can be significant in high latitude regions.

Modern technology does allow us to accurately measure the level of brightness, even if it is not possible to predict when that level of illumination will be reached. This technology is most notably seen in street lights which activate when illumination reaches a set level. This trigger, at a fixed level of illumination, means that the street lights will always activate regardless of the actual time. It is possible for street lights to activate in very dark storms or during solar eclipses, because they are not timer based but illumination based.

It is possible to use electronic instrumentation to detect, with great precision, exactly when the sky brightness begins to increase as the solar depression angle decreases (dawn to sunrise). Shariff et al. (2012) describe a study conducted in Malaysia, to establish the time for Isha, measuring the sky brightness decrease as the solar depression angle increases. Between May 2007 and April 2008, a team from the University of Malaya (Kuala Lumpur) intermittently recorded illumination levels using an electronic Sky Quality Meter (SQM), in an attempt to determine the disappearance of Shafaq Abyad and therefore the beginning of the night for Isha. The location for the SQM light readings was Port Klang in Malaysia (chosen for its obstruction-free horizon and lack of light pollution) which is closer to the equator (101° 17’ E, 3° 1’ N) than Makka and Bareilly. During the observation period, the team was able to establish a consistent level of darkness in the measurements (corresponding to absence of Shafaq Abyad - .i.e. night) and when this was correlated with a depression angle it gave varying angles during the observation period with the highest being 17.3° , smaller than the depression angle of 18°.

The Sky Quality Meter gives light readings in units of “magnitudes per square arcsecond”. This is a logarithmic measurement, in which large changes in sky brightness correspond to relatively small numerical changes on the display. This allows for a simple scale (shown in Figure 7) to be used to measure illumination levels, where a value of around 23 represents very dark, clear skies with no moonlight and far from streetlights, while a value of 17 reflects conditions such as those in the middle of a city, with substantial “light pollution” from streetlights, along with the additional effects of moonlight, where only the brightest stars can be seen - much like the definition of astronomical twilight. The closer the scale is to zero the brighter the sky is. A logarithmic scale is adopted instead of a linear one, because the human eye responds in a similar way, and this is why the logarithmic magnitude scale has been in use by astronomers for more than twenty centuries.

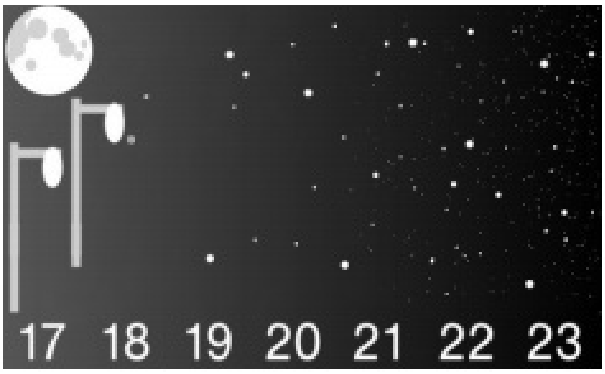

Figure 7. The magnitude scale used to measure the brightness of the sky background. In very light polluted areas, and on nights around full moon, the night sky brightness (in between the visible stars) is approximately magnitude 17. On clear, moonless nights far from city lights, the sky brightness is measured at approximately 23 magnitudes (where higher numbers indicate fainter/darker conditions). (Image: Unihedron.com)

Figure 8 (from Shariff et al.’s Malaysia study), shows the illumination level plotted against Sun depression angle for a given day during the observation period. The graph shows a light level curve divided into three phases. The most significant feature is the final stage when the illumination level stops changing, indicating the start of Isha. When this levelling of light at the darkest was measured against the Sun depression angle, it gave a depression level as high as 17.3°. Although the purpose of this paper is not to discuss how to establish Isha, the same principles behind the Malaysia study can be applied to determining dawn.

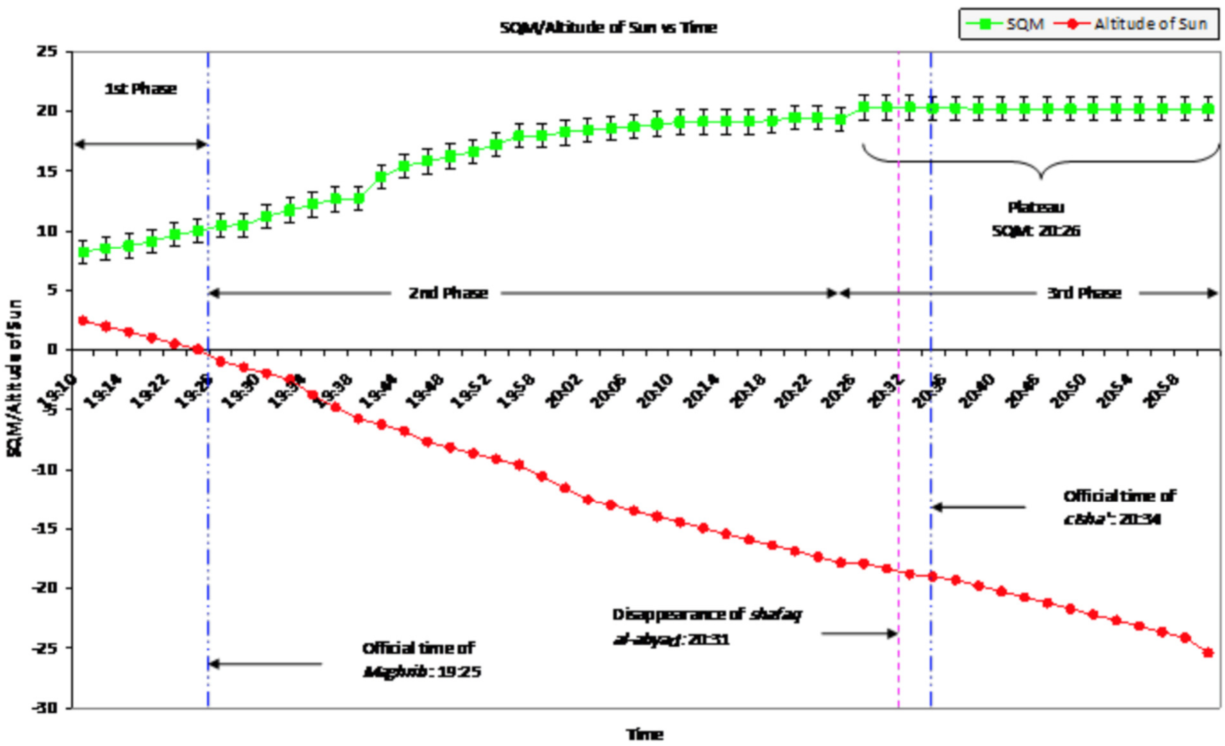

Figure 8. Sky Quality Meter results for a low latitude, clear sky site (from Shariff et al., 2012).

Others have also considered this subject. Two observation projects were conducted under the supervision Hafiz Gul Muhammad al-Azhari on the grounds of Jamia al-Karam[6], Retford, Nottinghamshire; the first during August and September 2011 and the second in April and May 2015. On both occasions, the team[7] conducted naked eye observations for dawn but during the second observation project in 2015, the team utilised a dark sky meter to measure illumination levels at the point of observed dawn. Table 4 shows the observed time of dawn during the August and September 2011 observations and the depression angle of the Sun at the time.

Date	Observed Time	Sun Depression Angle
20-Aug-2011	03:50	15.5°
23-Aug-2011	04:00	15.6°
27-Aug-2011	04:11	15.3°
30-Aug-2011	04:20	15.1°
03-Sep-2011	04:30	15.0°
07-Sep-2011	04:40	14.9°
10-Sep-2011	04:50	14.5°
14-Sep-2011	05:00	14.3°
19-Sep-2011	05:10	14.3°

Table 4. Sun depression angle at observed time of dawn

Although this is not a representative sample, the observations did show an observed dawn time when the Sun's depression angle was higher than 18° , varying between successive days.

[6] Observations was conducted independently and not on an official basis through Jamia al-Karam
[7] 2011 with Mubashir Iqbal & Umar Nawaz. 2015 with Muhammad Adam Patel, Kamran Ali & Hassan Jeelani.

During the 2015 observations, the naked eye observations were supported with a SQM app which gave illumination levels at dawn. Table 5 shows the time of observed dawn, the corresponding Sun depression angle and the SQM reading.

Date	Observed Time	Sun Depression Angle	SQM Light Reading
15-Apr-2015	4.15	15.2°	18.2
18-Apr-2015	3.51	16.8°	18.7
21-Apr-2015	3.41	16.8°	19.1
26-Apr-2015	3.15	17.5°	18.7
30-Apr-2015	3.05	17.0°	18.2
10-May-2015	2.15	17.4°	18.7
14-May-2015	1.39	17.7°	19.1

Table 5. Sun Depression angle at observed time of dawn with light reading

The significant differences in the depression angle of the Sun at observed dawn are accompanied by less extreme changes in the SQM reading, suggesting that local environmental effects (weather, light pollution, the eyesight of the observers, and human error) play a role in determining the point at which dawn was deemed to have occurred from day to day. These results indicate the complex nature of this subject, and highlight the need for careful, systematic study paying careful attention to the factors which affect the sensitivity of human vision to dawn – as required by the teachings of the Holy Quran.

7. Dawn Observations with Illumination Measurements

It is clear that in locations of extreme latitude like the UK, using the depression angle of the Sun alone may not truly reflect the time of dawn. Limited observation projects in the UK and abroad using light measuring equipment have shown that a flat period of illumination can be recorded representing night and the point at which the conditions the Quran and Sunnah describe as dawn can also be measured and attributed to a given light measurement. By applying this knowledge and establishing an observation project in the UK, it may be possible to produce a more accurate dawn timetable.

A number of tools are available to measure illumination levels during any observations. The first is a the SQM device described above, and manufactured by Canadian company *Unihedron*, but available from astronomy suppliers in the UK. It is available as a stand-alone monitor (Figure 9, left) as well as a USB and network-capable version which can be used in conjunction with a computer.

Figure 9. Left: SQM Meter. Right: Dark Sky Meter app screen example.

The second is the Dark Sky Meter (DSM) app (shown in Figure 9 right) available for the iPhone, and written by DDQ. This app allows the user to measure light levels using the phone camera, and to store the data on the phone. Data can be exported to a computer for analysis.

By performing an observation project over a number of years supported by instrumentation such as the Sky Quality Meter and at a number of locations, it will be possible to establish trends in the length of the night and the illumination levels which are associated with the observed dawn. The same illumination data could also support the calculation of Isha time. Figure 10 illustrates how light measurements on a given day when compared with the depression angle of the Sun could give a truer dawn time. The Holy Quran makes it clear that the onset of dawn must be determined by the observer. Hence, another instrument can be used to relate the SQM or DSM measurements to human observations. This additional instrument is the “Pitch Black Meter” (PBM), described in the popular US astronomy magazine “Sky and Telescope”[8], and used in another study of the conditions for Isha, described by Zainuddin et al. (2005). The PBM is a simple but effective device which displays a small light source of variable brightness, inside a viewing tube. The observer looks through the tube while pointing the tube at the sky, and turns down the brightness of the light source until it matches the brightness of the sky *as seen by the human observer* and hence calibrates the SQM in terms of the sensitivity of the human eye. The brightness of the light source can be recorded by means of a volt meter built into the device. The measurement on a SQM device is recorded at the same instant in time.

While previous studies have used SQM *or* PBM methods, to our knowledge, none have used both, and only when combining these methods can high quality information be provided to the community to aid discussion of this topic, in a form that is compatible with the teachings of the Holy Quran.

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[8]Sky and Telescope Magazine, A Simple Dark Sky Meter , Vol 101, No: 2 (February) , pg 138-139
Sky and Telescope Magazine, Introducing the Bortle Dark Sky Scale , Vol 101, No: 2 (February) , pg 126-129
Sky and Telescope Magazine, Application of Pitch Black Meter , Vol 101, No: 2 (February) , pg 140

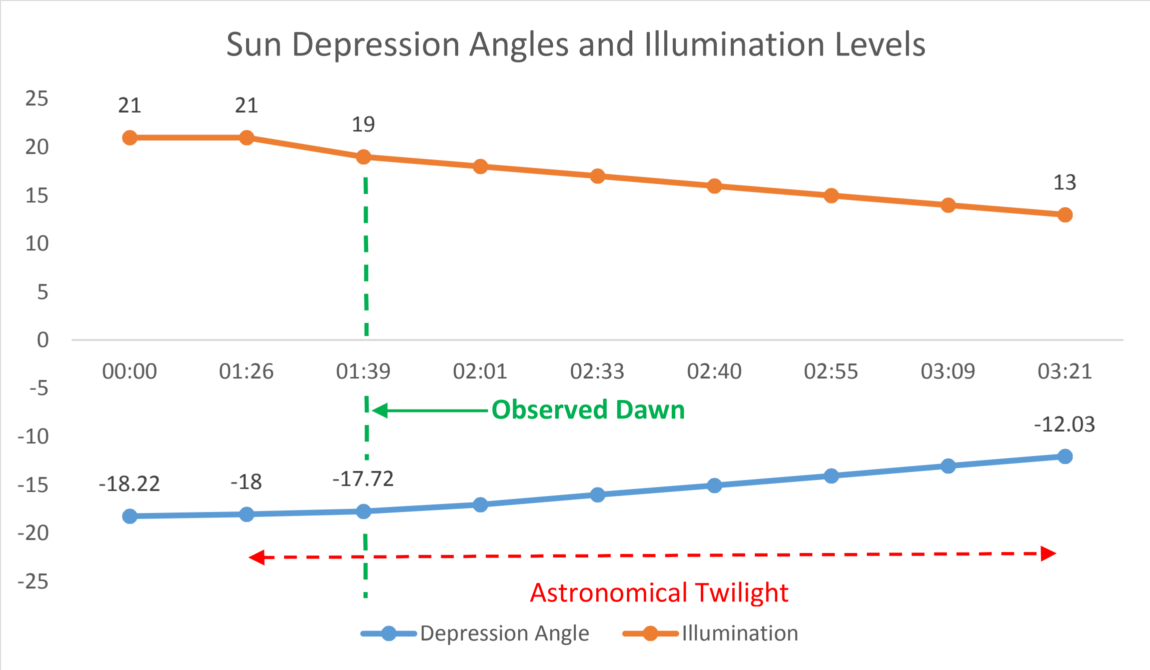

Figure 10. Example Sun depression angles and corresponding light reading graph (using 14th May 2015)

8. Dealing with Persistent Twilight

At extreme latitudes the twilight may persist between sunset and the next sunrise for certain months of the year. In these months the Sun does not go below the horizon by an amount sufficient to extinguish twilight. Hence there is no true night. On the summer solstice in Leicester the Sun only sets to the depression angle of 13.94°, and at these times of year, the blue twilight glow is obvious on clear nights, with a level that is well above the brightness of dawn in the winter months.

Makka and Bareilly do not experience this phenomenon as the Sun sets beyond 18°. Even at the summer solstice, the Sun reaches the depression angle of 45.13° in Makka and 38.12° in Bareilly.

Although the purpose of this paper is not to explore the merits of the alternative methods available to deal with persistent twilight, there is direct link with establishing observed dawn during the rest of the year. If a truer dawn time can be established for the year, then the period of persistent twilight can be reduced.

At the depression angle of 18°, persistent twilight remains for over two months. If observed dawn can be established at, for example, at the depression angle of 17°, this reduces the requirement for an alternative method by nine days; at 16° this is reduced by twenty days as shown in Table 6.

Depression Angle	Start Date	End Date	No. of Days
18°	17 May	27 July	72
17°	22 May	23 July	63
16°	27 May	17 July	52
15°	4 June	10 July	37
14°	17 June	27 June	11
13°	-	-	0
12°	-	-	0

Table 6. Period of persistent twilight (2015)

The principles described in this paper can be used to explore the validity and strengths of the alternative methods available and how applying an observed dawn as appose to an 18° depression angle calculation can have a significant impact on the results.

8.1 One Seventh of Night (Sub' al-Layl)

This is the most liberal of the four methods. The interval between sunset and sunrise is split into seven segments. Isha is offered after the first segment and Fajr is offered after the sixth segment.

For Leicester on the summer solstice, when the night is split into seven, dawn would result at **3:39AM** with sunrise at 4:41AM. At **3:39AM** the Sun is at a depression angle of only 6.97°.

Although the method has the advantage of establishing fixed periods for Maghrib, Isha and the dawn of Fajr, the position of the Sun at the calculated dawn is outside both the scientifically defined periods of astronomical and nautical twilight.

8.2 Nearest Latitude (Aqrab al-Bilad)

The length of time between dawn and sunrise at the nearest location where prayer times can be established (48.5° latitude) is taken and used to establish the time of dawn locally by subtracting this interval from local (Leicester) sunrise. Some Muslims have misinterpreted this to mean that the dawn-sunrise interval for Makka can be used in the UK. This is the incorrect application of this method as it would result in a dawn time much later than would result from a location close to 48.5° latitude.

The north-west coast of France[9] lies at a latitude of 48.5° where the interval between dawn at the depression angle of 18° and sunrise is 198 minutes. Sunrise on summer solstice in Leicester is 4:41 and so when 198 minutes is subtracted gives a calculated dawn time of **1:23AM**. At **1:23AM** the Sun is at a depression angle of 13.85°.

If Makka was used for the same method, it would result in dawn-sunrise gap of 87 minutes with a calculated dawn of 3:14AM and a Sun depression angle of only 6.79°. This calculated dawn is outside both the scientifically defined periods of astronomical and nautical twilight.

Any calculated dawn time using this method is based on establishing a location where prayer times could be calculated; namely at 48.5° latitude where the Sun depression angle reaches 18°. If it was found that dawn could be established at, say, the depression angle of 17° outside periods of persistent twilight, it would directly affect the reference location and shorten the period of persistent twilight where an alternative method is required.

8.3 Nearest Day (Aqrab al-Ayyam)

With this method the dawn time from the last day when it was possible to calculate Fajr is then used for the period of persistent twilight.

For Leicester, the last day at which dawn can be established at the depression angle of 18° is around 17th May at **1:23AM** and so this time is used throughout persistence twilight. It is not a coincidence that both Aqrab al-Ayyam and Aqrab al-Bilad result in the same calculated dawn as both methods are based on establishing dawn at 18°; one using a location and one using a date.

Any calculated dawn time using this method is based on establishing the date where prayer times could be calculated; namely at a date when the depression angle reaches 18°. If it was found that dawn could be established at, say, the depression angle of 17° outside periods of persistent twilight,

[9] Perros-Guirec - 3° 26' W, <u>48° 48' N</u> – Dawn 0:47 GMT– Sunrise 4:05 GMT

it would directly affect the reference date and shorten the period of persistent twilight where an alternative method is required.

8.4 Middle of Night (Nisf al-Layl)

The interval between sunrise and sunset is split into two halves. Isha is offered before the midpoint and dawn is set at the midpoint. This is the most conservative method and is a blunt instrument for establishing dawn. It also provides little provision for establishing Isha with no clear definition of when this prayer can be established.

In Leicester on the summer solstice, the calculated dawn is **1:06AM**. Due to the short night and the relative low depression of the Sun, there are many minutes when the Sun is at the same depression angle. The lowest depression angle of the Sun on the summer solstice in Leicester is 13.94° and the Sun remains at this angle between 1:02AM and 1:10AM.

Between 0:12AM and 2:01AM the Sun depression angle goes from 13.0°, peaks at 13.94° and returns to 13.0°. If this fraction of less than 1° twilight cannot be differentiated, then the argument can be made that 2:01AM is just as valid a dawn time as 1:06AM.

9. Conclusion

In fulfilling the instructions of the Quran and Sunnah, the Muslim world has been able to apply a fixed degree-related rule when establishing dawn. The upper astronomical twilight limit of 18° has served as an effective approximation for all locations below the latitude of 48.5°. There has been no requirement to establish a more accurate, observed dawn in the Muslim world, as a one degree difference translates to only a few minutes at such low latitudes. Even if dawn was observed at the lower astronomical twilight limit of 12°, this only represents a half hour difference in a night, which at its shortest is still over ten hours long from low latitudes.

Science has shown that the correlation between the depression angle of the Sun and the level of twilight for all locations is complicated by effects such as the clarity of the atmosphere and the amount of particles which it contains at a given location, date and time. For countries at latitude higher than 48.5° like the UK where the Sun does not set below the depression angle of 18° during the summer, a fresh approach is required which uses the depression angle of the Sun to frame the potential period of dawn in conjunction with the measurement of light using equipment like the Sky Quality Meter to determine more precisely, the onset of dawn.

By performing an observation project over a number of years and at a number of locations it will be possible to establish trends in the length of the night and the illumination levels which are associated with the observed dawn. The same illumination data could also support the calculation of Isha time. The secondary benefit of such a project would be to potentially reduce the period of persistent twilight and the associated alternative methods required during this period.

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