SKY BRIGHTNESS AT TWILIGHT: DETECTORS COMPARISON BETWEEN HUMAN EYE AND ELECTRONIC DEVICE FOR FOR ᶜISHĀ' & ṢUBḤ FROM ISLAMIC AND ASTRONOMICAL CONSIDERATIONS

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Abstrak

Penentuan waktu solat telah lama diselidik maka penyelidikan ini menawarkan pandangan kritikal mengenainya. Penulis mempersembahkan pengukuran kecerahan langit cahaya nampak ketika senja dari Mei 2007 hingga April 2008 secara bersela. Setelah memahami kehendak syarak, pengukuran telah dilakukan dengan mata manusia dan alat elektronik (Sky Quality Meter) yang mana ia adalah dari pendekatan Sunnah (kualitatif) dan saintifik (kuantitatif) secara berturut. Pengamatan kecerahan langit ini telah dijalankan di beberapa tempat yang meliputi kawasan pantai timur dan barat semenanjung Malaysia. Terdapat petunjuk yang jelas perubahan penerimaan cahaya ketika Matahari berada beberapa darjah di bawah ufuk dengan wujudnya dataran di dalam kecerahan langit melawan sudut zenit Matahari. Kedua-dua data bersepakat dengan pengiraan yang telah dilakukan oleh sarjana Islam lain walaupun terdapat perselisihan yang kecil. Penulis menyatakan bahawa purata tahunan sudut junaman cerapan adalah dalam julat 17.3° – 19.5° dan 17.5° – 20° bagi Isyak dan Subuh masing-masing. Penyelidikan ini mengerti bahawa kedua-dua pendekatan tersebut mempunyai nilai tolak ansur dan terhad di dalam Islam. Penulis dapat menyimpulkan dengan mengusulkan kajian lanjut perlu diteruskan bagi mencapai tahap ketepatan tertentu.

Abstract

The determination of Islamic prayer times has been extensively investigated thus this research offers critical insight of it. The author presents optical sky brightness at twilight measurements from May 2007 through April 2008 intermittently. After comprehend Islamic law code's requirement, the measurement were done using human eye and electronic device (Sky Quality Meter) which is Sunnah (qualitative) and scientific (quantitative) approaches respectively. The measurement of twilight sky brightness were performed various sites covering east and west coast of Peninsular Malaysia. There are clear indications of changes of the receipt of light when Sun at certain degree below horizon that manifest itself by plateau in twilight sky brightness dependences versus solar zenith angle. Both data are in reasonable agreement with measurements previously made by Islamic scholars, although there are discrepancies. The author finds that the yearly averages of solar depression by observation are best correlated with the range of 17.3° – 19.5° and 17.5° – 20° for ᶜIshā' and Ṣubḥ respectively. Research understands these approaches have both tolerance and limitations in Islamic law code. The author can concludes with the recommendations for further research concerning extended research is required in order to gain certain level of accuracy.

Anecdote

Sekumpulan ahli sains yang bertemu sebulan sekali di bawah bimbingan Dr. Arturo Rosenblueth. Nobert Wiener dan Rosenblueth bertemu untuk membincangkan kaedah saintifik. Kaedah saintifik ini adalah suatu cara menghadapi alam fizikal dengan jalan yang sesuai dan praktis untuk mempelajari keadaan alam fizikal dan bagaimana ia berfungsi. Mereka mendapati bahawa mereka berdua mempunyai minat yang sama. Di mana bidang yang berlainan mempunyai kecenderungan dan matlamat yang sama, maka di situ terdapat kemungkinan mereka bekerja bersama-sama. Sejak akhir-akhir ini manusia telah mempelajari banyak perkara tentang dunia sehingga dirasai amat sukar hendak mengetahui segala maklumat. Cerdik pandai biasanya mengkaji satu-satu perkara dengan mendalam dan ini juga bermakna mereka makin kurang mengkaji perkara lain. Sebagai analogi, orang pergi ke luar negara akan menghadapi masalah jika dia hanya boleh bertutur dalam satu bahasa sahaja. Perbezaan cara yang digunakan untuk membincangkan sesuatu masalah dan perkataan yang sama kadangkala mereka tidak menyedari hal itu. Disebabkan begitu, kerja yang penting telah tertangguh kerana tidak mengetahui penemuan mustahak dalam bidang lain.[1]

[1] Jacker (1981), pp. 1-2.

Inspired by

"Deemed ye then that We had created you for naught and that ye would not be returned?"
al-Mu'minūn: 115

"Lo! We have created everything by measure"
al-Qamar: 49

"Measure what can be measured and make measurable what can not be measured"
Galileo Galilei

"They condemn what they do not understand"
Latin proverb

Acknowledgement

All praises to Allah for only by His Grace was this work completed

Beloved RasūlulLah p.b.u.h

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Past, Present and Future

They will readily recognize their large contributions to this dissertation

I pray Allah would reward them generously

Dedication

List above

Person who peruse this dissertation

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Allāhu a'lam

List of Figures

List of Graphs

List of Tables

List of Symbols, Abbreviations, and Transliteration

λ – Longitude

δ – Declination

Φ - Latitude

Dr. – Doctor

e. – Edition

ca - circa

Et al. – et alia

Cf. – Confer (compare)

Ibid. – ibidem (in the same source as the one has been mentioned)

p. /pp. – Page

Vol. – Volume (book)

vol. – Volume (journal)

Op. cit – opere citato (refer to a source that has already been mentioned)

Trans. – Translation

Transliteration

Arabic Alphabets							
ا	A	د	d	ض	ḍ	ك	k
ب	b	ذ	dh	ط	ṭ	ل	l
ت	t	ر	r	ظ	ẓ	م	m
ث	th	ز	z	ع	ʿ	ن	n
ج	j	س	s	غ	gh	و	w
ح	ḥ	ش	sh	ف	f	ه	h
خ	kh	ص	ṣ	ق	q	ي	y
ة		t / h		ء		ʾ	

Long Vowels	
ا	ā
و	ū
ى	ī

Short Vowels		
َ	Fatḥah	a
ُ	Ḍommah	u
ِ	Kasrah	i

Diphthongs	
او	aw
اى	ay
يّ	iy / i
وّ	uww

Table of Content

Chapter 1

1.1 Introduction

Shafaq (afterglow or remnant of sunset at certain degree) and fajr (first light before sunrise)[1] both are astronomical phenomena part of twilight stage. Generally, this chapter discusses few topics in order to understand what the research is about.

1.2 Objective of Research

The objectives of this research are:

a. To provide a rational proof (dalīl aqlī) by clarifying correlation between qualitative[2] and quantitative[3] measurement with respect to dalīl naqlī or Islamic interpretation.
b. In search of reliable range of twilight angle.
c. To scrutinize the linkage between astronomy, history of science, human perception in Islamic religious observances.

1.3 Background of Research

Ṣalāt (prayer) is one of Islamic Commandments which has its own prescribed times.[4] If ṣalāt is performed before or after its fixed times, it will need to be repeated as qaḍā'. The recital of ṣalāt within its time set by Islamic law code should be a main solicitude for all Muslims. In this work, the author focuses on these two prayer times i.e. ᶜIshā' and Ṣubḥ. The definitions of the times of prayer were outlined in al-Qur'ān and al-Ḥadīth (prophetic statement). Those outlined prayer times were interpreted by fiqh (Islamic jurisprudence) which has numbers of school of thought (madhhāb), consequently it affect the parameter on establishing the beginnings and the endings of ᶜIshā' and Ṣubḥ.

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[1] From web http://content.com.sa/Language/LisanElArab accessed 13 January 2008.
[2] Eye (human visual perception).
[3] Sky Quality Meter (numerical data).
[4] Al-Qur'ān, 3: 103. "…Worship at fixed hours hath been enjoined on the believers".

According to these standard definitions, the interval for the ᶜIs͟hā' begins at nightfall and lasts until daybreak and Ṣubḥ during the interval between daybreak and sunrise. In this case, both determinations rely on the level of illumination in the night sky but not by the position of the Sun. The beginning of ᶜIs͟hā' and Ṣubḥ is indicated by the disappearance of shafaq and the appearance of fajr al-ṣādiq respectively. Those terms are similar in English terminology as nightfall and dawn/daybreak in that order. Twilight is also used to refer to the illuminated sky after sunset and before sunrise. There are different terms of twilight with respect of stages of illumination settings.

It is possible to perform ṣalāt from any age any locality, hence ᶜilm al-mīqāt[5] has evolved centuries ago.[6] The writings of these men consist mainly treatises on the determination of the prayer-times either by direct calculation or with the aid of analogue computers such as the astrolabe and astrolabic quadrant or calculating devices such as trigonometric quadrant.[7] For centuries Muslim astronomers tried to improve prayer times determination all over the world whether aided by instruments or unaided, relying on natural phenomena. To date, there are many methodology and equipment trying to suit fiqh. For instance, a Muslim society[8] in Britain performs observations for one whole year in order to identify ᶜIs͟hā' and Ṣubḥ prayer times with naked eye. Then a few years back, there was an attempt to build an instrument using electronic detectors. For the same purpose, this work is trying to answer with permitted methods which combine the traditional and modern ways i.e. with the human eyes and the electronic instrument (Sky Quality Meter).

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[5] Form from w-q-t, plural mawāqīt which means appointed or exact time. It is the science of astronomical timekeeping by the Sun and stars and the determination of the times (mawāqīt) of the religious obligation to pray at specific times. King (1993), pt. V, p. 1 and King (2004), p. 201.

[6] The most tangible and colourful evidence of the activity of the muwaqqits and their role in Islamic societies is to be found in the mathematical tables which they prepared displaying the prayer-times throughout the year for a particular locality. It is clearly convenient to have the prayer-times tabulated, either for each degree of solar longitude or for each day of the year, particularly in localities where clouds are frequent or where the local horizon is obscured by mountains or tall buildings. *Ibid.* King (2004), p. 201.

[7] *Op. cit.* King (2004), pt. V, p. 5.

[8] Hizbul Ulama UK's mus͟hāhadah carried out at Blackburn. Miftahi (2005), pp. 46-49 and Miftahi (2005), pp. 84-91.

1.4 Statement of Problem

"How can the horizon be bayyan (visible) when there is no light?"[9]

The problem above is at what twilight angle of the Sun does the horizon to be visible. To answer this, every opinion have their own raison d'être and arguments emerged due to which method and criteria suit dalīl naqlī. Previous researches limits to the utilization of the human eyes and also theoretical calculations. This work tries to show a correlation between quantitative and qualitative measurements which could alleviate the problem.

1.5 Limitation of Research

a. This work only uses two detectors i.e. human eye and Sky Quality Meter (SQM) at ᶜIshā' and Ṣubḥ prayer times (twilight).

b. The measurement of twilight sky brightness is performed various sites covering east and west coast of Peninsular Malaysia from May 2007 through April 2008 intermittently.

c. The study focuses only on the receipt of light perceived by detectors and not how it happens.

d. The expected result will serve as guidance for the prayer times determination.

1.6 Literature Review

The author organizes the literature thematically as in chapter 2 and 3 which include various disciplines. Inevitable sources are al-Qur'ān and al-Sunnah. Yet for the later, only certain status of al-Ḥadīth can be accepted. There is no doubt for Ṣaḥīḥain (al-Bukharī and Muslim) as their rigidity degree of admittance. However most of the ḥadīth in this work come from other books with acceptable level ḥadīth duly to those aḥādīth described phenomenon of prayer times. Remarkable Wahbah al-Zuhailī's book on Islamic compendium of Islamic jurisprudence; Al-Fiqh al-Islāmī wa-Adillatuh[10] is the main resource in Islamic consideration. It is not just an average compendium but endowed with analytical comparison and comments of four main schools of thought. Sultan throws the

[9] ICOP Yahoo Group.
[10] Al-Zuhailī (1997).

idea supported by the by observation on fajr al-ṣādiq which follows the astronomical phenomenon i.e. zodiacal light. In this paper, he edges analytical comments of other modern Muslim scholars. Furthermore, it carries well with Qur'anic verses and Prophetic statements.

Minnaert discusses those phenomena with scientific explanation combined with a dash of simple mathematics and some part of human physiology that is the eye. His book brings its best because it shows how a phenomenon happens precisely and it is easy to understand even by a layman. As its title: Sunsets, Twilights and Evening Skies,[11] this book is very relevant. Additionally, it has the same character with that of Minnaert above yet it attempts to unite scientific overview without missing any natural beauty of the phenomena. It has many figures to demonstrate those phenomena in order to enhance one's understanding.

Studies in the Islamic Exact Sciences[12] is a collection of articles of Kennedy (together with his colleagues and former students) which were divided into few sections and one of it is on astronomical timekeeping. Most of the articles are about critical analysis of ancient treatises of Muslim scholars which make it an authoritative secondary source. Astronomical timekeeping is stretched extensively by King and both books are compilations of articles, papers and proceedings by him solely especially in astronomical timekeeping. As Kennedy guided him on zij[13], these compilations are on deciphering medieval tables.

Lindberg provides theories of vision from al-Kindī to Kepler, and in doing so he both fills a gap in historical scholarship and constructs a model for tracing the development of scientific ideas. On the other hand, Goldstein goal is to gain better appreciation of ancient and medieval astronomy, taking into consideration the role of tradition in this discipline. The book discusses origin of some feature of Islamic, Greek and Chinese astronomy. A concise book on spherical astronomy is written by Smart which is still the best for decades. It expounds a variety of problem ranging from simple spherical astronomy to the complex one.

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[11] Meinels (1983).
[12] Kennedy (1983).
[13] Astronomical handbook with tables and explanatory text.

Book by Atrens & Curthoys is one of the key to comprehend how eye, as detector work and understand how it interprets from sensory faculty to brain. Bartley clarifies the forms of brightness discrimination and adaptation phenomena for twilight sky. Cornsweet caters experimental method for eye detector and builds an understanding on how eye perceive the light. Dark-adaptation and night vision is a chapter in Davson's which is directly related to this research. In order to understand those terminologies, Hartridge gives ample and lucid explanations.

1.7 Research Outline

The author resists the excitements of other related field, duly to that severe limits were imposed. In chapter 1, an introduction is given to the research. Background of the research is presented in accordance of problem arising. Chapter 2, a close look is taken at the comprehension of the subject and contemporary relevance of issue which is current practice culture with historical point of view. Chapter 3, observation language is outlined. In chapter 4, the result and data analysis and will be brought up in order to tackle the problem. Lastly chapter 5, discussions and a summary account of the theory-observation relationship are given.

Chapter 2 Background Theory

2.1 Introduction

In this chapter, the author prefers to discuss motivation of this research, twilight's properties and followed by some issues and criteria, simplified version of ᶜIshā' and Ṣubḥ times computation[1] and a preliminary introduction of detectors.

2.2 ᶜIshā' and Ṣubḥ times in al-Qur'ān and al-Ḥadīth

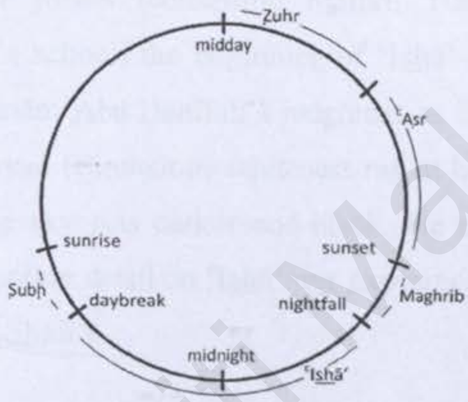

Figure 2.1: The timings of prayer times

ᶜIshā' time is followed by Ṣubḥ time as shown in Figure 2.1. By this mean the ending of ᶜIshā' is the beginning of Ṣubḥ. Occurrence of ᶜIshā' and Ṣubḥ are in twilight domain and both prayers are mentioned in al-Qur'ān generally:

> Therefore (O Muḥammad), bear with what they say, and celebrate the praises of thy Lord ere the rising of the Sun and ere the going down thereof. And glorify Him some hours of the night and at the two ends of the day that thou mayst be well pleased. Al-Qur'ān, 20: 130

Further explanation on the times is briefed by Prophet Muḥammad p.b.u.h:

> ...Then he (Gabriel) came at night and said, "Stand and pray", and they prayed the night prayer when the twilight had disappeared. He came again

[1] Since human nowadays hardly ever go and observe by himself to determine prayer times due to ever changing lifestyle. As a result human must develop a system to substitute the omitted practice by adapted knowledge of science & technology such as tables of prayer times. King (1986), pt. II, pp. 46-48.

> when dawn broke (and they prayed the Morning Prayer)…Then Gabriel said, "Between these times are the times for the prayers".[2]

As we observed, clearly ᶜIshā' and Ṣubḥ times are astronomically defined by the level of illumination of the night sky and it is not as easy as observing by the position of the Sun (other prayer times). The ḥadīth below clarifies for ᶜIshā' prayer time:

> Shafaq is redness light, when the shafaq disappeared therefore offer the pray (i.e. ᶜIshā')[3]

Shafaq al-aḥmar can be translated as redness at the sky due to Sun sets in west. According to consensus of jurists (consisting Mālikī, Ḥanafiyyah, Ḥanabilah and considered in former Shāfiᶜī's school) the beginning of ᶜIshā' is at the disappearance of shafaq al-aḥmar. However, Imām Abū Ḥanīfah's judgment as ᶜIshā' can be perform until disappearance of shafaq al-abyaḍ (continuous whiteness ray at horizon) which appear after shafaq al-aḥmar and soon the sky gets darker and black. He estimates between the two shafaq is 3^{o} (12 minutes).[4] Another detail on ᶜIshā' was explained in a verse from a poet by celebrated mujtahid, Imām al-Shāfiᶜī:

> …perform the night prayer when, looking at the sky, you see the upper part of the evening twilight fade away and disappear…[5]

Next ḥadīth detail clearly Ṣubḥ prayer time:

> There are two type of fajr viz. fajr that forbade eating and permitted prayer (i.e. fajr al-ṣādiq). Second is forbid prayer and permitted eating (i.e. fajr al-kādhib)[6]

In order to determine Ṣubḥ there are two types of fajr to be recognize i.e. fajr al-kādhib and fajr al-ṣādiq. Fajr al-kādhib (false dawn) is characterized as vertical light in the eastern sky that looks like a wolf's tail (dhanb al-sirḥān) and its rays spread out over the eastern horizon in the form of the letter "V". As the Sun moves closer to the horizon from below,

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[2] Narrated by Aḥmad and al-Nasa'i. al-Shaukānī (1994), Vol.1, pp.285-286.
[3] Narrated by Dāruquṭnī. al-Shaukānī (1994),Vol.1, p. 310.
[4] Elusive light of shafaq al-abyaḍ probably this is due to different location, amount of particle and so on.
[5] King (2004), p. 215.
[6] Al-Zuhailī (1997), p. 520.

the upper of "V" faded and the bottom of it is getting wider and brighter in form of inverted "V" ("Λ") to indicate fajr al-ṣādiq[7]. Thus, Imām al-Shāfiᶜī specify in his poet:

> …bear in mind that there are two stages of daybreak according to our doctrine: distinguish between them carefully – *you are the one who decides this*. The first daybreak looks like a wolf's tail rising in the sky: this is the false dawn. The later one is the true dawn: you see it illuminate the sky like a fire.[8]

Another parameter to recognize the beginning of Ṣubḥ is clearly stated in the second chapter of al-Qur'ān al-Karīm:

> …and eat and drink until the white thread becometh distinct to you from the black thread of the dawn… Al-Qur'ān, 2: 187

A ḥadīth[9] that followed after the verse above is when Prophet Muḥammad p.b.u.h explained to his companion that the verse mean the darkness of the night and the whiteness of the dawn. Prophet Muḥammad p.b.u.h restated that action of comparing two threads is senseless in practical term yet crucial to show its attribute. In brief, shariᶜah does not need that kind of accuracy. As a conclusion, fiqh reveals ᶜI<u>sh</u>ā' and Ṣubḥ prayer times' parameters at twilight which in short:

ᶜI<u>sh</u>ā': Begins as indicate by disappearance of shafaq al-aḥmar/al-abyaḍ. Ends as Ṣubḥ begins.

Ṣubḥ: Begins as indicate by appearance of fajr al-ṣadiq. Ends as Sun rises.

2.3 Properties of Twilight

The author reiterate that ᶜI<u>sh</u>ā' and Ṣubḥ occur when the Sun has certain angle of depression below the horizon[10] that is in twilight domain which fall easily into two as shown in Figure 2.2. Twilight is defined as a period of semi-darkness after sunset or before

[7] Fajr al-ṣādiq or true dawn is the whiteness at east sky.
[8] *Op. cit.* King (2004), p. 215.
[9] Narrated ᶜAdi bin Hatim - When āyah 2: 187 were revealed: "Until the white thread appears to you, distinct from the black thread", I took two (hair) strings, one black and the other white and kept them under pillow and went on looking at them throughout the night but could not make anything out of it. So, the next morning I went to Allah's Apostle and told him the whole story. He explained to me, "That verse means the darkness of the night and the whiteness of the dawn." Translation of Ṣaḥīḥ Bu<u>kh</u>ārī, Vol.3, Book 31, Number 140 from web http://www.usc.edu/dept/MSA/fundamentals/hadithsunnah/bukhari accessed 1 January 2008.
[10] *Op. cit.* King (2004), p. 205.

sunrise during which the Sun's zenith distance is more than 90° but less than some agreed number.[11] Another term is dusk which is the time when the light has almost gone, but it is not yet dark. This is evening twilight is connected with ᶜIs̲h̲ā'. Dawn is the time of the day when light first appears i.e. morning twilight which is related to Ṣubḥ. Yet Ibn Muᶜādh clarifies:

> Twilight is due to the reflection of sunlight falling on vapours that rise from the Earth; the air does not reflect sunlight because of its rarity. Thus morning twilight begins when the Sun's rays reach the uppermost vapours.[12]

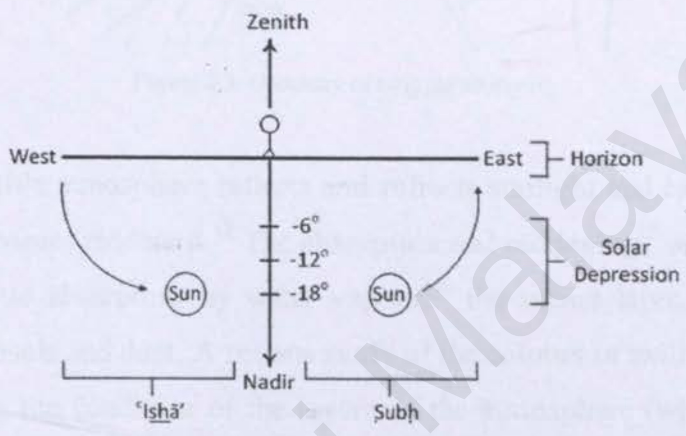

Figure 2.2: Geometrical of twilights

According Ibn al-Shāṭir, he described twilight as a horizon phenomenon and he considered night to be the time from the disappearance of light and the appearance of the stars to the appearance of light and the disappearance of the stars.[13] According to several Muslim astronomers such as Ibn Yūnus, dusk and dawn are asymmetry[14] yet differences are so small[15] and this is appropriate to daily movement of the Sun and the location of the observer. The twilight phenomenon occurs once the Sun sets or rises behind the horizon, there must be some sunlight visible as its rays propagate in a long distance through the atmosphere. Therefore twilight occurs due to sunlight hitting the Earth's atmosphere and being scattered or its path is bent – see Figure 2.3[16]. The geometry of twilight allows light

[11] Duffett-Smith (1981), p. 90.
[12] Goldstein (1985), pt. IX, pp. 105-107.
[13] *Ibid.* pt. X, p. 98.
[14] Look sub-chapter 2.4, *ibid.* pt. X, pp. 97-118, *cf.* Kennedy (1983), pp. 253-273 and Minnaert (1954), pp. 268-273.
[15] The important thing is the eye is completely rested in the morning and sees the light-intensity increase continuously, so that it is more sensitive to dawn phenomena than to dusk phenomena which have generally a greater richness of colour on account of the greater humidity of the air, and because the air is a little more turbulent and contains more particles of dust than in the morning. *Op. cit.* Minnaert (1954), p. 280.
[16] Ougolnikov (1999), pp. 159-166, Chamberlain (1957), Donahue & Resnick,

to reach us after the Sun has dropped below the horizon.[17] After sunset, as the depression of the Sun increases the sky gets darker gradually until no scattered light reaches the observer. On the contrary, in the early morning light starts to appear in the sky even before sunrise.

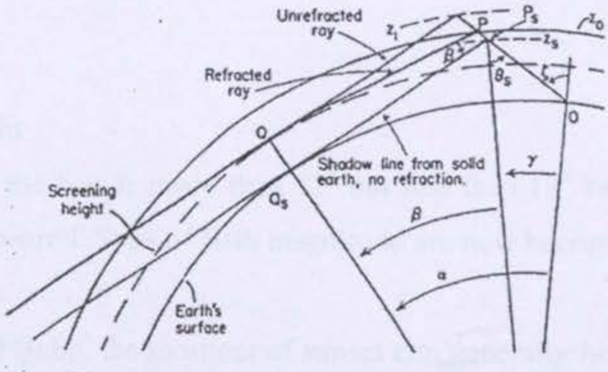

Figure 2.3: Geometry of twilight scattering

As a result the Earth's atmosphere reflects and refracts sunlight and causes the Sun to appear dimmer and becomes reddened.[18] The absorption and reddening[19] are caused by the combined effects of true absorption by water vapour,[20] the ozone layer, scattering[21] by atmospheric gases, aerosols and dust. A serious study of the colours of twilight will provide information concerning the condition of the layers of the atmosphere (where cloud were formed) which light was scattered.[22] There are three stages of twilight that have been standardised and each is defined by how far the sun's center is below the horizon – see Figure 2.2.[23]

a. Civil twilight

It happens when centre of the Sun is 6^{o} below horizon. The brightest stars are visible and the horizon is clearly visible at sea. The purple light[24] begins to fade away, apparently mingling with the horizontal stripes, for these are getting brighter and orange-coloured.

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[17] Minnaert (1993), pp. 272-273.

[18] Whilst the molecules of air scatter the violet, blue and green rays. The amount of colouration depends on the air itself or rather on the aerosols or particulate matter suspended in the air. Meinels (1983), p. 10.

[19] The red light from the Sun penetrates to your eye; its blue light is lost in producing the blue sky colouration. The normal blue sky caused about half by Rayleigh scattering and half by aerosol and ozone scattering and absorption *ibid.*

[20] Everything depends on the size of the drops of mist; the source of light appears reddish when the drops are so small as to approach the wavelength of light and therefore scatter chiefly the blue and violet rays, while the yellow and red rays are scattered to a smaller degree. *Op. cit.* Minnaert (1954), pp. 268-282.

[21] Three type of scattering: Rayleigh scattering by air molecules, Mie scattering by aerosols and multiple scattering. Haber *et al* (n), pp. 11-12.

[22] *Op. cit.* Minnaert (1954), p. 268. The length of time after sunset can be easily converts into altitude of atmosphere stratum. *Op. cit.* Meinels (1983), pp. 66-70.

[23] By Royal Greenwich Observatory (RGO).

[24] *Ibid.* The intensity of the purple light varies very much frpm one day to another.

b. Nautical twilight

This type of twilight occurs whilst the centre of the Sun is more than 6° but less than 12° below the horizon. The horizontal stripes are considerably weakened and are now a faded green.

c. Astronomical twilight

Appear while centre of the Sun is more than 12° but less than 18° below horizon. The twilight glow has disappeared. Stars of fifth magnitude are now becoming visible.

In the case of ᶜIsh̲ā' and Ṣubḥ, the moment of sunset can generally be ascertained from the vantage of a minaret and the twilight phenomena are likewise readily observable.[25] As for the limitation, Ibn Yūnus limits twilight as 'the first appearance of the true morning twilight glow' and 'the disappearance of the red twilight glow'.[26]

2.4 Some Issues and Criteria[27]

The motivation to identify the value of twilight angle comes from Islamic obligation of ṣalāt. In order to determine, dalā'il naqlī signify prayer times with ocular indicators. Even though ḥadīth on black and white threads (which is narrated by ᶜAdī al-Hatim – see footnote n°. 9, p. 8), to the author's understanding there is no need to measure up to that level as this work intend to. None of his sayings are contradicting but verify each other, yet he shows another choice of measurement that is by the value of the twilight angle.

With full understanding that a stated phenomena occur at a certain angle and in this dissertation, 'criteria' as a term being used to show varying value from the parameters that depends on few factors such as latitude of observer, seasonal factor and so on. From these parameters[28] it becomes criteria and from the criteria becomes conventions to use in various regions. Fixed twilight angle as convened is a must quantity to compute ᶜIsh̲ā' and Ṣubḥ times.

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[25] *Op. cit.* King (2004), p. 206.
[26] *Op. cit.* Goldstein (1985), pp. 105-107.
[27] King (1986).
[28] Fix quality but its value varies. In this case, shafaq al-aḥmar & shafaq al-abyaḍ and fajr al-kādhib & fajr al-ṣādiq for ᶜIshā' and Ṣubḥ respectively.

With prescribed prayer times conditions and observations done by astronomers such as Ibn Mu^cādh, al-Bīrūnī, al-Qāyinī, Ibn Yūnus etc. Ibn al-Shāṭir adopted various value for each prayer times such as 17° for ᶜIshā' and 16°, 19° and 20° for Ṣubḥ for different manuscript (which means asymmetry).[29] In the following list are the criteria used by almost the whole world for both prayer times:

a. Sun being 15° below horizon[30]
b. Sun being 16° below horizon[31]
c. Sun being 17° below horizon[32]
d. Sun being 17.5° below horizon[33]
e. Sun being 18° below horizon[34]
f. Sun being 19° below horizon[35]
g. Sun being 19.5° below horizon
h. Sun being 20° below horizon[36]
i. 90 minutes before sunrise and 90 minutes after sunset[37]
j. 120 minutes after sunset[38]
k. Function of latitude and the day of the year (seasons)[39]
l. Recitation between 60 to 100 ayāt of the al-Qur'ān[40]

Currently there are still some discussions on which twilight angle should be used. General ᶜIshā' and Ṣubḥ computations[41] in the next section has no opposition except the values of Z which is the value of the twilight angle that become one of the most speculating dilemma around the Islamic world. Officially JAKIM accepts 18° and 20° for ᶜIshā' and Ṣubḥ respectively. In addition, ICOP[42] serve as virtual concourse of Muslim from all

[29] Goldstein (1985).
[30] Islamic Society of North America (ISNA) for both prayer times.
[31] Al-Marrākushī for ᶜIshā', Ibn al-Shāṭir for Ṣubḥ
[32] Ibn Yūnus and Ibn al-Shāṭir for ᶜIshā', *ibid.* King (1986), pt. IX, pp. 365-368, pt. X, pp. 77-78.
[33] Al-Bīrūnī. *op. cit.* Kennedy (1983), p. 306 and accepted by Egypt General Authority of Survey for ᶜIshā'.
[34] Najm al-Dīn, Ḥabash (ca. 850), al-Nayrīzī (ca. 900), al-Bīrūnī (ca. 1025), Ibn Muᶜādh and Ulum Islamiah University of Karachi for both prayer times.
[35] Ibn Yūnus and Ibn al-Shāṭir for Ṣubḥ
[36] Al-Marrākushī and Ibn al-Shāṭir for Ṣubḥ
[37] United of Arab Emirates for ᶜIshā'.
[38] University of Ummul Qura, Saudi Arabia for ᶜIshā' in Ramaḍān.
[39] Khalid Shaukat, Hizbul Ulama UK. Chiplonkar & Kulkarni (1959) and Tyson & Gal (1993).
[40] Translation of Ṣāḥīḥ Bukhārī. Vol. 1, Book 10, Number 516 from web http://www.usc.edu/dept/MSA/fundamentals/hadithsunnah/bukhari accessed 1 January 2008.
[41] Taken from JAKIM (Department of Islamic Development Malaysia). According Haji Abdul Ghani there are 37 methods of calculations, Abdul Ghani (1999).
[42] International Crescent Observation Project.

around the world to agitate those emerging issues concerning prayer times such as ḥadīth on redness compared to whiteness of sky for ʿIshā’, overlapping of fajr al-kādhib and fajr al-ṣādiq (on al-Bīrūnī’s al-Qānūn al-Masʿūdī).

To make things easy, tables were built for regulating times of prayer. This has been known to be used from the tenth century. Most of Muslim astronomers have their own corpus of tables for timekeeping. Tables computed by Ibn Yūnus for the latitude of Cairo contained numerous functions such as duration of evening and morning twilight, and total darkness are also were tabulated for each degree of the solar longitude. Nowadays, prayer times are also regulated by tables, and also computed for each day by modern methods either in almanacs, pocket diaries or prepared by Islamic authoritative department as requested.

Undeniable fact is that some contemporary Muslim astronomers are influenced by the twilight definitions from Her Majesty Nautical Almanac Office, RGO[43], thus giving a few disagreements on that regard. There are many efforts made on sky twilight measurement using a photometer and a CCD camera, yet they are not specific on prayer times determination.[44] While for this research, the author considers from two pertinent reflections i.e. Islamic and scientific considerations which the later is “Islamic” in the deepest sense of the word.

2.5 General ʿIshā’ and Ṣubḥ Times Computations[45]

The criteria values play a vital role for computing the prayer times. In the preceding section we present the simplified version of the basis for the computation of ʿIshā’ and Ṣubḥ prayer times to avoid complication. In order to calculate those prayer times, quantities such as coordinate of observer, standard longitude and declination values are provided. As prayer times are based on location, it is required to know the Local Standard Time. Whilst the Sun at noon i.e. the centre of the Sun passes the Local Celestial Meridian,[46] the Local

[43] Royal Greenwich Observatory, Cambridge.
[44] Nawar & Mikhail, Chiplonkar & Kulkarni (1959), Ugolnikov et al (2004), Tyson & Gal (1993).
[45] Calculation using Falak Syarie Almanac which based on fundamental formula of spherical trigonometry. GHA & declinations values are from the almanac at web http://www.islam.gov.my accessed 15 August 2007. Smart (1965), pp. 1-156. Muneer, King (1986), pt. X, pp. 76-77. Duffett-Smith (1981), pp. 90-91.
[46] Location or site.

Hour Angle (LHA) equal 0h or 24h.[47] The connection between LHA and Greenwich Hour Angle (GHA) is as shown below:

$$GHA = LHA - \lambda_L \tag{2.1}$$

The correlation linking GHA and Local Standard Time (LST) is:

$$LST = \frac{GHA - GHA\,@\,h_1}{GHA\,@\,h_2 - GHA\,@\,h_1} \times 24h \tag{2.2}$$

Where, GHA @ h_1 = Greenwich hour time 0h on calculated date
And, GHA @ h_2 = Greenwich hour time 0h + 24h

Then we obtain $\Delta\delta$[48] by estimating the time for ᶜIshā' and Ṣubḥ which is around 8 pm and 6 am respectively as follow:-

$$\Delta\delta = \frac{\text{Estimation time}}{24} \times (\delta_{24} - \delta_0) \tag{2.3}$$

Next, we define Z[49] as the twilight angle for ᶜIshā' and Ṣubḥ. After that, hour angle is calculated using this equation:-

$$t = \cos^{-1}\left[\frac{\cos Z_A - \sin\delta_A \sin\phi_L}{\cos\delta_A \cos\phi_L}\right] \tag{2.4}$$

Therefore ᶜIshā' or Ṣubḥ times = LST + t (2.5)

To conclude, the twilight angle is important and so does its value. Variable values give different result to prayer times for different location. Therefore an example is provided in Appendix A.

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[47] If it was referred to previous day.
[48] Increment of declination.
[49] This is what the author termed as criteria.

2.6 Relevance of Detectors

In this sub-chapter, the author opts to explain deliberately the relevancy of detectors and this also serves as an introduction for detectors. Further elucidation on performance of detectors is in Chapter 3.

a. The Human Eye

The author choose human eye as a detector based on traditional proof (dalīl naqlī) and rational proof (dalīl aqlī). This is undoubtedly for dalīl naqlī, as for dalīl aqlī it is taken from al-Jurjani's Sharḥ al-Mawāqif i.e. sense perception (mushahadah) as one of the six varieties of premises in certain knowledge and the stated parameters are ocular proof. Furthermore, Ibn Raḥīq begins his treatise by asserting that the times of prayer should be determined by observation with one's own eyes (al-ᶜiyān wa al-raṣad). He states that he will follow the ḥadīth about the Archangel Gabriel recorded in the canonical collections of Muslim and al-Bukhārī. Physiologically, the eye is fit to be the most suitable sense due to its cells sensitivity to light and this will be discussed in Chapter 3.

b. Sky Quality Meter (SQM)

The Sky Quality Meter was adapted for its compliance performance in this research. It was chosen due to its photometric[50] unit; that is the magnitudes which use the standard response curve similar o that of the eye. The most important to understand, this is not a spot meter because it accepts light from a wide cone-roughly 80 degrees diameter. It also features both effects of dark frequency and microcontroller oscillator is removed. Furthermore, the brightness of the numeric LED display has two (automatic) settings which under dark skies, we will not have our dark adaptation ruined by use of the SQM and under urban skies, the display will be correspondingly brighter.[51]

[50] Photometry is the measurement of the intensity of electromagnetic radiation in photometric units.
[51] From web www.taosinc.com accessed 25 September 2007.

2.7 Conclusion

This chapter explains the current of ᶜilm al-miqāt which beneath it lays many theories. It only covers mainly on twilight regardless the implementation of observation. The connection between sub-chapters is as illustrated in Figure 2.4.

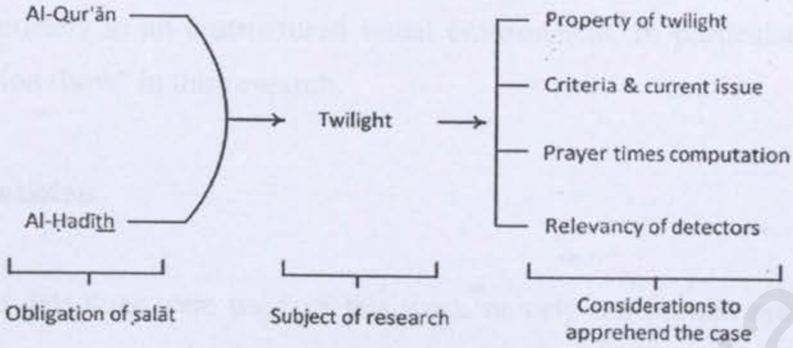

Figure 2.4: Correlation in this chapter

Chapter 3 Methodology

3.1 Introduction

This chapter describes the instrumentation and observing techniques for identifying prayer times parameters in an unstructured visual environment. In particular, this chapter answers the question 'how' in this research.

3.2 Instrumentation

There are two detectors were used in this work namely the human eye and the Sky Quality Meter and the stimulus is of course light and both represent logarithmic changes.

a. The Human Eye

The most important fact to note is that the eye operates between 380 and 760 nm which is visible to us and vision occurs the rays of light enters the eye.[1] In this case the eye operates under the twilight state which it encounters dark adaptation condition.[2] Dark adaptation refers to how the eye recovers its sensitivity in the dark following exposure to bright light. The eye to perceive colour, determined by three dimensions namely hue, saturation and brightness.[3] Figure 3.1 shows some colour samples, all with the same hue but with different levels of brightness and saturation. Anatomically the photoreceptors in the retina detect the presence of light. Humans were blessed because of the two types of photoreceptors i.e. cones[4] and rods[5] mechanisms which provides photopic and scotopic (night) vision respectively.

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[1] Ibn al-Haytham theory on light intromission. Lindberg (1976), pp.58-86.

[2] Adaptation is decreasing in a great of number of stimulus' spike instantly. The Purkinje effect (sometimes called the Purkinje shift or dark adaptation) is the tendency for the peak sensitivity of the human eye to shift toward the blue end of the color spectrum at low illumination levels. Atrens & Curthoys (1995), p. 53.

[3] Hue: The visible spectrum displays the range of hues that our eyes can detect. Saturation: Relative purity of the light that is being perceived. Brightness: If the intensity of the electromagnetic radiation is increased, the apparent brightness increases too. Carlson (2008), pp. 155-156.

[4] Cone cells (approximately 6 million) are most prevalent in the central retina (fovea) also sensitive to moderate-to-high levels of light but retain their function up to high illumination via use of the pigment Iodopsin. Besides provide information about hue and excellent acuity, *op. cit.* Carlson (2008), p. 157.

[5] Rod cells (approximately120 million) are most prevalent in peripheral retina. It also sensitive to low levels of light depends on the amount of Rhodopsin present which is itself generated within the cells. Rhodopsin is extremely sensitive to light, and enables night-vision. Exposed to white light, the pigment immediately bleaches, and it takes about 30 minutes to regenerate fully in humans. It provide monochromatic information and poor acuity, *ibid.* p. 157.

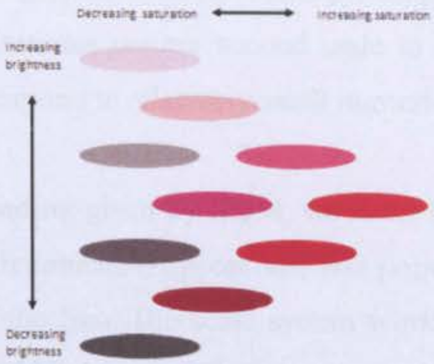

Figure 3.1: Example of colours with the same dominant wavelength (hue) but different levels of saturations or brightness

At twilight these two mechanisms are operating together in the mesopic range, as there is not an abrupt transition between the two mechanisms. This is the reason why we can not notice small changes of light.[6] Since at twilight are surrounded with a mixture of colours thus for its detection, three types of cone cells present within the retina to cover the visible spectrum. This is because each type is sensitive to a different range of wavelengths with maximums corresponding to red (long), green (medium) or blue (short).

b. The Sky Quality Meter (SQM)

The Unihedron Sky Quality Meter was designed by Anthony Tekatch and Doug Walsh.[7] Beside the readings, temperature, model and serial number are also displayed. The SQM used light-to-frequency silicon photodiode; TSL237S[8] as its sensor. The sensor is covered with a HOYA CM-500 filter to block near-infrared light. It is calibrated using a NIST light meter and the absolute precision is ±10% (±0.10 mag/arcsec^2). The SQM is specially built to report accurate sky brightness.

It measures the brightness of the night sky in magnitudes per square arc second. The magnitude is not monochromatic, the sensitivity of the detector varies according to the wavelength and the type of detector. For this reason, it is necessary to specify how the magnitude is measured in order for the value to be meaningful. The V band was chosen for

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[6] See Lindberg (1976), pp. 58-86.

[7] From web http://www.unihedron.com, accessed on 14 July 2007.

[8] TSL237 has been temperature compensated for the ultraviolet-to-visible range of 320 nm to 700 nm and responds over the light range of 320 nm to 1050 nm. Although it is very close to human eye response, the designer deposits the Hoya CM-500 filter to cuts off the entire infrared part of the spectrum. From web http://www.taosinc.com, accessed on 28 August 2007.

spectral purposes and gives magnitudes closely corresponding to those seen by the light-adapted human eye. The magnitudes per arc second scale is logarithmic, therefore large changes in sky brightness correspond to relatively small numerical changes.

In order to interpret the reading given by SQM, we must know principle of the scale. The crude scale origin in the Hellenistic (Hipparchus) was popularized by Ptolemy and did not measure the magnitude of the Sun. The scale system works by defining a typical first magnitude star as a star that is 100 times as bright as a typical sixth magnitude star.[9] Thus the difference in brightness between magnitude (m) is a factor of 2.512. Comparing a fourth magnitude star with a fifth magnitude star, a fourth magnitude star is about 2.5 times as bright as a fifth magnitude star.[10]

In this case, we are not measuring magnitude of the star but sky. If the reading gives value for example, 19.82 (mag) which lies between 19 and 20 (Fig. 3.2), it means the sky is moderately dark. When the reading shows value 23 or above, it means the sky is truly dark (for moonless night or rural area). If the reading gives value 17 or below than that, it means the sky is bright (in presence of light source such as moon or street lamp). Thumb of rule, the greater the magnitude number the darker the sky. The schematic diagram below shows the interpretation of the readings:

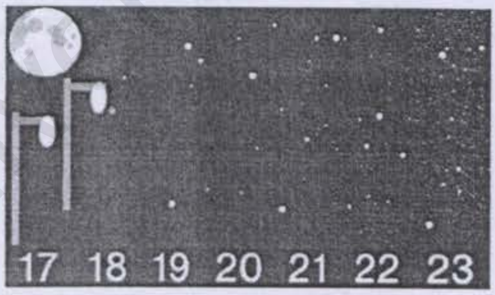

Figure 3.2: Schematic diagram shows interpretation of readings

c. Accessories

i. Finder scope – to guide SQM to point free-obstruction horizon
ii. Binoculars – to observe details on sky and cloud formation and direction

[9] Formalized by Norman R. Pogson in 1856.
[10] Budding & Demircan (2007) and from web http://en.wikipedia.org.wiki/Apparent_magnitude accessed 25 December 2007.

iii. Travel Barometer – as weather forecast

iv. Hygrometer – to monitor humidity

v. Thermometer – to monitor temperature

vi. Tripod, 10" x 10" Wooden Platform & Leveler – provide stability

vii. Compass – to assist direction

viii. Mirror – to reflection opposite sky

ix. Camera – to capture the scenes

3.2.1 Instrumentation Performance

This section provided performance and limitation of each instrument. It was laboratory tested and was proven to comply for this research.

a. Human Eye

According to Hecht, Schlaer and Pirenne Experiment[11] that a subject is more sensitive to dim flashes[12] of light if he has been in the dark for a period of time than if he has just come in out of the light. It is a common experience to be almost blind when first entering a movie theater but to be able to see quite a lot after 5 or 10 minutes. This phenomenon is dark adaptation. A Threads Experiment was conducted to verify the correlation between the human eye and SQM.[13] From the experiment, the human eye can distinguish white and black threads when SQM readings are 20 to 22 magnitudes per arc second for ambient light. On the other hand, the human sense i.e. eye and conscious mind according William James:[14]

> Millions of items of the outward order are present to my senses which never properly enter into my experience. Why? Because they have no interest for me. *My experience is what I agree to attend to*. Only those items which I notice shape my mind–without selective interest, experience is an utter chaos.

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[11] Cornsweet (1970), pp. 6-26.

[12] Known as Troxler Phenomenon. Human eye sensitive when there is moving object.This was proven by experienced astronomer. According to them, elusive faint light source (such as nebulae) is much easy to notice when it moves (and it is impossible to move the object) so they panned the telescope. Arago the astronomer said epigrammatically that "in order to see a dim star one must not 'look' at it". Davson (1962), p. 25. From web http://stjarnhimlen.se/com/radfaq.html accessed 28 August 2007.

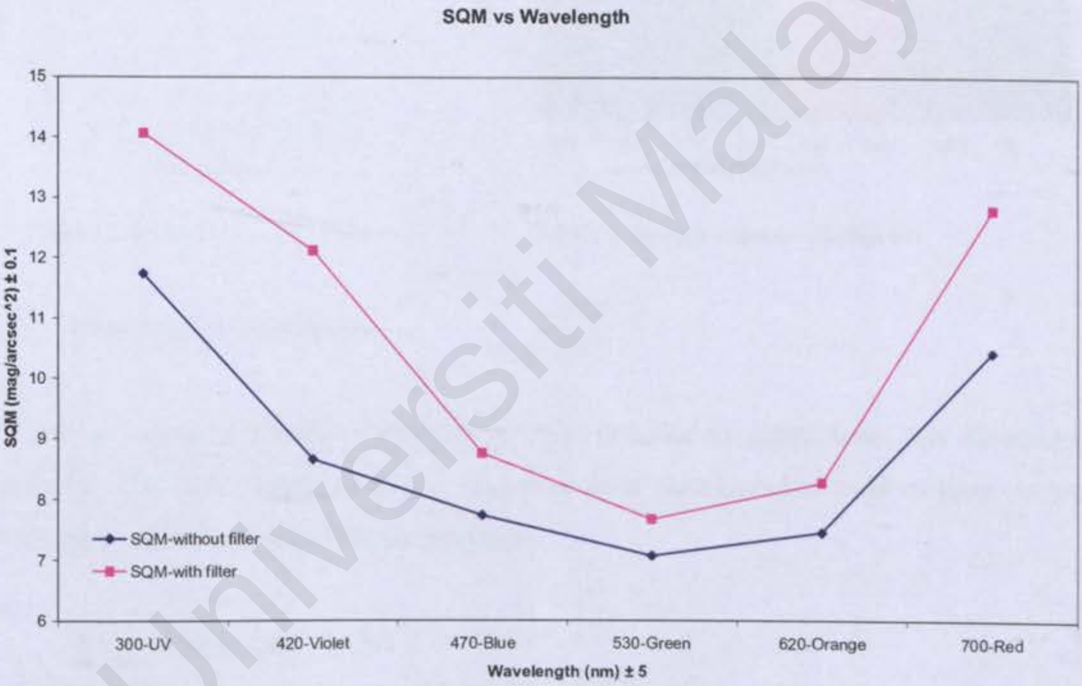
[13] Instigated from ḥadīth Prophet Muḥammad p.b.u.h on white and black threads.

[14] An eminent American philosopher and psychologist. From web http://plato.stanford.edu/entries/james accessed on 14 July 2007.

In this case, the human eye system solitarily can discriminate whether it receives light or not. The connection between the eye and the brain which physiologically and psychologically have the ability to form what we want to see in our mind.[15]. By this mean observer must be careful not trap into the snare.

b. SQM

In order to understand the measurements, it was tested and characterized by checking the acceptance angle, linearity and spectral responsivity.[16]. Photoelectric effects experiments were done at Science Foundation Centre of Universiti Malaya and 1st Year Laboratory of Physics Department to check its linearity.

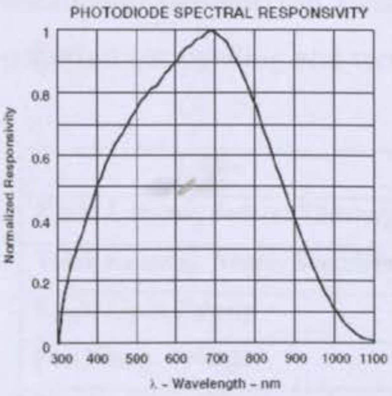


Graph 3.1: Graph of SQM versus wavelength

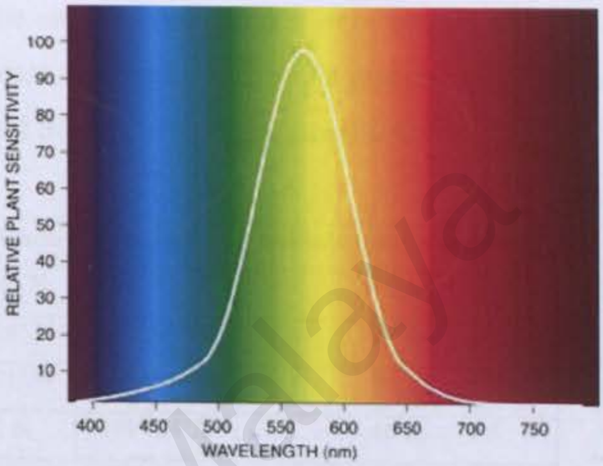
As illustrated in Graph 3.1, shows the value of y (SQM) declines quite considerably and then rises steeply with wavelength. A trough is formed on the graph as evidence of SQM

[15]. Atrens & Curthoys (1995), Carlson (2008), Kendal *et al* (2000).
[16]. Cinzano (2005), pp. 1-14.

characteristic to behave when certain colours (wavelength) strike on its sensor. Both values have a high correlation and clearly when twilight colours (lower wavelength colours) hit the sensor, it consistently gives high readings – see Figure 3.2. The obtained response curve of our SQM multiplying the spectral responsivity of the TAOS TSL237 photodiode by the transmittance of the Hoya CM-500 filter, both provided by manufacturers – see Graph 3.2 which have a high correlation with human eye spectral response graph (Graph 3.3).



Graph 3.2: Spectral response of SQM



Graph 3.3: Spectral response of human eye

3.3 Observation Technique

This sub-chapter presents properties of light in order to comprehend this observation technique. The author categorized this section to three parts based on track of time viz. pre-observation, observation and post-observation.

3.3.1 Observing Target

The observing target is light of the Sun that passes through the Earth's atmosphere. Light, or visible light, is electromagnetic radiation of wavelength that are visible to the human eye (about 400–700 nm). Light is composed of particles called photons. This follows light property which is referred to as wave–particle duality. From physics perspective, visible light consists of electromagnetic radiation and theoretically best characterized by its frequency; ν and practically by its wavelength; λ and both are related as $\nu = c/\lambda$ where c is velocity of light.[17]

3.3.2 Pre-Observational

The brightness of twilight sky observations were carried out at various places from May 2007 until April 2008 intermittently in accordance of photometric night. The author chooses a few places around Malaysia. The sites of observations were chosen according to best obstruction-free horizon (west and east for ^{c}Ishā’ and Ṣubḥ respectively), the least light-pollution surrounding and were carried out in the city peripheral below:

Site	Latitude	Longitude	Altitude (above sea level)
Kuala Lumpur, Federal Territory	3° 9’ N	101° 41’ E	60 m
Teluk Kemang, Negeri Sembilan	2° 28’ N	101° 52’ E	27 m
Kuala Lipis, Pahang	4° 11’ N	102° 3’E	75 m
Port Klang, Selangor	3° N	101° 24’E	46 m
Merang, Terengganu	5° 31’ N	102° 57’ E	42 m

Table 3.1: Coordinate and altitude of site

The instruments axis was directed to the horizon depending on which prayer times’ sky being measured.[18] For ^{c}Ishā’, observation it was performed as soon as the Sun sets and extend approximately 1½ to 1¾ hours. For Ṣubḥ, the author expected 1½ to 1¾ hours before the estimated time. The stated period were excluding the preparation time. Measurements from the instruments were taken in simultaneous theoretically.

3.3.3 Observation

The measurement was performed several times with the aid of synchronized timer. Forms for Sunnah and scientific approach were prepared to assist categorizing the data from different instrument.

[17] Davson (1962), p. 3, Waqar (1999), pp. 175-182.
[18] It is much better if the instruments were pointed based on azimuth of Sun direction.

a. Human eye

Since the human eye is a stand-alone instrument, there is no need of supporting equipment. Yet the most essential is prior to commencing observing the elusive phenomenon, the eye must be in rest condition. It is important for the observer to avoid looking at bright light due to dark adaptation. The field of view of normal human eyes is 140°, even with this limitation the eye work very best, interalia instrument. Observer requires to log swiftly any significant changes of the sky condition at certain time on the provided form. Another item of concern to the observer is the type of cloud formation[19] at the time of data taking. Besides observer should acclimatize with Bortle Dark Sky Scale[20] as it quantifies the observability of astronomical object and the interference caused by light pollution and sky glow.

b. SQM

SQM is parallel-arranged together with a 1.5" finder scope (pointed to the west/east horizon) on a flat platform which being previously attached to a steady tripod (Fig. 3.3 and 3.4). In averting unwanted light, a special hood was used in front of the detectors. The equipments were arranged suitable to the author. Data were taken in two minutes interval. As for the SQM, the observer must press a button in order to activate the detector and then wait for a few second to obtain a reading. The readings were then logged into appropriate forms.

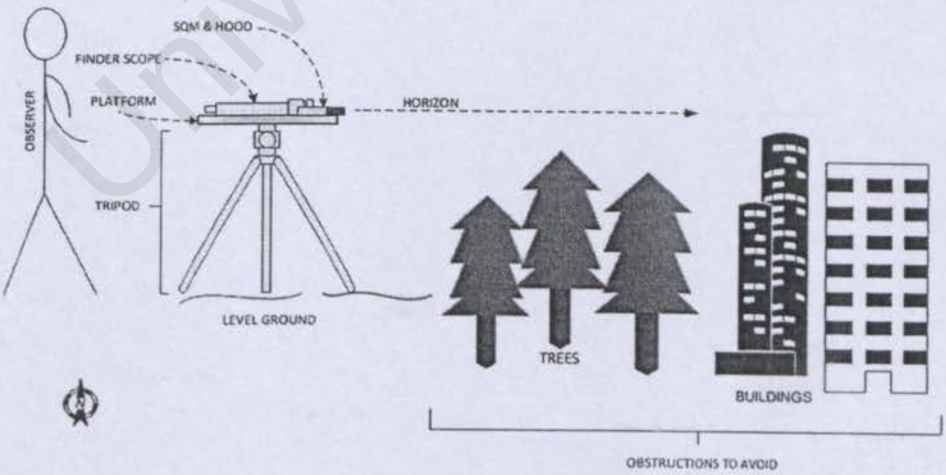


Figure 3.3: Side view of observation

[19] Affect colour of sky which involving refracted atmosphere.
[20] Idiosyncratic scale as benchmark is invented by John Bortle.

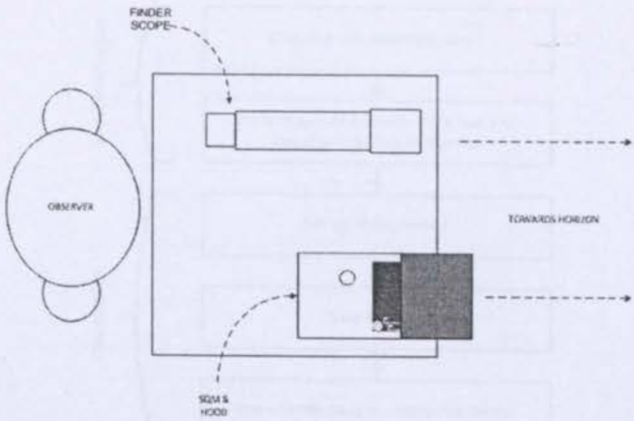


Figure 3.4: Aerial view of instruments

3.3.4 Post-Observation

Commercial software for the Windows XP operating system was selected that allowed fully automated data processing. Since the input is in the form of numerical data, the author used Microsoft Excel software to transform these data into a spreadsheet after taking into account all the errors.[21] For qualitative data, on the other hand the author performed critical evaluation for the sceneries. For standard values of various quantities such as altitude of the Sun, the author used software called TheSky version 5. After much comparison and evaluation, the results are as presented in chapter 4. A summary of the process is illustrated in Figure 3.5.

[21] Ghosh (2007), pp. 10-24, Meeus, pp. 35-46.

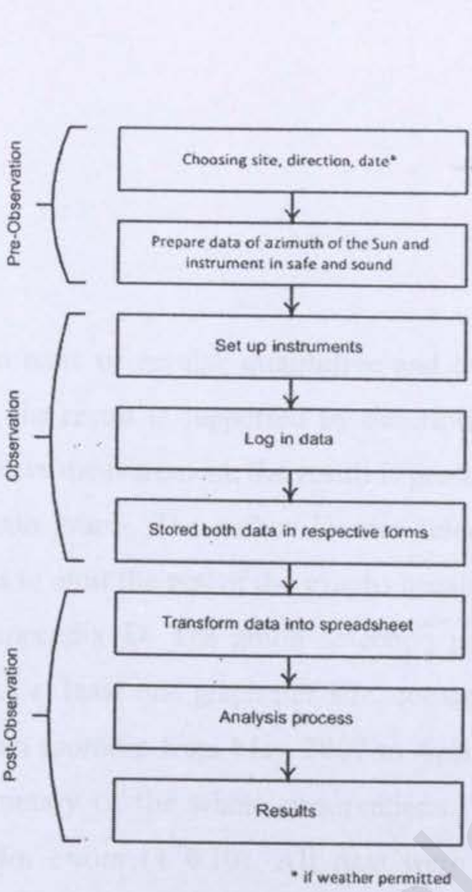


Figure 3.5: Flow chart of process

Chapter 4 Results

4.1 Introduction

This chapter presents two parts of results; qualitative and quantitative measurements. For qualitative measurement, the result is supported by descriptive figure and photograph (Appendix E). As for quantitative measurement, the result is presented in form of numerical data which later transform into graph. The author locates selected graphs (seven of 29 graphs) in this chapter and has to omit the rest of the graphs because the data show a similar pattern but still located in Appendix D. The graph selection is based on best-compared graph which is according: pick at least one graph per site, consist at least three graphs per prayer time and graphs is taken sporadic from May 2007 to April 2008. At the end of this chapter, there is table of summary of the whole observations. The tabulated data of 29 observations were analysed for errors (± 0.10). All data were for SQM's value are in magnitudes per square arc second (mag/arcsec^2) and altitude of the Sun in degree.

4.2 Results

A – Qualitative

i. The beginning of ᶜIshā' is most indicated by the disappearance of shafaq al-abyaḍ rather than shafaq al-aḥmar.

ii. The appearance of fajr al-kā<u>dh</u>ib were rarely evident, most of it were noticed by the beginning of fajr al-ṣādiq. Fajr al-kā<u>dh</u>ib is faint and hardly perceptible in the form of vertical light of the letter"V" (with no certain border). While fajr al-ṣādiq is the noticeable horizontal light spreading from north to south.

iii. The twilight colours were observed in the west sky and along the horizon, lays a few bands of colours horizontally. The colours were from below upwards generally when was Sun at a certain degree below horizon (Fig. 4.1):

0° – Whitish yellow, orange, yellow, washed grey and blue.

6° – Dark purple, yellowish orange, tinge of crimson, whitish yellow, blue and a bit grey.

12° – Gloomy orange, murky red, maroon, faded blue and dark blue.

18° – Faded blue, royal blue, black and coal black.

20° – Blue and blue black.

26° – Royal blue, blue black and black.

28° – Navy blue and night black.

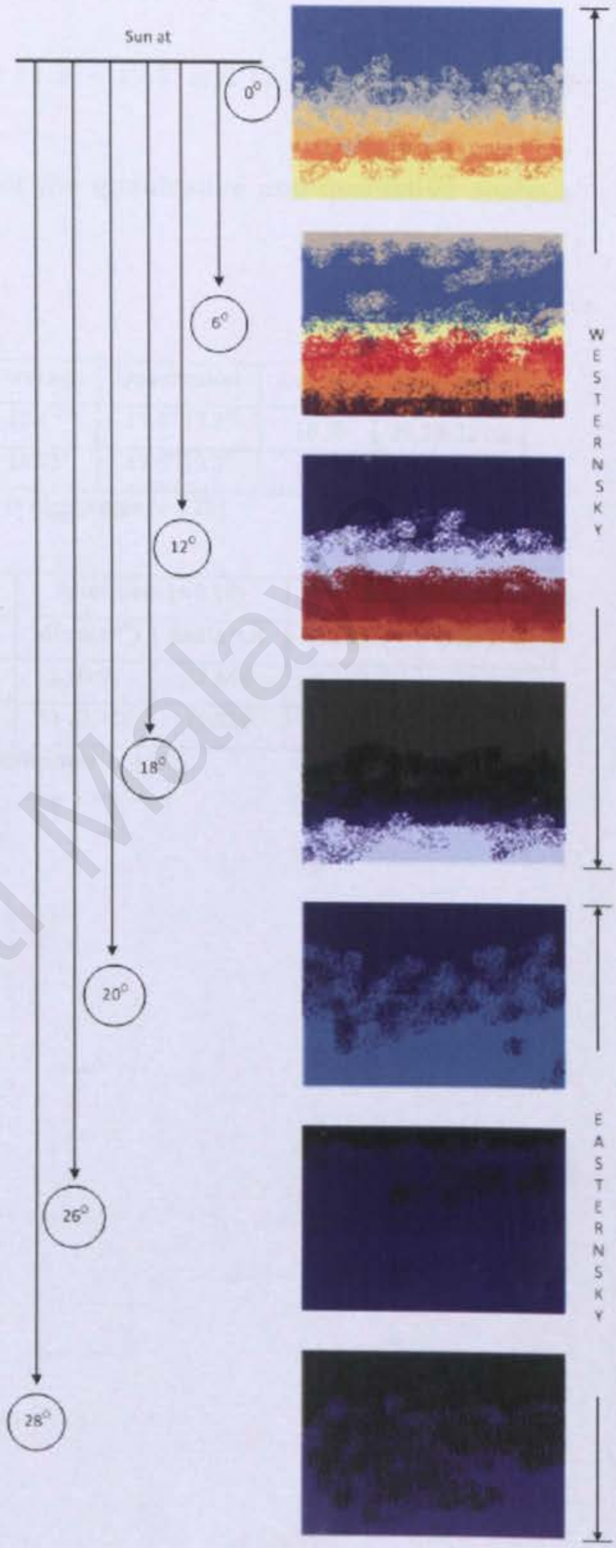


Figure 4.1: Sky colours strata

B – Quantitative

iv. Both criteria fluctuate between range 17.3° – 19.5° and 17.5° – 20° for ᶜIshā' and Ṣubḥ respectively.

v. The percentages of the accuracies for the quantitative and qualitative analysis were 0.5% and 0.8% respectively.

Prayer times	Theory	Average	Qualitative	Average	Quantitative	Average	Magnitude
ᶜIshā'	17.3°-19.2°	18.25°	17.4°-19.5°	18.45°	17.4°-19.2°	18.3°	20.23-22.02
Ṣubḥ	17.6°-19.9°	18.75°	17.5°-20°	18.75°	17.6°-19.8°	18.7°	21.52-22.10

Table 4.1: Range comparison twilight angle (± 0.10)

Time Difference	Maximum (± 0.10)		Minimum (± 0.10)		Average (± 0.10)	
	Minute (°)	Sun's Alt.	Minute (°)	Sun's Alt.	Minute (°)	Sun's Alt.
Shafaq al-aḥmar – shafaq al-abyaḍ	15 (3.75)	18.707	2 (0.5)	17.646	8.5 (2.2)	18.177
Fajr al-kāḏhib – fajr al-ṣādiq	23 (5.75)	19.428	11 (2.75)	19.329	17 (4.25)	19.379

Table 4.2: Time difference

a. Selected numerical data of SQM

Time	SQM	Altitude
04:58	22.16	-29.918
05:00	22.13	-29.002
05:02	22.09	-28.544
05:04	22.12	-28.085
05:06	22.14	-27.626
05:08	22.21	-27.166
05:10	22.15	-26.705
05:12	22.15	-26.244
05:14	22.17	-25.783
05:16	22.05	-25.321
05:18	22.13	-24.858
05:20	22.11	-24.396
05:22	22.12	-23.933
05:24	22.18	-23.469
05:26	22.12	-23.006
05:28	22.13	-22.541
05:30	22.12	-22.077
05:32	22.1	-21.611
05:34	22.15	-21.146
05:38	22.14	-20.68
05:40	22.15	-20.214
05:42	22.11	-19.748
05:45	21.46	-18.813
05:46	21.3	-18.346
05:48	22.1	-17.578
05:50	21.47	-17.176
05:52	21.44	-16.941
05:54	21.41	-16.473
05:56	21.41	-16.004
06:01	21.38	-15.534
06:02	21.37	-15.065
06:04	21.26	-14.595
06:06	21.17	-13.419
06:08	21.11	-13.184
06:10	20.86	-12.713
06:12	20.19	-12.242
06:14	20.44	-11.77
06:16	21.04	-11.299
06:18	19.6	-10.827
06:20	19.2	-10.355
06:22	19.75	-9.883
06:24	17.85	-9.41
06:26	17.34	-8.938
06:28	19.47	-8.465
06:30	16.17	-7.994
06:32	15.54	-7.519
06:34	15.11	-7.046
06:38	14.49	-6.58
06:40	13.95	-6.098
06:42	13.46	-5.624
06:44	12.82	-4.676
06:46	12.28	-4.201
06:48	11.75	-3.727
06:50	11.34	-3.251
06:52	10.99	-2.777
06:54	10.66	-2.302
06:56	10.41	-1.827
06:58	10.11	-1.351
07:00	9.9	-0.833
07:02	9.59	0.104
07:04	9.33	0.401
07:06	9.08	0.551
07:08	8.8	1.027
07:10	8.78	1.502
07:12	8.62	1.977
07:14	8.45	2.452
07:16	8.32	2.927
07:18	8.21	3.402
07:20	8.14	3.877

Table 4.3: Ṣubḥ at Merang, 8 May 2007

Time	SQM	Altitude
19:11	8.84	2.189
19:13	8.41	1.706
19:15	8.75	1.222
19:17	8.84	0.738
19:19	9.17	0.254
19:21	9.36	-0.228
19:23	9.65	-0.711
19:25	10.02	-1.194
19:27	10.63	-1.677
19:29	10.83	-2.16
19:31	11.2	-2.643
19:33	11.89	-3.126
19:35	12.58	-3.609
19:37	12.83	-4.092
19:39	13.5	-4.574
19:41	14.75	-5.567
19:43	15.33	-6.022
19:45	15.94	-6.505
19:47	16.59	-6.987
19:53	17.58	-7.951
19:55	17.97	-8.43
19:57	18.56	-8.916
19:59	18.73	-9.397
20:01	19.09	-9.88
20:03	19.69	-10.361
20:05	20.07	-10.84
20:07	20.43	-11.324
20:09	20.68	-11.805
20:11	20.9	-12.28
20:13	20.09	-12.708
20:15	21.24	-13.249
20:17	21.59	-13.73
20:19	21.38	-14.211
20:21	21.42	-14.691
20:23	21.41	-15.172
20:25	21.44	-15.652
20:27	21.48	-16.132
20:29	21.47	-16.612
20:31	21.49	-17.092
20:33	21.48	-17.572
20:35	21.5	-18.052
20:37	21.49	-18.531
20:39	22.48	-19.011
20:43	22.31	-19.969
20:45	22.46	-20.447
20:47	22.32	-20.926
20:49	22.39	-21.405
21:01	22.46	-21.884
21:03	22.45	-22.363
21:05	22.44	-22.842

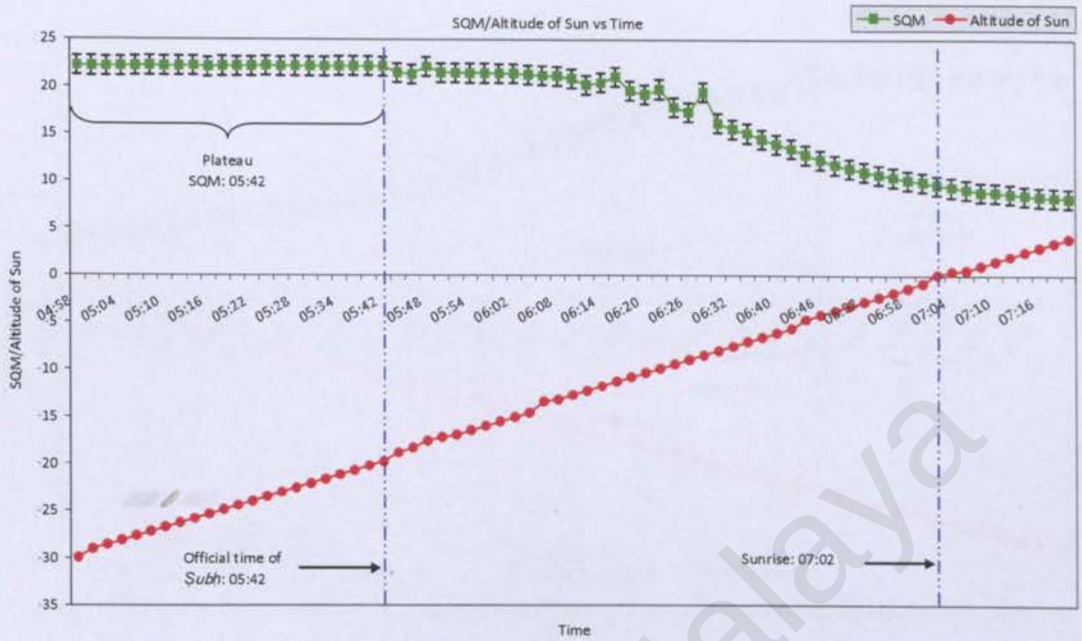
Time	SQM	Altitude
21:07	22.42	-23.321
21:09	22.4	-23.8
21:11	22.45	-24.279
21:13	22.49	-24.758

Table 4.4: ᶜIshā' at Teluk Kemang, 13 August 2007

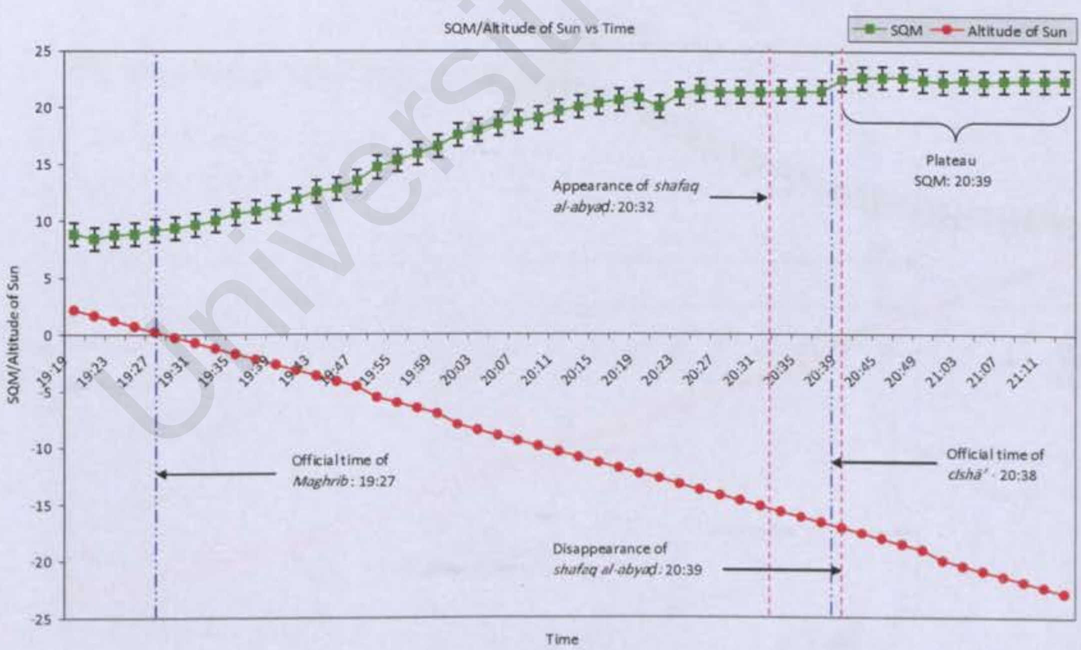
Time	SQM	Altitude
19:10	8.22	2.461
19:12	8.55	1.978
19:14	8.73	1.495
19:18	9.12	1.012
19:22	9.69	0.529
19:24	9.98	0.046
19:26	10.47	-0.956
19:28	10.48	-1.456
19:30	11.24	-1.955
19:32	11.73	-2.454
19:34	12.21	-3.753
19:36	12.65	-4.786
19:38	12.76	-5.752
19:40	14.55	-6.236
19:44	15.44	-6.789
19:46	15.81	-7.686
19:48	16.25	-8.169
19:50	16.66	-8.653
19:52	17.23	-9.136
19:56	17.96	-9.619
19:58	17.99	-10.586
20:00	18.23	-11.553
20:02	18.46	-12.553
20:04	18.55	-13.003
20:06	18.69	-13.487
20:08	18.95	-13.97
20:10	19.11	-14.454
2012	19.12	-14.938
20:14	19.13	-15.422
20:16	19.13	-15.906
20:18	19.23	-16.39
20:20	19.5	-16.874
20:22	19.48	-17.358
20:24	19.36	-17.842
20:26	20.32	-17.927
20:28	20.33	-18.326
20:32	20.32	-18.81
20:34	20.3	-19.03
20:36	20.28	-19.294
20:38	20.23	-19.778
20:40	20.22	-20.262
20:44	20.23	-20.746
20:46	20.21	-21.23
20:48	20.23	-21.714
20:50	20.23	-22.198
20:52	20.24	-22.682
20:54	20.22	-23.166
20:56	20.23	-23.65
20:58	20.21	-24.134
21:00	20.2	-25.393

Table 4.5: ʿIshāʾ at Port Klang, 5 April 2008

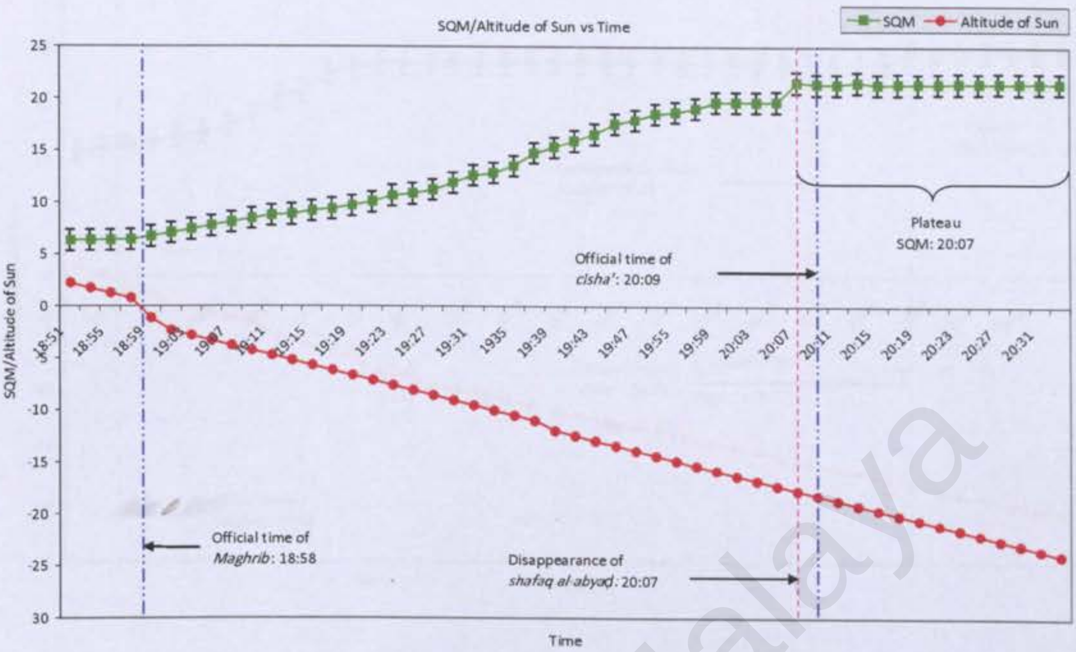
b. Selected graph



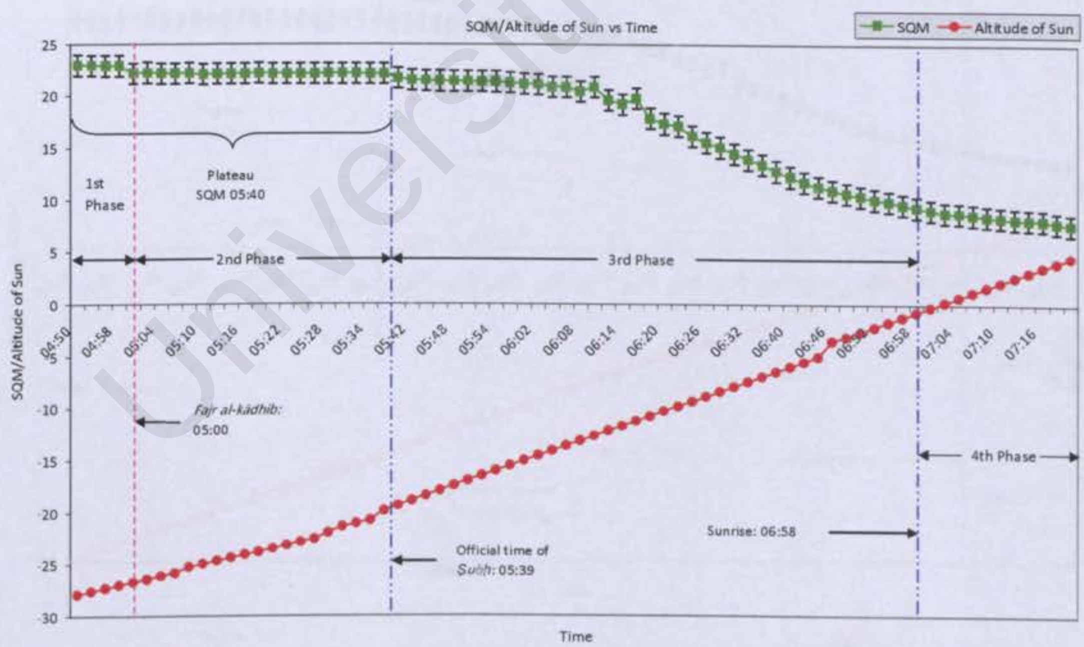
Graph 4.1: Ṣubḥ at Merang, 8 May 2007



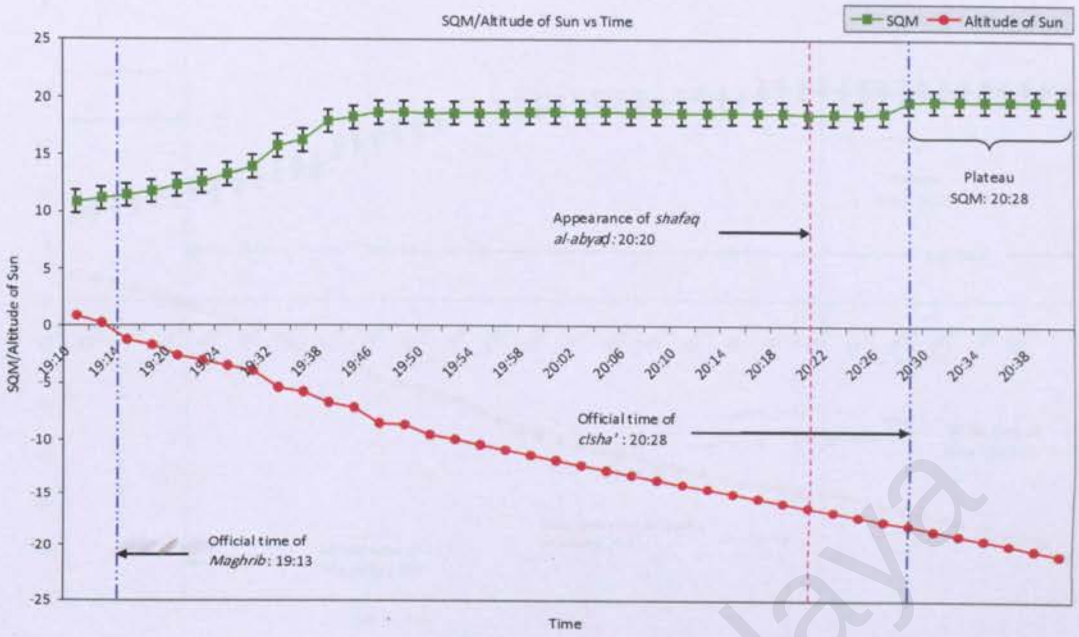
Graph 4.2: ʿI<u>sh</u>āʾ at Teluk Kemang, 13 August 2007



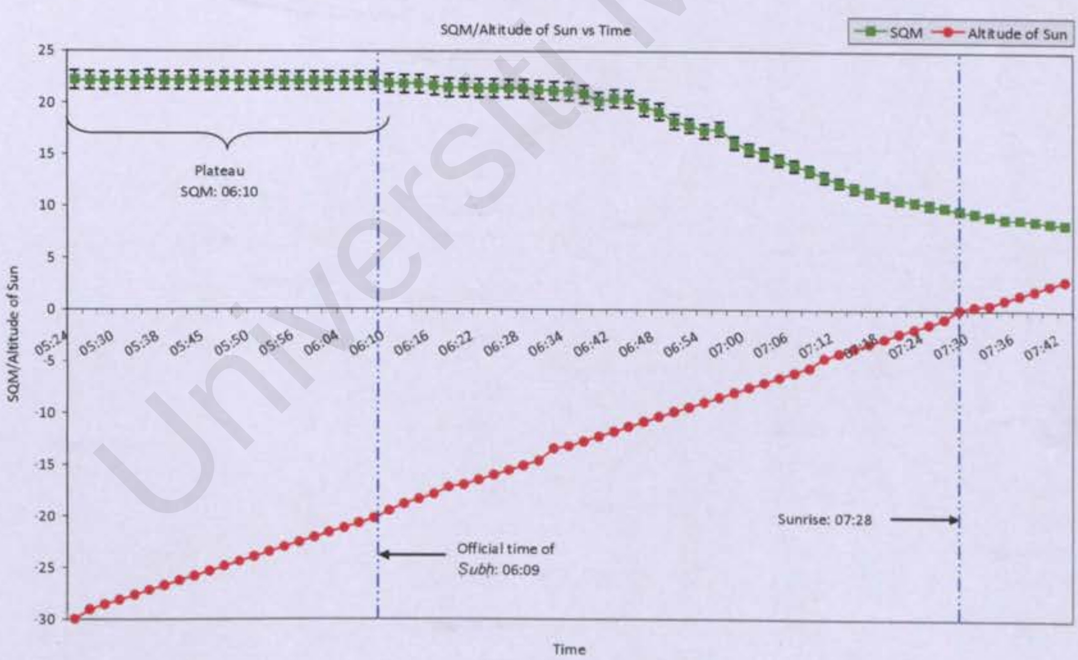
Graph 4.3: ᶜI<u>sh</u>ā' at Kuala Lumpur, 27 October 2007



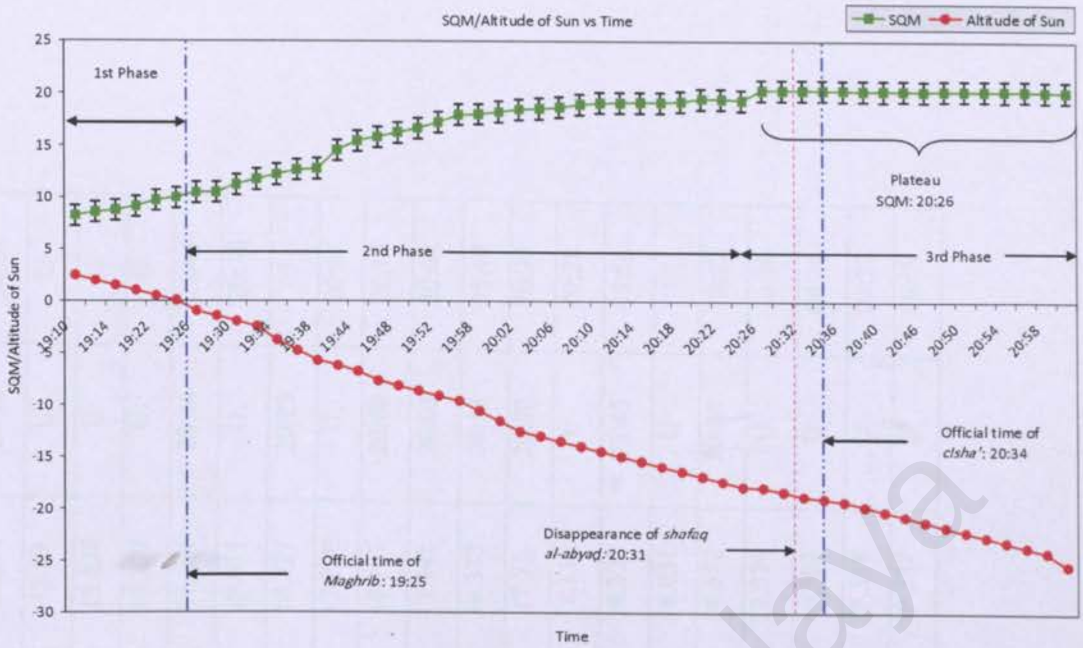
Graph 4.4: Ṣubḥ at Kuala Lipis, 10 November 2007



Graph 4.5: ᶜIshā' at Kuala Lipis, 29 December 2007



Graph 4.6: Ṣubḥ at Kuala Lipis, 9 February 2008



Graph 4.7: ᶜIshā' at Port Klang, 5 April 2008

Date	Location	Theory (± 0.10)			Quantitative (± 0.10)			Qualitative (± 0.10)	
		Sunset/sunrise	Official I/S	Alt.	SQM I/S	Mag.	Alt.	A/a	B/b
8 May 07	M	07:02	05:42	17.518	05:42	22.10	17.578	U	U
		19:19	20:31	17.908	20:32	21.97	18.277	20:28	20:31
18 May 07	TK	19:20	20:33	18.449	20:32	19.69	18.09	U	U
19 May 07		19:21	20:31	18.15	20:34	20.10	18.838	U	U
15 Jun 07		19:25	20:38	17.376	20:40	22.00	18.277	U	U
1 Jul 07	KL	19:28	20:44	9.176	20:44	22.02	19.176	20:34	20:44
13 Aug 07	TK	19:27	20:38	18.416	20:39	22.48	19.011	U	20:39
4 Sep 07	KL	19:19	20:29	18.565	20:30	21.99	18.727	20:23	U
27 Oct 07		18:58	20:09	17.204	20:07	21.27	17.739	U	20:07
5 Nov 07		18:57	20:09	17.365	20:15	21.24	18.707	20:00	20:15
9 Nov 07	KLPS	18:57	20:09	17.448	20:09	21.61	17.448	20:03	20:09
10 Nov 07		06:58	05:39	19.582	05:40	21.68	19.337	04:58	05:40
27 Dec 07	KL	19:12	20:27	17.979	20:26	19.58	17.75	20:20	20:26
29 Dec 07	KLPS	19:13	20:28	18.152	20:28	19.60	18.152	U	20:28
		07:18	05:55	19.557	05:56	20.90	19.329	05:45	05:56
11 Jan 08		07:23	06:01	19.649	06:06	21.47	18.031	U	U
		19:19	20:33	17.892	20:36	20.22	18.572	20:30	20:32
12 Jan 08		19:19	20:33	17.811	20:32	20.15	17.579	U	20:32
9 Feb 08		07:28	06:09	19.745	06:10	21.87	19.503	U	06:10
		19:27	20:38	17.358	20:38	20.23	17.358	U	20:38
10 Feb 08		07:28	06:09	19.764	06:10	20.56	19.537	U	06:09

Date	Location	Sunset/Sunrise	Official I/S	Altitude	SQM I/S	Mag.	Altitude	A/a	B/b
22 Mar 08	KLPS	07:16	06:00	19.17	06:02	21.52	19.748	05:46	06:01
		19:24	20:33	18.177	20:34	20.45	18.426	20:28	20:32
23 Mar 08		07:16	06:00	19.867	06:02	21.50	19.368	U	06:00
23 Mar 08		19:24	20:33	18.227	20:34	20.30	18.476	20:26	20:33
5 Apr 08	PK	19:25	20:34	19.03	20:26	20.32	17.927	U	20:31
6 Apr 08		19:24	20:34	19.06	20:26	20.35	18.326	U	20:32
		07:13	05:57	19.131	05:58	22.13	18.934	05:33	05:56
7 Apr 08		07:13	05:56	19.271	05:56	23.35	18.271	U	05:56

Table 4.6: Data tabulation

Legend

A – Disappearance of shafaq al-aḥmar

B – Disappearance of shafaq al-abyaḍ

a – Appearance of fajr al-kā<u>dh</u>ib

b – Beginning of fajr al-ṣādiq

M – Merang

Mag. – Magnitude

TK – Teluk Kemang

KL – Kuala Lumpur

KLPS – Kuala Lipis

PK – Port Klang

U – Unnoticed/Nil

Chapter 5 Discussions and Conclusions

5.1 Discussions

A – Philosophical

a. Islam is a religion that on emphasize application of a system of empiricism and rationalisms. It can be seen clearly through dalā'il naqlī which advocates the employment the use of human eye and legist consensus on this matter and other obligations. Furthermore, Islam admits and employs the development of technology as long as there are on track with shariᶜah.

b. The author had chosen the two prayer times i.e. ᶜIshā' and Ṣubḥ by the reason that they have delicate condition that need to be determine it; illumination of the Sun rather than other prayer times.

c. Literature shows that previous research was limited with the application of the human eye and theoretical calculation, therefore this research intends to fill the gap. From the results, human eye and SQM are the most reliable detectors to compare, confidently at the moment, because they measure the amount of perceived light at twilights which is coherent with the statement of the problem on visibility when there is no light.

d. Most of the beginning of ᶜIshā' is the disappearance of shafaq al-abyaḍ as advocates by Imām Abū Ḥanifah. The author presumes it happens due to the similarity of latitude or condition of atmosphere. So do the fajr al-kādhib phenomenon and one might have an oversight it because it is such an elusive faint.[1]

e. It is undeniable to state that every research has its own difficulty. Nevertheless it is not an excuse for not to do so since Muslims live everywhere and have to perform ṣalāt in any circumstances. As for this study, the weather is the main limitation which gives a big impact on this research. Even though the observations were done in the city peripheral, still SQM is sensitive enough to detect the changes.

[1] *Cf.* Sultan (2004).

B – Measurements

f. For ᶜIshā', receipt of light is measured in terms of increase in magnitude values (decreasing of light). By plotting the magnitude values against time, a characteristic growth curve can be observed. The curve is divided into 3 phases. The first phase is slow growth which means there was still bright light even the Sun just set. In the second phase shows a minimum of two gradual acclivities is increase at the some rate. The gradual acclivity demonstrates receipt of light when the Sun is at certain degrees below horizon (6° and 12°). The third stage is the stationary phase when growth stops and no increase in magnitude values for a period of time and this prove the beginning of ᶜIshā' is indicated by a formed plateau – see Graph 4.7.

g. For Ṣubḥ, a declivity curve is obtain after plotting receipt of light is measured in terms of decrease of magnitude values versus time and divided into 4 phases. The first phase a constant receipt of light in high magnitude values that means the dark is still. For second phase, suddenly the curve drops a bit yet maintaining magnitude values in constant which shows presence of fajr al-kā<u>dh</u>ib. The third phase, the curve also drops with gradual declivity the curve which indicate the beginning of Ṣubḥ (the letter "V" turns inverted of "V" ("Λ")). Then forth phase, the curve decline at same rate until the SQM is saturated – see Graph 4.4.

h. According to result A-i – chapter 4 – the most visible shafaq is shafaq al-abyaḍ, this is because sky background is reddish in colour.

i. Fajr al-kādhib overlaps phenomenon with fajr al-ṣādiq and happens when the Sun is below horizon more than 18° (approximately 78 minutes) before sunrise.

j. The value of twilight angle agrees with previous convention – see Table 4.4 and chapter 2.4 with an average 18.4° for ᶜIshā' and 18.8° for Ṣubḥ and the duration of both twilights: 70 to 80 minutes.

k. From observation, most of data show that both measurements are ahead from official prayer times. This is because the measurements are made directly at the time rather than official prayer times which generate based on fix criterion (Table 4.6).

l. From Table 4.6, theory value of ᶜIshā' is much closer to quantitative measurement rather than qualitative measurement. Contrary for Ṣubḥ which its theory value is much closer to qualitative measurement rather than quantitative measurement. There is 17.24% chance that those three values are the same (Table 4.5).

m. All five sites show its consistency of data (Table 4.6), the author believes it is because all the five sites are located in the same time zone (+8). Contour of land and altitude do affect the result, but in this case, degree of altitude is plausible between sites (Table 3.1) because its range is small. Moreover, nearly all data were taken during similar local sky and weather condition.

The bottom line, it is crucial to understand that this research is reporting the actual phenomena and has made thorough observations, experiments and measurements. Moreover it is out of author's authority to declare certain criteria is the best fit.

5.2 Conclusions

The goal is to advance qualitative and quantitative understanding of sky brightness at twilight for the optical range of wavelengths and twilight stages from daylight till nighttime. It was found out that there are strong relationships between astronomy, history of science and human perception in Islamic religious observances – is the principal in each situation. It is important for the choice of the observational technique based on the Sunnah and scientific approach.

To answer the question of this title, it depends on the necessary whether for daily use or to revise current criteria. From the evidence which is clearly in the Results (4.2), SQM is able to assist the process of determining the value of criteria; *Z* (p. 14) due to its precision, which *Z* is use to generate prayer times table (suggested for revising criteria). Yet, there is no substitutes for human eye since SQM just give numerical result (which has to analyse) rather than human eye which give almost immediate result. In addition, human eye still give its best performance without SQM (daily use). At this point, the author can conclude that human eye and SQM correct each other and both approaches proved to be good for determining prayer times.

The author proposed, it is plausible that the value of twilight angle is fluctuate between for ᶜIshā' and Ṣubḥ according what is given by the instruments. A summary of this research is illustrated in Figure 5.1 beneath.

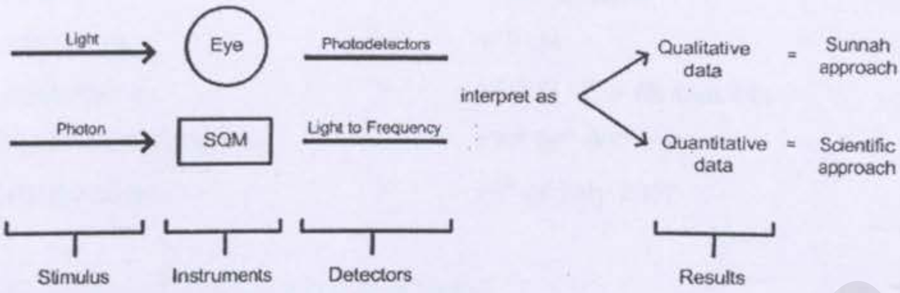


Figure 5.1: Summary

5.3 Suggestions

It is hoped that this research would provide readers not only with a birds-eye view of Islamic and scientific considerations, but also help to establish back bridges between Islam and modern science. The author also hopes that this research can be extended by replicating to verify the results and validate the value. In addition, the author looks forward for improvement on instrumentation i.e. to design more specific detector. By doing so we could tabulate more data and enhance the level of accuracy.

Appendix A

For instance,

Location	=	Kuala Lumpur
Latitude; φ_L	=	3° 9' N
Longitude; λ_L	=	101° 41' E ~ 6h 46m 44s
Standard Longitude; λ_S	=	120° 00' 00" ~ 8h
Calculated date	=	14th of July 2007

To obtain beginnings & endings of ʿIshā' & Ṣubḥ:

a. Calculation of Sun at noon

Whilst Sun at noon i.e. centre of Sun pass Local Celestial Meridian[1], Local Hour Angle (LHA) equal 0h or 24h[2]. Connection between LHA and Greenwich Hour Angle (GHA) is shown as:

$$GHA = LHA - \lambda_L \qquad \text{(A-1)}$$

$$GHA = 24h\ 0m\ 0s - 6h\ 46m\ 44s$$

$$= 17h\ 13m\ 16s$$

Correlation linking GHA and Local Standard Time (LST) is:

$$LST = \frac{GHA - GHA @ h_1}{GHA @ h_2 - GHA @ h_1} X\ 24h \qquad \text{(A-2)}$$

Where, GHA @ h_1 = Greenwich hour time 0h on calculated date.

And, GHA @ h_2 = Greenwich hour time 0h + 24h.

According to referred data for 14th of July 2007:

$$h_1 = 14.0$$

$$h_2 = 15.0$$

$$GHA = 17h\ 13m\ 16s$$

$$GHA @ h_1 = 3h\ 54m\ 16s$$

$$GHA @ h_2 = 3h\ 54m\ 9s + 24h$$

$$= 27h\ 54m\ 9s$$

[1] Location or site

[2] If it was referred to previous day

Hence,

$$LST = \frac{17h\,13m\,16s - 3h\,54m\,16s}{27h\,54m\,9s - 3h\,54m\,16s} X\,24h$$

$$= 13h\ 19m\ 3.88s$$

As a conclusion, noon at Kuala Lumpur on 14th of July 2007 is 13h 19m 3.88s or 1:20 pm.

b. Calculation of ʿIshā' time

Estimation time for ʿIshā' is around 8 o'clock

i. Calculation of declination, δ_I

$$\Delta\,\delta_I = \frac{20}{24} X (\delta_{24} - \delta_0) \quad \text{(A-3)}$$

$$= \frac{20}{24} X (21°40'\,5" - 21°49'\,1")$$

$$= -0°\,7'\,26.67"$$

$$= \delta_o + \delta\Delta_A$$

$$\therefore\ \delta_I = 21°\,49'\,1" - 0°\,7'\,26.67"$$

$$= 21°\,41'34.33"$$

ii. Define Z_I as $= 108°$

iii. Calculation of hour angle, t_I

$$t_I = \cos^{-1}\left[\frac{\cos Z_A - \sin\delta_A \quad \sin\phi_L}{\cos\delta_A \quad \cos\phi_L}\right] \quad \text{(A-4)}$$

$$= \frac{\cos 108° - \sin(21°\,41'\,34.33")\sin(3°\,9')}{\cos(21°\,41'\,34.33")\cos(3°\,9')}$$

$$= \frac{-0.329328291}{0.927774681}$$

$$= -\,0.354965809$$

$$t_I = 110°\,47'\,28.8" \sim 7h\ 23m\ 9.92s$$

$$\therefore\ {}^{c}\text{Ishā' times} = LST + t_I \quad \text{(A-5)}$$

$$= 13h\ 19m\ 3.88s + 7h\ 23m\ 9.92s$$

$$= 20h\ 42m\ 29s \sim 8{:}43\ pm$$

c. Calculation of Ṣubḥ time

Estimation time for Ṣubḥ is around 6 o'clock

i. Calculation of declination, δS

$$\Delta\ \delta_S = \frac{6}{24} \times (21^\circ 40' 5'' - 21^\circ 49' 1'') \qquad \text{(A-6)}$$

$$= -0^\circ\ 2'\ 14''$$

$$\therefore\ \delta_S = 21^\circ\ 49'\ 1'' - 0^\circ\ 2'\ 14''$$

$$= 21^\circ\ 46'\ 47''$$

ii. Define Z_S as = 110°

iii. Calculation of hour angle, t_S

$$t_S = \frac{\cos 110^\circ - \sin(21^\circ\ 46'\ 47'')(\sin 3^\circ\ 9')}{\cos(21^\circ\ 46'\ 47'')\cos(3^\circ\ 9')}$$

$$= \frac{-0.362408814}{0.92721415}$$

$$= -\ 0.390857725$$

$$t_S = 113^\circ\ 0'\ 28.37'' \sim 7h\ 32m\ 1.89s$$

$$\therefore\ \text{Ṣubḥ time} = LST - t_S \qquad \text{(A-7)}$$

$$= 13h\ 19m\ 3.88s - 7h\ 32m\ 1.89s$$

$$= 5h\ 47m\ 1.99s \sim 5{:}48\ am$$

Appendix B

Form: ᶜIshā' / Ṣubḥ

Date: Coordinate: Long: Lat: Loc.:
Time[3]: Bortle Seeing Scale: N°. of Observers:
Azimuth of Sun: Azimuth of SQM: Moon/moonless

Prayers	Phenomena	Time	Sun's alt.
ᶜIshā'	Sunset		
	Appearance of shafaq aḥmar		
	Disappearance of red after glow; shafaq aḥmar		
	Appearance of shafaq abyaḍ		
	Disappearance of whiteness; shafaq abyaḍ		
	Official time for ᶜIshā'		
Ṣubḥ	Vertical light; fajr kadhīb		
	Disappearance of fajr kadhīb		
	Spread of horizontal light; fajr ṣādiq		
	Sunrise		
	Official time for Ṣubḥ		

Time	Description	Cloud type	Sun's alt.

[3] Calibrated by SIRIM (1051) and using 24 hour system.

Appendix C

Form: ᶜIshā' / Ṣubḥ

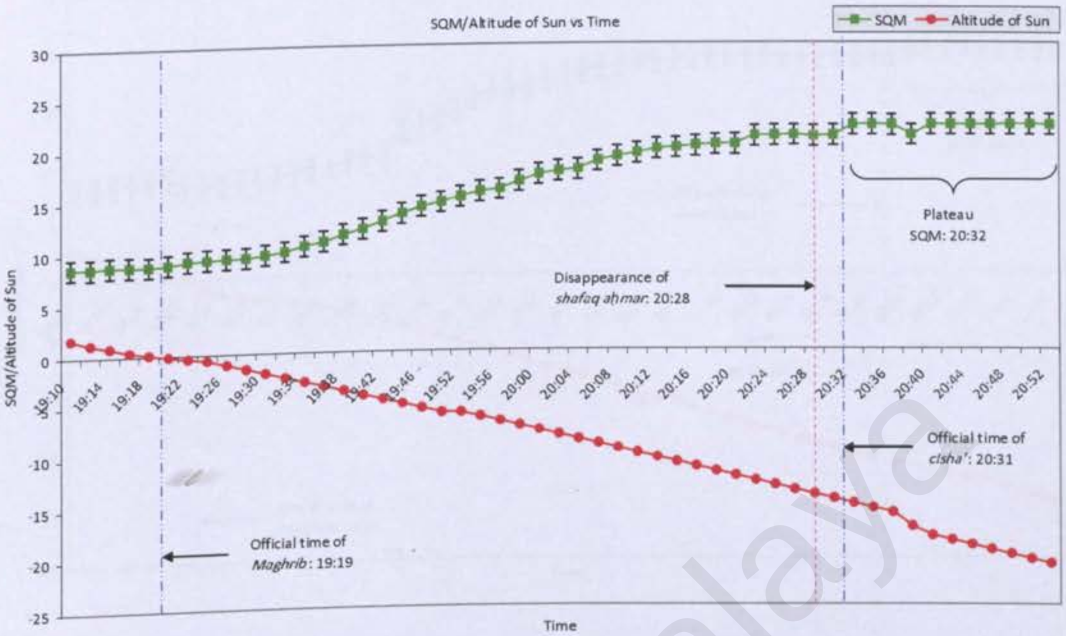
Date: Coordinate: Long: Lat: Loc.:
Time[4]: Seeing: Excellent/Good/Fair/Poor Nº. of Observers:
Azimuth of Sun: Azimuth of SQM: Moon/moonless

Time	SQM	Altitude	Remarks

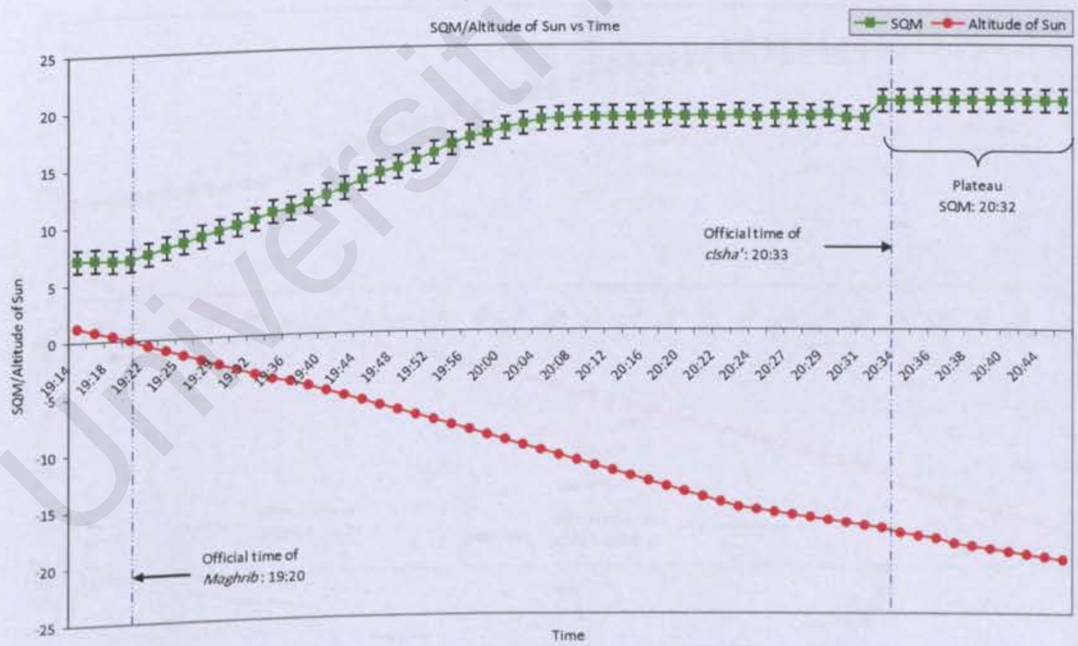
Time	SQM	Altitude	Remarks

4 Calibrated by SIRIM (1051) and using 24 hour system.

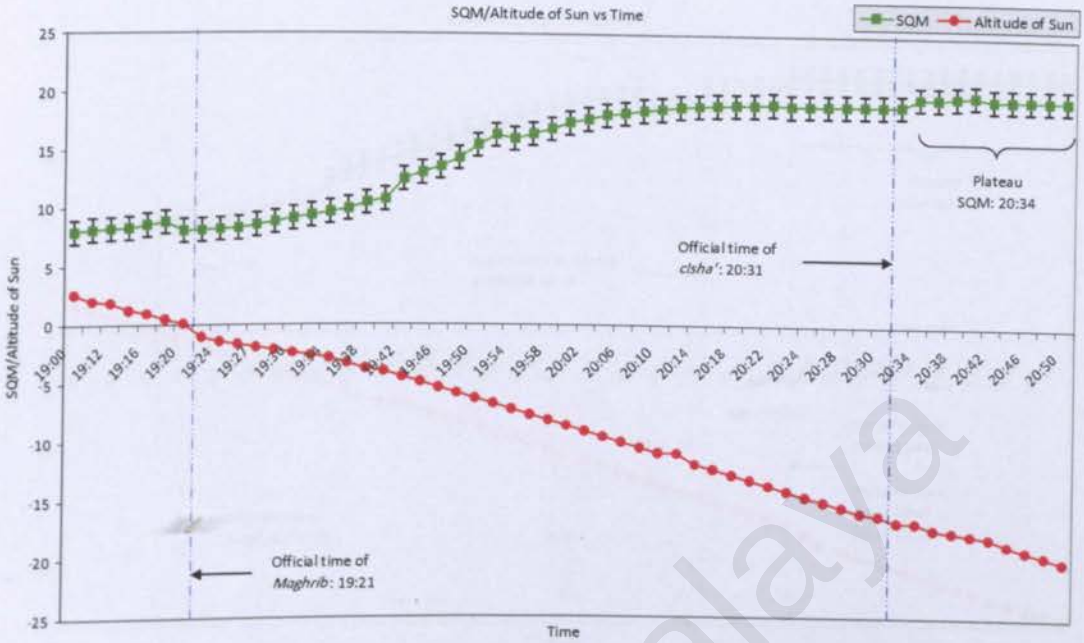
Appendix D



Graph D.1: ʿI**sh**ā' at Merang, 8 May 2007

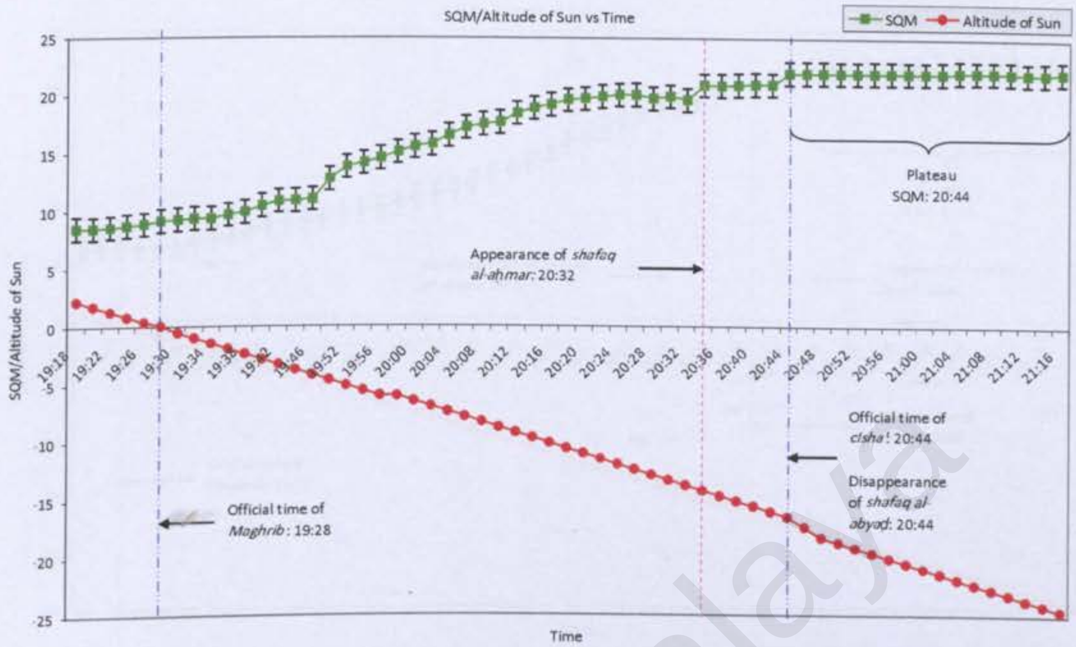


Graph D.2: ʿI**sh**ā' at Teluk Kemang, 18 May 2007

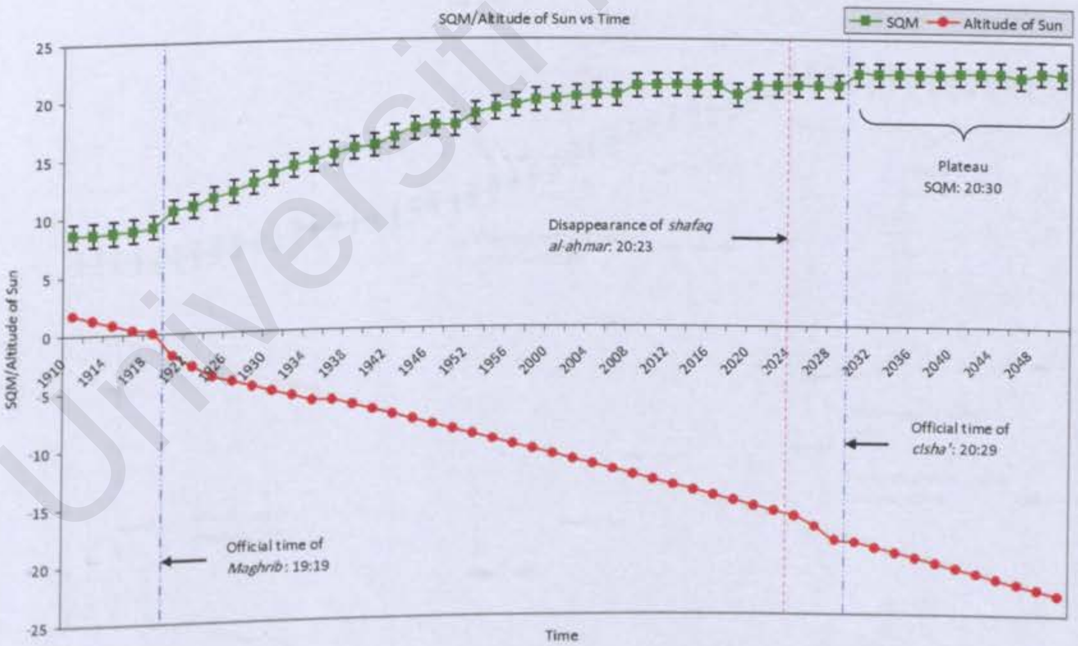


Graph D.3: ʿIs̲h̲ā' at Teluk Kemang, 19 May 2007

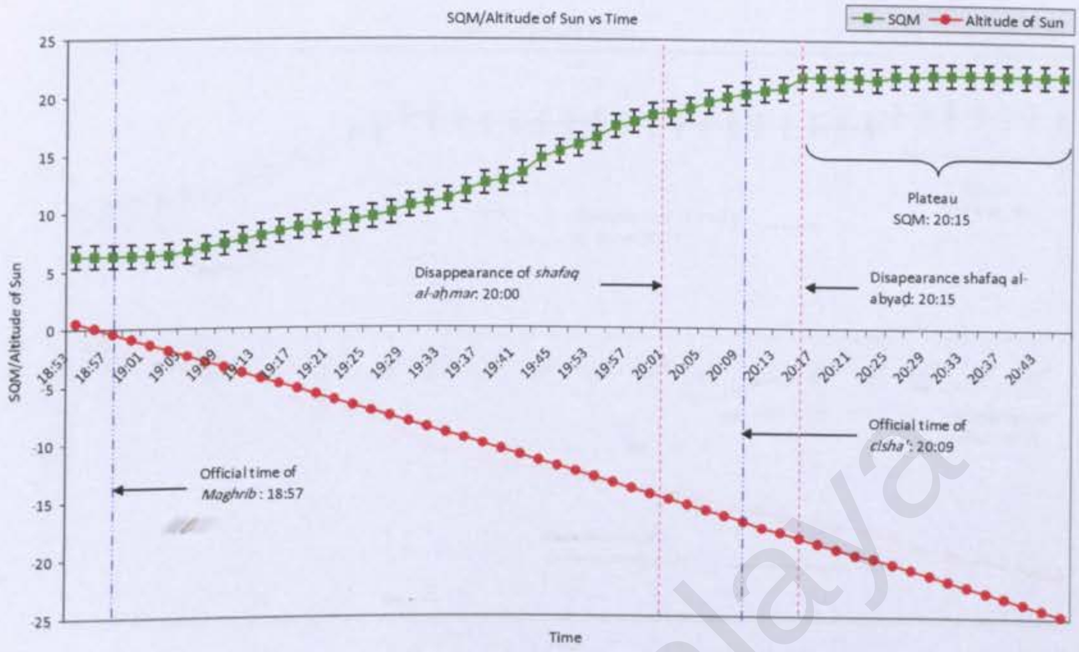
Graph D.4: ʿIs̲h̲ā' at Teluk Kemang, 19 Jun 2007



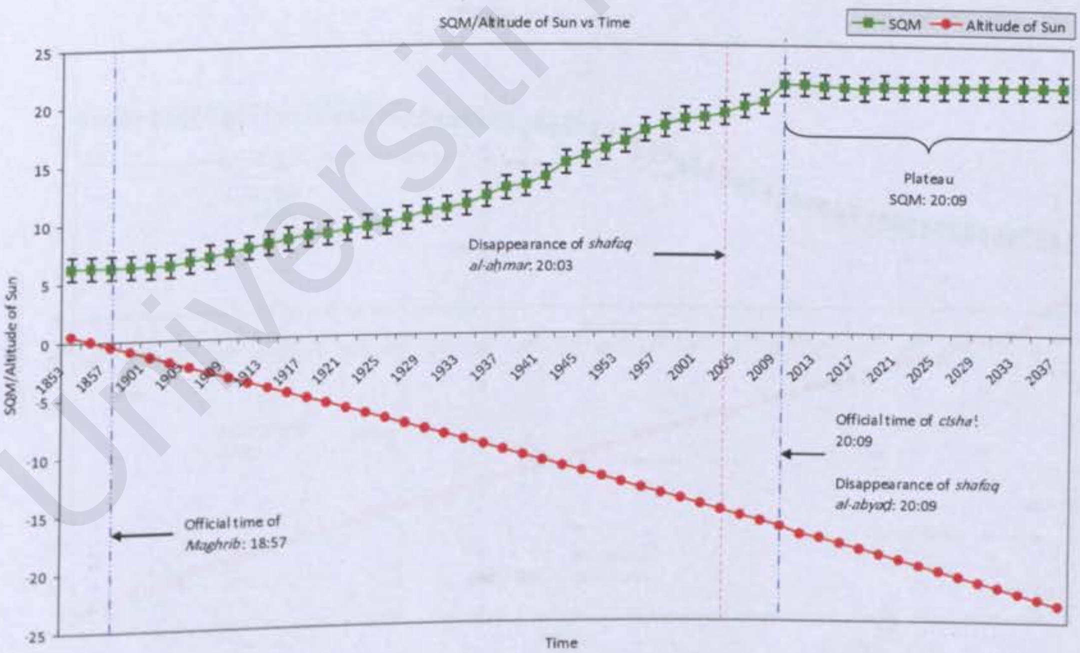
Graph D.5: ᶜIs͟hā' at Kuala Lumpur, 1 July 2007



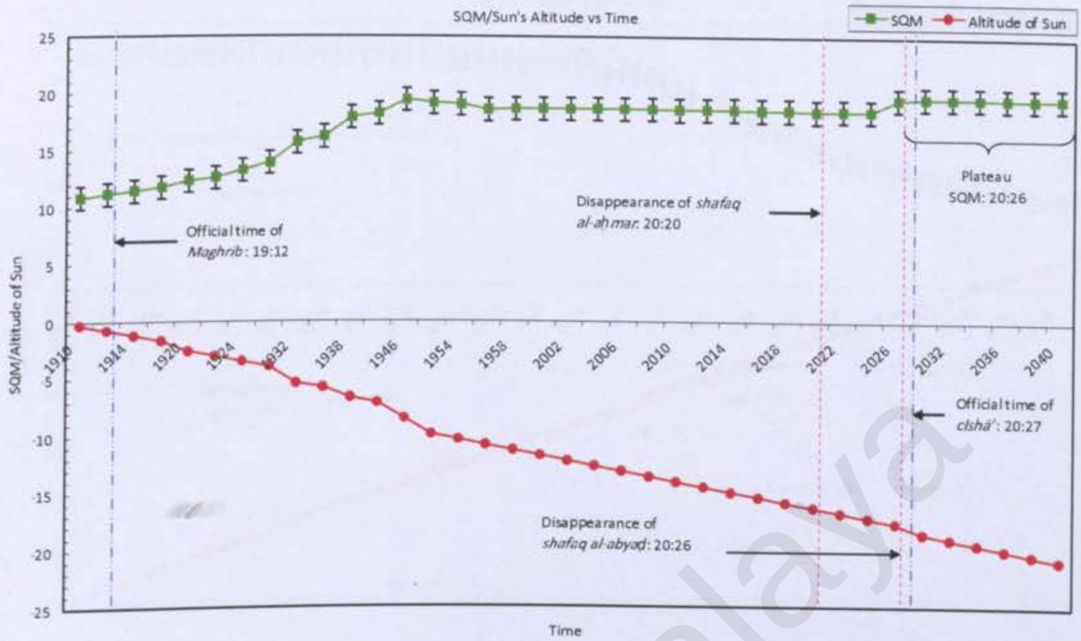
Graph D.6: ᶜIs͟hā' at Kuala Lumpur, 4 September 2007



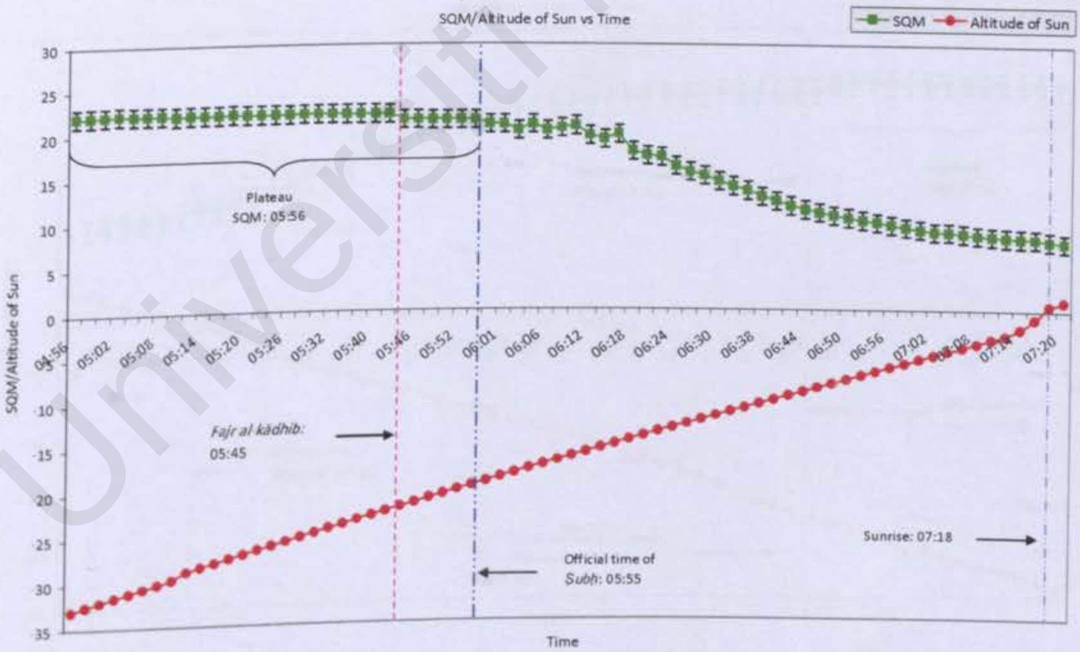
Graph D.7: ᶜI<u>sh</u>ā' at Kuala Lumpur, 5 November 2007



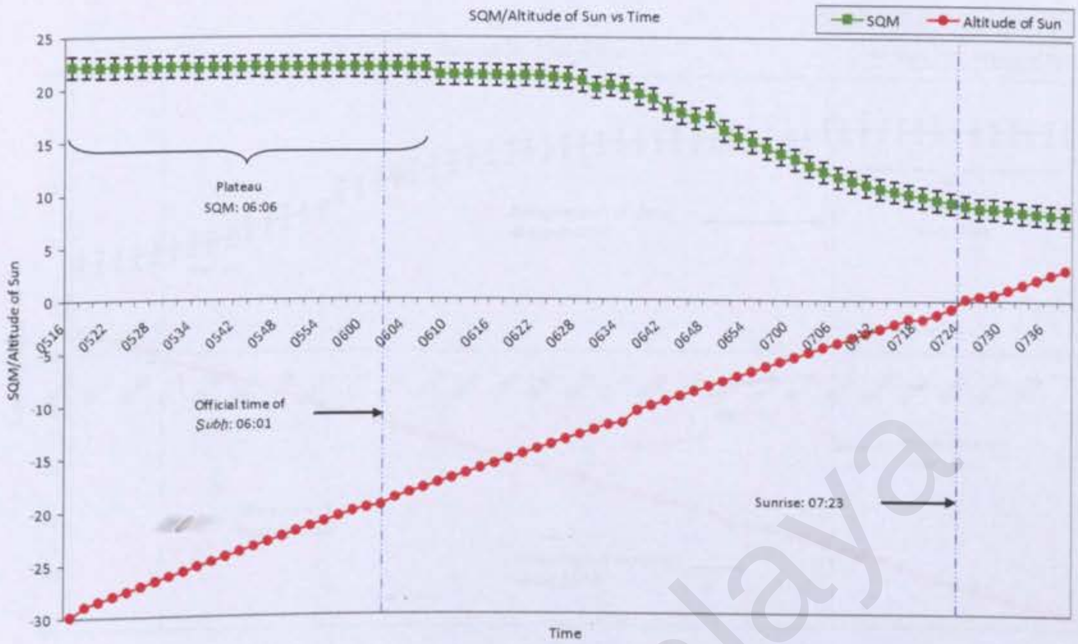
Graph D.8: ᶜI<u>sh</u>ā' at Kuala Lipis, 9 November 2007



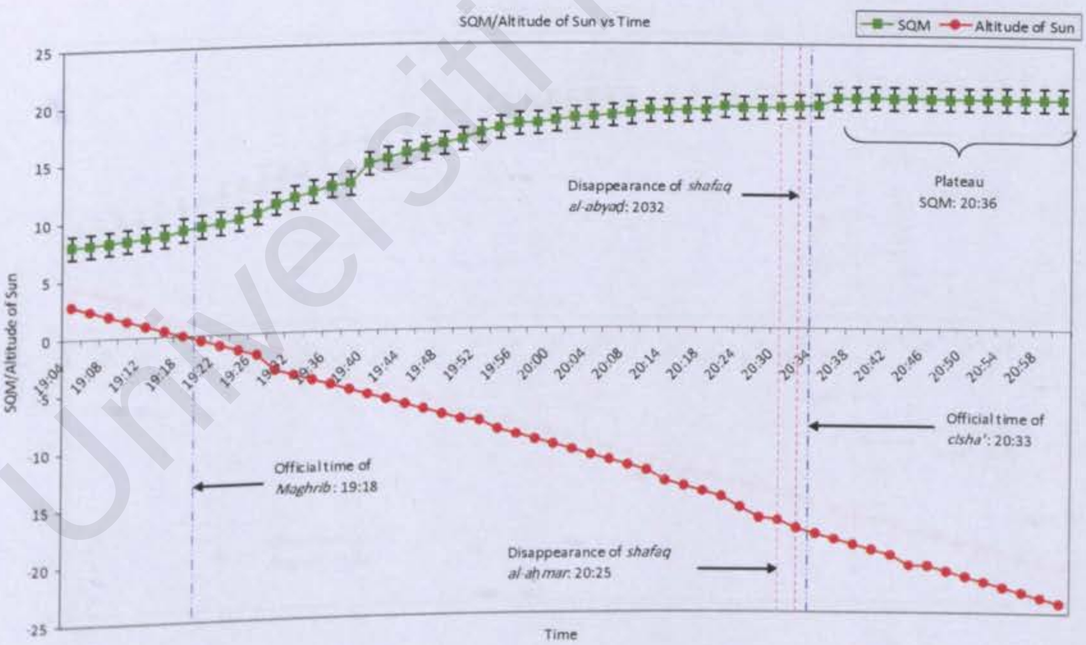
Graph D.9: ᶜIs̲h̲ā' at Kuala Lumpur, 27 December 2007



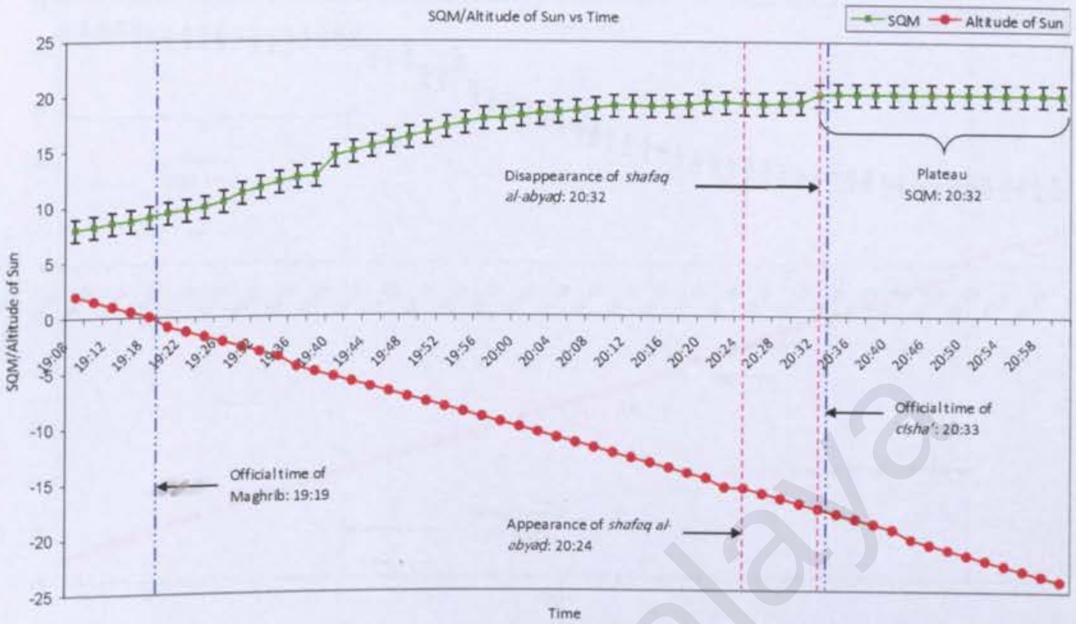
Graph D.10: Ṣubḥ at Kuala Lipis, 29 December 2007



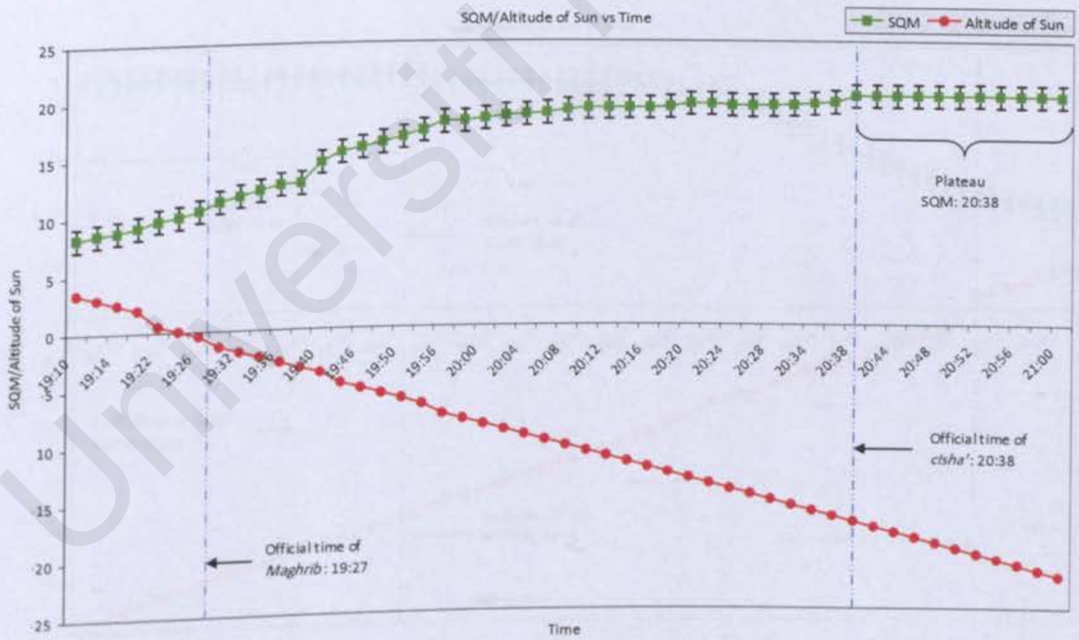
Graph D.11: Ṣubḥ at Kuala Lipis, 11 January 2008



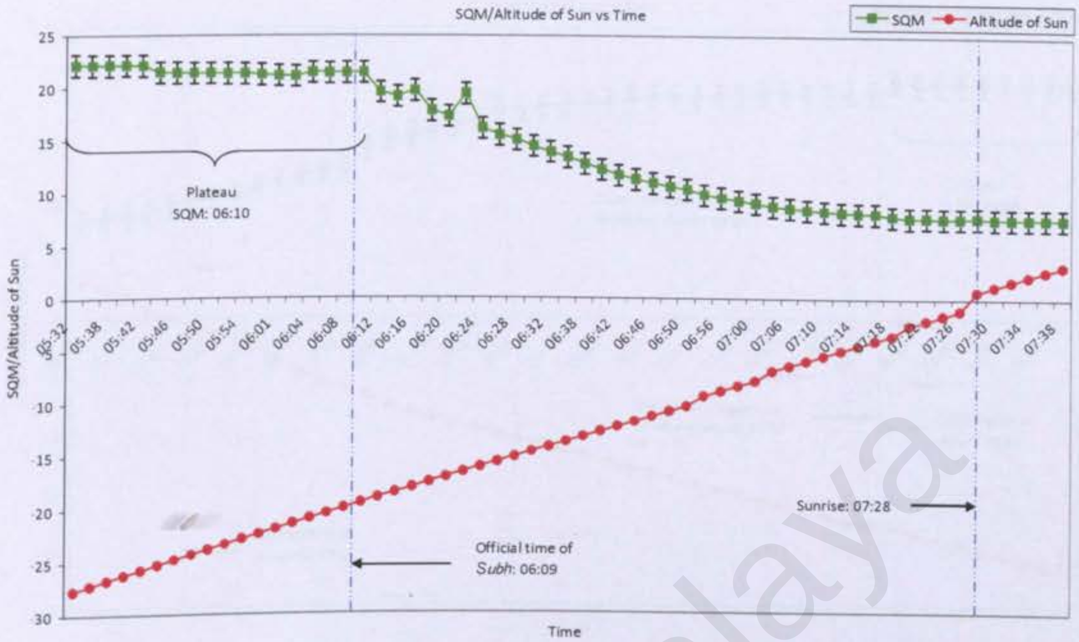
Graph D.12: ʿIshā' at Kuala Lipis, 11 January 2008



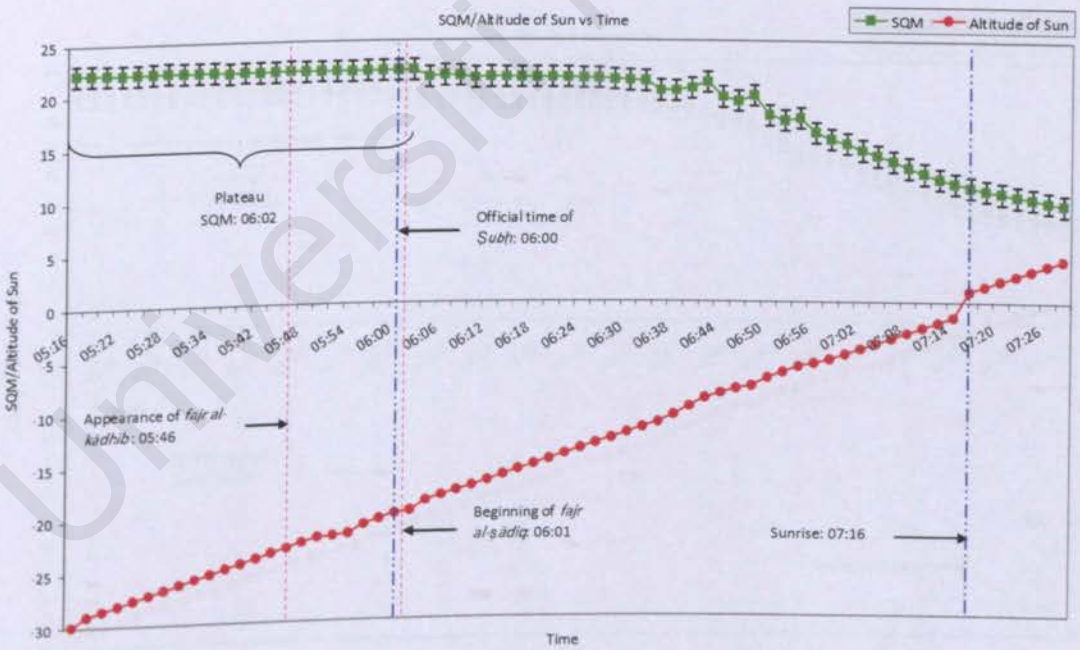
Graph D.13: ᶜI<u>sh</u>ā' at Kuala Lipis, 12 January 2008



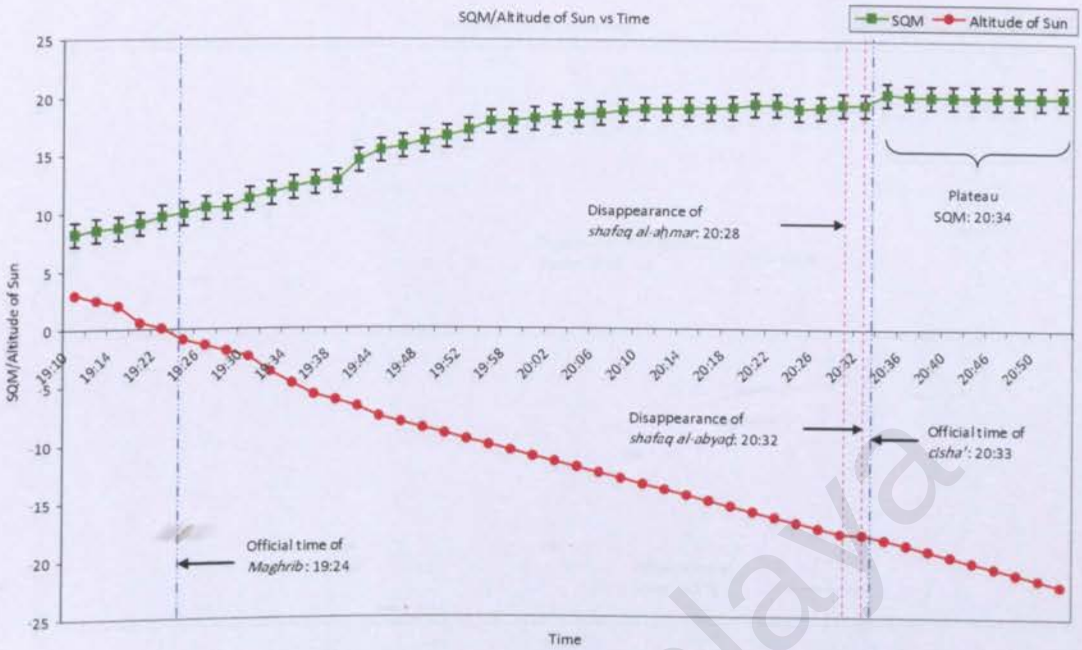
Graph D.14: ᶜI<u>sh</u>ā' Kuala Lipis, 9 February 2008



Graph D.15: Ṣubḥ at Kuala Lipis, 10 February 2008

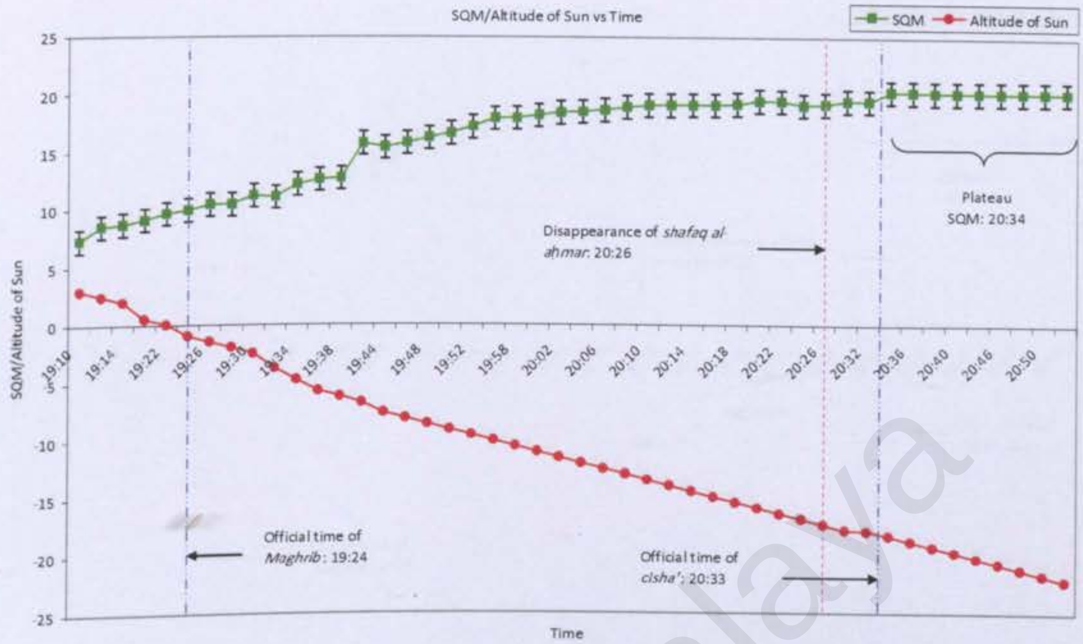


Graph D.16: Ṣubḥ at Kuala Lipis, 22 March 2008



Graph D.17: ᶜIshā' at Kuala Lipis, 22 March 2008

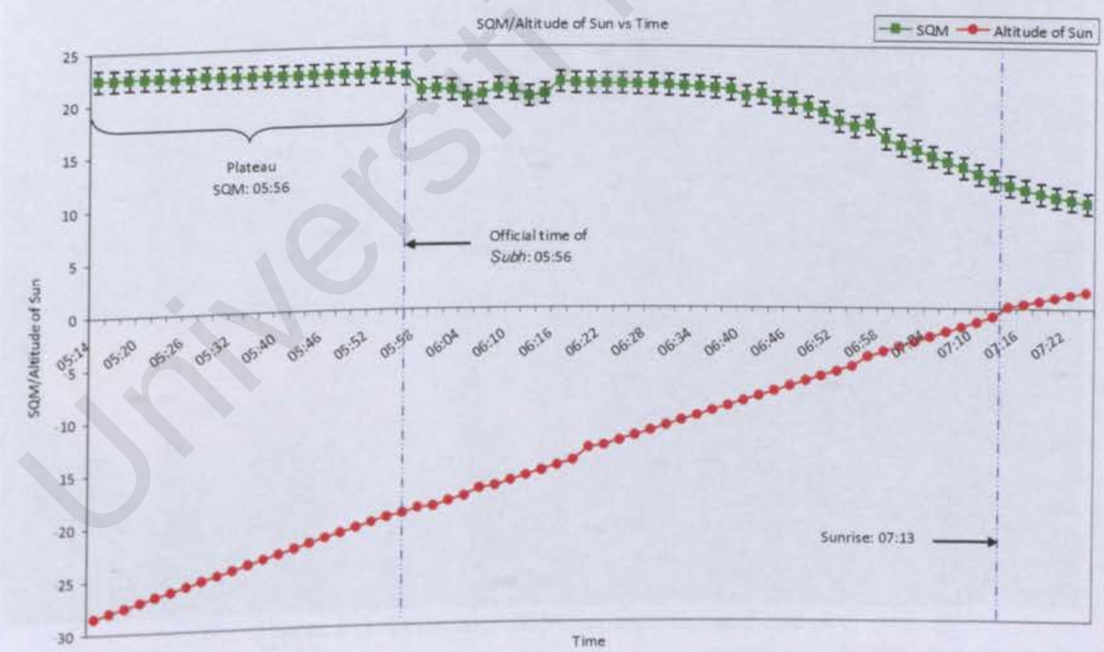
Graph D.18: Ṣubḥ at Kuala Lipis, 23 March 2008



Graph D.19: ᶜIshā' at Kuala Lipis, 23 March 2008

Graph D.20: Ṣubḥ at Port Klang, 6 April 2008

Graph D.21: ᶜIshā' at Port Klang, 6 April 2008



Graph D.22: Ṣubḥ at Port Klang, 7 April 2008

Appendix E

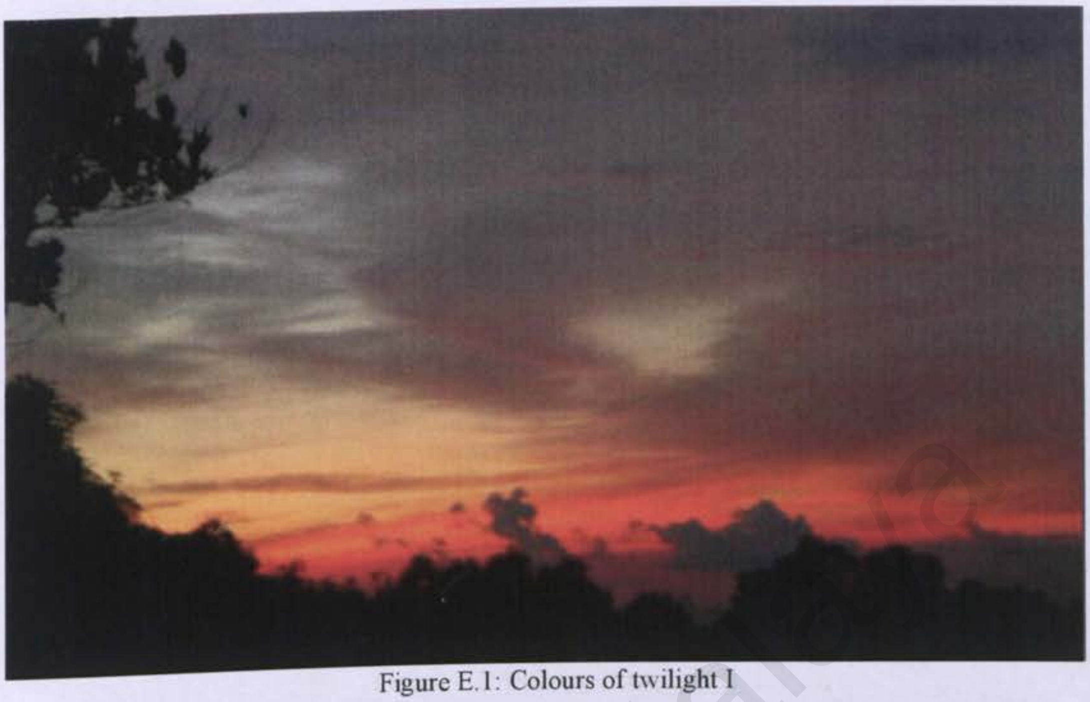


Figure E.1: Colours of twilight I

Figure E.2: Difference between west sky and east sky

Figure E.3: Colours of twilight II

Figure E.4: Colours of twilight III

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