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Improving the Accuracy of Prayer Times and Calculating Their Change with Geographical Latitudes during the Year 2021 AD

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Abstract:
The entry time of the prayer in Islam is a prerequisite condition for performing obligatory prayers, and prayer times to be performed in Islam coincides with the time changes of the position of the sun. The elliptical and equatorial coordinates of the sun were calculated for different latitudes. The prayer times for the city of Baghdad were calculated at (latitude = 33.34º N, longitude = 44.43 E) with high accuracy for the year 2021 AD. The results showed that all prayer times are affected by latitude according to each region except (Dhuhr prayer) , it changes with the change of the equation of time, because the equation of time does not depend on latitude, but rather on the sun's declination, which depends on date. We also made improvements to the accuracy of calculating prayer times, where the disappearance of evening twilight (Isha prayer) was calculated when the sun was below the western horizon at an angle of (17^0) and for (Fajr prayer) at an angle of (18^0) below the eastern horizon. Minutes were added to enable entering the time for (Dhuhr prayer) (5 minutes) and (Asr prayer) (3 minutes).

The results show that the shadow of the meridian varies every day of the year from one point to another on the surface of the globe, so it is non-existent if the sun is perpendicular to the earth at the time of the meridian, and it has a specific length if the latitude of the place exceeds the value (23.5^0) the Tropic of Cancer or the Tropic of Capricorn), and its length increases as we move towards higher latitudes.

In addition, the results of our program were compared with the program of the Islamic project for all prayer times for the cities of Baghdad and Mosul for one year, and it showed a good match for the results, with a difference in some times and days of no more than one minute due to the modifications we added to calculate the effect of altitude above sea level. Practical observation was also conducted to check the times of the Dhuhr, Asr and Maghrib prayers for several days during the year 2021 AD, and the results were identical with our theoretical results.

Keywords: Prayer times, Sunrise time, Sunset time, Equation of time, Shadow length.

تحسين دقة مواقيت الصلاة وحساب تغيرها مع خطوط العرض الجغرافية خلال عام 2021م.

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ان دخول وقت الصلاة في الإسلام شرط أساسي لأداء الصلوات المفروضة، ومواقيت الصلوات المفروضة في الإسلام تتزامن مع التغيرات لموقع لشمس. حيث تم حساب احداثيات الشمس البروجية والاستوائية ولخطوط عرض مختلفة، وقد حسب منها مواقيت الصلاة لمدينة بغداد عند (عرض=N 33.34^0، طول=E 44.43^0) بدقة عالية لعام 2021م، واظهرت النتائج ان جميع مواقيت الصلاة تتأثر بتغير خط العرض الجغرافي للمنطقة عدا وقت صلاة الظهر فأنه يتغير بتغير معادلة الزمن فقط وذلك لان معادلة الزمن لا تعتمد على خطوط العرض وانما تعتمد على ميل الشمس الذي يعتمد على التاريخ.

كذلك اجرينا تحسينات على دقة حساب مواقيت الصلاة حيث تم احتساب غياب الشفق المسائي (صلاة العشاء) عندما تكون الشمس تحت الأفق الغربي بزاوية مقدارها (17^0) ولصلاة الفجر بزاوية (18^0) تحت الأفق الشرقي، وتم اضافة دقائق للتمكين من دخول وقت صلاة وهي للظهر (5دقائق) وللعصر (3دقائق).

تظهر النتائج ان ظل الزوال يختلف في كل يوم من السنة من نقطة إلى أخرى على سطح الكرة الأرضية، فيكون معدوما إذا كانت الشمس عمودية على الأرض وقت الزوال، وله طول محدد إذا تجاوز خط عرض المكان القيمة (23.5^0) (مدار السرطان أو مدار الجدي)، ويزداد طوله كلما ارتفعنا باتجاه خطوط العرض العليا. بالإضافة الى ذلك تمت مقارنة نتائج برنامجنا مع برنامج المشروع الاسلامي لجميع مواقيت الصلاة لمدن بغداد والموصل ولسنة واحدة. واظهرت تطابق جيد للنتائج مع وجود فرق في بعض الأوقات والأيام لا يزيد عن دقيقة واحدة وسببه التعديلات التي تم اضافتها لحساب تأثير الارتفاع عن سطح البحر. كما تم اجراء رصد عملي لتدقيق مواقيت صلاة الظهر والعصر والمغرب لعدة أيام خلال عام2021م وكانت النتائج متطابقة مع نتائجنا النظرية.

Introduction

The daily prayer times in all months of the year, as well as the times of Iftar and Imsak in the blessed month of Ramadan, differ from one place to another because they depend on the apparent movement of the sun and its position in the sky relative to a specific location on Earth. The occurrence of astronomical natural phenomena associated with it, for each time of prayer is a natural astronomical phenomenon that occurs during the day as a result of the Earth's rotation around itself or the apparent movement of the sun, closely related to it. Dhuhr prayer is related to the phenomenon of the entire sun's disk crossing the meridian in the desired area, Maghrib prayer is related to the phenomenon of setting the upper edge of the sun disk behind the true horizon, Isha prayer is related to the disappearance of the red evening twilight, and Fajer prayer is related to the phenomenon of the birth of the true morning twilight. The phenomena of evening and morning twilights are dependent and related to the extent of the sun's descent behind the horizon after sunset and before sunrise. As for calculating prayer times, it is done by using accurate astronomical equations to find out the position of the sun in the sky of the desired area, after knowing the geographic longitude (ℓ) and latitude (ϕ) of that region [1].

Theory

Before going into the issue of calculating prayer times, we explain how to calculate the coordinates of the celestial equatorial coordinate of the sun (declination and right ascension as well as the hour angle) at any day of the year because they are necessary to be involved in the process of calculating prayer times [2].

1. Calculate the coordinates of the sun as the following:

a. The Julian date

The Julian Date (JD) is the number of days and fractions beginning from mean noon on January 1st, 4713 BC, Gregorian date in which the coordinates of the sun are to be calculated is measured using the following mathematical operation [3]:

$$JD=INT(365.25\,y)+(INT(30.6001(m+1))+d+(U.T/24)+1720994.5+B \quad (1)$$

Where y: Year number, m: Month number, d: Day number,
U.T: Universal Time, B: Gregorian correction.

When the required year y is greater than the year (15/10/1582) of the Gregorian calendar, we calculate the quantities A and B as follows [4]:
A= INT (y / 100)
B=2-A+INT (A/4)
The Julian centuries (T) was calculated since 1900 by the following equation [3]:

$$T = (JD - 2415020) / 36525 \quad (2)$$

b. The coordinates of the sun

Firstly, calculate the ecliptical coordinates of the sun the longitude of the sun (L) using the following relationship [5]:

$$L=279.69668 + 36000.76892\,T + 0.0003025\,T^2 \quad (3)$$

Corrections (I_1, I_2, I_3, I_4, I_5) are added to it due to the influence of other planets when the accuracy of the calculation is high, and they are [6]:

$I_1=153.23+22518.7541\,T$
$I_2=216.57+45037.5082\,T$
$I_3=312.69+32964.3577\,T$
$I_4=350.74+445267.1142\,T-0.00144\,T^2$
$I_5=231.19+20.2\,T$

$$L= L+ 0.00134 \cos (I_1) + 0.00154 \cos (I_2) + 0.002 \cos (I_3) + 0.00179 \sin (I_4) + 0.00178 \sin (I_5) \quad (4)$$

The second calculation to find the mean anomaly of the sun (M) which is measured using:

$$M= 358.47583+35999.04975\,T- 0.00015\,T^2-0.0000033\,T^3 \quad (5)$$

Then the sun's equation of the center (C) is [4]:

$$C= (1.91946 - 0.004709T- 0.000014T) \sin (M) + (0.020094 10^{-4}T) - \sin (2M) + 0.00293 \sin (3M) \quad (6)$$

The equation of the center (C) used to extract the value of the true longitude of the sun (λ_0) through the following equation [4]:

$$\lambda_0 = L + C - 0.0569 - 0.00479 \sin (W) \quad (7)$$

Where W: A correction for nutation and aberration.
The last two terms represent the correction on the zodiacal line of longitude when the apparent longitude of the sun returns to the true vernal equinox point of history due to reeling and extension.
When a high accuracy of the calculation is needed [6]:

$$W=259.18 + 1934.142\,T+ 0.00207\,T^2 + (2.2)10^{-6}\,T^3 \quad (8)$$

The value of (λ_0) is confined between zero and 360, and for the purpose of knowing the equatorial coordinates of the sun at a certain date, the zodiacal coordinates we obtained were converted into equatorial coordinates as in [4,7].
The obliquity angle of the ecliptic on the equator (ε) is calculated by [9]:

$$\varepsilon_0 = 23.452294 - 0.030125T- 0.00000164T^2 + 0.000000503T^3 \quad (9)$$

The correction is added to it as follows [9]:

$$\varepsilon = \varepsilon_0 + 0.00256 \cos (W) \quad (10)$$

So, the right ascension (α_0) of the sun is [7]:

$$\tan (\alpha_0) = \cos (\varepsilon) \tan (\lambda_0) \quad (11)$$

Where it is converted to hours by dividing by 15 and its value is between zero and 24.
The declination of the sun is calculated at midnight (δ_0) [7]:

$$\sin (\delta_0) = \sin (\varepsilon) \sin (\lambda_0) \quad (12)$$

2.Calculation of the prayer times:

a. The Dhuhr time

It commences immediately after midday when the sun has passed the local meridian (reaching the highest point in the sky) of a particular location and ends when the shadow of an

object is equal to its height plus the object's shadow. There always exists shadow meridian throughout the year except just two times at places located between the two tropics (the tropic of Cancer and the tropic of Capricorn) [7].
The basic astronomical equations to determine the time of Dhuhr prayer by calculating the value of the equation of time (ET) which represents the difference between two solar time and mean solar time, in other words it is the difference between the hour angles of the true sun and the mean sun, the equation of time at a given instant by[5,8]:

$$ET = y \sin(2L) - 2e\sin(M) + 4ey\sin(M)\cos(2L)\ 1/2\ y^2 - \sin(4L) - 5/4\, e^2 \sin(2M) \quad (13)$$

Where: $y = \tan^2(\varepsilon/2)$
L: Ecliptical longitude of the sun calculated by eq.4.
M: The mean anomaly of the sun calculated by eq.5.
e: Eccentricity of the Earth's orbit calculated as follows [11]:

$$e = 0.01075104 - 0.0000416T - 0.000000126T^2 \quad (14)$$

The quantity ET (Equation of time) is measured in the radial angle (Radians) (here we must convert the value of (e) to degrees by multiplying it by (180/π), then convert the degrees to hours unit dividing it by 15.
The time of Dhuhr prayer (in hours unit) will be as follows [2]:

$$Dhuhr = \{12 - ET + (5/60)\} + (dt) \quad (15)$$

Where (dt): Represents the time difference from the standard longitude of the country, and this difference is included in the calculation of some other prayer times and is calculated after knowing the standard longitude of the country (ℓ) and the longitude of the desired location (ℓ ') in degree as follows [7]:

$$dt = (\ell - \ell'/15)/60 \quad \text{(in hours unit)} \quad (16)$$

b. The Asr prayer time

The beginning of Asr prayer time depends on the height of objects shadow after the sun declines to the west. There is a consensus among the majority of Islamic jurisprudences school that the time of Asr prayer commences when the shadow length is equal to the height of a body plus the shadow at noon for the north latitude when the shadow of objects is equal to the hour angle defining the time offset for the height of shadows to reach objects' length [1]:
(1) Calculate the altitude of the sun (a) when the sun crosses the meridian, i.e. when the hour angle of the sun is zero ($H_0 = 0^0$) from the formula [12]:

$$\sin(a) = \sin(\phi)\sin(\delta_0) + \cos(\phi)\cos(\delta_0)\cos(H_0) \quad (17)$$

(2) Calculate the altitude of the sun (a1) at the time when the shadow length is equal to the height of the object plus the meridian shadow from the equation [1]:

$$a1 = \tan[1/((1/\tan(a)) + 1)] \quad (18)$$

(3) The hour angle of the sun (H1) when the altitude of the sun (a1) is calculated from the following equation [7]:

$$\cos(H1) = \sin(a1) - \sin(\delta)\sin(\alpha)/\cos(\delta_0)\cos(\alpha) \quad (19)$$

(4) Convert the hour angle of the sun (H1) from degrees to hours by dividing by the formula [1].

$$Asr = Dhuhr + (\cos^{-1}[\sin(a1) - \sin(\delta)\sin(\alpha)/\cos(\delta_0)\cos(\alpha)]/15) \quad (20)$$

c. The Maghrib prayer time and the Shuroq time (sunrise)

The time for Maghrib prayer comes when the entire sun disk has disappeared behind the western horizon, i.e. when the upper edge of the sun disk has completely disappeared behind the true horizon. This is calculated astronomically with high accuracy as follows [13]:
1.Calculate the value of the hour angle (H_0) from the equation:

$$H_0 = (\ell/15)[\cos^{-1}(\tan(\phi)\tan(\delta_0)] \quad (21)$$

2.The sidereal time of rising ($S.T_r$) and setting ($S.T_s$) are calculated as:

$S.T_r = 24 - \alpha_0 - H_0$ (22)

$S.T_s = \alpha_0 + H_0$ (23)

Where α_0: Right ascension of the sun at rising or setting .

3. Calculate the corrections of refraction (R) at the moment of rising or setting from Schaefer (1990) who found the refraction near the horizon measurements fluctuated 1.678 degree, and the total refraction varied over a range of R= $0.^0 64$ or 34`.4 [14] .

4. The correction value of horizontal parallax at rising and setting = (8``. 79) [15]

5. The correction value of semi diameter at rising and setting = $0.^0 53$[15]

The total corrections at sunset or sunrise (X_{sun}) are [13]:

$$X_{sun} = 0.^0 533/2 + 34'.4 + 8''.79 = 0.^0 83560 \quad (24)$$

6.The time of sunrise (T_r) and sunset (T_s) with corrections in local sidereal time (LST)[13]:

$$T_r =- S.T_r - X_{sun} \quad (25)$$

$$T_s =- S.T_s + X_{sun} \quad (26)$$

Converts the correct local sidereal time of Shuroq and Magreb to sidereal time according to the Greentech Time (G.S.T), then to Universal Time (U.T) and then to the local time of the desired place, so we get the time of sunset and sunrise time in the local time of the desired place, the equation for the actual sunset, Maghrib time is based on the fixed angle of (a_0= -0.833^0) hour angle offset time as follows [2]:

$$\text{Maghrib}=\text{Dhuhr} + \cos^{-1}[\sin(-0.^0 833) - \sin(\delta_0)\sin(\phi)/\cos(\delta_0)\cos(\phi)]/15 \quad (27)$$

Similarly, the equation for the actual sunrise is defined [1]:

$$\text{Shuroq} = \text{Dhuhr} - \cos^{-1}[\sin(-0.^0 833) - \sin(\delta_0)\sin(\phi)/\cos(\delta_0)\cos(\phi)]/15 \quad (28)$$

d. The Isha & Fajer prayer times:

The Isha and Fajer prayers begin at the start of the evening and true morning twilights, respectively. These twilights are mirror images of one another and correspond to certain sun depression angles after and before the sunset or sunrise. Nonetheless, there is no precise and universal depression angle for Isha /Fajer times across the board and different views exist for the best and the practical angle depending on the observer's region and/or country. The earlier the Fajer and later the Isha times [2].

In this work the values adopted for the depression angle were: for Isha prayer (-17°) and Fajer prayer (-18°), respectively which is as follows [1]:

$$\text{Fajer} =\text{Dhuhr} - (\cos^{-1}[\sin(-18) - \sin(\delta_0)\sin(\phi)/\cos(\delta_0)\cos(\phi)])/15 \quad (29)$$

$$\text{Isha} =\text{Dhuhr} + (\cos^{-1}[\sin(-17) - \sin(\delta_0)\sin(\phi)/\cos(\delta_0)\cos(\phi)])/15 \quad (30)$$

Results and discussion

Computer programs were written by using Q-Basic language to calculate the prayer times during one year for Baghdad city (ϕ =33.34º N, ℓ =44.43ºE). All the above calculations during 2021AD depended on practical formulas, as in equations (1 to 30) respectively. In addition, the results of our program were compared with the practical observation, which was also conducted to check the times of the Dhuhr, Asr and Maghrib prayers for several days during the year 2021 AD, and the results were identical with the calculated results in this work and as follows:

1. The results of calculating the Equation of time (ET) according to eq. (13), as we can see in Figure 1, the variation of (ET) during the year 2021, in the form of a wave with two non-similar positive values and two non-similar negative values as well, and four values (four days) in which it is zero and which has the noon time is exactly 12 o'clock, where ET is positive when the noon time passes at 12 o'clock and it is negative when the noon time is before 12 o'clock, and the reason for this is that the Earth's orbit around the sun is an oval, so its rotational speed is not constant value.

2. Figure 2 shows the change in the time of sunrise (Shuroq) in Baghdad during one year and it appears that sunrise (Shuroq) time changes in a curved and concave shape that shows its

highest value at the beginning and end of the year, which are winter days at (7^h:08^m am), and the lowest values in summer at (4^h:59^m am).

3. Figure 3 represents the variation of sunset (Maghrib) time behavior is a similar way to sunrise, where it has the lowest value in winter, reaching (5^h:00^m pm), and its highest value in midsummer reaches (7^h:20^m pm). The reason for this is that the path of the sun over the Baghdad skyline is long in summer and reaches up to about 14 hours, while winter decreases to about 10 hours, depending on the angle of the sun's azimuth at noon, which depends on the changing inclination of the sun during the year.

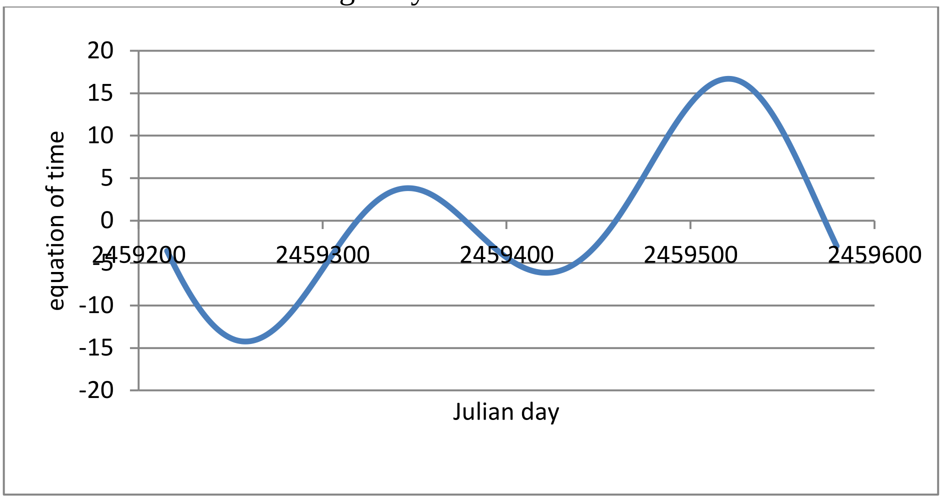

Figure1-The Equation of time (ET) during the year 2021.

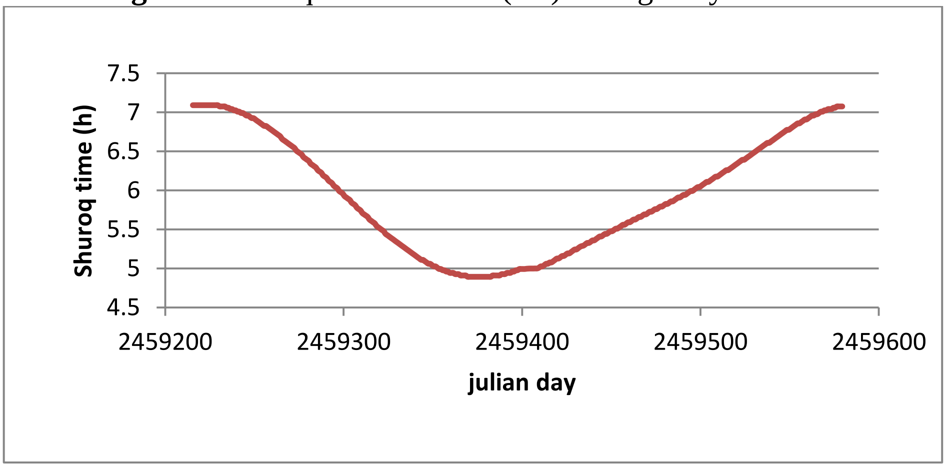

Figure 2-The variation of sunrise time (Shuroq) in Baghdad during the year 2021.

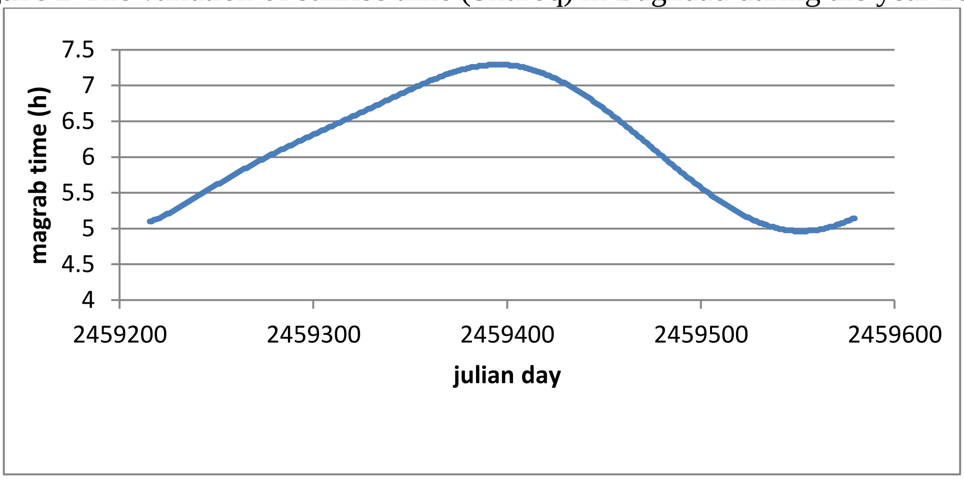

Figure 3-The variation time of sunset in Baghdad during the year 2021.

The following Figures (4) to (9) show a comparison of our program results with the Islamic project (accurate times program) [15] results for Baghdad during the year 2021.

4. The Figures (4) and (5) show the times of Fajer prayer and sunrise, where the lowest value of sunrise time is (4^h:56^m am) in June, and the highest value is (7^h: 08^m am) in January, as well as the lowest value for Fajer prayer time is (3^h:11^m am) in June, and the highest value is (5^h:38^m am) in December.

5. Figure 6 shows the change in Dhuhr prayer time is similar to the behaver of the equation of time, as the highest peak is (12^h: 20^mpm) in February, and (12^h: 12^m pm) in July. While the lowest peak is (12^h: 03^mpm) in May, and (11^h: 51^mpm) in October.

6. Figure 7 shows the change of Asr prayer time irregularly, as its highest value is (3^h: 46^mpm) in July, and its lowest value is (2^h: 48^mpm) in November.

7. The Figures (8) and (9) show the time of Maghrib and Isha prayers changes in a manner similar to the guideline since the greatest value of sunset time is (7^h:20^mpm) in June, and its lowest value (5^h: 01^mpm) in November. The greatest value of the time of the Isha prayer (9^h: 05^mpm) in June, and its lowest value (6^h: 30^mpm) in November, the reason is the change in declination of the sun, since the beginning and ending of the year is negative, and in the sixth and seventh months it is positive.

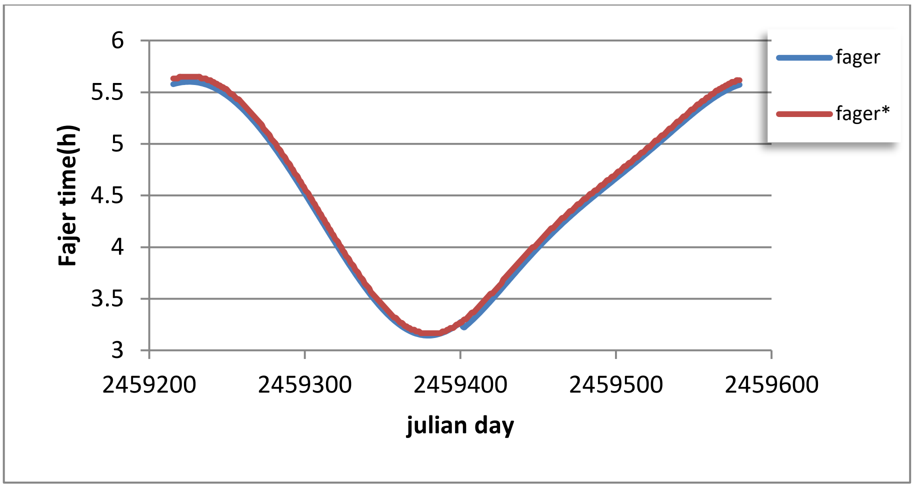

Figure 4-Fajer prayer time changed compared with the Islamic project 2021.

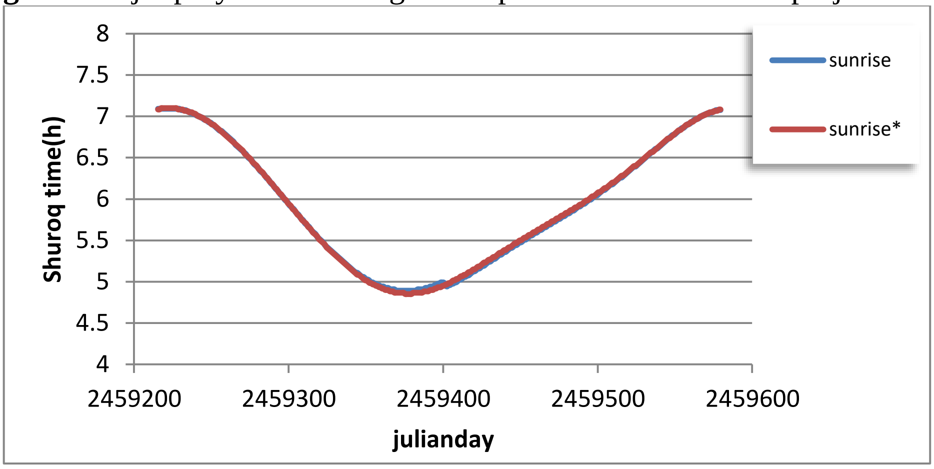

Figure 5-Sunrise time (Shuroq) compared to the Islamic project for 2021.

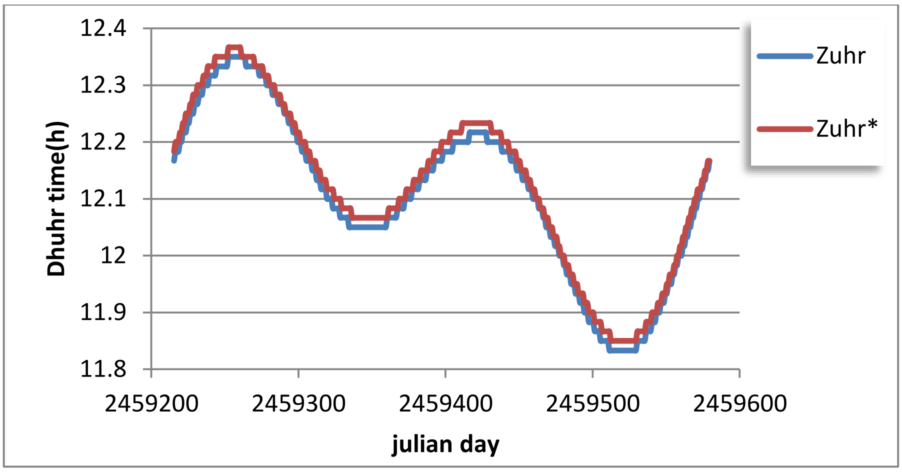

Figure 6- Dhuhr prayer time compared to the Islamic project 2021

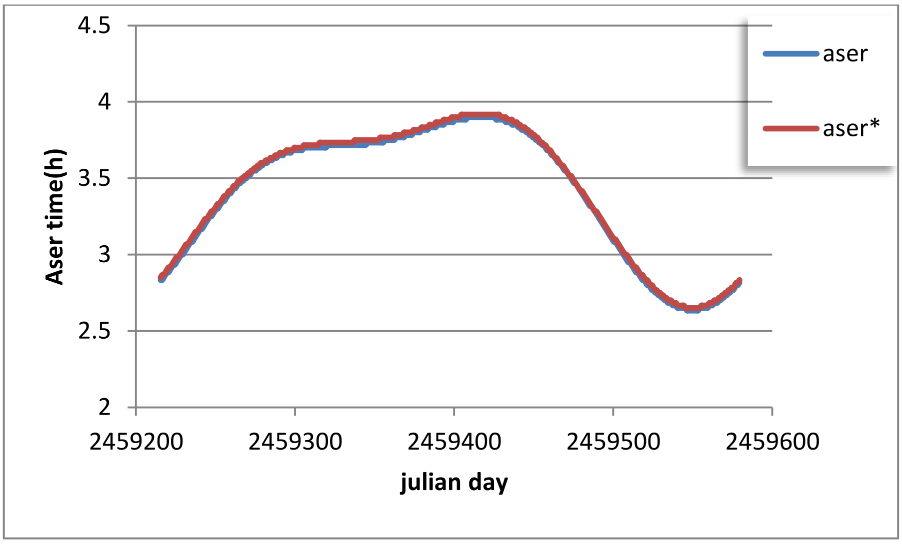

Figure 7- Asr prayer time compared to the Islamic project 2021.

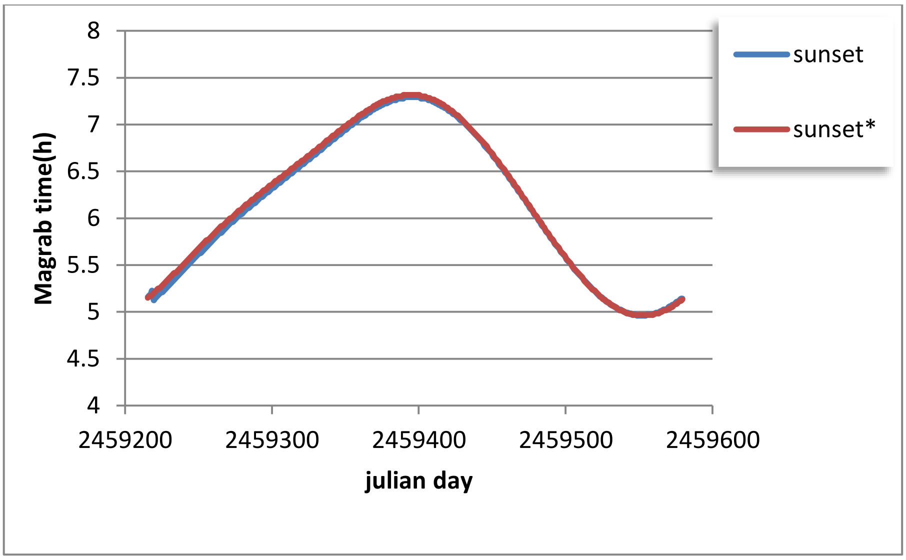

Figure 8-Maghrib prayer time has changed compared to the Islamic project 2021.

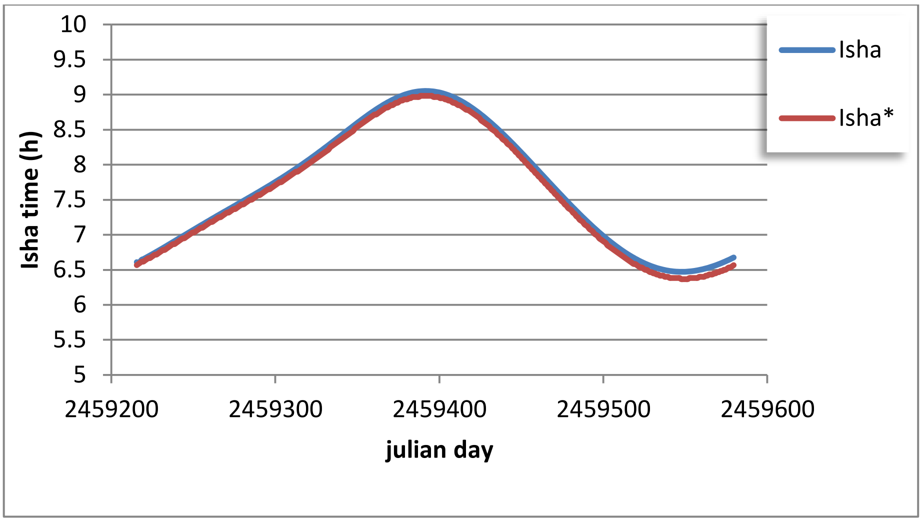

Figure 9- Isha prayer time compared to the Islamic project 2021

The results of prayer times vary with the change in geographical latitudes (ϕ) during the year 2021 AD for four months as shown in figures (10) to (15), and we can extract the following information:

8. It is clear from Figure 10 that the variations of Fajer prayer time with the latitude, where in January the increase is linear, and in February the increase is less in a curved manner, and in March it's stable and then decreases. That is, when the sun is close to the point of the vernal equinox and on the equator, while in the fourth month April, it decreases from (4^h:45^m am) to (3^h:00^m am) because the sun goes to the north equator where its declination becomes positive and the city latitude is also positive.

9. Figure 11 shows the variations of (sunrise)Shuroq time with different latitudes in 4 months. In January, Shuroq increases in a curved upward manner, and in February, it increases by less than the first month, and in March it is more stable, and by the end of the month, it begins to increase, and in April, the time of sunrise decreases slightly towards the bottom. It is also clear from Figure 11 that the effect of latitude is high when we are close to the two points of the spring and autumn equinox, while the opposite happens when approaching the two points of summer or winter, the effect will be less.

10. It is clear from Figure 12 that the variations of Dhuhr prayer time with different latitudes in 4 months, the time of Dhuhr prayer does not depend on the latitude, but it depends on the date where the sun's declination changes, so we do not notice any change in the month, because the sun is located on the meridian, which all latitudes have the same ET (equation of time) fixed.

11. Figure 13 shows that the time of Asr prayer depends on the date at any point of the latitude. The time changes from (3^h:30^m pm) to (1^h:35^m pm), and in March it decreases slowly, and in April it increases and then stabilizes, and this is evidence of the effect of latitude on the time of the Asr prayer.

12. Figure 14 shows the variations of Maghrib prayer time with different latitudes in 4 months. The Maghrib prayer time is clear that January falls at the equator at (6^h:00^m pm), while the northern latitudes 60^0 reach the (3^h:00^m pm), and the sun sets in this month before the equator. The reason for this is because we choose a city north equator and the sun is in the south of the equator, so the sun sets early in the regions of the north of the equator, while in April it will be the opposite, the sun sets on the equator before its setting in the regions north of the equator. In March, the descent is very slow, because the sun is close to the equator.

14. Figure 15 shows clearly the variations of Isha prayer time with different latitudes in 4 months. The time of the Isha prayer begins to descend slightly slowly in a curved manner in

January and February. In March it's stable, then begins to rise at approximately 40^0 latitude, while in April it also begins to rise at 60^0 latitude.
When the summer months are taken, the time of Isha will change upwards faster at altitude of more than 65^0 the sun does not set, as there is no Isha time in these areas.

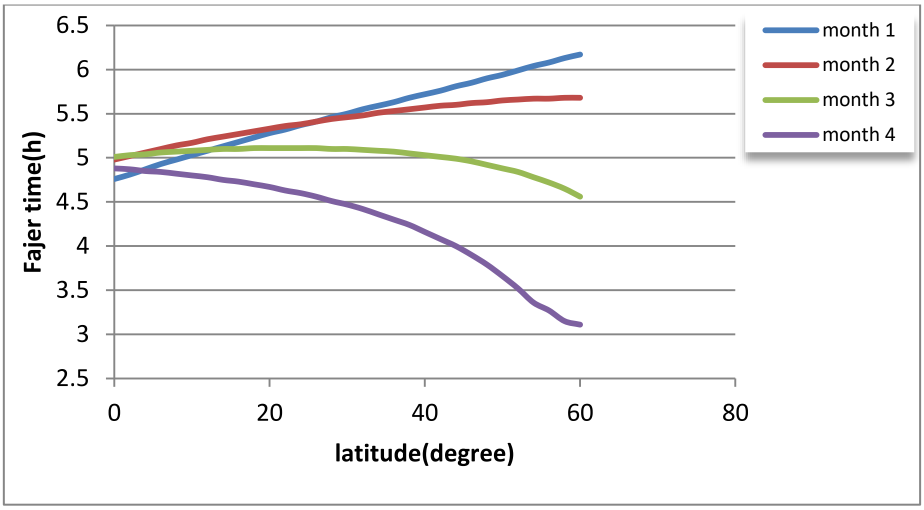

Figure 10-The variations of Fajer prayer time with different latitudes in 4 months.

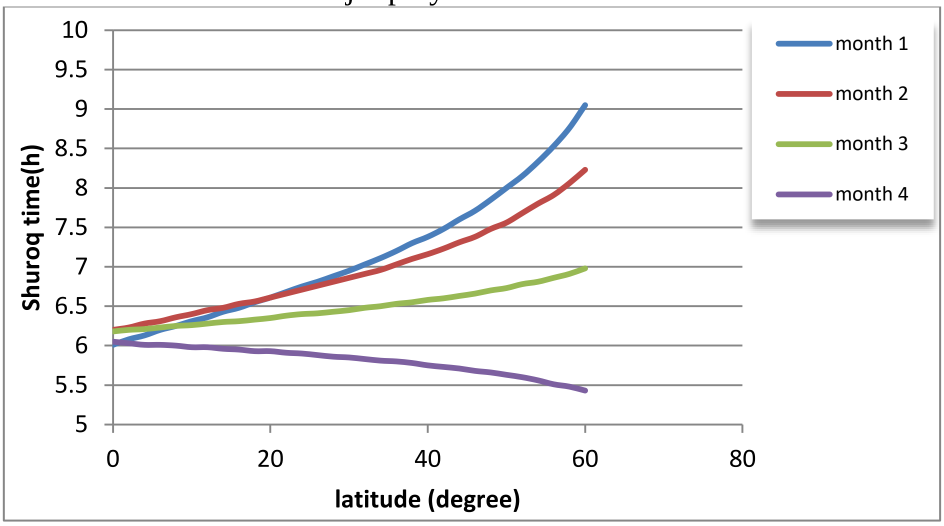

Figure 11-The variations of (sunrise)Shuroq time with different latitudes in 4 months

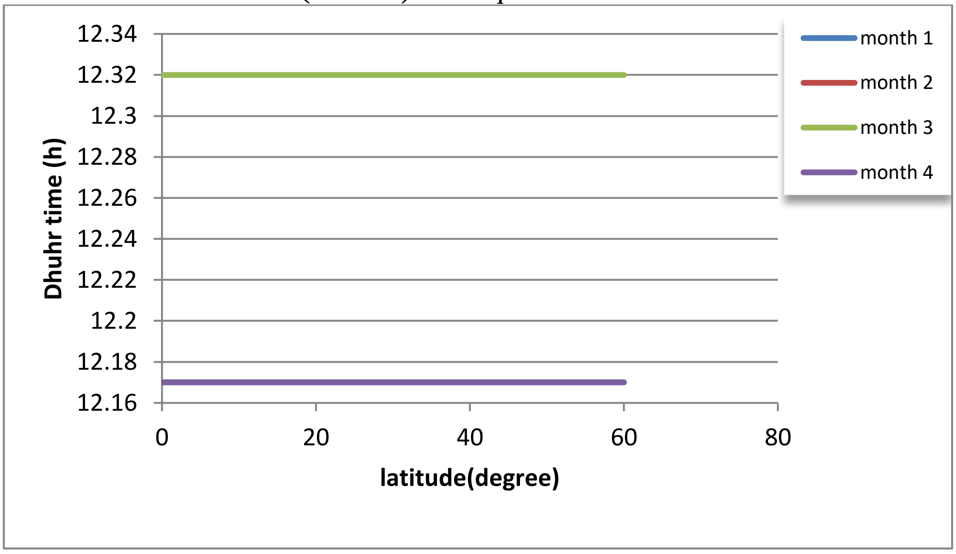

Figure12-The variations of Dhuhr prayer time with different latitudes in 4 months

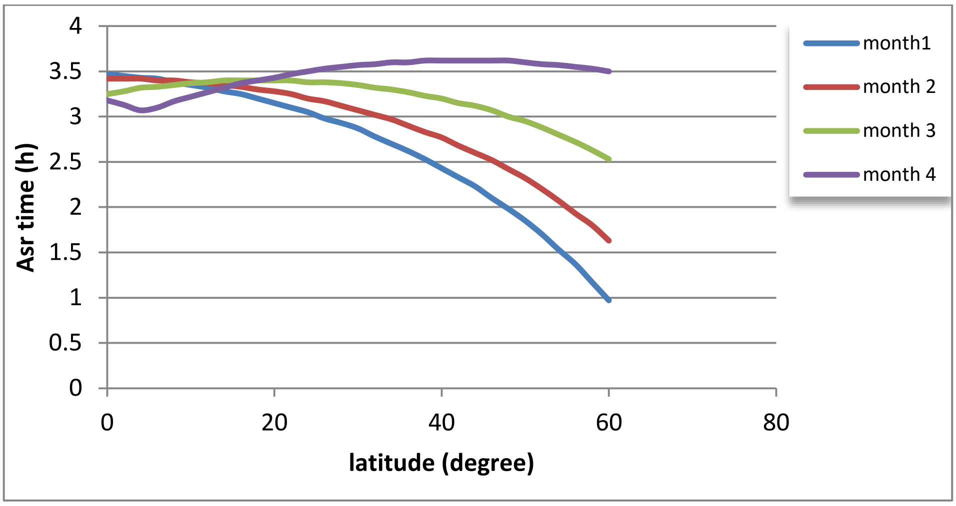

Figure 13-The variations of Asr prayer time with different latitudes in 4 months.

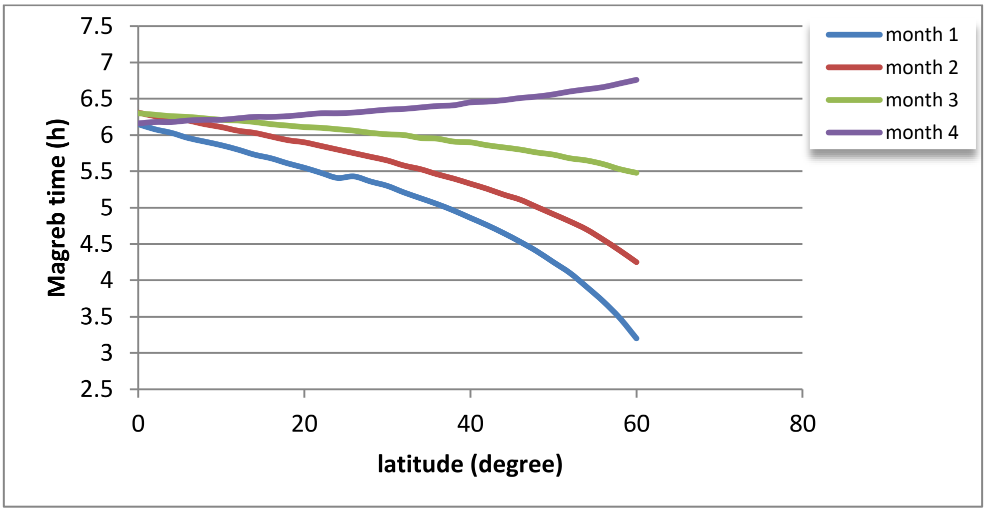

Figure 14-The variations of Maghrib prayer time with different latitudes in 4 months.

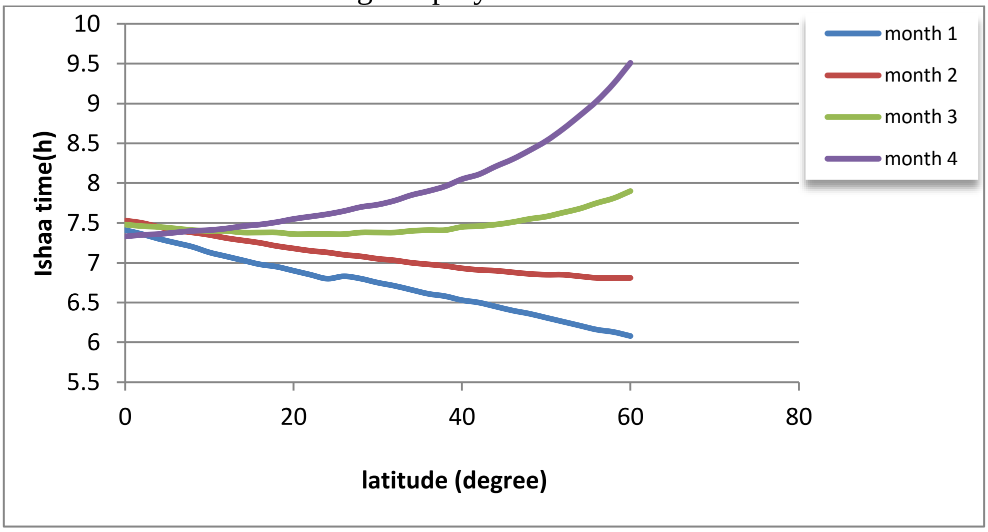

Figure 15-The variations of Isha prayer time with different latitudes in 4 months.

Conclusions

The main conclusions from this study could be summarized as follows:

1) All prayer times are affected by latitude according to each region except Dhuhr prayer, it changes with the change of the equation of time.

2) The time of Dhuhr prayer does not depend on the latitude.

3) The shadow of the meridian varies every day of the year from one point to another on the surface of the globe.

4) The locations of high latitude (above latitude 48^0) have irregular behavior for prayer times.

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