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Assessing the Accuracy of Approximated Ephemeris Data for Prayer Time Calculations

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Abstract

Prayer (*ṣalāh*) is an obligatory act of worship in Islam, with its timing determined by astronomical parameters derived from ephemeris data. Although many mobile applications are available to calculate prayer times, most depend on internet connectivity, limiting their usability in certain conditions. As an alternative, prayer times can be determined independently using the hisab method, which requires ephemeris data. This study proposes using approximated ephemeris data and evaluates its accuracy in prayer-time calculations. A quantitative computational approach was employed by developing a Microsoft Excel-based model to generate approximated ephemeris data and calculate prayer times. The approximated data were compared with official ephemeris data from the Ministry of Religious Affairs of Indonesia over one year (2026) across multiple locations. The results indicate that the approximated ephemeris data produce only minor deviations, resulting in prayer time differences of a few seconds. These findings demonstrate that the approximation method can be reliably used, and the developed Excel-based tool provides a practical solution for offline prayer time determination.

Keywords: prayer time, ephemeris, approximation, accuracy, Microsoft Excel.

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Salat merupakan ibadah wajib dalam Islam yang waktunya ditentukan berdasarkan parameter astronomi yang diperoleh dari data ephemeris. Saat ini, banyak aplikasi berbasis mobile yang dapat digunakan untuk menghitung waktu salat, namun sebagian besar bergantung pada koneksi internet sehingga penggunaannya terbatas dalam kondisi tertentu. Sebagai alternatif, waktu salat dapat ditentukan secara mandiri menggunakan metode hisab yang memerlukan data ephemeris. Penelitian ini mengusulkan penggunaan data ephemeris hasil pendekatan (aproksimasi) serta mengevaluasi tingkat akurasinya dalam perhitungan waktu salat. Metode yang digunakan adalah pendekatan kuantitatif komputasional dengan mengembangkan model berbasis *Microsoft Excel* untuk menghasilkan data ephemeris aproksimasi dan menghitung waktu salat. Data hasil aproksimasi kemudian dibandingkan dengan data ephemeris resmi dari Kementerian Agama Republik Indonesia selama periode satu tahun (2026) pada beberapa lokasi. Hasil penelitian menunjukkan bahwa data ephemeris aproksimasi menghasilkan deviasi yang sangat kecil, sehingga perbedaan waktu salat yang dihasilkan hanya berada dalam kisaran beberapa detik. Temuan ini menunjukkan bahwa metode aproksimasi dapat digunakan secara andal, serta aplikasi berbasis *Excel* yang dikembangkan dapat menjadi solusi praktis untuk penentuan waktu salat secara *offline*.

Kata Kunci: waktu salat, ephemeris, pendekatan, akurasi, *Microsoft Excel*.

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A. Introduction

Prayer (*ṣalāh*) is an obligatory act of worship performed five times daily by Muslims, with prescribed rules regarding movements, recitations, direction, and timing.[1] The determination of prayer times is fundamentally based on the apparent motion of the Sun, as each prayer corresponds to specific astronomical phenomena such as solar culmination, shadow length, sunset, and twilight. Therefore, accurately determining prayer times requires reliable astronomical parameters and precise computational methods.[2]

In general, prayer times can be determined through direct observation (*rukyat*) or mathematical calculation (*ḥisāb*). In contemporary practice, the use of digital technology has led to the widespread adoption of prayer time applications, particularly those based on mobile devices.[3] These applications provide practical, accessible solutions for everyday use. However, previous studies have shown that different applications can yield different prayer times, raising concerns about their accuracy and consistency. For instance, a study comparing online prayer time applications found discrepancies of up to several minutes across platforms, indicating that not all applications can be relied upon equally.

From an astronomical perspective, prayer time calculations depend on ephemeris data, including the Sun's declination, equation of time, and semi-diameter. These parameters are derived from mathematical models of solar motion and are influenced by a location's latitude and longitude. Previous research has demonstrated that prayer times vary across regions due to differences in latitude and solar position, and accurate calculations require precise astronomical equations and corrections.[4]

Despite the availability of digital tools and official ephemeris data provided by institutions such as the Ministry of Religious Affairs of Indonesia, several challenges remain. *First*, many applications rely on internet connectivity, limiting their usability in remote areas or during emergencies. *Second*, ephemeris data in tabular form is not easily accessible to non-expert users, making independent calculation difficult. *Third*, although various studies have examined prayer time accuracy and its dependence on astronomical parameters, limited attention has been given to the use of approximation methods for generating ephemeris data and evaluating their impact on prayer time calculations. In addition, determining prayer times is relevant not only to terrestrial conditions but also raises broader conceptual challenges, such as how to define them in extreme environments

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[1] Arino Bemi Sado, "Waktu Shalat Dalam Perspektif Astronomi; Sebuah Integrasi Antara Sains Dan Agama," *Mu'amalat: Jurnal Kajian Hukum Ekonomi Syariah* 7, no. 1 (2015): 69–83.

[2] Riza Afrian Mustaqim, "Relevansi Jadwal Waktu Salat Sepanjang Masa," *Jurnal Alwatzikhoebillah : Kajian Islam, Pendidikan, Ekonomi, Humaniora* 6, no. 2 (November 19, 2020): 22–34, https://doi.org/10.37567/alwatzikhoebillah.v6i2.282.

[3] Budi Mulyono et al., "Analisis Dampak Implementasi Teknologi 5G Terhadap Infrastruktur Jaringan Di Indonesia," *Jurnal Minfo Polgan* 13, no. 2 (September 11, 2024): 1462–67, https://doi.org/10.33395/jmp.v13i2.14103.

[4] Doaa J. Saad, Fouad M. Abdulla, and Abdulrahman H. Saleh, "Improving the Accuracy of Prayer Times and Calculating Their Change with Geographical Latitudes during the Year 2021 AD," *Iraqi Journal of Science*, September 30, 2022, 4090–4101, https://doi.org/10.24996/ijs.2022.63.9.37; Muhamad Adib Abdul Haq, "Problems of Prayer Time and Qibla Direction in Outer Space," *Al-Hilal: Journal of Islamic Astronomy* 4, no. 2 (October 31, 2022): 153–64, https://doi.org/10.21580/al-hilal.2022.4.2.13251; Encep Abdul Rojak, "The Accuracy of Online-Based Prayer Times Applications," *Ijtihad : Jurnal Wacana Hukum Islam Dan Kemanusiaan* 21, no. 1 (June 30, 2021): 21–38, https://doi.org/10.18326/ijtihad.v21i1.21-38.

where conventional solar references may not apply. This highlights the importance of developing flexible, computational approaches to determining prayer times.[5]

Therefore, this study aims to: (1) evaluate the accuracy of ephemeris data generated using approximation methods by comparing them with official ephemeris data, (2) assess the accuracy of prayer time calculations based on the approximated data, and (3) develop a Microsoft Excel-based application for offline prayer time calculation. This study is expected to contribute to the development of practical, accessible, and reliable methods for determining prayer times, particularly in environments with limited internet connectivity.

B. Method

This study employs a quantitative computational approach to evaluate the accuracy of approximated ephemeris data in prayer time calculations. The research was conducted by developing a Microsoft Excel-based model to generate solar ephemeris parameters, including declination, equation of time, and semi-diameter, using an approximation method. The approximated data were then compared with official ephemeris data issued by the Ministry of Religious Affairs of Indonesia. The analysis was carried out over one year (January–December 2026), covering five daily prayer times (Fajr, Dhuhr, Asr, Maghrib, and Isha) across seven locations in Indonesia within the same time zone.

Data analysis was performed by calculating differences between approximated and official ephemeris data and the resulting prayer times derived from both datasets. All calculations were conducted using identical parameters, including geographical coordinates, solar altitude assumptions, and time correction factors, to ensure consistency. The level of accuracy was assessed based on the magnitude of deviations in seconds and arcseconds. The workflow consisted of generating approximated ephemeris data, computing prayer times, and comparing the results with reference data to determine the reliability of the approximation method for offline prayer time calculation.

C. Result and Discussion

1. Accuracy of Approximated Ephemeris Data

The comparison between approximated ephemeris data and the official dataset issued by the Ministry of Religious Affairs shows strong agreement across all evaluated parameters. Over one year, the maximum differences were recorded as 17.25″ for solar declination, 7.51 seconds for the equation of time, and 2.03″ for the semi-diameter, with average deviations of 5.73″, 1.72 seconds, and 1.70″, respectively. These results indicate that the approximation method can reproduce solar ephemeris parameters with high consistency relative to standardized reference data.

[5] Alfan Maghfuri, "Akurasi Perhitungan Gerhana Matahari Dengan Data Ephemeris Hisab Rukyat," *Al-Afaq: Jurnal Ilmu Falak Dan Astronomi* 2, no. 1 (June 30, 2020): 1–14, https://doi.org/10.20414/afaq.v2i1.2292.

Table 1: Ephemeris Data Comparison for 1 Year Period

Comparation Result	Ephemeris Data		
	Declination	Equation of Time	Semi Diameter
Minimum Difference	0.0”	0.0 s	1.19”
Maximum Difference	17.25”	7.51 s	2.03”
Average Difference	5.73”	1.72 s	1.70”

To provide a clearer illustration of the comparison results, a sample of the ephemeris data is presented in Table 2, covering 15 days from 1 to January 15, 2026, at a fixed observation time. The table displays a direct comparison between the approximated ephemeris values and the official data issued by the Ministry of Religious Affairs, including solar declination, equation of time, and semi-diameter.

Table 2: Comparison of approximate Ephemeris data with data from the Ministry of Religious Affairs from January 1, 2026, to January 15, 2026, at 5:00 GMT

Date	Ephemeris Data	Approximated	Ministry of Religion	Difference
January 1, 2026	Declination	-82802.27”	-82801.00”	1.27”
	Equation of Time	-204.18 s	-206.00 s	1.82 s
	Semi Diameter	977.81”	975.91”	1.90”
January 2, 2026	Declination	-82491.98”	-82491.00”	0.98”
	Equation of Time	-232.35 s	-234.00 s	1.65 s
	Semi Diameter	977.82”	975.92”	1.90”
January 3, 2026	Declination	-82154.32”	-82153.00”	1.32”
	Equation of Time	-260.17 s	-262.00 s	1.83 s
	Semi Diameter	977.82”	975.93”	1.89”
January 4, 2026	Declination	-81789.43”	-81789.00”	0.43”
	Equation of Time	-287.61 s	-289.00 s	1.39 s
	Semi Diameter	977.82”	975.93”	1.89”
January 5, 2026	Declination	-81397.50”	-81397.00”	0.50”
	Equation of Time	-314.65 s	-316.00 s	1.35 s
	Semi Diameter	977.82”	975.92”	1.90”
January 6, 2026	Declination	-80978.73”	-80979.00”	0.27”
	Equation of Time	-341.25 s	-342.00 s	0.75 s
	Semi Diameter	977.81”	975.91”	1.90”
January 7, 2026	Declination	-80533.31”	-80534.00”	0.69”
	Equation of Time	-367.39 s	-368.00 s	0.61 s
	Semi Diameter	977.79”	975.89”	1.90”
January 8, 2026	Declination	-80061.46”	-80062.00”	0.54”
	Equation of Time	-393.04 s	-394.00 s	0.96 s
	Semi Diameter	977.77”	975.86”	1.91”
January 9, 2026	Declination	-79563.42”	-79564.00”	0.58”

Date	Ephemeris Data	Approximated	Ministry of Religion	Difference
	Equation of Time	-418.17 s	-419.00 s	0.83 s
	Semi Diameter	977.75”	975.83”	1.92”
January 10, 2026	Declination	-79039.42”	-79041.00”	1.58”
	Equation of Time	-442.77 s	-444.00 s	1.23 s
	Semi Diameter	977.72”	975.79”	1.93”
January 11, 2026	Declination	-78489.71”	-78491.00”	1.29”
	Equation of Time	-466.79 s	-468.00 s	1.21 s
	Semi Diameter	977.68”	975.75”	1.93”
January 12, 2026	Declination	-77914.57”	-77916.00”	1.43”
	Equation of Time	-490.23 s	-491.00 s	0.77 s
	Semi Diameter	977.64”	975.71”	1.93”
January 13, 2026	Declination	-77314.25”	-77316.00”	1.75”
	Equation of Time	-513.06 s	-514.00 s	0.94 s
	Semi Diameter	977.60”	975.66”	1.94”
January 14, 2026	Declination	-76689.05”	-76691.00”	1.95”
	Equation of Time	-535.26 s	-536.00 s	0.74 s
	Semi Diameter	977.55”	975.60”	1.95”
January 15, 2026	Declination	-76039.27”	-76041.00”	1.73”
	Equation of Time	-556.81 s	-558.00 s	1.19 s
	Semi Diameter	977.50”	975.54”	1.96”

As shown in Table 2, the differences between the two datasets remain consistently small across all observed dates. The deviations are generally limited to a few arcseconds for declination and semi-diameter, and only a few seconds for the equation of time. This pattern supports the overall findings presented in Table 3, indicating that the approximation method produces stable and closely aligned results with the reference data.

From an astronomical standpoint, these deviations are relatively small and remain within acceptable limits for practical solar position calculations. The minor differences observed can be attributed to the simplification of higher-order correction terms typically included in more rigorous ephemeris models. In precise astronomical computations, such corrections account for perturbations and orbital irregularities; however, their omission in approximation-based methods only introduces marginal errors at the level observed in this study. Furthermore, the consistency of the deviations across the dataset suggests that the approximation method produces stable, systematic results rather than random errors. This stability is important in computational applications, as systematic deviations are generally more predictable and easier to account for than fluctuating inaccuracies. The relatively low average differences also indicate that the approximation method effectively captures the dominant components of solar motion required for time-based calculations.[6]

[6] Muhajir Muhajir, “Analisis Pemikiran Saadoe’ddin Djambek Tentang Waktu Shalat Di Daerah Abnormal (Kutub),” *Madinah: Jurnal Studi Islam* 5, no. 2 (December 1, 2018): 148–58, https://doi.org/10.58518/madinah.v5i2.1277; Rifki Hasan Hasan, “Astronomical Interpretation of Early Prayer Times: Study of Differences in Determination of Early Prayer Times From The Text and Astronomical Prespective,” *Al-Hilal: Journal of Islamic Astronomy* 2, no. 2 (October 31, 2020): 194–213,

In comparison with high-precision astronomical models, the approximation approach offers a practical trade-off between computational simplicity and accuracy. While it does not achieve sub-arcsecond precision, the resulting level of accuracy is sufficient for applications that do not require extremely high resolution, such as prayer time determination. Therefore, the approximation method can be considered a reliable alternative for generating ephemeris data in contexts where accessibility and efficiency are prioritized.

2. Impact on Prayer Time Calculation

The differences observed in the approximated ephemeris data directly influence the calculation of prayer times. However, the results show that the resulting discrepancies remain very small. Across all locations and prayer types, the differences range from −7 seconds to +2 seconds, with an average deviation of approximately 1 second. This indicates that the transformation from astronomical parameters to prayer-time values does not significantly amplify the initial approximation error. In other words, the computational process for prayer time determination is relatively stable, allowing small deviations in input data to be minimal in the final results. This stability is essential in ensuring that simplified ephemeris models can still produce reliable outputs for practical use.

From a computational perspective, the limited propagation of error can be explained by the gradual, continuous nature of solar motion. Small differences in parameters such as declination and the equation of time result in very minor temporal shifts when converted to clock time. As a result, even when approximation is applied, the overall structure of the calculation remains robust. This finding suggests that the approximation approach can preserve the integrity of computational results without introducing significant distortion. Therefore, the method is not only computationally efficient but also sufficiently accurate for practical applications, particularly for prayer time determination.[7]

A more detailed examination shows that the discrepancies are not uniformly distributed across all prayer times. The Maghrib prayer tends to exhibit the largest variation, which can be attributed to the involvement of multiple ephemeris parameters, including declination, equation of time, and semi-diameter. The combination of these variables increases the calculation's sensitivity to input differences. In contrast, the Dhuhr prayer shows nearly constant deviations, as it primarily depends on the equation of time. This indicates that prayer times calculated with fewer astronomical variables are less sensitive to approximation errors, whereas those calculated with multiple parameters are more susceptible to cumulative errors.

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https://doi.org/10.21580/al-hilal.2020.2.2.6640; Ryotaro Uemura, "Visiting Religious Places for Prayer in Japan: How Does Religious Identity Affect Religious Behavior?," *Review of Religious Research* 62, no. 1 (March 1, 2020): 45–65, https://doi.org/10.1007/s13644-019-00389-8; Muhammad Himmatur Riza, Thomas Djamaluddin, and Ahmad Izzuddin, "Transformation of Prayer Time Schedules: From A Static-Passive to A Dynamic-Variative Perspective," *Ulul Albab: Jurnal Studi Dan Penelitian Hukum Islam* 6, no. 1 (May 7, 2024): 39, https://doi.org/10.30659/jua.v6i1.22826.

[7] Jayusman Jayusman, "Urgensi Ihtiyath Dalam Perhitungan Awal Waktu Salat," *Al-´Adalah* 10, no. 3 (2012): 279–91, https://doi.org/10.24042/adalah.v10i1.269; Rojak, "The Accuracy of Online-Based Prayer Times Applications."

Despite these variations, the magnitude of the differences remains well within acceptable limits. In practical applications, prayer time schedules commonly incorporate a safety margin (*ihtiyāt*) of one to several minutes to ensure the validity of worship. Therefore, discrepancies of a few seconds do not affect the practical implementation of prayer times. This finding is particularly important when compared with previous studies that reported differences of several minutes across various prayer-time applications. The significantly smaller deviations observed in this study demonstrate that the approximation method provides greater consistency and reliability than uncontrolled variations in existing digital applications.

3. Fiqh Perspective on Prayer Time Accuracy

The small discrepancies observed in the calculated prayer times raise an important question regarding their significance from an Islamic jurisprudential perspective. In Islamic law, the determination of prayer times is fundamentally linked to observable astronomical phenomena, particularly the Sun's position. Classical sources, including the Qur'an and Hadith, define prayer times based on natural indicators such as the Sun's culmination, the length of its shadow, sunset, and twilight.[8] Consequently, the primary objective in prayer time determination is to ensure that the prescribed time has definitively begun (*dukhūl al-waqt*), rather than achieving absolute astronomical precision.

In practical implementations, Islamic scholars have long recognized the necessity of incorporating a safety margin (*iḥtiyāṭ*) in prayer time calculations. This precautionary addition, typically ranging from one to several minutes, is intended to ensure that prayer is not performed before its valid time begins. The concept of *iḥtiyāṭ* reflects a jurisprudential principle that prioritizes certainty (*yaqīn*) over doubt (*shakk*) in acts of worship. Therefore, minor computational discrepancies, especially those within the range of seconds, are generally considered negligible and do not affect the validity of prayer.[9]

The findings of this study, which show deviations of only a few seconds in calculated prayer times, fall well within this accepted margin of tolerance. From a *fiqh* perspective, such differences are insignificant when compared to the established practice of adding precautionary time buffers. This indicates that the approximation method used in this study remains fully compatible with Islamic law. In other words, the level of accuracy achieved is sufficient to ensure that prayer times are valid and reliable for practical use. Moreover, contemporary studies on prayer time applications have reported discrepancies of several minutes between different systems, highlighting inconsistencies in computational methods and data sources. In comparison, the much smaller deviations observed in this study indicate greater precision and consistency. This suggests that the approximation-based approach not only meets but exceeds the practical accuracy requirements commonly encountered in real-world applications.

[8] Ahmad Abdillah Rauf Syam et al., "Determining Tahrim Prayer Times Based on Sky Brightness and Sun Altitude Parameters with a Sky Quality Meter," *Al-Afaq: Jurnal Ilmu Falak Dan Astronomi* 7, no. 2 (2025): 270–86.

[9] Muḥammad Ibn 'Abdullāh Ibn Qudāmah, *Al-Mughnī* (Riyāḍ: Dār 'Alam al-Kutub, 1997); Wahbah Az-Zuhaili, *Fiqih Islam Wa Adillatuhu Jilid 2* (Jakarta: Gema Insani, 2010).

In a broader context, integrating computational methods with considerations of *fiqh* underscores the interdisciplinary nature of prayer time determination. While astronomical models provide the technical foundation, jurisprudential principles ensure their proper application in religious practice. [10] Therefore, the results of this study support the view that simplified computational approaches, when properly validated, can be effectively adopted without compromising the legal and religious validity of prayer time determination.

4. Implications for Offline Prayer Time Computation

The findings of this study demonstrate that approximated ephemeris data can be effectively utilized in practical applications of prayer time calculation. Despite using simplified computational models, the resulting accuracy remains high, with deviations limited to a few seconds. This level of precision confirms that approximation methods are sufficient for applications that do not require highly complex astronomical modeling. Consequently, the approach provides a viable alternative to conventional ephemeris data sources, particularly in contexts where accessibility and computational efficiency are prioritized.

One of the primary contributions of this study is the development of an Excel-based application for offline calculation of prayer times. The use of spreadsheet software offers several advantages, including ease of use, transparency of calculation processes, and flexibility in modifying input parameters. Unlike many existing digital applications that depend on internet connectivity, this tool enables users to perform independent calculations without external data access. This feature is particularly beneficial for users in remote areas, during travel, or in emergencies where internet access is limited or unavailable.[11]

Furthermore, implementing an offline computational model enhances the reproducibility and controllability of prayer-time calculations. Users can directly examine the underlying formulas, adjust parameters such as geographical coordinates, and validate the results independently. This level of transparency is often lacking in proprietary or black-box applications, which may produce inconsistent results due to hidden algorithms or varying data sources. By contrast, the approach proposed in this study offers a more standardized, verifiable method for determining prayer times.[12]

In a broader context, integrating approximation methods with readily available computational tools offers the potential to develop low-resource, high-reliability solutions in Islamic

[10] Ahmad Izzuddin, *Ilmu Falak Praktis* (Semarang: Rizki Putra, 2012); Slamet Hambali, *Ilmu Falak 1; Penentuan Awal Waktu Shalat Dan Arah Kiblat Seluruh Dunia* (Semarang: Program Pascasarjan IAIN Walisongo Semarang, 2011); Susiknan Azhari, *Ilmu Falak: Perjumpaan Khazanah Islam Dan Sains Modern* (Yogyakarta: Suara Muhammadiyah, 2007).

[11] Muhammad Jamaluddin, "Development of Astro Time Islamic Prayer Schedule Application and Altitude Correction Test," *Al-Hilal: Journal of Islamic Astronomy* 4, no. 2 (2023): 133–52, https://doi.org/https://doi.org/10.21580/al-hilal.2022.4.2.12330; Silvia Andriani Bahri and Sarma Hasibuan, "Muslim Prayer Times on Astronomy and Fuqaha," *Al-Hisab: Journal of Islamic Astronomy* 1, no. 4 (2024): 163–73, https://doi.org/https://doi.org/10.33096/jah.v1i4.21428; Era Zufialina, "Study of Determining Prayer Maghrib Time in the Al-Falaqiyyah Manuscript," *Al-Hilal: Journal of Islamic Astronomy* 5, no. 2 (October 30, 2023): 189–206, https://doi.org/10.21580/al-hilal.2023.5.2.18328; Uemura, "Visiting Religious Places for Prayer in Japan: How Does Religious Identity Affect Religious Behavior?"

[12] Nihayatur Rohmah, "The Effect of Atmospheric Humidity Level to the Determination of Islamic Fajr/Morning Prayer Time and Twilight Appearance," *Journal of Physics: Conference Series* 771 (November 2016): 012048, https://doi.org/10.1088/1742-6596/771/1/012048.

astronomy.[13] The results of this study suggest that accurate and practical prayer time determination does not necessarily require sophisticated software or continuous data connectivity. Instead, simplified yet well-validated models can provide reliable outcomes while maintaining usability. This approach opens opportunities for further development of educational tools, community-based applications, and adaptable systems that support both scientific rigor and practical implementation.

D. Conclusion

This study demonstrates that approximated ephemeris data can achieve high accuracy when applied to prayer time calculations. The comparison with official ephemeris data shows only minor deviations, with average differences in solar parameters remaining within a few arcseconds and seconds. These small discrepancies result in differences of only a few seconds in prayer times, indicating minimal error propagation from astronomical data to computed times. The findings confirm that the approximation method is sufficiently accurate for practical use and remains consistent across different locations and prayer times. From both astronomical and jurisprudential perspectives, the resulting accuracy falls well within acceptable limits, particularly when considering the commonly applied precautionary margin (*iḥtiyāṭ*) in prayer time determination.

Despite these promising results, several limitations should be acknowledged. *First*, the approximation method employed in this study is based on simplified astronomical models that do not incorporate higher-order corrections found in more advanced ephemeris systems. As a result, the accuracy may be lower than that of high-precision astronomical standards. *Second*, the validation of results relies on comparison with a single reference dataset issued by the Ministry of Religious Affairs, without incorporating other global ephemeris models as benchmarks. *Third*, implementing the model in Microsoft Excel, while practical and accessible, may limit scalability and automation for large-scale or real-time applications.

Future research is recommended to enhance both the accuracy and applicability of the proposed method. Further studies may incorporate more advanced astronomical models, such as higher-order solar position algorithms, to evaluate potential improvements in precision. Comparative analysis with international ephemeris datasets would also strengthen the robustness of the findings. In addition, the development of lightweight offline applications, including mobile platforms, could extend the method's usability to a broader audience. Finally, integrating user-centered design and validation in real-world contexts would provide further insight into the practical effectiveness of approximation-based prayer time calculation systems.

[13] Muhammad Rasywan Syarif et al., "The Transformation of Rukyah Al-Hilal: Integrating Digital Imaging Technology in Islamic Moon Sighting Practices," *Malaysian Journal of Syariah and Law* 13, no. 1 (April 30, 2025): 314–24, https://doi.org/10.33102/mjsl.vol13no1.751; Ismail Fahmi et al., "Zodiacal Light and Astronomical Twilight Measurement at Timau Nasional Observatory Site," 2024, 070003, https://doi.org/10.1063/5.0211329; AW. Raihana, K. Norihan, and M. Muhamad Hazman, "Issues on Determination Of-Accurate Fajr and Dhuha Prayer Times According to Fiqh and Astronomical Perspectives in Malaysia: A Bibliography Study," in *Conference Proceedings* (Bali, 2016), 675–80.

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