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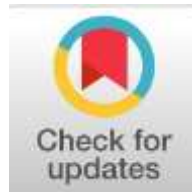
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Computational Modeling of Temporal Boundaries in Islamic Calendrical Systems: Pemodelan Komputasional Batas Waktu dalam Sistem Penanggalan Islam

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Abstract

General Background The Hijri framework functions as a fundamental lunar tracking mechanism for organizing Islamic religious observances. **Specific Background** Converting continuous astronomical periods into discrete daily units creates mathematical challenges, requiring precise structural boundaries to maintain an alternating cycle duration of 29 or 30 days. **Knowledge Gap** Although administrative proposals suggest starting the daily cycle at midnight, there is a distinct lack of comprehensive simulation data verifying how different temporal boundaries systematically affect overall system stability. **Aims** This study analyzes the structural consistency of the Unified Global Hijri Calendar across four boundary paradigms—dawn, sunset, 18:00, and 00:00—using a thirty-year global algorithmic projection from 1447 AH to 1477 AH. **Results** The analysis demonstrates that initiating the daily cycle at 18:00 achieves the highest stability, yielding a normal cycle duration proportion of 64.68%. Conversely, dawn and sunset boundaries exhibit extreme spatial variability, while the 00:00 standard demonstrates a systematic bias towards longer anomalous durations. **Novelty** This research proves that the selection of the daily starting point is not merely a technical administrative choice but a fundamental systemic parameter governing long-term structural consistency. **Implications** To eliminate regional worship discrepancies and bridge astronomical limitations, framework developers should officially adopt the 18:00 reference point as the optimal compromise for worldwide implementation.

Highlights

- ♦ The fixed 18:00 reference point provided the highest structural stability with 64.68% standard lunar cycle durations.
- ♦ Dawn and sunset criteria demonstrated severe spatial variability alongside local astronomical limitations worldwide.
- ♦ Administrative midnight settings systematically generated anomalous periods exceeding standard normative limits.

Keywords

Unified Global Hijri Calendar; Day Beginning Definition; Computational Simulation; Month Duration; Calendar Stability

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Introduction

The Hijri calendar is a lunar-based calendrical system that plays a fundamental role in the observance of Islamic religious practices, including the determination of the beginning of Ramadan, Eid al-Fitr, and Eid al-Adha. In calendrical science, a calendar system is essentially a mechanism for transforming continuous astronomical time into a discrete and computable structure expressed in units of days, months, and years [1]. Edward M. Reingold (2018) asserts that all calendar systems may be represented as mathematical mappings from the number of days elapsed since a specific reference point (epoch) into cyclic structures such as months and years. Within this framework, the day constitutes the fundamental unit underlying all calendrical calculations, while months and years are derived from the grouping of days based on astronomical phenomena [2]. Nevertheless, the complexity of lunar-based calendar systems arises from the incommensurability between astronomical periods and their mathematical representation. The current duration or mean length of the synodic month is 29,5305879 [3]. This non-integer value cannot be represented exactly within a discrete day-based system. Consequently, the calendar system must employ approximations by assigning alternating month length of 29 and 30 days, conventionally referred to in the literature as hollow months and full [2]. This principle is consistent with a tradition (hadith) of the Prophet Muhammad, who stated: "...The month is sometimes twenty-nine days and sometimes thirty days...." [4].

Inaccuracies arising from this discretization process may potentially generate structural inconsistencies within a calendar system, which, in the context of the Hijri calendar, can manifest as anomalies in month durations beyond the normative range. Therefore, every calendrical system requires mechanisms of approximation and correction in order to preserve its internal consistency [5]. From a historical perspective, all calendrical systems whether lunar, solar, or luni-solar, are constructed upon the same hierarchical temporal units, namely the day as the fundamental unit, followed by the month and the year as larger cyclical units [2]. However, because astronomical phenomena do not always yield integer values, differences in defining the fundamental parameters, particularly the beginning of the day, become crucial factors in shaping calendrical structures. The definition of the beginning of the day determines how the unit of the day is constructed and grouped into months, thereby exerting a direct influence on the overall stability of the calendar system [1].

In the Islamic tradition, the day begins at sunset [6], [7], which constitutes a local astronomical phenomenon. However, this approach encounters significant challenges in a global context, particularly in high-latitude regions such as the Arctic Circle, where the Sun may not set during summer or may not rise during winter. Such conditions create uncertainty in determining the beginning of the day based on the phenomenon of sunset, thereby making global standardization difficult [1]. As an alternative, fixed-time approaches have emerged, such as defining the beginning of the day at 18:00, which represents an approximation of the average time of sunset. This approach also possesses historical precedent; the Jewish colony at Elephantine, Egypt, in the fifth century BCE employed a calculated calendrical system by determining the beginning of the month when the mean sunset (approximately 18:00) occurred after the mean conjunction [2]. This demonstrates that the fixed-time approach is not merely a modern innovation, but rather part of the historical evolution of calculated calendar systems.

On the other hand, modern calendar systems, particularly the Gregorian calendar, define the beginning of the day at 00:00 as the international civil time standard, reflecting an administrative-global paradigm [8]. Based on papers presented at the National Halaqah on the Unified Global Hijri Calendar (Kalender Hijriah Global Tunggal/KHGT), held on 19–20 April 2025 in Yogyakarta, several speakers asserted that the beginning of the day in the KHGT system should be set at 00:00 [9], [10], [11], [12]. Muslihin stated that the universal beginning of the day in the KHGT framework refers to an international convention whereby the day begins and ends at midnight (00:00) on the 180-degree meridian [11]. Meanwhile, Butar-Butar argued that the beginning of the day should occur at midnight with its reference point located on the 180-degree meridian, based on the thought of Jamaluddin 'Abd ar-Raziq, who conducted research on 600 lunar months and concluded that the beginning of the day should commence at 00:00 Universal Time [12]. Nevertheless, although scholars such as Darsono [9], Fathurrahman [10], Muslihin [11], and Butar-Butar [12] all maintained that the beginning of the day in the KHGT system should be fixed at 00:00, none of them provided comprehensive data supporting their arguments, including detailed analyses and simulations regarding the consistency of the KHGT calendrical system. Based on the KHGT concept with the beginning of the day at 00:00 which has been socialized so far, responses have emerged such as from Lembaga Falakiah Nahdlatul Ulama (LFNU) with 33 LFNU Notes, especially note number 19 [13]. Likewise from Persatuan Islam (PERSIS), although not specifically highlighting the concept of the beginning of the day in KHGT, PERSIS concluded that KHGT is not in accordance with sharia and science [14].

In addition to these three approaches, modern astronomical studies also recognize the concept of astronomical dawn, namely the moment when the center of the Sun is positioned at an altitude of -18° below the horizon [15], [16], [17], [18]. The value of -18° is conventionally employed as the threshold at which the scattering of sunlight within the atmosphere becomes sufficiently significant to eliminate the complete darkness of the night sky, thereby marking the transition from astronomical night to the dawn phase [19]. In this context, astronomical dawn represents a more globally consistent phenomenon than sunset, since it depends upon the geometric position of the Sun relative to the horizon rather than solely upon local visual conditions. Within the Islamic tradition, the concept of dawn likewise possesses juridical significance, particularly in determining the time of the Fajr prayer, which is associated with fajr *ṣādiq* (true dawn). A number of studies indicate that fajr *ṣādiq*, from an astronomical perspective, correlates with a solar depression angle ranging between -18° and -15° below the horizon [20], although variations exist among different religious authorities in practical determinations. Consequently, the use of the Sun's altitude at -18° as the definition of the beginning of the day offers an alternative based upon a globally standardized astronomical phenomenon while simultaneously maintaining a connection with religious observance. Accordingly, there are four principal paradigms in defining the beginning of the day:

- 1) the religious-astronomical paradigm based on sunset,
- 2) the semi-astronomical paradigm based on a fixed approximation (18:00),
- 3) the administrative paradigm based on 00:00 (midnight), and
- 4) the astronomical paradigm based on dawn time (solar altitude of -18°).

Each of these definitions of the beginning of the day has direct implications for the calendar structure, especially in the consistency of month duration or the number of days within a Hijri month. In the context of contemporary Islam, the need for a unified and systematic global calendar is becoming increasingly urgent alongside the globalization of the Moslems community. Currently, there is no single form of the Hijri calendar that is universally accepted and globally applicable, thereby causing differences in the determining dates, which ultimately results in variations in the timing of religious observances. Efforts toward the unification of the Hijri calendar have been pursued through various approaches, including both zonal and global systems; however, none has yet fully succeeded in simultaneously satisfying the requirements of Islamic law (sharī'ah) and astronomical consistency [21].

In recent developments, the concept of the Unified Global Hijri Calendar (Kalender Hijriah Global Tunggal/ KHGT) has emerged as an integrative solution that combines sharī'ah principles, astronomical accuracy, and the demands of global applicability, founded upon the principal doctrine of "one day, one date throughout the world." The KHGT framework, as articulated in the Tanfidz document of the Central Executive Board of Muhammadiyah concerning the Unified Global Hijri Calendar (KHGT), published in Berita Resmi Muhammadiyah No. 05/2022–2027/Zulkaidah 1446 H/May 2025 CE, does not explicitly define or formulate the concept of the beginning of the day [22]. Within the literature, Islamic calendars themselves may generally be classified into two principal approaches: the arithmetic calendar, which employs fixed cycles such as 30 years or 10,631 days, and the astronomical calendar, which follows the actual phases of the Moon [1]. The KHGT seeks to bridge these two approaches in order to produce a system that is both structurally stable and astronomically accurate. This demonstrates that the stability of calendrical structure, including the consistency of month duration or the number of days within a month within the normative range of 29 to 30 days, constitutes a strategic aspect in the development of a global Hijri calendar.

Within this framework, the definition of the beginning of the day becomes a fundamental parameter that is not merely technical in nature, but also systemic. Differences in determining the beginning of the day have the potential to produce variations in month duration or the number of days within a month that deviate from normative provisions. In the computational approach to modern calendrical systems, discrepancies between mathematical models and astronomical phenomena may generate structural anomalies, such as months consisting of fewer than 29 days or more than 30 days[1]. Although numerous studies have examined crescent visibility criteria and global Hijri calendar models, most have focused primarily on determining the beginning of the month rather than on the influence of the definition of the beginning of the day upon overall calendrical stability. In fact, as demonstrated in calendrical studies, the selection of fundamental parameters within a calendar system exerts systemic effects upon the consistency of the resulting temporal structure[1]. The KHGT, which has been promoted using the concept of the beginning of the day at 00:00, faces serious problems regarding the implementation of Islamic worship and customs, such as starting the sunnah Tarawih prayer, which typically begins after the Isha prayer on the first night of Ramadan.

Accordingly, this study aims to compare four systems for defining the beginning of the day, namely: the beginning of the day based on the phenomenon of sunset, the beginning of the day at 18:00, the beginning of the day at 00:00, and the beginning of the day based on the phenomenon of astronomical dawn, on the basis of the degree of anomalies in month duration or the number of days within a month in the global Hijri calendar during the period 1447 AH to 1477 AH using official data. By employing a data-driven approach spanning thirty Hijri years, this study is expected to contribute scientifically toward identifying the most optimal model for defining the beginning of the day, both in terms of conformity with sharī'ah principles and the stability of the calendrical system within the framework of the Unified Global Hijri Calendar.

Method

This study employs a quantitative approach based on computational simulation to evaluate the influence of the definition of the beginning of the day on the stability of the global Hijri calendar. The principal normative foundation adopted in this study is the Prophetic tradition (hadith) stating that the duration of a month in the Hijri calendar consists only of 29 or 30 days. The primary data were obtained from the official dataset of the Unified Global Hijri Calendar (KHGT) in the form of the induk.csv master file, which contains several parameters, namely the Hijri year (Tahun), Hijri month (Bulan), conjunction time (JDUT_NewMoon), and the starting date of the month (JD_START_KHGT). The dataset covers a period of thirty years, extending from Muḥarram 1447 AH to Dhū al-Hijjah 1477 AH. The simulation was conducted by considering consecutive month pairs, namely month x and month $(x+1)$. This approach enables the measurement of month duration as the time interval between astronomical events or calendrical system events.

A. Calculation of month duration

Month duration was analyzed using three calculation modes: from the conjunction time in month (x) to the conjunction time in the subsequent month, from the beginning date of month (x) to the conjunction time in the subsequent month, and from the beginning date of month (x) to the beginning date of the subsequent month.

Mode 1: Conjunction-to-Conjunction

Month duration was calculated as the time interval between two consecutive conjunctions, as expressed in Equation (1):

$$\Delta t_1 = JD_{\text{NewMoon}}^{(x+1)} - JD_{\text{NewMoon}}^{(x)}$$

This mode represents the purely astronomical synodic duration of the lunar month.

Mode 2: Beginning of the Month-to-Conjunction

Month duration was calculated from the beginning date of month x to the conjunction of the following month, as expressed in Equation (2):

$$\Delta t_2 = JD_{\text{NewMoon}}^{(x+1)} - JD_{\text{Start}}^{(x)}$$

This mode describes the relationship between the calendrical system and astronomical phenomena.

Mode 3: Beginning of the Month-to-Beginning of the Month

Month duration was calculated from the beginning date of month x to the beginning date of the subsequent month, as expressed in Equation (3):

$$\Delta t_2 = JD_{\text{Start}}^{(x+1)} - JD_{\text{Start}}^{(x)}$$

This mode represents the operational duration of the month within the calendrical system.

B. Beginning of the day Scenarios

The simulation was conducted on a global grid with a spatial resolution of $1^\circ \times 1^\circ$, covering latitudes from -90° to 90° and longitudes from 180° to -180° , thereby producing 65,341 observation points. At each point, the beginning of the day was determined according to four scenarios:

- 1) sunset time (based on astronomical calculations),
- 2) fixed time at 18:00,
- 3) fixed time at 00:00, and
- 4) dawn time with the Sun at an altitude of -18° .

Each scenario produced different beginning of the day values, which were subsequently used in the calculation of month duration.

C. Validity and Anomaly Criteria

The resulting month durations were evaluated according to the normative criterion of the Hijri calendar, namely $29 \leq \Delta t \leq 30$, in accordance with the Prophetic tradition (hadith) of the Prophet Muhammad. If the month duration fell within this range, it was categorized as normal. Conversely, if it fell outside this range, it was categorized as an anomaly. The definition of anomaly is expressed in Equation (4):

$$A(\Delta t) = \begin{cases} -1, & \text{Jika } \Delta t < 29 \\ 0, & \text{Jika } 29 \leq \Delta t \leq 30 \\ -1, & \text{Jika } \Delta t > 30 \end{cases} \quad (4)$$

where:

A=-1: Type 1 anomaly (duration less than 29 days),

A=0: Normal,

A=1: Type 2 anomaly (duration greater than 30 days).

D. System Stability Analysis

The stability of the KHGT calendrical system was evaluated based on the consistency of month duration under each calculation mode and beginning of the day scenario. The system was considered stable when the majority of simulation results satisfied the normative duration criterion (29 to 30 days) and did not produce significant anomalies in the global spatial distribution. The simulation results were subsequently analyzed quantitatively and spatially in order to identify patterns of anomaly distribution and to evaluate the influence of the definition of the beginning of the day on the stability of

the global Hijri calendar.

Result and Discussion

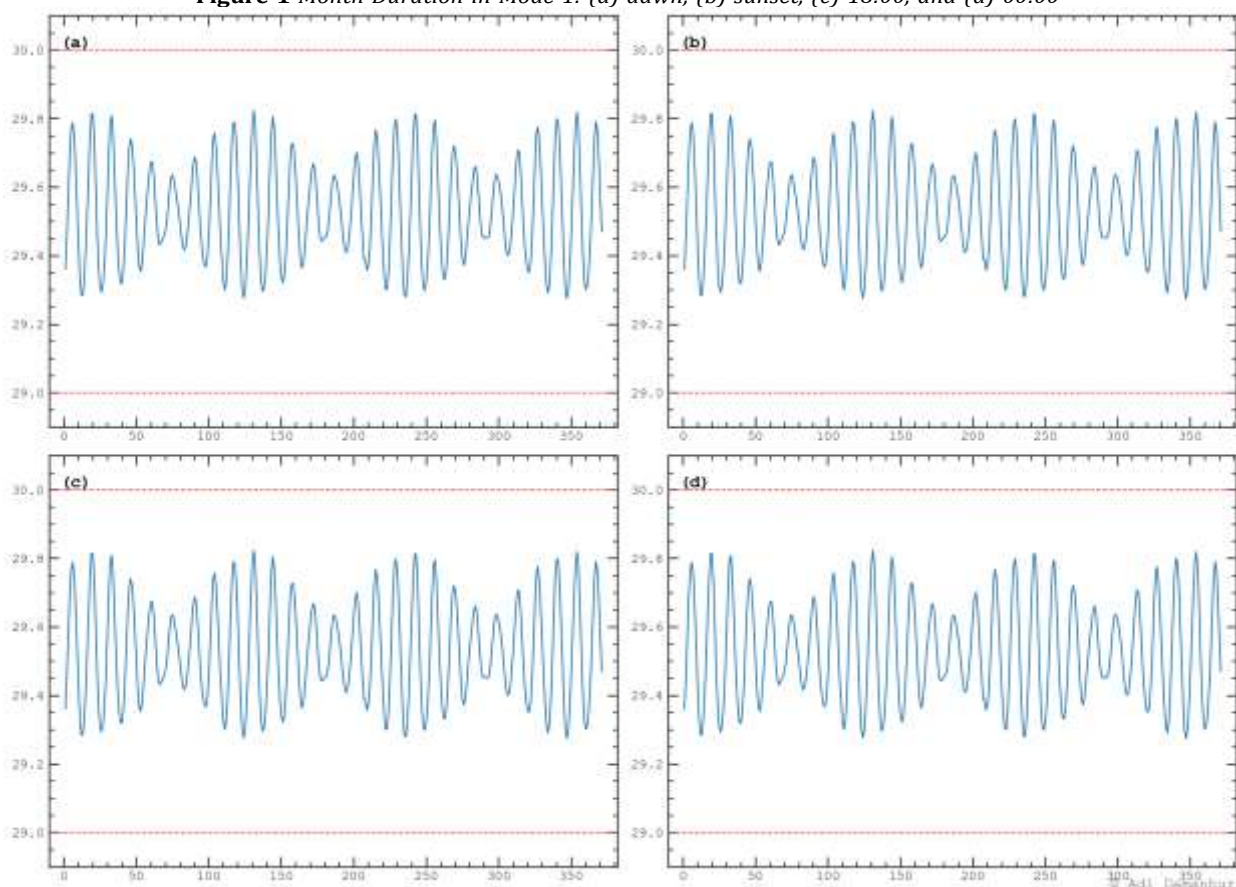
A. Distribution of Month Duration

The analysis of month duration in this study was conducted through three calculation modes, as described in the subsection Duration Modes. These three modes provide complementary perspectives for understanding the relationship between continuous astronomical phenomena and the discrete nature of calendrical systems.

Month Duration in Mode 1

Month duration was calculated as the interval between two consecutive conjunctions. The simulation results indicate that all scenarios produce identical and stable distribution patterns, with values oscillating periodically around the mean synodic month (~ 29.53 days).

Figure 1 Month Duration in Mode 1: (a) dawn, (b) sunset, (c) 18:00, and (d) 00:00

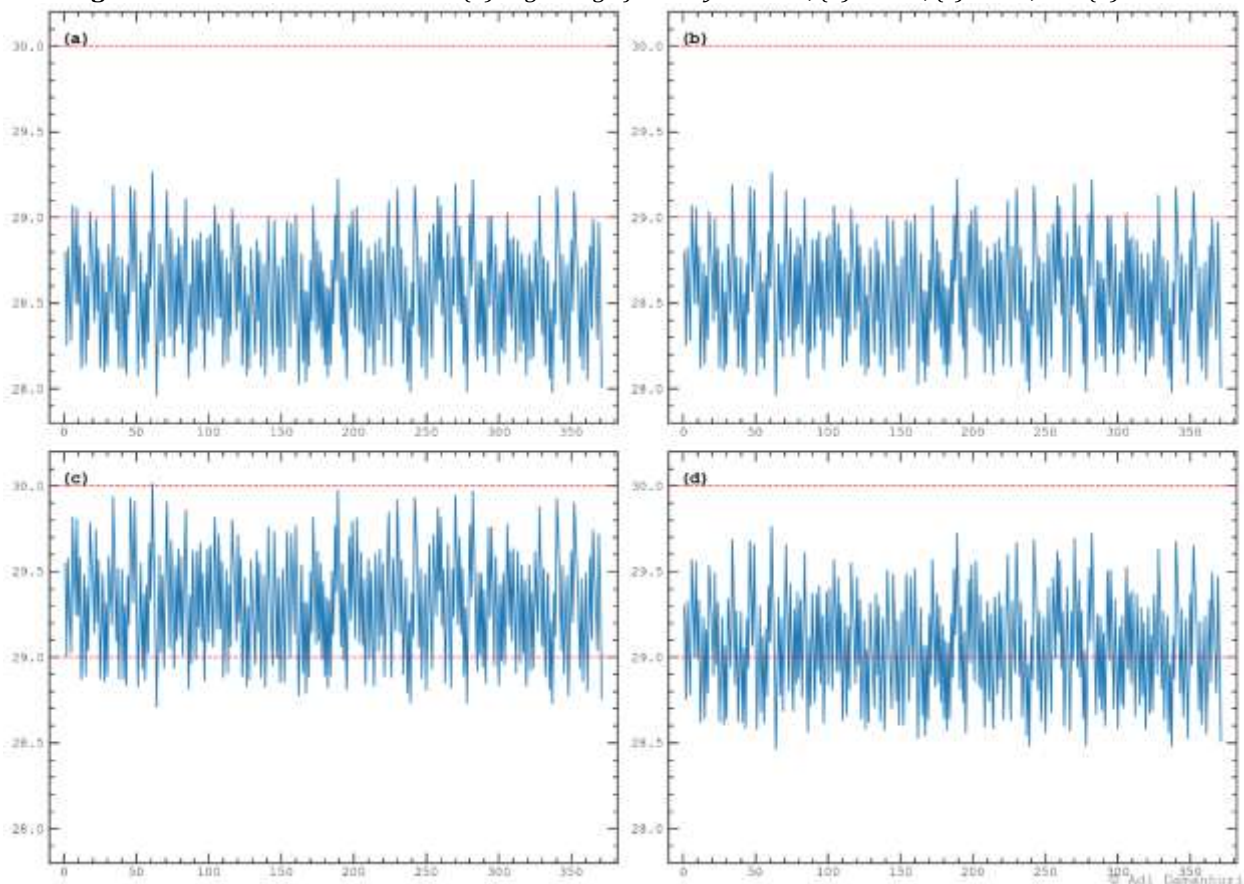


As illustrated in Figure 1, this finding demonstrates that Mode 1 fully represents a purely astronomical phenomenon and is therefore unaffected by the definition of the beginning of the day. Consequently, no anomalies were identified in this mode, since month duration is naturally determined by the continuous and stable dynamics of the Earth–Moon–Sun system.

Month Duration in Mode 2

In Mode 2, month duration was calculated from the beginning of month x to the conjunction time of the subsequent month. In contrast to Mode 1, the duration distribution in this mode is strongly influenced by the definition of the beginning of the day.

Figure 2 Month Duration in Mode 2: (a) beginning of the day at dawn, (b) sunset, (c) 18:00, and (d) 00:00



As shown in Figure 2, the dawn scenario exhibits the widest variation with high fluctuations, whereas the 18:00 scenario produces the most concentrated and stable distribution. The 00:00 scenario demonstrates a tendency toward shorter durations, while the sunset scenario displays substantial variation due to its dependence on local conditions. These findings indicate that the duration in Mode 2 is a critical point in the calendar system, as it can demonstrate the discretization process in converting continuous astronomical time into discrete calendar time, and makes the system highly sensitive to the chosen beginning of the day. This Mode 2 duration becomes the main reference for observing month duration anomalies. The number of anomalies also shows significant fluctuations throughout the range of months. Its distribution shows irregularities at certain periods with a higher intensity of anomalies. The beginning of the day at 00:00 and at sunset have relatively large variations in anomalies, whereas the beginning of the day at 18:00 is more stable. For the beginning of the day at dawn, it consistently shows a high level of instability and reflects its sensitivity to local astronomical conditions. These findings indicate that day duration anomalies are not only spatial in nature, but also have a temporal structure influenced by the dynamics of the lunar cycle and its interaction with the definition of the beginning of the day.

Month Duration in Mode 3

In Mode 3, month duration was calculated as the interval between two consecutive beginning-of-the-month dates. The resulting distribution is discrete and consists exclusively of two values, namely 29 and 30 days.

Figure 3 Month Duration in Mode 3: (a) dawn, (b) sunset, (c) 18:00, and (d) 00:00

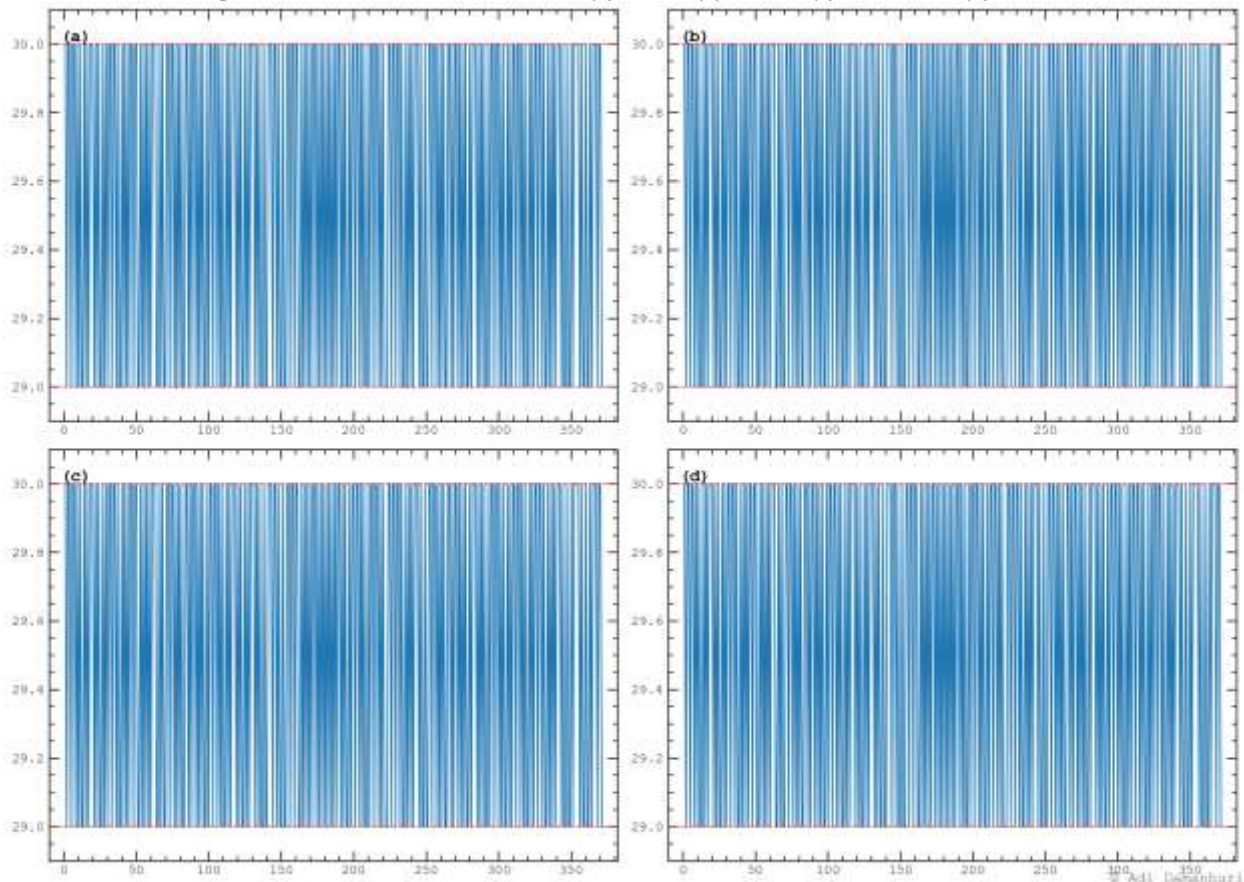


Figure 3 demonstrates that Mode 3 fully conforms to the normative structure of the Hijri calendar. Consequently, no anomalies were identified in this mode, since month duration has been systemically predetermined according to calendrical rules. In Mode 3, anomaly distributions appear only in the dawn and sunset scenarios, whereas no anomalies were found in the fixed-time scenarios (18:00 and 00:00). In general, the number of anomalies in this mode is very limited and does not exhibit significant fluctuations.

Based on the overall findings, it may be concluded that:

- 1) Mode 1 does not produce anomalies because it corresponds directly to the continuous and astronomically stable synodic month duration;
- 2) Mode 2 is the only mode that produces significant anomalies, both spatially and temporally; and
- 3) Mode 3 does not exhibit anomalies because month duration has been systemically discretized into values of 29 or 30 days.

Accordingly, the principal source of anomalies in the global Hijri calendar does not originate from astronomical phenomena themselves, but rather from the process of time discretization in Mode 2, which is highly sensitive to the definition of the beginning of the day.

B. Proportional Accumulation of Month-Duration Anomalies

The total number of calculation points in this simulation was 24,241,511 for each scenario. Quantitative analysis of the simulation results, as presented in Table 1, demonstrates significant differences in the level of month-duration anomalies among the scenarios. Month duration was classified as normal when satisfying the criterion $29 \leq \Delta t \leq 30$, whereas values outside this range were categorized as anomalies. According to the classification adopted in this study, month duration is considered normal when it falls within the range of 29 to 30 days, and anomalous when it lies outside this interval. The 18:00 scenario exhibits the highest level of stability, with a proportion of normal durations reaching 64.68%. This value is substantially higher than those of the other scenarios, indicating that the fixed-time approach is more capable of minimizing deviations arising from astronomical and spatial variations.

Table 1 Distribution of Month Duration

Scenario	Normal	<29 Days	>30 Days	Ignored
Dawn	5.354.728 (22,09%)	21.114 (0,09%)	13.489.108 (55,64%)	5.376.561 (22,18%)

Sunset	9.853.088 (40,65\%)	4.999.504 (20,62\%)	5.287.259 (21,81\%)	4.101.660 (16,92\%)
at 18:00	15.678.763 (64,68\%)	1.184.464 (4,89\%)	7.378.284 (30,44\%)	0
at 00:00	11.709.976 (48,31\%)	265.889 (1,10\%)	12.265.646 (50,60\%)	0

Conversely, the beginning of the day at dawn has the lowest proportion of normal duration, which is only 22,09%, with an upper anomaly (>30 days) of 55,64%. This beginning of the day scenario has a fairly large proportion of undefined (NaN) data points due to the fact that the dawn phenomenon does not occur at several coordinate points, reaching 22,18% of the total, and occurs in high-latitude regions. For the beginning of the day at 00.00, it shows a different pattern, where upper anomalies dominate its anomaly distribution at 50,60%, while lower anomalies (<29 days) are relatively small at 1,10%. This indicates a systematic bias towards longer day durations. For the beginning of the day at sunset, it shows a relatively balanced distribution between normal and anomalous durations, but with a considerable proportion of ignored (NaN) data points or coordinates that do not experience sunset phenomena, amounting to 16,92%. These findings reinforce the conclusion that inaccuracies in the discretization of astronomical time may generate structural anomalies within the calendrical system.

C. Astronomical and Systemic Interpretation

Differences in anomaly levels among the beginning-of-the-day scenarios may be explained by the characteristics of each definition. The sunset- and dawn-based scenarios depend upon local astronomical phenomena that are strongly influenced by latitude and by the geometric relationship of the Sun to the horizon. In a global context, such dependence produces substantial temporal variation and even the absence of the relevant phenomenon under certain conditions, particularly in high-latitude regions. Meanwhile, the beginning of the day scenarios with fixed times, such as at 18.00 and at 00.00, do not depend on local astronomical phenomena, thereby producing a day duration distribution that is spatially more homogeneous. The difference between the beginning of the day at 18.00 and at 00.00 shows that not all fixed-time definitions yield the same stability. The beginning of the day at 18.00 historically represents the mean time of sunset or Maghrib, proven to be more capable of maintaining a balance between astronomical representation and mathematical stability compared to the beginning of the day at 00.00. The results of this study reinforce that the definition of the beginning of the day is not merely a technical parameter, but rather a fundamental element determining the structure and consistency of the calendrical system as a whole.

D. Implications for the Unified Global Hijri Calendar

Within the context of developing the Unified Global Hijri Calendar (KHGT), the findings of this study carry significant implications. The principal doctrine of the KHGT called “one day, one date throughout the world” requires a system that is stable, consistent, and globally applicable without dependence upon local conditions. Scenarios based on local phenomena, such as sunset and dawn, demonstrate limitations in fulfilling these criteria because they generate high variability and incomplete data at the global scale. By contrast, fixed-time approaches, particularly the 18.00 definition, exhibit greater potential for supporting global consistency without disregarding their relationship to astronomical phenomena. Therefore, the selection of the definition of the beginning of the day within the KHGT framework must consider not only normative and historical aspects, but also the stability of the resulting system in global implementation.

Conclusion

This study demonstrates that the definition of the beginning of the day in a calendar system is a fundamental parameter with a very significant influence on the stability of the global Hijri calendar, particularly within the KHGT framework. Through computational simulations conducted in this study on official KHGT data over a 30-year range, it was found that each beginning of the day scenario produces distinct characteristics in the distribution of month duration, both in term of variability and anomaly levels. The finding indicates that the fixed-time approach at 18.00 has a highest level of stability, with the largest proportion of normal month duration and the lowest anomaly level among all beginning of the day scenarios. Conversely, the beginning of the day based on local astronomical phenomena, such as sunset and dawn, has substantial limitations in global implementation due to high spatial variability and the absence of local astronomical phenomena in certain geographical areas, especially at high latitudes. Another finding of this study reinforces that structural anomalies in the global Hijri calendar do not only originate from the astronomical phenomena themselves, but also from the process of changing the continuous discretization of astronomical time into a discrete calendar system. Therefore, this study makes a significant contribution to the development of the KHGT in selecting the beginning of the day scenario as a fundamental calendar parameter that not only complies with the normative rules of Islamic law (shariah) but must also be systematically stable from mathematical and astronomical perspectives. Specifically, the definition of the beginning of the day in the KHGT using a fixed-time approach at 18.00—which historically represents the mean sunset time or Maghrib—is the most effective compromise between normative or religious considerations and practical requirements for a globally consistent calendar system. This study recommends the beginning of the day at 18.00 as the definition of the beginning of the day within the KHGT framework.

Conversely, definitions relying upon local astronomical phenomena such as sunset and dawn are less suitable for global implementation due to their strong dependence on geographical and seasonal conditions. The implementation of the start of the day at 18:00 on KHGT is able to eliminate the problem of differences in the time of performing the sunnah tarawih prayers and also becomes a bridge between the discrete calendar system and the culture that Muslims have been practicing. Since the KHGT is currently only officially adopted by Muhammadiyah in Indonesia, this study suggests that the definition of the beginning of the day must be explicitly formulated in the official KHGT document, supported by rigorous mathematical and astronomical justification. Future research is also recommended over a longer timeframe, alongside investigations into the sensitivity of the calendar system to other parameters, such as variations in visibility criteria and integration with global time-zone systems, in order to further strengthen the consistency and universality of the global Hijri calendar.

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