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A Semantic Literature Review on Crescent Visibility: Trends, Models, and Implications for the Islamic Calendar

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Abstract

The visibility of the *hilāl* is a fundamental aspect in determining the beginning of the Hijri month, which significantly impacts the implementation of worship and the social order of Muslims in various parts of the world. This study adopts a Semantic Literature Review approach to analyze research trends, prediction models, and the scientific and social implications of *hilāl* visibility in the Islamic calendar system. Various methods have been developed, ranging from classical astronomical models such as *imkān ar-rukyat* to the utilization of artificial intelligence and digital imaging technology. The results show that integrating astronomical methods with data-driven modeling and machine learning algorithms can improve the accuracy of *hilāl* visibility predictions. However, applying these models still faces challenges, especially regarding acceptance from Muslim communities and religious authorities. This study emphasizes the importance of collaboration between astronomical scientists and religious scholars in formulating a more accurate, inclusive, and globally acceptable Hijri calendar system.

Keywords: *hilāl* visibility, Islamic calendar, prediction model, *ḥisāb*, *rukyat*

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Visibilitas *hilāl* merupakan aspek fundamental dalam penetapan awal bulan Hijriah, yang berdampak signifikan terhadap pelaksanaan ibadah dan tatanan sosial umat Islam di berbagai belahan dunia. Kajian ini mengadopsi pendekatan *Semantic Literature Review* untuk menganalisis tren penelitian, model prediksi, serta implikasi ilmiah dan sosial dari visibilitas *hilāl* dalam sistem kalender Islam. Beragam pendekatan telah dikembangkan, mulai dari model astronomi klasik seperti *imkān ar-rukyat* hingga pemanfaatan kecerdasan buatan dan teknologi pencitraan digital. Hasil kajian menunjukkan bahwa integrasi metode astronomis dengan pemodelan berbasis data dan algoritma *machine learning* berpotensi meningkatkan akurasi prediksi visibilitas *hilāl*. Meski demikian, penerapan model-model ini masih menghadapi tantangan, khususnya dalam hal penerimaan dari komunitas Muslim dan otoritas keagamaan. Studi ini menegaskan pentingnya kolaborasi antara ilmuwan astronomi dan ulama dalam merumuskan sistem kalender Hijriah yang lebih akurat, inklusif, dan dapat diterima secara global.

Kata Kunci: visibilitas *hilāl* , kalender Islam, model prediksi, *ḥisāb*, *rukyat*

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A. Introduction

The determination of the beginning of the Hijri month is a crucial aspect of the Islamic calendar that directly impacts the religious and social practices of Muslims worldwide. Disagreements in determining the beginning of the month often cause differences in the implementation of worship, such as Ramadan, Eid al-Fitr, and Eid al-Adha in various countries. One of the main challenges in this system is the visibility of the *hilāl*, which is the basis for the *rukyat* (direct observation) and *ḥisāb* (astronomical calculations) methods. Along with the development of technology and scientific methodology, various models have been developed to improve the accuracy of the prediction of the moon's visibility.[1] However, adopting these models still faces social and religious challenges, especially regarding acceptance by Islamic authorities and the wider community. Therefore, studying trends and models of hilāl visibility is essential to understand how scientific approaches can contribute to the preparation of a more accurate and universal Islamic calendar.

Research on moon visibility has developed rapidly, encompassing various approaches such as empirical models, astronomical algorithms, digital imaging technology, and artificial intelligence.[2] The *imkān ar-rukyat* model, which is used in the MABIMS standard, is one of the references in determining the beginning of the Hijri month in the Southeast Asian region.[3] In addition, several studies propose approaches based on image processing, big data processing,[4] and machine learning in estimating the likelihood of *rukyat al-hilāl*. Although many studies have discussed these models, no research has comprehensively examined the trends and development of the method of determining the *hilāl* using the Semantic Literature Review approach. Most previous research has

[1] M Raharto et al., "New Approach On Study Of New Young Crescent (Hilal) Visibility And New Month Of Hijri Calendar," *Journal of Physics: Conference Series* 1170 (March 2019): 012080, https://doi.org/10.1088/1742-6596/1170/1/012080; Robiatul Muztaba, Hakim L. Malasan, and Mitra Djamal, "Development of an Automated Moon Observation System Using the ALTS-07 Robotic Telescope: 2. Progress Report on Standard Contrast Enhancement of Moon Crescent Image with OpenCV," *Journal of Physics: Conference Series* 2214, no. 1 (February 1, 2022): 012004, https://doi.org/10.1088/1742-6596/2214/1/012004.

[2] Ziyad T. Allawi, "Crescent Moon Visibility: A New Criterion Using Deep Learned Artificial Neural-Network," *Iraqi Journal of Science*, April 30, 2024, 2332–43, https://doi.org/10.24996/ijs.2024.65.4.45; Ziyad T. Allawi, "A Pattern-Recognizer Artificial Neural Network for the Prediction of New Crescent Visibility in Iraq," *Computation* 10, no. 10 (October 13, 2022): 186, https://doi.org/10.3390/computation10100186; Ahmad Adib Rofiuddin and Moelki Fahmi Ardliansyah, "The Utilization of Artificial Intelligence in Determining the Beginning of Islamic Calendar in Indonesia," *Al-Marshad: Jurnal Astronomi Islam Dan Ilmu-Ilmu Berkaitan* 10, no. 82–94 (2024).

[3] Maskufa Maskufa et al., "Implementation of the New MABIMS Crescent Visibility Criteria: Efforts to Unite the Hijriyah Calendar in the Southeast Asian Region," *AHKAM : Jurnal Ilmu Syariah* 22, no. 1 (June 30, 2022), https://doi.org/10.15408/ajis.v22i1.22275; Abdul Mufid and Thomas Djamaluddin, "The Implementation of New Minister of Religion of Brunei, Indonesia, Malaysia, and Singapore Criteria Towards the Hijri Calendar Unification," *HTS Teologiese Studies / Theological Studies* 79, no. 1 (June 30, 2023), https://doi.org/10.4102/hts.v79i1.8774; Mohd Saiful Anwar Mohd Nawawi et al., "Hijri Month Determination in Southeast Asia: An Illustration Between Religion, Science, and Cultural Background," *Heliyon* 10, no. 20 (October 2024): e38668, https://doi.org/10.1016/j.heliyon.2024.e38668.

[4] Teresa Guarda et al., "Database Marketing Tools for SMEs The Case of RFM Model," in *International Conference on Logistics, Engineering, Management and Computer Science, LEMCS 2014* (Portugal: Atlantis Press, 2014), 995–99, https://doi.org/10.2991/lemcs-14.2014.224; M.S. Faid, M.S.A. Mohd Nawawi, and M.H. Mohd Saadon, "Analysis Tool for Lunar Crescent Visibility Criterion Based on Integrated Lunar Crescent Database," *Astronomy and Computing* 45 (October 2023): 100752, https://doi.org/10.1016/j.ascom.2023.100752; Nazhatulshima Ahmad et al., "Analysis Data of the 22 Years of Observations on the Young Crescent Moon at Telok Kemang Observatory in Relation to the Imkanur Rukyah Criteria 1995," *Sains Malaysiana* 51, no. 10 (October 31, 2022): 3415–22, https://doi.org/10.17576/jsm-2022-5110-24.

focused more on models' technical or comparative aspects. However, not much has addressed how these models are applied in socio-religious contexts and how they are accepted in the global Muslim community.

This study uses the Semantic Literature Review approach to identify and analyze research trends regarding the visibility of the *hilāl* based on scientific publications in a specific time frame. Classify lunar visibility models in astronomical approaches, imaging technology, and modern computing methods such as artificial intelligence and machine learning. Analyze the implications of various models of *hilāl* visibility on the Islamic calendar determination system, especially in supporting the unification of the Islamic calendar globally.

This study has some novelties compared to previous research. By using a Semantic Literature Review based on Natural Language Processing (NLP), this study allows for systematic and more objective literature exploration compared to conventional literature review methods. This study discusses classical astronomical models such as *imkān ar-rukyat* and explores artificial intelligence-based approaches, digital imaging techniques, and big data processing to predict the moon's visibility.

Not only focusing on technical aspects, this study also discusses the challenges of accepting new models by the Muslim community and religious authorities, thus providing broader insight into the prospects for implementing the *hilāl* visibility model in the Islamic calendar system. Furthermore, this study also discusses the implications of various models of *hilāl* visibility on the determination of the Islamic calendar, especially in efforts to unify the Islamic calendar globally. By highlighting the challenges and potential adoption of various models, this study is expected to significantly contribute to developing a more scientific, accurate, and widely accepted Islamic calendar system by Muslims in different countries.

For Muslims, determining when a Hijri month begins is essential for properly observing religious events like Ramadan and the two Eids. However, a central challenge remains ensuring the crescent moon is visible, as this underlies traditional sighting (*rukyat*) and modern calculation (*ḥisāb*) methods.[5] Scientific and technological progress has led to the development of various *hilāl* visibility prediction models to improve the accuracy of Hijri month determination. Yet, widespread acceptance of these models remains challenging, especially among global religious leaders and Muslim societies.[6] This study employs a Semantic Literature Review to analyze the evolution of *hilāl* visibility models and assess their scientific value in supporting a more accurate and globally accepted Islamic calendar.

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[5] Mohd Nawawi et al., "Hijri Month Determination in Southeast Asia: An Illustration Between Religion, Science, and Cultural Background"; Mohammaddin Abdul Niri et al., "Kesan Penggunaan Hitungan Astronomi Dan Alatan Moden Dalam Cerapan Hilal Di Malaysia: Satu Penelitian," *Jurnal Fiqh* 9, no. 1 (December 30, 2012): 45–64, https://doi.org/10.22452/fiqh.vol9no1.3; Achmad Mulyadi, "Non-Astronomical Aspects of the Success of Rukyatul Hilal in East Java," *Samarah: Jurnal Hukum Keluarga Dan Hukum Islam* 8, no. 3 (November 16, 2024): 1859, https://doi.org/10.22373/sjhk.v8i3.25258.

[6] Sakirman Sakirman, "Respon Fikih Terhadap Perkembangan Teknologi Rukyat," *Al-Manahij: Jurnal Kajian Hukum Islam* 14, no. 1 (June 2, 2020): 69–86, https://doi.org/10.24090/mnh.v14i1.3190; Muhammad Hasan, "The Interaction of Fiqh and Science in the Dynamics of Determining the Beginning of the Hijri Month in Indonesia," *JIL: Journal of Islamic Law* 4, no. 2 (August 31, 2023): 237–57, https://doi.org/10.24260/jil.v4i2.1433; Muh. Arif Royyani et al., "Shahadah 'Ilmy; Integrating Fiqh and Astronomy Paradigm in Determining The Arrival of Lunar Months in Indonesia," *AL-IHKAM: Jurnal Hukum & Pranata Sosial* 16, no. 2 (January 4, 2022): 503–24, https://doi.org/10.19105/al-lhkam.v16i2.5320.

The determination of the beginning of the Hijri month is an essential part of the Islamic calendar system that affects worship practices such as Ramadan, Eid al-Fitr, and Eid al-Adha. In the Islamic tradition, there are two main approaches to determining the *hilāl*: *rukyat* (direct observation) method and *ḥisāb* (astronomical calculations).[7] This calculation is a calculation method based on the movement of the Moon, Earth and Sun to determine the time of the conjunction phenomenon (*ijtimā'*) and the height of the crescent (*irtifā' al-hilāl*).[8] However, atmospheric factors, weather conditions, and limited human senses are often obstacles to observing the new moon, thus giving rise to various predictive models to improve the accuracy of the visibility of the new moon. Astronomical research has resulted in various criteria for the visibility of the moon used by various Islamic countries, such as the *imkān ar-rukyat* criteria,[9] the Yallop criterion,[10] the Danjon criteria,[11] as well as algorithm-based and robotic approaches.[12] These criteria have advantages and disadvantages in determining the likelihood that the *hilāl* can be seen on the first day after the conjunction.

Various models have been developed to improve the prediction accuracy of the new moon, both based on empirical and astronomical approaches, and by utilizing artificial intelligence and imaging technology. Empirical and astronomical models such as the *imkān ar-rukyat* criteria and the Yallop criterion are based on historical data on lunar observations and astronomical parameters such as moon-sun elongation and lunar elevation.[13] This model has been used in various Islamic dating systems worldwide, including in the MABIMS calendar for Southeast Asian countries.[14] In addition, a moon visibility model based on artificial intelligence has also been developed.[15] With the development of computing technology, some studies have begun to use machine learning[16] and

[7] Sakirman Sakirman, "Menelisik Metodologi Hisab-Rukyat Di Indonesia," *HUNAFA: Jurnal Studia Islamika* 8, no. 2 (December 17, 2011): 341, https://doi.org/10.24239/jsi.v8i2.368.341-362.

[8] Muhamad Zainal Mawahib, "Implikasi Penggunaan Sistem Perhitungan Aboge Dalam Penetapan Awal Bulan Hijriah," *Syaksia : Jurnal Hukum Perdata Islam* 23, no. 2 (May 2, 2022): 182–210, https://doi.org/10.37035/syaksia.v23i2.7052.

[9] Watni Marpaung, "Hisab Imkan Rukyat An Effort Unification In Determining Of The Beginning Of Months Of Qamariah," *MIQOT: Jurnal Ilmu-Ilmu Keislaman* 39, no. 2 (December 9, 2015), https://doi.org/10.30821/miqot.v39i2.70; Arino Bemi Sado, "Imkan Al-Rukyat Mabims Solusi Penyeragaman Kelender Hijriyah," *Istinbath: Jurnal HukumIstinbath: Jurnal Hukum* 13, no. 1 (2014).

[10] Leroy E. Doggett and Bradley E. Schaefer, "Lunar Crescent Visibility," *Icarus* 107, no. 2 (February 1994): 388–403, https://doi.org/10.1006/icar.1994.1031.

[11] L J Fatoohi, F R Stephenson, and S S Al-Dargazelli, "The Danjon Limit of First Visibility of the Lunar Crescent," *Observatory* 118, no. 1143 (1998): 65–72.

[12] Muztaba, Malasan, and Djamal, "Development of an Automated Moon Observation System Using the ALTS-07 Robotic Telescope: 2. Progress Report on Standard Contrast Enhancement of Moon Crescent Image with OpenCV."

[13] Doggett and Schaefer, "Lunar Crescent Visibility."

[14] Mufid and Djamaluddin, "The Implementation of New Minister of Religion of Brunei, Indonesia, Malaysia, and Singapore Criteria Towards the Hijri Calendar Unification."

[15] Allawi, "Crescent Moon Visibility: A New Criterion Using Deep Learned Artificial Neural-Network"; Allawi, "A Pattern-Recognizer Artificial Neural Network for the Prediction of New Crescent Visibility in Iraq"; Rofiuddin and Ardliansyah, "The Utilization of Artificial Intelligence in Determining the Beginning of Islamic Calendar in Indonesia."

[16] Murad Al-Rajab, Samia Loucif, and Yazan Al Risheh, "Predicting New Crescent Moon Visibility Applying Machine Learning Algorithms," *Scientific Reports* 13, no. 1 (April 24, 2023): 6674, https://doi.org/10.1038/s41598-023-32807-x; Samia Loucif et al., "Toward a Globally Lunar Calendar: A Machine Learning-Driven Approach for Crescent Moon Visibility Prediction," *Journal of Big Data* 11, no. 1 (August 12, 2024): 114, https://doi.org/10.1186/s40537-024-00979-6.

deep learning approaches [17] to predict the visibility of the moon based on astronomical and atmospheric data. This approach allows for a more accurate analysis of factors that influence the likelihood of *rukyat*, including the effects of light pollution and local atmospheric conditions. Modern optical technologies, such as digital telescopes and digital image processing, have been used to increase the likelihood of moon detection, especially in situations where the moon is very dim and difficult to observe with the naked eye.[18] The use of CCD (Charge-Coupled Device)[19] cameras and infrared sensors also allows for observing the moon in more challenging conditions, including during the day before sunset.

The Semantic Literature Review approach is a new method in literature analysis that utilizes Natural Language Processing (NLP) technology to classify and analyze research trends more systematically.[20] In contrast to conventional literature reviews, Semantic Literature Review allows for large-scale exploration of literature by identifying inter-topic relationships and evolving research trends. In the context of this study, the Semantic Literature Review will be used to identify trends in *hilāl* visibility research, both from the aspects of astronomy, imaging technology, and computational methods, and analyze the contribution of various hilāl visibility models in improving the accuracy of the Islamic calendar as well as explore the challenges and opportunities for the adoption of the *hilāl* visibility model in the global Islamic calendar system.

This study identifies and analyzes various models of *hilāl* visibility predictions, ranging from empirical models such as Danjon,[21] Yallop,[22] and Kastner,[23] to artificial intelligence and machine learning-based approaches. In addition, factors that affect the success of the moon observation, such as atmospheric conditions, the moon's height above the horizon, elongation, and the light of the twilight sky, are also essential in evaluating the accuracy of predictions. By comparing various models of moon visibility prediction, this study evaluates the reliability of conventional methods compared to modern technology-based approaches. This comparison aims to assess the extent to which the latest models can improve the accuracy of predictions and provide solutions to challenges in the Islamic calendar system.

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[17] Allawi, "Crescent Moon Visibility: A New Criterion Using Deep Learned Artificial Neural-Network."

[18] T. Hidayat et al., "Developing Information System on Lunar Crescent Observations," *ITB Journal of Sciences* 42, no. 1 (2010): 67–80, https://doi.org/10.5614/itbj.sci.2010.42.1.6; A.L.A.M. Nasir et al., "New Crescent Moon Detection Using Circular Hough Transform (CHT)," *Astronomy and Computing* 51 (April 2025): 100902, https://doi.org/10.1016/j.ascom.2024.100902; Jitesh Vij et al., "The First Application of a Cloud-Based Well Engineering Solution in the Middle East Region," in *SPE Canadian Energy Technology Conference and Exhibition* (SPE, 2023), https://doi.org/10.2118/212822-MS.

[19] Mohammed Y. Taher and Fouad M. Abdulla, "Evaluating the Development of the Crescent Visibility Criteria," *Iraqi Journal of Science*, January 30, 2024, 555–66, https://doi.org/10.24996/ijs.2024.65.1.43.

[20] Romi Satria Wahono, "A Systematic Literature Review of Software Defect Prediction: Research Trends, Datasets, Methods and Frameworks," *Journal of Software Engineering* 1, no. 1 (2015): 1–16.

[21] A.H. Sultan, "First Visibility of the Lunar Crescent: Beyond Danjon's Limit," *Observatory* 127, no. 1196 (2007): 53–59; Fatoohi, Stephenson, and Al-Dargazelli, "The Danjon Limit of First Visibility of the Lunar Crescent"; Mohammad Sh. Odeh, "New Criterion for Lunar Crescent Visibility," *Experimental Astronomy* 18, no. 1–3 (December 29, 2004): 39–64, https://doi.org/10.1007/s10686-005-9002-5.

[22] Doggett and Schaefer, "Lunar Crescent Visibility"; A.H. Sultan, "Best Time' for the First Visibility of the Lunar Crescent," *Observatory* 126, no. 1191 (2006): 115–18.

[23] J A Utama, F M Simatupang, and Amsor, "The New Hilaal Visibility Criterion for Tropical Region," *Journal of Physics: Conference Series* 1280, no. 2 (November 1, 2019): 022073, https://doi.org/10.1088/1742-6596/1280/2/022073.

This study also focuses on the scientific and social implications of research on the visibility of the new moon on the unification of the Islamic calendar. Differences in methods and criteria used by different countries often lead to misunderstandings in determining the beginning of the Hijri month at the international level. By understanding research trends and the development of prediction models, this study can contribute to developing a scientifically based, accurate, and widely accepted Islamic calendar system. This study confirms that collaboration between astronomy researchers, *rukyat al-hilāl* experts, and religious authorities is key in designing a more systematic and objective Islamic calendar system.

B. Method

In this study, the PICOC Framework approach was used to formulate and answer various research questions related to the visibility of the new moon and its implications for the Islamic calendar system. This framework helps identify relevant research populations, intervention methods, comparisons of various prediction models, and research outcomes and contexts in astronomy and Islamic law.[24] The following are the answers to each research question prepared based on the PICOC Framework, covering research trends on the visibility of the *hilāl*, the accuracy of prediction models in various atmospheric conditions, astronomical and atmospheric factors that affect the observation of the *hilāl*, the advantages and disadvantages of the machine learning-based approach, and its impact on the unification of the global Islamic calendar.

The trend of research on the moon's visibility has undergone significant development with the emergence of various more accurate scientific approaches. Based on the Semantic Literature Review analysis, *hilāl* visibility research has developed from a classical approach based on empirical observation to astronomy-based prediction models, digital imaging technology, and artificial intelligence. The literature shows that since the 1990s, models such as Danjon, Yallop, and *imkān ar-rukyat* have begun to be widely used and scientifically compared. In the past decade, research has led more toward using machine learning, deep learning, and modern optical technology to improve the accuracy of moon predictions.

Its accuracy depends mainly on the parameters used in each model. The Danjon model has limitations because it does not consider specific atmospheric factors. In contrast, the Yallop model is more accurate in certain atmospheric conditions but still limited in extreme conditions such as high light pollution or high humidity. AI/machine learning-based models have shown the potential to improve accuracy by considering more atmospheric factors, including aerosol content, light pollution, and the brightness of the twilight sky. Studies show that historical data-driven models with digital imagery integration can achieve higher accuracy than conventional models.

The main astronomical factors that affect the moon's visibility include the moon-sun elongation, the moon's altitude above the horizon, the age of the moon after the conjunction, and the contrast between the moon and the light of the twilight sky. Meanwhile, air humidity, light pollution, atmospheric turbulence, and aerosol content are the most influential atmospheric factors. Research shows that poor atmospheric conditions can cause the moon that should be visible to become

[24] Anita Anita, "Pengaruh Akupresur Lo4 (He Kuk) Dan Thai Cong Terhadap Tingkat Nyeri Persalinan Kala I Pada Ibu Bersalin," *Jurnal Kesehatan* 9, no. 3 (December 31, 2018): 471–77, https://doi.org/10.26630/jk.v9i3.1166.

unobservable, even if it astronomically meets the visibility criteria. Therefore, prediction models must combine astronomical and atmospheric data to improve accuracy.

The advantages of the machine learning approach include its ability to process large amounts of data, identify complex patterns, and adjust models based on the latest observational data. The model can also combine factors such as astronomy, atmosphere, and digital imaging, which is difficult for conventional prediction models. However, the main drawback of this approach is the reliance on training data that must be of high quality and representative. In addition, machine learning models require significant computing resources and are difficult to implement in areas with technological limitations. Compared to empirical models such as Yallop and *imkān ar-rukyat*, AI-based approaches still need further validation to ensure that the predicted results match the realities of field observations.

Research on the visibility of the new moon has a significant impact on efforts to unify the global Islamic calendar. With more accurate and science-based prediction models, Islamic authorities in various countries can have a stronger basis for agreeing on a consistent calendar system. However, the main challenge in the unification of the calendar is the difference in *mazhab* (Islamic legal school) and *fiqh* approaches, where some countries still prioritize the local *rukyat* method rather than a *ḥisāb*-based global approach. Therefore, an interdisciplinary approach is needed between astronomers, scholars, and religious authorities to develop an Islamic calendar system based on scientific data but still based on Sharia principles.

C. Result and Discussion

1. Publication Analysis in the *Hilāl* Visibility Study

The study of the visibility of the *hilāl* is a multidisciplinary topic spread across various scientific journals, reflecting the diversity of research perspectives that include astronomy, environment, history, and sociocultural. Based on the analysis of publications carried out, it was found that the number of publications discussing the new moon's visibility was uneven across journals, with the dominance of several major journals.

The journal with the highest number of publications in the study was Astrophysical Journal Letters, followed by Science of the Total Environment and Scientific Reports. This shows that astronomical and environmental aspects are the primary focus of research related to moon visibility. Publications in the Astrophysical Journal Letters indicate that theoretical models and astronomical observations are essential to this study. Meanwhile, the existence of Science of the Total Environment in the list of top journals demonstrates that there is attention to atmospheric and environmental factors in the visibility of the new moon. In addition, journals such as Icarus and Vistas in Astronomy also have a significant number of publications, showing that this study not only focuses on the phenomenon of the moon itself but also on how mathematical models and simulation approaches are used to understand the pattern of moon visibility.

In addition to astronomical and environmental aspects, research on the moon's visibility is also found in journals such as the Journal for the History of Astronomy, Media, Culture and Society, and Sains Malaysiana. This shows an interest in the historical, sociocultural, and public acceptance aspects of determining the beginning of the Hijri month. Studies in these journals focus on

developing methods for determining the visibility of the new moon over time and the social and religious implications of the various proposed models.

One of the biggest challenges in determining the Islamic calendar is the different criteria and methods Islamic countries and organizations use. Although models such as *imkān ar-rukyat* have been widely used, there are still differences in the interpretation and implementation of the criteria for the visibility of the new moon in different regions.[25] The study of the *hilāl* visibility model not only has an impact on the technical aspect but also has socio-religious implications in efforts to unify the Islamic calendar globally.[26] By understanding the reliability and validity of various models, this study is expected to provide broader insights into the potential adoption of a more accurate, scientific, and accepted Islamic calendar system by various Muslim communities worldwide.

The dominance of publications in astronomical and environmental journals shows that the scientific approach to determining the moon is growing, especially with the increasing use of predictive models based on atmospheric and astronomical data. However, publications in social and historical journals confirm that social and religious aspects remain essential factors that need to be considered in implementing astronomical research results into the Islamic calendar system. Thus, this research trend shows that the study of the visibility of the new moon is not only limited to the technical aspects of astronomy but also has broad implications in the social, historical, and environmental realms. Future research can further emphasize the integration of scientific models with socio-religious aspects to support efforts to unify the Islamic calendar. The following graph presents the distribution of journals that publish about *hilāl* visibility research.

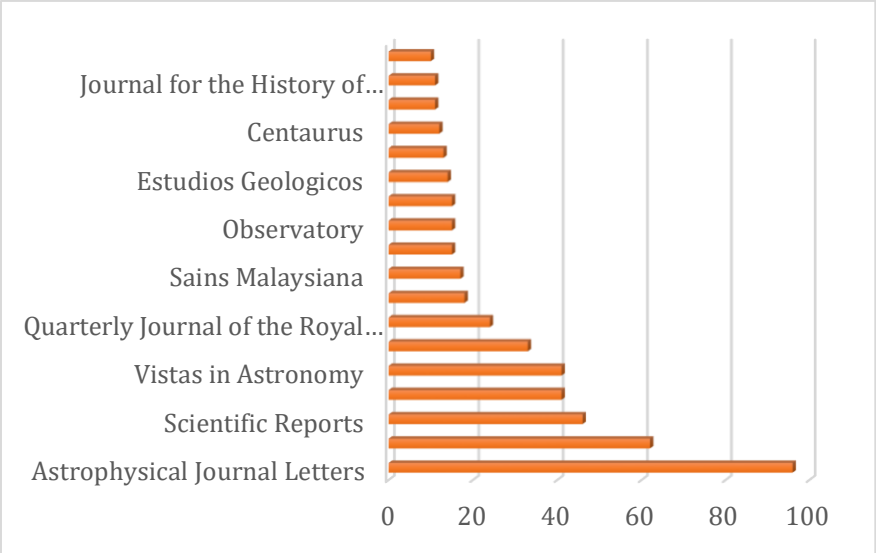

Figure 1. Graph of the number of journal publications

[25] Tiksna Bayu Ramadhan, Thomas Djamaluddin, and Judhistira Aria Utama, "Re-Evaluation of Hilaal Visibility Criteria in Indonesia by Using Indonesia and International Observational Data," in *Proceeding of International Conference On Research, Implementation and Education of Mathematics And Sciences* (Yogyakarta: Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Negeri Yogyakarta, 2014), 87–92.

[26] Mohd Nawawi et al., "Hijri Month Determination in Southeast Asia: An Illustration Between Religion, Science, and Cultural Background."

2. Geographical Analysis of Publications in the Study of *Hilāl* Visibility

Research on the moon's visibility is spread across various journals and shows an interesting geographical distribution. Based on the analysis of publications, Indonesia and Malaysia rank top as the countries with the highest research on this topic, with 15 and 14 publications, respectively. This position indicates the high academic and scientific attention in both countries to the study of the visibility of the *hilāl*, which can be attributed to the practical needs in implementing the Islamic calendar.

As two countries with large Muslim populations, Indonesia and Malaysia are interested in accurately determining the beginning of the Hijri month. The Islamic calendar policy in these two countries is often a reference at the regional level, which encourages academics to conduct more in-depth research on the criteria for the visibility of the new moon. It can also reflect the involvement of institutions such as the Ministry of Religious Affairs, the Falakiyah Institute, and the astronomical community in related research.

The United States ranks third with nine publications, which shows the interest of academics and astronomers in the country in the phenomenon of lunar visibility, both from the aspects of astronomy and atmospheric science. Meanwhile, several countries in the Middle East, such as Iraq (4 publications), Iran (3 publications), Saudi Arabia (2 publications), and the United Arab Emirates (2 publications), also contributed to the study. These countries are essential in determining the global Islamic calendar and are often involved in official lunar observance. Interestingly, several non-Muslim countries such as Israel (3 publications), Japan (3 publications), Portugal (2 publications), and the United Kingdom (2 publications) also have contributed to the study of the visibility of the moon. This suggests that this study is limited to religious interests and involves broader scientific aspects, including astronomy, climatology, and atmospheric modeling.

The visibility of the new moon is not just a local or regional issue but is a global topic that has received attention from various countries. The dominance of Indonesia and Malaysia confirms that this study is particularly relevant for Muslim-majority countries that rely on observing the new moon to determine the beginning of the Hijri month. Meanwhile, the involvement of Western and Middle Eastern countries signals that there is potential for international collaboration in developing more accurate models of *hilāl* visibility predictions, which could ultimately contribute to the unification of the Islamic calendar at the global level.

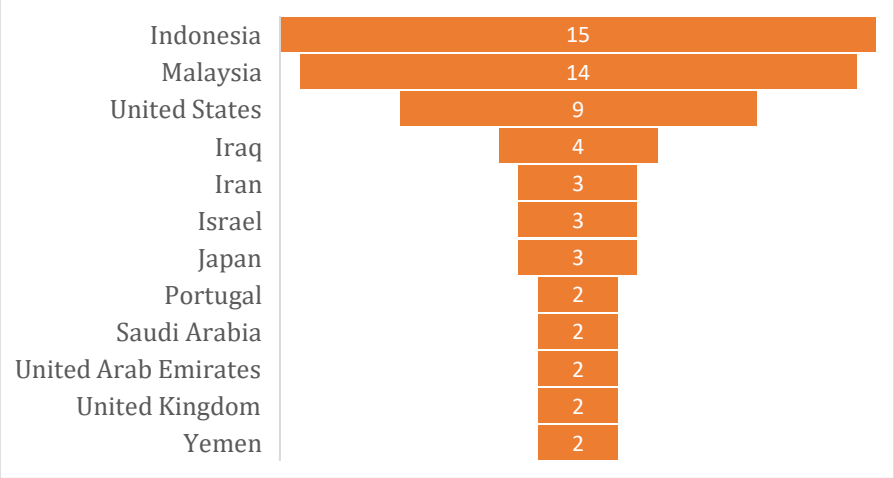

Figure 2. Graph of the number of journal distributions

3. Trend Analysis of Methods and Models in the Study of *Hilāl* Visibility

Based on the bibliometric analysis carried out, research on the visibility of the new moon has used various scientific approaches, both in theoretical and technical aspects. This pie chart shows the distribution of the multiple methods and models used in the study of *hilāl* visibility, with some dominant methods standing out. The following table summarizes the various methods and techniques in *hilāl* visibility research and the percentage of their use.

Table 1. Distribution of Methods in *Hilāl* Visibility Research

No.	Method	Percentage	Description
1	General Relativistic Magnetohydrodynamic (GRMHD)	26%	Astrophysical techniques to model the dynamics of magnetic fields in relativistic fluids play a role in understanding the physical and atmospheric aspects of predicting the moon's visibility.
2	Moderate Resolution Imaging Spectroradiometer (MODIS)	17%	When observing the moon, satellite-based remote sensing instruments evaluate atmospheric factors such as air pollution and humidity.
3	Circular Regression Model	12%	A circular regression model is used to analyze the pattern of *hilāl* visibility based on previous observation data, considering astronomical and atmospheric factors.
4	Accurate Treatment	11%	An analysis method that considers high accuracy in calculating the position of the *hilāl* to improve the accuracy of predictions.
5	Moon watches	11%	A community-based *hilāl* observation program involves community participation in direct observation.
6	Ultra-Thin Crescent-Shaped Fabry-Perot	6%	Optical interferometry techniques for detecting ultra-thin crescent moons aid

	observations in difficult atmospheric conditions.

This table illustrates the proportion of the use of various methods in the study of the visibility of the *hilāl* , showing that astrophysics-based approaches, remote sensing, and statistical modeling have a significant role in improving the accuracy of the hilāl prediction. The other categories include a variety of techniques, each of which has a small contribution to the study of *hilāl* visibility but is still relevant in developing more accurate methods.

4. Implications for the Study of the Islamic Calendar

With globalization, the differences in the beginning of the month between countries have become an issue, prompting the idea of unifying the Islamic calendar. The accuracy of *hilāl* visibility plays a vital role in this. In recent decades, models for predicting *hilāl* visibility, such as Yallop,[27] Odeh,[28] and the Neo-MABIMS *imkān ar-rukyat* criteria,[29] have been developed, using observational data and scientific parameters to determine the likelihood of the *hilāl* being visible.

With the support of these predictive models, several countries have started adopting an Islamic calendar based on *ḥisāb imkān ar-rukyat*. This opens opportunities for the unification of the Islamic calendar internationally, integrating *fiqh* and astronomy in contemporary *ijtihād* efforts that support the principles of unity,[30] ease,[31] and public interest. [32] The accuracy of *hilāl* visibility is crucial in building a global consensus for a more inclusive and reliable Islamic calendar.

The distribution of methods used in the *hilāl* visibility research shows a multidisciplinary approach in this field. The combination of physics models, remote sensing, data processing techniques, and direct observation suggests that research on lunar visibility does not rely solely on one discipline but involves various aspects of astronomy, atmosphere, and computation. This has implications for increasing accuracy in determining the beginning of the Hijri month and efforts to unify the Islamic calendar globally.

[27] Sultan, "Best Time' for the First Visibility of the Lunar Crescent."

[28] Odeh, "New Criterion for Lunar Crescent Visibility."

[29] Mohd Nawawi et al., "Hijri Month Determination in Southeast Asia: An Illustration Between Religion, Science, and Cultural Background."

[30] Susiknan Azhari, "Penyatuan Kalender Islam: Mendialogkan Wujûd Al-Hilâl Dan Visibilitas Hilal," *AHKAM : Jurnal Ilmu Syariah* 13, no. 2 (August 7, 2013), https://doi.org/10.15408/ajis.v13i2.931.

[31] Marwadi Marwadi, Rina Heriyanti, and Farah Nuril Izza, "The Fiqh of Hisab-Ru'ya in the Twentieth Century Indonesia: Study on the Thoughts of Hamka, Hasbi Ash-Shiddieqy, and Moenawar Chalil about the Unification of Hijri Calendar," *Al-Manahij: Jurnal Kajian Hukum Islam* 17, no. 1 (April 6, 2023): 13–26, https://doi.org/10.24090/mnh.v17i1.7902.

[32] Thomas Djamaluddin, *Menggagas Fiqh Astronomi* (Bandung: Kaki Langit, 2005).

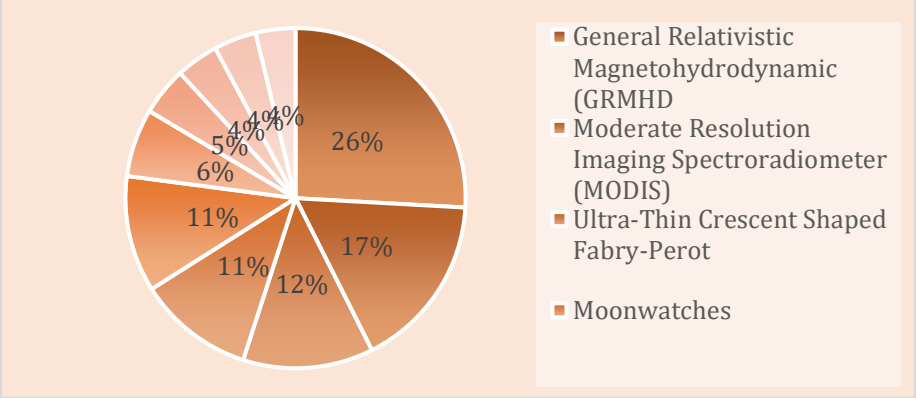

Figure 3. Graph of the *hilāl* visibility research method

5. Evolution of Methods and Technology in the Study of *Hilāl* Visibility

This data shows the development of methods and technologies used in *hilāl* visibility research from 1977 to 2020. This development reflects how the scientific approach to crescent moon observations evolves as astronomical and computational technology advances. The following is a table that summarizes the development of methods and technologies in *hilāl* visibility research based on the year of their implementation:

Table 2: Evolution of Methods and Technologies in Hilāl Visibility Research

No.	Method	Years	Description
1	Accurate Treatment	1977	The initial method in the study of the visibility of the *hilāl* emphasizes the accuracy of astronomical calculations based on classical theory.
2	Moon watches and Telescopic Assistance	1996	Community-based observation programs began to be introduced, supported by the use of telescopes to improve the detection of the new moon.
3	Photometric	2007	A more accurate method of measuring the intensity of the *hilāl* light through photometric techniques.
4	CTH - Circular Hough Transform	2014	Image processing algorithm to automatically detect crescent moon shape through circular Hough transformation.
5	Ultra-Thin Crescent-Shaped Fabry-Perot	2016	An interferometry approach to improve the sensitivity of ultra-thin *hilāl* detection to light.
6	Digital Imagery	2017	The use of digital imagery in *hilāl* analysis improves data processing accuracy and objectivity.
7	General Relativistic Magnetohydrodynamic (GRMHD)	2019	Astrophysical models to understand the influence of magnetic fields and atmospheric dynamics on the visibility of the *hilāl*.

8	MODIS - Moderate Resolution Imaging Spectroradiometer	2020	Satellite instruments for atmospheric monitoring provide data on atmospheric conditions that affect the observation of the new moon.
9	Circular Regression Model	2020	The circular regression model is used in the analysis of the visibility of the new moon for more precise predictions based on historical observation patterns.

This table shows significant developments in *hilāl* visibility research, from traditional methods based on astronomical calculations to modern technologies such as digital image processing and satellite-based models.

6. Implications for the Development of *Ḥisāb* and Rukyat Methods

The evolution of these methods shows a shift from manual and community-based approaches to high-tech methods, including digital image processing, computational modeling, and satellite-based atmospheric monitoring. Although various religious authorities adopt different criteria in determining the beginning of the Hijri month, such as *wujūd al-hilāl* used by Muhammadiyah or testimonial-based approaches like in Saudi Arabia, the increasing accuracy in predicting the visibility of the new moon can serve as a standard scientific ground. When integrated with collective *ijtihād* and interschool dialogue, this accuracy may help bridge differences and foster a more unified and objective Islamic calendar system in the future.

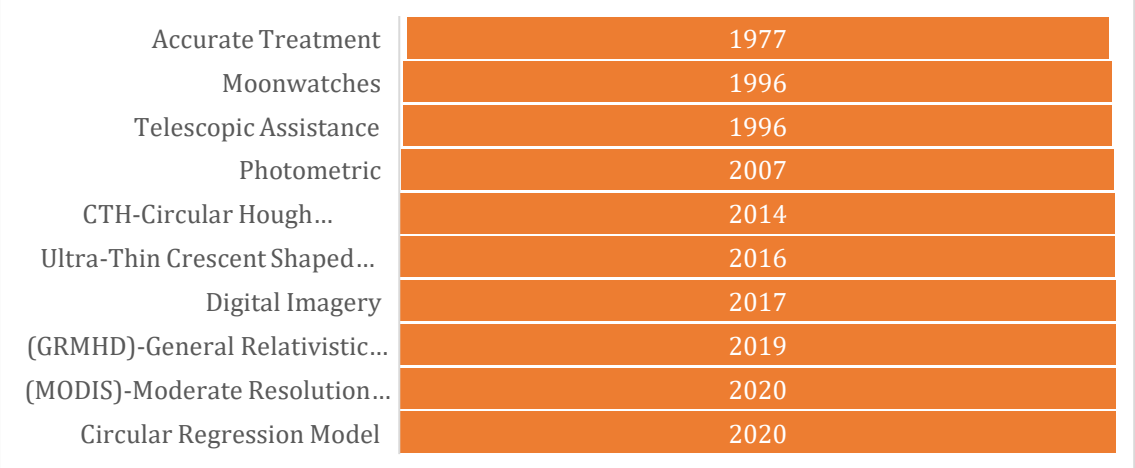

Figure 4. Graph of the evolution of the *ḥisāb-rukyat* method

7. Development of Methods and Technology in the *Hilāl* Visibility Study (2020–2025)

This data reflects the latest advances in the methods and technologies used to analyze the moon's visibility, especially in image processing, artificial intelligence, and statistical analysis. This development represents a significant shift from traditional approaches towards machine learning-

based methods and Python-based data processing. The following is a table that summarizes the development of techniques and technologies in the study of *hilāl* visibility based on periods:

Table 3. Development of Methods and Technology in *Hilāl* Visibility Research

Period	Methods/Models	Description
2020–2023 *(Foundations of Computational Models)*	Circular Regression Model (2020)	A circular regression model was introduced to improve the prediction of *hilāl* visibility based on historical observation patterns.
	MODIS - Moderate Resolution Imaging Spectroradiometer (2020)	It is used to observe atmospheric conditions that affect the visibility of the new moon, providing further insight into environmental factors in crescent moon observations.
	SVM - Support Vector Machine (2023)	Support Vector Machine (SVM)-based machine learning methods are beginning to be applied for *hilāl* analysis, allowing for data classification with high accuracy.
	Skyfield Python Library (2023)	The Skyfield library calculates the position of celestial bodies precisely, replacing classical astronomical calculation methods with modern computing-based approaches.
2024–2025 *(Artificial Intelligence and Advanced Data Processing)*	Python (2024)	Python is increasingly used in *hilāl* research, especially for numerical data processing, image analysis, and machine learning.
	Artificial Neural Network (ANN) (2024)	ANN is applied to detect the new moon automatically through an artificial neural network-based approach, improving predictive capabilities in various atmospheric conditions.
	Contrast Limited Adaptive Histogram Equalization (CLAHE) (2024)	The CLAHE technique was introduced to improve the contrast of the *hilāl* image, allowing the detection of the crescent moon against a background of brighter or cloudier skies.
	Statistical Methods (2024)	A statistical-based approach is increasingly crucial in processing moon observation data, helping to improve the accuracy of prediction models.
	Machine Learning Algorithms and Techniques (2024)	The year 2024 will be the main era for adopting machine learning algorithms in analyzing lunar visibility, including the classification of observational data and predictive modeling.

	Circular Hough Transform (CTH) (2025)	The CTH technique was introduced to improve the automatic detection of crescent moon shapes in digital images, making it easier to identify the moon objectively and quickly.

This table shows how approaches in *hilāl* visibility research continue to evolve, from basic statistical models to the use of artificial intelligence and more sophisticated digital image processing. Technological advances in the study of moon visibility are increasingly leading to the use of machine learning, digital image processing, and Python-based computing. This development has made a significant contribution to improving accuracy in the observation of the new moon. It opens up opportunities for automation in the Islamic calendar determination system in the future.

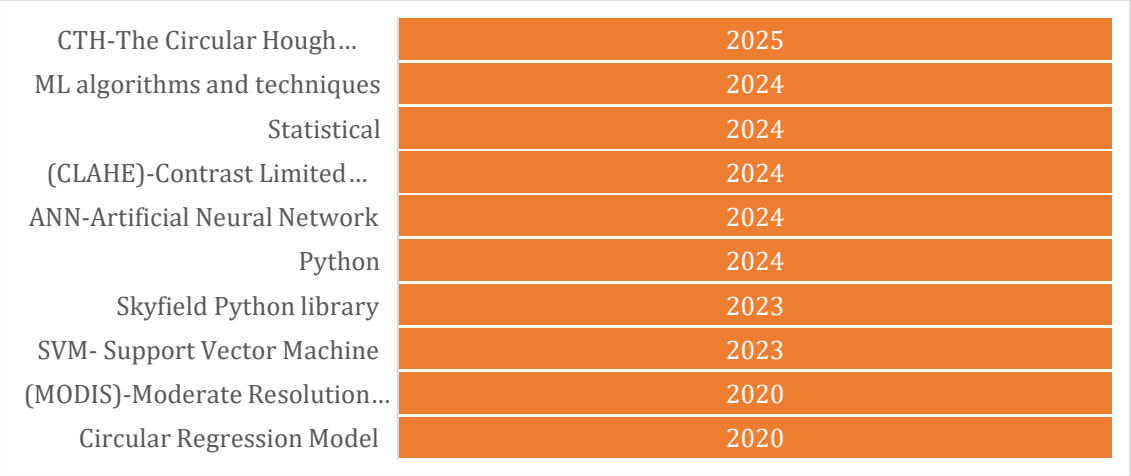

Figure 5. Graph of the *hilāl* visibility research approach

8. Analysis of the Author's Contribution to Related Studies

This graph shows the number of published contributions from various authors that focus on a particular study, which may be related to astronomy, moon visibility, or technology-based prediction models. The following is a table that summarizes the author's contribution to the study of hilāl visibility based on the number of publications or citations:

Table 4. The Author's Contribution to the *Hilāl* Visibility Research

No.	Author's	Number of Publications/Citations	Description
1	Akiyama K. et al.	> 100	The group with the most significant contribution is likely related to international projects in astronomy or modeling.
2	Al-Hemoud A. et al.	60–80	Contributes to image analysis, data processing, and astronomical observation.

3	Liu Y.; Wang D.N.; Chen W.P.	50–60	Focus on image processing techniques and computational data analysis.
4	Doggett L.E.; Schaefer B.E.	30–50	Contributed to observational astronomy, *hilāl* detection methods, and *hilāl* visibility calculations.
5	Bruin F.	30–50	Develop a method of detecting the *hilāl* in the context of observational astronomy.
6	Odeh M.Sh.	30–50	Focusing on prediction models and moon observation techniques.
7	Schaefer B.E.	< 30	Smaller contributions in statistical models and analysis of the new moon.
8	Hoffman R.E.	< 30	Playing a role in an empirical approach in the study of *hilāl* visibility.
9	Ahmad N.; Mohd Nawawi M.S.A.; Zainuddin M.Z.; Nasir Z.M.; Yunus R.M.; Mohamed I.	< 30	A group of authors who contribute to statistical models and empirical approaches.
10	Sultan A.H.	Least	It is likely to be new in this field or have a specific contribution in a particular aspect of *hilāl* visibility research.

This table illustrates the level of contributions of various authors to the study of lunar visibility, with the leading author group dominating publications in astronomy, image processing, and prediction models. The above data shows that research in this area involves varying levels of contribution from individuals and groups of researchers. The authors with the highest contributions are most likely to be involved in large-scale projects or have many related publications in astronomy and prediction modeling. Meanwhile, contributions from other researchers remain significant in enriching this study through a more specific approach or focus on a particular aspect of the problem being studied.

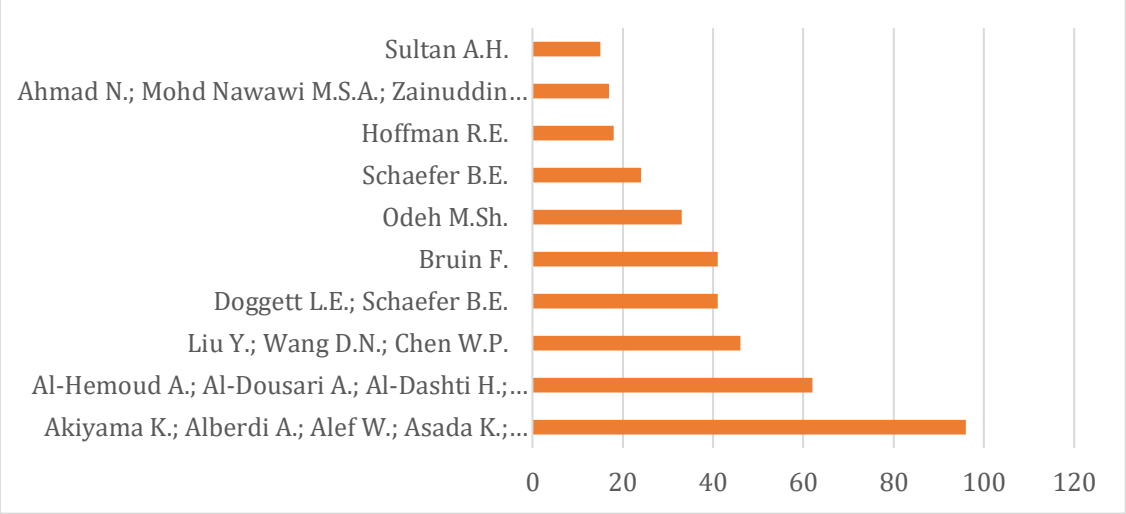

Figure 6: Graph of the author's contribution to the visibility of the *hilāl*

9. Analysis of Scientific Publishers by Number of Publications

This graph shows the number of scientific publications published by various academic publishers and research institutions. This data shows a variation in the number of publications issued by each publisher, which reflects the level of activity and their contribution to the academic and research world. The following is a table that summarizes the number of publications from various publishers in the *hilāl* visibility research:

Table 5. Number of Publications by Scientific Publisher

No.	Publisher	Number of Publications	Description
Publisher with the Highest Number of Publications			
1	Institute of Physics Publishing	~100	Publisher with the highest number of publications, dominant in physics and related sciences.
2	Elsevier B.V.	60–80	One of the largest scientific publishers covering disciplines such as physics, astronomy, and engineering.
3	Nature Publishing Group	30–40	Prestigious scientific journals with influential research in various fields of science.
Publishers with Medium Publication Numbers			
4	Blackwell Publishing Ltd	10–20	A widely known publisher in the fields of social sciences and sciences.
5	Universiti Kebangsaan Malaysia Publisher	10–20	Contributes to academic publications in the field of astronomy and technology.

6	SAGE Publications Ltd	10–20	A leading publisher in the fields of social, science, and technology.
7	CSIC Consejo Superior de Investigaciones Científicas	10–20	Scientific research institutes in Spain that are active in science and technology publications.
	Publishers with Low Publication Numbers		
8	Rutherford Appleton Laboratory	<10	Research institutions that contribute to the fields of physics and astronomy.
9	EDP Sciences	<10	Publishers that focus on physical sciences, engineering, and applied science.

This table shows the dominance of large scientific publishers, such as the Institute of Physics Publishing and Elsevier, in lunar visibility research. In contrast, publishers with fewer publications continue to play a role in more specific scientific fields. This data shows that the Institute of Physics Publishing, Elsevier, and Nature Publishing Group dominate scientific publications, showing their contribution to the global academic world. Meanwhile, other publishers continue to play an essential role in specific disciplines despite the smaller number of publications.

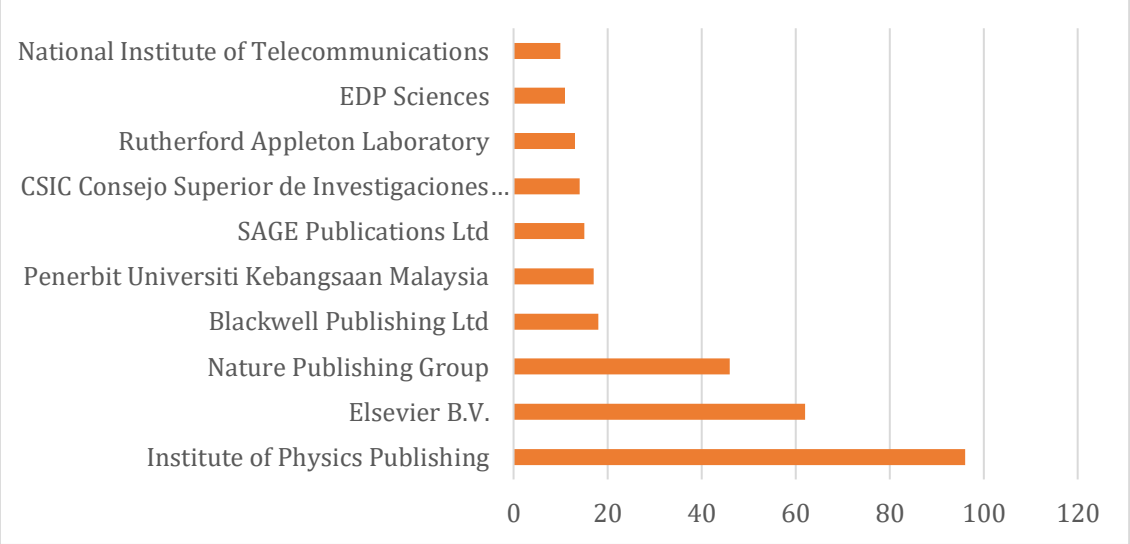

Figure 7. Publication graph by publisher

D. Conclusion

This research has highlighted the development of trends, models, and scientific implications of the visibility of the new moon in determining the Islamic calendar. The Semantic Literature Review approach found that the study of moon visibility has evolved from traditional observation methods to more complex astronomical models, including Danjon, Yallop, and Kastner models, as well as artificial intelligence and machine learning-based approaches. The analysis shows that each model has advantages and limitations in predicting the visibility of the *hilāl*, depending on the

astronomical and atmospheric factors that influence the rukyat process. AI-based models and imaging technologies are increasingly recognized for their ability to improve the accuracy of predictions. However, further validation still needs to be widely accepted by the astronomical community and religious authorities.

In terms of implications, this study emphasizes that a better scientific understanding of the visibility of the new moon can support the unification of the Islamic calendar, which has been facing challenges due to differences in methodology and fiqh approaches. Therefore, collaboration between astronomical scientists, scholars, and religious authorities is crucial in integrating scientific findings with *fiqh* rules to produce an Islamic calendar system that is more accurate, universal, and acceptable to various Muslim countries. Thus, this study makes an essential contribution to formulating a data-driven approach that not only improves the accuracy of the prediction of the new moon but also supports the harmonization of the Islamic calendar system at the global level. Further studies are expected to develop more adaptive prediction models and explore the integration of digital technology in real-time *hilāl* monitoring.

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