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# Critical Analysis and Reformulation of the Qibla Deviation Formula in the Book of *Mekanika Benda Langit*

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## Abstract

The calculation of Qibla deviation using the formula presented in the book *Mekanika Benda Langit* has become widely adopted and frequently cited in academic studies. However, this method still produces noticeable inaccuracies. This research aims to identify the causes of error in the Qibla deviation formula described in *Mekanika Benda Langit* and to reformulate a more accurate method for determining the Qibla direction. The study employed a literature-based qualitative design, with data obtained through documentation and interviews. Data analysis was conducted using descriptive statistical methods within a multidisciplinary approach. The findings reveal that the inaccuracy arises from the formula's reliance on the ratio between an arc and a flat circle, making it valid only for short distances (up to 2,000 km). A reformulation using spherical trigonometry provides higher precision and consistency across all distance and longitudinal variations. This new formulation significantly improves the accuracy of Qibla deviation calculations compared to the original method in *Mekanika Benda Langit*.

**Keyword**: qibla deviation, spherical trigonometry, direction accuracy, reformulation method, mekanika benda langit

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Perhitungan deviasi kiblat menggunakan rumus dalam buku Mekanika Benda Langit telah banyak digunakan dan sering dijadikan rujukan dalam kajian akademik. Namun, metode tersebut masih menunjukkan ketidakakuratan yang cukup signifikan. Penelitian ini bertujuan untuk mengidentifikasi penyebab kesalahan dalam rumus deviasi kiblat sebagaimana dijelaskan dalam Mekanika Benda Langit serta merumuskan kembali metode perhitungan yang lebih akurat untuk penentuan arah kiblat. Penelitian ini menggunakan pendekatan kualitatif berbasis studi pustaka dengan pengumpulan data melalui dokumentasi dan wawancara. Analisis data dilakukan dengan metode statistik deskriptif dalam kerangka pendekatan multidisipliner. Hasil penelitian menunjukkan bahwa ketidakakuratan tersebut berasal dari penggunaan rumus yang didasarkan pada perbandingan antara busur dan lingkaran datar, yang hanya valid untuk jarak pendek (hingga 2.000 km). Reformulasi dengan menggunakan pendekatan trigonometri bola menghasilkan tingkat presisi dan konsistensi yang lebih tinggi pada berbagai variasi jarak dan bujur. Formulasi baru ini secara signifikan meningkatkan akurasi perhitungan deviasi kiblat dibandingkan metode sebelumnya dalam Mekanika Benda Langit.

**Kata Kunci**: deviasi kiblat, trigonometri bola, akurasi arah, metode reformulasi, mekanika benda langit

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## A. Introduction

A substantial body of literature provides various methods for calculating Qibla deviation, one of which is the book *Mekanika Benda Langit.*[1] This work, a compilation of Rinto Anugraha's writings on *ḥisāb* (Islamic astronomical calculation), integrates fundamental concepts of astronomy. It explains the Earth's geometry, spherical coordinates, and coordinate transformations between the geocentric ecliptic, geocentric equatorial, and horizontal systems. This book also describes the calculation of distances between two points on the Earth's surface and the determination of the Qibla azimuth angle. Due to its comprehensive and accessible presentation, complete with formulas and illustrative calculations, the book has become popular among astronomy enthusiasts and is frequently cited in academic studies. However, preliminary research by the author revealed a one-degree discrepancy between the Qibla deviation calculated using the method in *Mekanika Benda Langit* and the result obtained from the Google Earth application. A study by Ismail et al., titled "Tolerance of Qibla Direction Deviation in Indonesia: An Islamic Astronomy and Law Perspective," reported that for the Baiturrahim Grand Mosque in Gorontalo Regency, the one-degree deviation based on Celestial Mechanics was 162.20 km,[2] whereas Google Earth measured it at 110.26 km.

Furthermore, a distinct pattern emerges between the two methods. The calculation method presented in Celestial Mechanics demonstrates that the farther a location is from the Kaaba, the greater the deviation value per degree becomes. In contrast, measurements obtained using Google Earth do not exhibit a consistent increase in deviation with distance from the Kaaba. Although the calculation method in *Mekanika Benda Langit* is widely recognized and frequently referenced, it still produces inaccuracies in determining Qibla deviation. A comparison between the results derived from *Mekanika Benda Langit* and those obtained from a precise geospatial tool such as Google Earth reveals a substantial difference of 51.95 km (Table 1). This discrepancy is significant, considering that the boundary of the *ḥarām* (sacred) area, serving as the Qibla reference for those outside Mecca, extends only about 17.29 km from north to south.[3]

Furthermore, there is a difference in the pattern between the two methods. The calculation method in "Celestial Mechanics" shows a pattern where the farther a location is from the Kaaba, the higher the deviation value per degree. This differs from the Google Earth measurement method, where not all locations farther from the Kaaba have a larger deviation value per degree. Although the calculation method in *Mekanika Benda Langit* is popular and widely referenced, its calculation of Qibla deviation still yields inaccurate results. The comparison between the *Mekanika Benda Langit* calculation and an accurate measurement tool like Google Earth reveals a significant difference of 51.95 km (Table 1), especially when considering that the boundary of the *ḥarām* (sacred) area, which serves as the Qibla for people outside Mecca, is only 17.29 km from north to south.

**Table 1.** Qibla Deviation per Degree at Baiturrahim Grand Mosque, Gorontalo

| Method | Distance |
|---|---|
| Google Earth | 162,20 km |
| "Celestial Mechanics" Book | 110,26 km |
| Deviation | 51,95 km |

[1] Rinto Anugraha, *Mekanika Benda Langit* (Universitas Gadjah Mada, 2012). 32

[2] Ismail Ismail et al., "Toleransi Pelencengan Arah Kiblat Di Indonesia Perspektif Ilmu Falak Dan Hukum Islam," *Al-Mizan* 17, no. 1 (2021): 115–38, https://doi.org/10.30603/am.v17i1.2070.

[3] Agung Laksana, "Telaah Matematis Variasi Lebar Arah Kiblat Di Wilayah Indonesia," *El-Falaky* 4, no. 1 (2017): 9–15.

There are two possible reasons for the inaccuracy of the Qibla deviation calculation per degree using the formula in *Mekanika Benda Langit. First*, it could be due to differences in the coordinate data for the Kaaba and the location. Second, it could be due to an error in the calculation method itself. The first possibility seems unlikely to be the cause. When comparing the coordinate data for the Kaaba between Google Earth and the method in the book, there is no significant difference. Google Earth is used as a reference to analyze the accuracy of the coordinates because its data is considered the most accurate.

**Table 2.** Comparison of Kaaba Coordinates

| Ka'bah Coordinates | Latitude | Longitude |
|---|---|---|
| *Google Earth* | 21° 25’ 21" N | 39° 49’ 34" E |
| Calculation Method | 21° 25’ 21" N | 39° 49’ 34" E |
| Deviation | 0 | 0 |

**Table 3.** Comparison of Location Coordinates (Baiturrahim Mosque, Gorontalo)

| Ka'bah Coordinates | Latitude | Longitude |
|---|---|---|
| *Google Earth* | 00° 32’ 15" N | 123° 03’ 37" E |
| Calculation Method | 00° 32’ 17" N | 123° 03’ 37" E |
| Deviation | 2" | 0 |

A comparison of the coordinate data presented in Tables 2 and 3 shows that the latitude and longitude values for both the Kaaba and the selected location are identical, except for a minor two-second difference in the location’s latitude. This slight variation is insufficient to account for a distance discrepancy of up to 51.95 km. Therefore, the coordinate data used in the calculation can be regarded as highly accurate. Based on this accuracy, it can be concluded that the inaccuracy in the Qibla deviation calculation derived from the formula in *Mekanika Benda Langit* does not originate from the coordinate data, but rather from the formula or the calculation method itself. Given these findings, the issue of determining the Qibla direction in Indonesia remains highly relevant for further investigation. The formulation of the Qibla deviation value per degree requires a more comprehensive analysis to identify the source of computational errors. Accordingly, this study aims to develop a more accurate calculation formula that enables a precise reformulation of the method for determining Qibla deviation per degree relative to actual distances on Earth.

Previous studies have examined the issue of Qibla deviation tolerance from various perspectives. Izzuddin’s research on the typology of *jihat al-Kaʻbah* in mosque orientations in Semarang explained that a mosque is considered accurately aligned if its orientation deviates no more than 2° of arc from the true direction of the Kaaba.[4] Mulyadi’s study revealed that even a minor error of a few degrees in determining the Qibla direction in locations far from Mecca, such as Pamekasan City, where a 2° deviation to the north results in a positional shift of approximately 300 km, can lead to significant directional inaccuracy.[5] Similarly, Somawinata analyzed the tolerance for Qibla deviation in Serang City using a computational approach and found that the acceptable margin

[4] Ahmad Izzuddin, “Typology Jihatul Ka’bah on Qibla Direction of Mosques in Semarang,” *Ulul Albab: Jurnal Studi Dan Penelitian Hukum Islam* 4, no. 1 (2020): 1, https://doi.org/10.30659/jua.v4i1.12186.

[5] Achmad Mulyadi, “Akurasi Arah Kiblat Masjid-Masjid Di Kabupaten Pamekasan,” *Jurnal Penelitian Ilmu Sosial Dan Keagamaan Islam* 10, no. 1 (2013): 71–100.

of deviation decreases with increasing distance from the *ḥarām* region.[6] Meanwhile, Ismail et al. identified two categories of tolerance: mathematical and sociological. Mathematically, the Qibla may face one of three orientations, the Kaaba itself, the *Masjid al-Ḥarām*, or the broader sacred area (*al-ḥarām*). Sociologically, however, a deviation of up to 6° of arc to the left or right of the Kaaba is still considered acceptable.[7]

The present study shares similarities with previous works in employing mathematical calculations to measure Qibla deviation in kilometers but differs in its methodological formulation.[8] In particular, this research introduces an accuracy validation using Google Earth, an approach not previously adopted in earlier studies. The aim of this research is to investigate the inaccuracy of the Qibla deviation formula presented in the book *Mekanika Benda Langit* and to reformulate it into a more precise computational model. Unlike prior studies that focus solely on defining tolerance limits, this work emphasizes accuracy testing to assess the reliability of the existing formula. Conducting such a validation is essential for determining the extent to which the current calculation method aligns with actual geospatial measurements, thereby providing a stronger foundation for reformulating a more accurate Qibla deviation model.

## B. Method

This study employs a qualitative research design aimed at developing a comprehensive understanding of the factors contributing to the inaccuracy of the one-degree Qibla deviation calculation presented in Celestial Mechanics. The research is categorized as library research, as the primary sources and data are derived from scholarly works, particularly books and journal articles, that discuss the methods and formulas for determining Qibla deviation. A multidisciplinary approach is adopted, integrating mathematics, geodesy, and statistics to address the research objectives. The mathematical approach is used to reformulate the calculation of Qibla deviation per degree in relation to actual terrestrial distances through the application of trigonometric laws. The geodetic approach serves to explain the Earth's representation and distance measurement within

[6] Yusuf Sowamita, *ILMU FALAK: Pedoman Lengkap Waktu Shalat, Arah Kiblat, Perbandingan Tarikh, Awal Bulan Qamariyah, Dan Hisab Rukyat*, 1st ed., ed. Monalisa (Rajawali Press, 2020).

[7] Ismail et al., "Toleransi Pelencengan Arah Kiblat Di Indonesia Perspektif Ilmu Falak Dan Hukum Islam."

[8] Muh Rasywan Syarif and Zulhasari Mustafa, *Analisis Keakurasian Azimuth Bintang sebagai Acuan Penentu Arah Kiblat*, 3, no. 3 (n.d.): 19–35; UIN Ar-Raniry Banda Aceh and Riza Afrian Mustaqim, "Analisis Metode Penentuan Arah Kiblat Masjid Agung Baitul Makmur Meulaboh Aceh Barat," *Al-Marshad: Jurnal Astronomi Islam dan Ilmu-Ilmu Berkaitan* 6, no. 2 (2020): 181–94, https://doi.org/10.30596/jam.v6i2.5229; Amirah Himayah Husna et al., *ANALISIS ORTHODROM DAN LOXODROM DALAM PENENTUAN ARAH KIBLAT DI TOKYO JEPANG*, 2, no. 2 (2021); Walter R. Schumm, "How Accurately Could Early (622-900 C.E.) Muslims Determine the Direction of Prayers (Qibla)?," *Religions* 11, no. 3 (2020): 102, https://doi.org/10.3390/rel11030102; Abd. Haji Amahoru and Sri Rahmadani Pulu, "Pemetaan Data Astronomi untuk Mengidentifikasi Pergeseran Arah Kiblat Masjid di Pulau Ambon," *JURNAL PENDIDIKAN MIPA* 13, no. 1 (2023): 150–58, https://doi.org/10.37630/jpm.v13i1.848; Agus Solikin, "Pertemuan Rumus Cosinus dan Sinus dengan Haversine dalam Perhitungan Arah Kiblat," *Teorema: Teori dan Riset Matematika* 5, no. 2 (2020): 211, https://doi.org/10.25157/teorema.v5i2.3671; UIN Alauddin Makassar et al., "Rumus Arah Kiblat Saadoeddin Djambek Perspektif Spherical Trigonometry," *Al-Marshad: Jurnal Astronomi Islam dan Ilmu-Ilmu Berkaitan* 6, no. 2 (2020): 149–61, https://doi.org/10.30596/jam.v6i2.5092; Agung Laksana and Muh Rasywan Syarif, "Telaah Matematis Variasi Lebar Arah Kiblat di Wilayah Indonesia," *ELFALAKY* 6, no. 1 (2022): 18–37, https://doi.org/10.24252/ifk.v6i1.29587; Dhiauddin Tanjung, "Urgensi Kalibrasi Arah Kiblat Dalam Penyempurnaan Ibadah Salat," *Al-Manahij: Jurnal Kajian Hukum Islam* 11, no. 1 (2018): 113–32, https://doi.org/10.24090/mnh.v11i1.1273.

the Google Earth platform, while the statistical approach is applied to analyze and interpret the resulting data patterns.

Primary data for this study were obtained from the book of *Mekanika Benda Langit* by Rinto Anugraha, supplemented by a direct interview with the author to clarify his explanation of the one-degree deviation formula. Additional primary data were gathered from Google Earth, which provided coordinate-based measurements and reference distances for the validation of the deviation calculations. Secondary data were collected from relevant scholarly literature discussing the Qibla deviation formula and its applications. The analysis employs descriptive statistical techniques, focusing on illustrating the data as observed without generalizing beyond the examined cases. The calculation process from Celestial Mechanics is systematically deconstructed to identify its computational pattern and compared with the method deemed most accurate, using Google Earth as the reference model. Based on this comparison, the study reformulates the Qibla deviation calculation through spherical trigonometric principles to produce a more precise and reliable formula.

## C. Result and Discussion

### 1. History and Legal Basis of Scholars Regarding the Qibla

Historically, *Bayt al-Maqdis* in Palestine and the Kaaba in Mecca are two sacred sites that have served as the Qibla, or direction of prayer, in the history of divine religions. [9] The Prophet Muhammad initially faced *Bayt al-Maqdis* during prayer before a revelation instructed him to turn toward the Kaaba in the Sacred Mosque (*Masjid al-Haram*) in Mecca, as stated in the Qur'an, Surah al-Baqarah, verse 144. The term Qibla derives from the Arabic word *muqābalah*, meaning *muwājahah* or "facing." Thus, Qibla refers to the direction or position toward which one faces during prayer.[10] Islamic scholars unanimously agree that facing the Qibla, as prescribed in Islamic law, is a fundamental condition for the validity of prayer. Consequently, any prayer performed without facing the Qibla, specifically, the Kaaba in Masjid al-Haram, Mecca, is considered invalid, as affirmed in the sayings (*hadiths*) of the Prophet Muhammad. [11]

In the Shafi'i school of thought, which represents the majority of Islamic jurisprudential adherence in Indonesia, there are two primary opinions regarding the obligation of facing the Qibla: facing the general direction of the Kaaba (*jihat al-Ka'bah*) and facing the physical structure of the Kaaba itself *('ain al-Ka'bah*). Imam Muhammad ibn Idris al-Shafi'i, in his seminal work *al-Umm*, emphasized that the obligatory requirement is to face precisely toward the Kaaba's physical structure (*'ain al-Ka'bah*). He argued that this obligation applies universally, both to those who can directly see the Kaaba and to those who are distant and cannot visually observe it. However, Imam al-Muzani, a distinguished student of Imam al-Shafi'i, presented a different interpretation. He maintained that the obligation is to face only the general direction of the Kaaba (*jihat al-Ka'bah*). His reasoning was that if one were required to face the exact physical structure, then during congregational prayers extending beyond the Kaaba's actual width, the prayers of individuals positioned outside the physical boundaries of the structure would be deemed invalid.[12]

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[9] Sayful Mujab, "Kiblat Dalam Prespektif Mazhab-Mazhab Fiqh," *Jurnal Pemikiran Hukum Dan Hukum Islam* 5 (2014): 434.

[10] Moelki Fahmi Ardliansyah, "Korelasi Fikih Dan Sains Dalam Penentuan Arah Kiblat," *MASLAHAH (Jurnal Hukum Islam Dan Perbankan Syariah)* 8, no. 1 (2017): 13–30.

[11] Abi Abdillah Muhammad bin Ismail bin Ibrahim al- Bukhari, *Shahih Al-Bukhari* (Dar Ibn al-Haitsam, 2004). 55

[12] Imam Al-Syirazi, *Al-Muhadzdzab* (Darul Fikr, n.d.). 95

Imam al-Nawawi conducted *tarjih* (a critical analysis to determine the strongest opinion) between the two views and concluded that the most authentic and reliable position within the Shafi'i school of thought is the obligation to face the physical structure of the Kaaba (*'ain al-Ka'bah*). This perspective is also supported by several scholars from the Maliki school and has been narrated from Imam Ahmad. In contrast, Imam Abu Hanifah held a different view, asserting that for individuals who cannot directly see the Kaaba, the obligation is limited to facing its general direction (*jihat al-Ka'bah*).[13]

It can thus be concluded that within the Shafi'i school of thought, there are two prevailing views regarding the Qibla orientation. The first view, attributed to Imam al-Muzani, aligns with the perspectives of the other three major schools of Islamic jurisprudence, the Hanafi, Maliki, and Hanbali schools, which emphasize facing the general direction of the Kaaba (*jihat al-Ka'bah*). The second view, articulated by Imam al-Nawawi, asserts that the obligation is to face the physical structure of the Kaaba (*'ain al-Ka'bah*). This requirement applies to both those who are near and can visually see the Kaaba, as well as those who are distant. However, for individuals residing far from Mecca, such as in Indonesia, located more than 7,000 kilometers away,[14] it is sufficient to have a strong conviction (*ẓann*) that they are facing the Kaaba accurately. These theological interpretations highlight the significance of ensuring that prayer spaces are oriented precisely toward the correct Qibla direction, thereby enabling worshippers to perform their prayers with firm conviction that they are truly facing the Kaaba.

## 2. Qibla Deviation Calculation Method in the Book of *Mekanika Benda Langit*

The calculation of Qibla deviation in the book Celestial Mechanics employs coordinate data with a high degree of precision, as the values obtained through this method closely correspond to those derived from Google Earth. As previously mentioned, the difference between the coordinate data from both methods amounts only to a few seconds of arc. The following section outlines the steps for calculating the Qibla deviation relative to the distance on the Earth's surface, as presented in Celestial Mechanics.

a. Determining the Distance to the Kaaba

To determine the distance to the Kaaba, *Mekanika Benda Langit* book introduces two formulas: a simple formula and a more complex one. The *first*, referred to as the simple formula, assumes that the Earth is a perfect sphere and therefore does not include a correction for the Earth's flattening. However, as discussed earlier, the Earth is more accurately represented as an ellipsoid. In a spherical model, the radius remains constant across the entire surface, whereas the actual Earth's radius varies slightly, being greatest at the equator and smallest at the poles. Although this difference is minor compared to the Earth's mean radius, it still affects the precision of distance calculations. Consequently, while the simple formula provides less accurate results, it remains acceptable for practical purposes.

Before performing the calculations, the latitude and longitude coordinates of both the observation site and the Kaabaare obtained, in this case using the Google Earth application. The simple formula is expressed as follows:

$$\cos(d) = \sin(L_1)*\sin(L_2) + \cos(L_1)*\cos(L_2)*\cos(B_1 - B_2)$$

[13] Abu Zakariya Muhyiddin bin Syaraf An-Nawawi, *Al-Majmu' Syarah al-Muhadzdzab*, trans. Muhammad Najib Al-Muthi'i (Pustaka Azzam, n.d.). 444

[14] Kementerian Agama RI, *Ilmu Falak Praktik* (2013). 25

If the angle $d$ is in radians, the distance $s$ in kilometers is:

$$s = 6378{,}137 * d \text{ [km]}$$

If the angle d is in degrees, the distance s in kilometers is:

$$s = 6378{,}137 * \pi * d / 180 \text{ [km] where } \pi = 3{,}14159265359.$$

Remember, 1 radian = $180/\pi$ = 57.2957795 degree.

The second, more complex formula provides higher accuracy because it models the Earth as an ellipsoid and includes a correction for its flattening. As the distance from the Earth's surface to its center varies with latitude, this correction enhances precision. The formula is expressed as follows:

$U = (\varphi_t + \varphi_k) / 2.$

$G = (\varphi_t - \varphi_k) / 2.$

$J = (\lambda_t - \lambda_k) / 2.$

$M = \sin(G) \text{ x } \sin(G) \text{ x } \cos(J) \text{ x } \cos(J) + \cos(U) \text{ x } \cos(U) \text{ x } \sin(J) \text{ x } \sin(J).$

$N = \cos(G) \text{ x } \cos(G) \text{ x } \cos(J) \text{ x } \cos(J) + \sin(U) \text{ x } \sin(U) \text{ x } \sin(J) \text{ x } \sin(J).$

$W = \tan(w) = \text{SQRT}(M/N)$ where $w$ is in radian

$P = \text{SQRT } (M \text{ x } N)/w$

$D = 2 \text{ x } W \text{ x } a$, where $a$ = 6378,137 kilometers.

$S = D \text{ x } \{1 + f \text{ x } E_1 \text{ x } \sin(U) \text{ x } \sin(U) \text{ x } \cos(G) \text{ x } \cos(G) - f \text{ x } E_2 \text{ x } \cos(U) \text{ x } \cos(U) \text{ x } \sin(G) \text{ x } \sin(G)\}$

where $f$ = 0,0033528107.2 [15]

b. Determining the Qibla Deviation Value

After obtaining the distance to the Kaaba, the next step involves calculating the deviation value of the Qibla direction for every one-degree difference on the Earth's surface. *Mekanika Benda Langit* book explains that the greater the distance from the Kaaba, the larger the linear displacement caused by even a one-degree deviation in the Qibla direction. To determine the magnitude of this deviation, the equation $s*\pi / 180$ is used. Here, $s$ is the distance to the Ka'bah, which can be calculated using the previously mentioned formulas. $r=s\times\pi/180$ is derived from the formula for the ratio of a circular arc.

The relationship between arc length and circumference can be expressed as:

| | |
|---|---|
| (Arc Length)/(Circumference of Circle) | = (angle $\theta$)/(angle of one rotation) [16] |
| $(r) / (2*\pi*s)$ | = (angle $\theta$) / (360 degrees) |
| $r$ | = $(1° * 2*\pi*s)$ / (360 degrees) |
| $r$ | = $s* (1°*\pi)$ / (180 degress) |

[15] World Geodetic System 1984 Reference System, "Https://Earth-Info.Nga.Mil/Index.Php?Dir=wgs84&action=wgs84," 2024. accessed on June 12, 2025 at 12:33 WIB

[16] Fathurin Zen, *Trigonometri* (ALFABETA CV, 2018). 41

### 3. Analysis of the Qibla Deviation Calculation Method in the Book *Mekanika Benda Langit*

The method for calculating Qibla deviation, as described in the book *Mekanika Benda Langit*, consists of two main stages. The first stage involves determining the distance between two points on the Earth's surface, while the second stage involves calculating the deviation value for each degree of angular difference. In calculating the distance between two locations, Anugraha proposes two alternative formulas: a simple formula and a complex one. The simple formula assumes that the Earth is a perfect sphere, whereas the complex formula treats the Earth as an ellipsoid. Naturally, the results obtained from these two approaches differ, with the complex formula providing a higher level of accuracy. This increased precision arises from the inclusion of a correction factor for the Earth's flattening, which is omitted in the simpler, spherical model. It is important to note that both formulas assume that the two locations lie exactly on the Earth's surface, corresponding to an elevation of zero above sea level. In practice, however, each location has its own elevation, which may introduce minor variations in the calculated distance.

To validate the accuracy of the distance measurements derived from these formulas, I use the *Ruler* feature in Google Earth as a reference tool. The procedure involves locating the Kaaba by typing "*Ka'bah*" in the search bar, recording its coordinates, and then calculating the distance using the formulas provided in *Mekanika Benda Langit*. From the comparison of the distance calculations between the Google Earth method and the method in the book of *Mekanika Benda Langit* using the second formula, the results are pretty accurate, having a slight difference (under 1 kilometer), except at distances of 5,000 km, 10,000 km, and 15,000 km, which have a difference of under 3 km (Table 4). Thus, the calculation method in the book of *Mekanika Benda Langit* for determining the distance between two places is still considered quite accurate and can be used for various distances, both long and short.

**Table 4.** Comparison of the distance between two places on the Earth's surface

| *Google Earth* (km) | *Mekanika Benda Langit* (km) | Deviation (km) |
|---|---|---|
| 100 | 99.99804348 | 0.019204837 |
| 1000 | 999.9807952 | 0.557151442 |
| 2000 | 2000.557151 | 0.009505644 |
| 5000 | 5000.009506 | 2.376537933 |
| 10000 | 10002.37654 | 2.986533019 |
| 15000 | 15002.98653 | 2.768734124 |
| 18000 | 18002.76873 | 0.934506727 |
| 19860 | 19860.93451 | 0.934506727 |

The second stage involves calculating the deviation value per degree. A comparison between the calculation method presented in the *Mekanika Benda Langit* book and a high-precision measurement tool such as Google Earth reveals a substantial discrepancy of approximately 51.95 km. Consequently, the method of calculating the deviation value per degree in *Mekanika Benda Langit* book is considered to lack accuracy, as previously noted in the introduction. There are two possible explanations for this inaccuracy. The first relates to potential differences in the coordinate data used for the Kaaba and the observed location. The second concerns potential errors inherent in the calculation method itself. The first possibility, however, can be dismissed, as the coordinate data for both the Kaaba and the location obtained from Google Earth and those used in *Mekanika Benda Langit* book show only minimal variation.

A comparison of the coordinate data for the Kaaba between Google Earth and the calculation method described in the introduction demonstrates that both latitude and longitude values are nearly identical. The only variation lies in the latitude of the observed location, differing by merely a few arcseconds. Such a small discrepancy cannot account for the 51.95 km difference in the Qibla deviation, as observed in the case of the Baiturrahman Mosque in Gorontalo, discussed earlier. This finding indicates that the coordinate data employed in the Celestial Mechanics method are sufficiently precise.

Therefore, it can be concluded that the inaccuracy in the Qibla deviation per degree calculated using the Celestial Mechanics formula stems not from coordinate discrepancies but from the computational model or formula itself. This conclusion is further supported by comparative analysis, which shows that when the distance between a location and the Kaaba is less than 2,000 km, the deviation between the *Mekanika Benda Langit* calculation and the Google Earth measurement remains under 1 km (ranging from 0.015329 to 0.376585 km). However, the inaccuracy increases significantly at distances exceeding 2,000 km, where the deviation ranges from 9.126 to 63.5329252 km, as presented in Table 5.

**Table 5.** Comparison of Qibla Deviation Values

| Distance (km) | *Mekanika Benda Langit* (km) | Google Earth (km) | Deviation(km) |
|---|---|---|---|
| 100 | 1.745329 | 1.73 | 0.015329 |
| 1000 | 17.45329 | 17.37 | 0.083293 |
| 2000 | 34.90659 | 34.53 | 0.376585 |
| 5000 | 87.26646 | 78.14 | 9.126463 |
| 10000 | 174.53292 | 111 | 63.532925 |

Table 5shows that the calculation method presented in *Mekanika Benda Langit* demonstrates a high degree of accuracy for short distances but loses precision as the distance increases. Upon closer examination, the primary reason for this difference lies in the foundational assumption underlying the Qibla deviation formula. The formula is derived from the comparison of a circular arc, which assumes a planar triangle geometry. However, as previously discussed, the Earth's shape more closely resembles a sphere, or, more accurately, an ellipsoid, rather than a flat plane. This interpretation is corroborated by the author of *Mekanika Benda Langit*, Anugraha, during an interview, in which he explained that the Qibla deviation formula in the book was developed using the assumption of a planar triangle. He further acknowledged that applying this method to locations situated far from the Kaaba would result in lower accuracy.

It is important to emphasize that the inaccuracy identified in the Qibla deviation formula does not extend to all formulas presented in *Mekanika Benda Langit*. Other formulas, such as those used for determining the Qibla direction, the distance between two points on Earth, and the distance from the Earth's surface to its center, as discussed in the same chapter, "The Earth and Spherical Coordinates", are based on spherical or ellipsoidal Earth models and therefore yield accurate results. The Qibla deviation formula, however, exhibits reduced accuracy because it is secondary in nature and not the primary focus of the discussion. Its inclusion in the text primarily serves to emphasize the importance of ensuring that a place of worship is oriented precisely toward the Qibla direction, thereby preventing any potential deviation that could affect the validity of prayer.

## 4. Algorithm for Reformulating the Qibla Deviation Calculation Based on Actual Distances on the Earth's Surface

The geodetic data presented in the *Mekanika Benda Langit* book demonstrates a high degree of accuracy. This is evident from the comparison between the coordinate data of the Baiturrahim Grand Mosque in Gorontalo Regency obtained from Google Earth and those recorded in thisbook, as described in the background of this study. The comparison shows that the coordinate values in this book differ only by a few seconds of arc from those in Google Earth, indicating a negligible margin of error. Given this high level of precision, it would be scientifically valuable to fully utilize these coordinates for more advanced applications, one of which is the calculation of Qibla direction deviation. Therefore, this study seeks to reformulate the Qibla deviation formula presented in *Mekanika Benda Langit* by employing a spherical trigonometric approach. The use of spherical trigonometry is justified by the fact that the Earth's shape closely approximates a sphere, making this method more suitable for accurately modeling the geometry involved in Qibla direction determination.

The utilization of coordinate data for calculating Qibla deviation relative to the distance on the Earth's surface can be accomplished through the following steps:

1. Determining the Distance Between Two Places on the Earth's Surface

   Before calculating the deviation per degree, the first step is to find the distance between the Kaaba and the location whose Qibla direction is sought. As explained before, although the results from the distance calculation methods in *Mekanika Benda Langit* and Google Earth differ by less than 3 km, this discrepancy significantly affects the results of the reformulated Qibla deviation calculation. Therefore, I will use Google Earth data as the source for the distance between two places on Earth. Another reason I use distance measurements from Google Earth instead of those from the *Mekanika Benda Langit* book is to focus solely on testing the Qibla deviation formula, rather than determining the distance between two places. Thus, the data used to determine the Qibla deviation for both the reformulated method and Google Earth come from the same source, which is Google Earth.

2. Determining Qibla Deviation Using the Law of Spherical Trigonometry

   To find the deviation value, I reformulate the Qibla deviation formula in *Mekanika Benda Langit* using a spherical trigonometry approach. This approach is used because the Earth's shape resembles a sphere. Thus, the resulting calculation is more accurate compared to the formula in that book, which still employs a circular arc comparison, resulting in a plane triangle assumption. The steps for reformulating the formula with a spherical trigonometry approach. If we assume the Earth is a sphere, then finding the deviation value relative to the distance on the Earth's surface using a spherical trigonometry approach is the same as finding the value of arc c (the distance between the Kaaba and the deviation point). Here are the steps of the reformulation:

   a. Spherical Trigonometry Formula

      To find the value of arc $c$, we can use the rules of spherical trigonometry. In spherical trigonometry, there is a standard formula as follows:

      $\cos(c) = \cos(a)\cos(b) + \sin(a)\sin(b)\cos(C)$[17]

   b. Finding the value of cos(c)

      In determining the Qibla deviation relative to the distance on Earth, what must first be known is the distance between the location and the Kaaba and the degree of deviation used. Once known, to facilitate the calculation, convert the distance value into radians using the equation:

[17] M. Sayuti Ali, *Ilmu Falak* (PT Raja Grafindo Persada, 1997). 83

(Arc Length) / (Circumference) = (angle $\theta$) / (angle of one rotation)[18]

One full rotation = $360° = 2\pi$ rad, so:

(Arc a/b) / (Circumference) = ($\theta$ radians) / ($2\pi$ radians)

$\theta$ radians = (Arc a/b * $2\pi$ radians) / (Circumference)

In this case, the circumference is the Earth's circumference, so the equation becomes:

(Arc a/b * $2\pi$) / (Earth's circumference) = ... (radians)

After converting to radians, substitute it into the spherical trigonometry equation:

$\cos(c) = \cos(a(\text{rad})) \cos(b(\text{rad})) + \sin(a(\text{rad})) \sin(b(\text{rad})) \cos(C)$

The value of C is the degree of arc deviation; this number can be adjusted according to the tolerance perspective used. For example, using a value of 1°.

$\cos(c) = \cos(a(\text{rad})) \cos(b(\text{rad})) + \sin(a(\text{rad})) \sin(b(\text{rad})) \cos(1°)$

After finding the result for $\cos(c)$, the next step is to convert it back to radians using the Arc cos function. Arc $\cos(c)$ is the inverse of cos(c):

$c$ (in rad) = Arc cos (value of $\cos(c)$)

c. Converting Radians to a unit of distance

After obtaining the value in radians, the final step is to convert it into kilometers, using:

(Arc Length) / (Circumference) = (angle $\theta$) / (angle of one rotation)[19]

One full rotation = $360° = 2\pi$ rad, so:

(Arc $c$) / (Circumference) = ($\theta$ radians) / ($2\pi$ radians)

(Arc $c$) / (Circumference) = ($c$(rad)) / ($2\pi$ radians)

Thus,

Arc c = ($c$(rad) * circumference) / ($2\pi$)

c (km) = ($c$(rad)) / ($2\pi$) x Earth's Circumference

The value of arc c in kilometers is the Qibla deviation figure for the distance on the Earth's surface.

## 5. Accuracy Analysis of the Reformulated Qibla Deviation Calculation

This reformulation of the Qibla deviation calculation method aims to enhance the accuracy of the resulting values. By applying the principles of spherical trigonometry, the reformulated method is expected to yield more precise results in determining the deviation relative to distance on the Earth's surface. Although the data used in the *Mekanika Benda Langit* book are based on an ellipsoidal Earth model, already providing high accuracy in geodetic terms, the deviation values obtained from its formula are inconsistent with actual measurements. Therefore, the inaccuracy

[18] Zen, *Trigonometri*. 41

[19] Zen, *Trigonometri*. 41

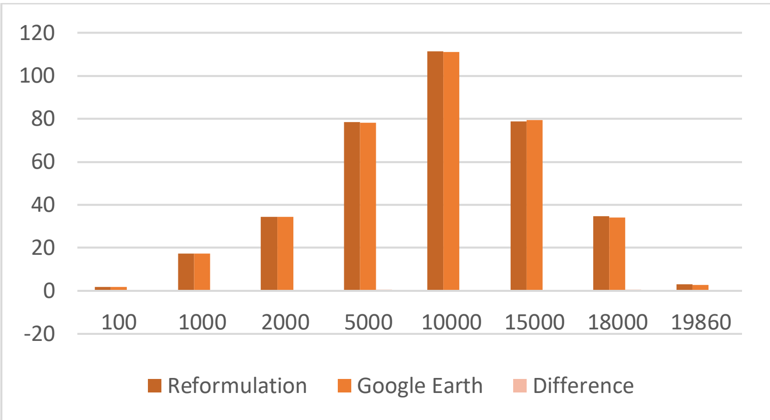
observed in the Qibla deviation calculation of *Mekanika Benda Langit* book does not stem from the data used but rather from the formulation of the equation and the computational method applied.

For comparison purposes, this study employs Google Earth as the accuracy benchmark. The platform's internal coordinate system is based on the geographic coordinate system (latitude and longitude) within the World Geodetic System 1984 (WGS84) datum, which is also the reference system used by the Global Positioning System (GPS).[20] Consequently, the accuracy of Google Earth in representing spatial data is highly reliable. Supporting this, Muammar Al-Khairi's research concluded that the use of Google Earth for determining the Qibla direction is classified as accurate and can be considered a valid reference for geospatial analysis.[21]

For the variation of the Deviation Value Against the Distance Variable, the author uses several distance variations: 100 km, 1000 km, 2000 km, 5000 km, 10000 km, 15000 km, and 19,860 km. These figures were not chosen without reason; they are intended to represent one-eighth, one-quarter, and one-half of the Earth. The degree variations used are 1 and 4 degrees, so that differences are seen in small and large degrees.

**Table 6.** Comparison of Qibla Deviation Values at 1° Distance

| Distance (km) | Reformulation | Google Earth | Deviation (km) |
|---|---|---|---|
| 100 | 1.745235524 | 1.73 | 0.01523552 |
| 1000 | 17.38158135 | 17.37 | 0.01158135 |
| 2000 | 34.33633096 | 34.53 | 0.193669 |
| 5000 | 78.58921832 | 78.14 | 0.44921832 |
| 10000 | 111.258093 | 111 | 0.25809299 |
| 15000 | 78.91592565 | 79.411 | 0.4950744 |
| 18000 | 34.7759637 | 34.06 | 0.7159637 |
| 19860 | 2.905605948 | 2.63 | 0.27560595 |




**Graph 1.** Comparison of Qibla Deviation Values at 1° Distance

Based on the data presented in the table and graph, the highest Qibla direction deviation occurs at a distance of approximately 10,000 km, equivalent to one-quarter of the Earth's circumference. Conversely, the lowest deviation appears at distances of 100 km and 19,860 km, the

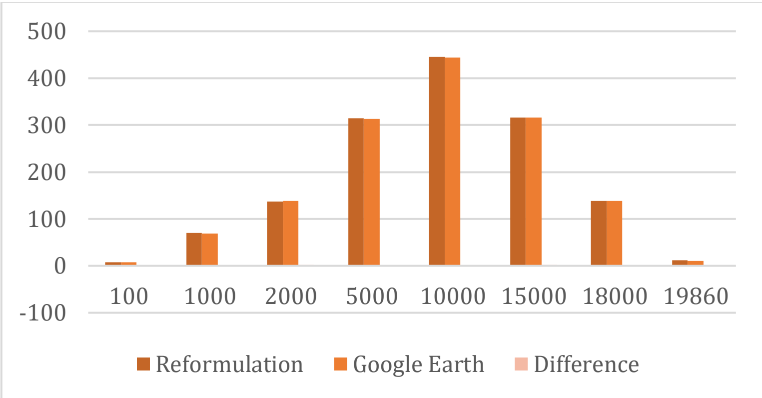
[20] Nagi Zomrawi Mohammed et al., "Positional Accuracy Testing of Google Earth," *International Journal of Multidisciplinari Sciences and Engineering* 1984 (2013): 6–9.

[21] Muammar Al-Khairi, "Uji Akurasi Citra Google Earth dalam Menentukan Arah Kiblat Masjid di Kecamatan Langsa Timur" (Undergraduate Thesis, Universitas Islam Negeri Walisongo, 2022).

latter corresponding to half of the Earth's circumference. For a location situated at the Earth's antipode relative to the Kaaba, the Qibla deviation value is zero, indicating that one may face the Qibla in any direction. The plotted graph of the Qibla deviation values, comparing the reformulated method and Google Earth, illustrates a fluctuating pattern, with the maximum deviation observed at a distance of around 10,000 km.

**Table 7.** Comparison of Qibla Deviation Values at 4° Distance

| Distance (km) | Reformulation | Google Earth | Deviation (km) |
|---|---|---|---|
| 100 | 6.979613415 | 6.959 | 0.020613415 |
| 1000 | 69.51341215 | 69.189 | 0.324412145 |
| 2000 | 137.3216658 | 138.094 | 0.77233423 |
| 5000 | 314.3268795 | 313.7 | 0.626879539 |
| 10000 | 445.0323716 | 444.034 | 0.998371588 |
| 15000 | 315.633834 | 316.557 | 0.923165996 |
| 18000 | 139.0799588 | 138.233 | 0.846958797 |
| 19860 | 11.62021267 | 10.623 | 0.997212668 |



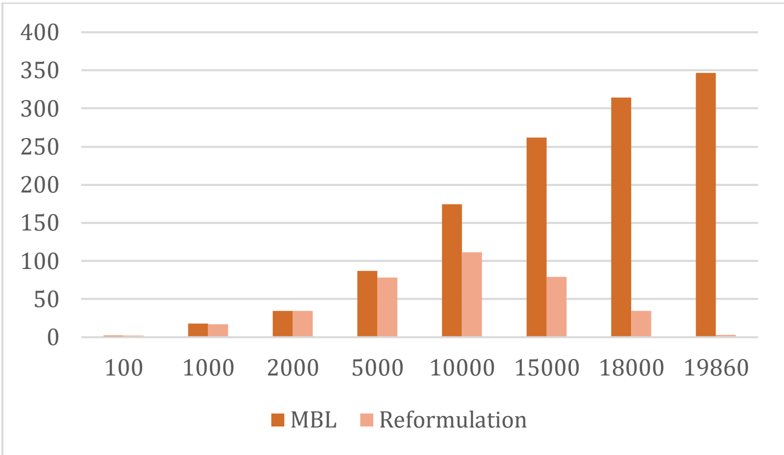

**Graph 2.** Comparison of Qibla Deviation Values at 4° Distance

**Table 8.** Deviation Comparison: *Mekanika Benda Langit* (MBL) & Google Earth (1°)

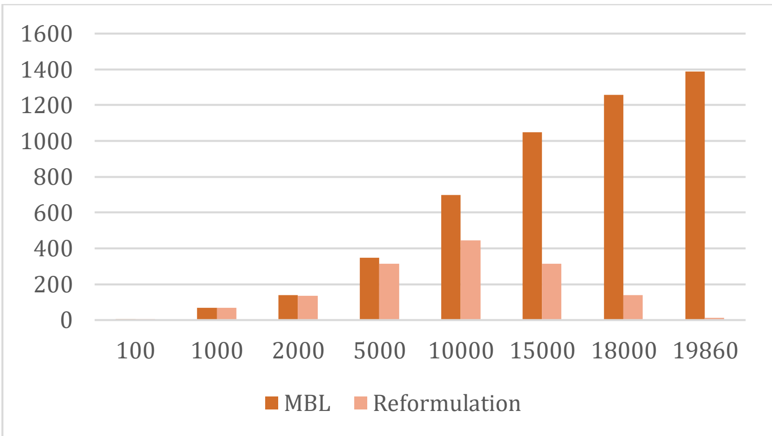
| Distances (km) | MBL (km) | Google Earth (km) | Deviation (km) |
|---|---|---|---|
| 100 | 1.745329 | 1.73 | 0.015329 |
| 1000 | 17.45329 | 17.37 | 0.083293 |
| 2000 | 34.90659 | 34.53 | 0.376585 |
| 5000 | 87.26646 | 78.14 | 9.126463 |
| 10000 | 174.5329 | 111 | 63.53293 |
| 15000 | 261.7994 | 79.411 | 182.3884 |
| 18000 | 314.1593 | 34.06 | 280.0993 |
| 19860 | 346.6224 | 2.63 | 343.9924 |

**Table 9.** Deviation Comparison: *Mekanika Benda Langit* (MBL) & Google Earth (4°)

| Distances (km) | MBL (km) | Google Earth (km) | Deviation (km) |
|---|---|---|---|
| 100 | 6.981317 | 6.959 | 0.022317 |
| 1000 | 69.81317 | 69.189 | 0.62417 |
| 2000 | 139.6263 | 138.094 | 1.53234 |
| 5000 | 349.0659 | 313.7 | 35.36585 |
| 10000 | 698.1317 | 444.034 | 254.0977 |
| 15000 | 1047.198 | 316.557 | 730.6406 |
| 18000 | 1256.637 | 138.233 | 1118.404 |
| 19860 | 1386.49 | 10.623 | 1375.867 |




**Graph 3.** Deviation Comparison: *Mekanika Benda Langit* (MBL) & Google Earth (1°)




**Graph 4.** Deviation Comparison: *Mekanika Benda Langit* (MBL) & Google Earth (1°)

The comparison of Qibla deviation values between the method presented in *Mekanika Benda Langit* book and Google Earth demonstrate that for distances up to 2000 km, the deviation remains within 1 km at both one- and four-degree variations. However, for distances ranging from 5000 km to 19,860 km, the deviation increases significantly, reaching values between 9.12 km and 1375.867 km. The largest deviation occurs at the farthest point (19,860 km) with a difference of 1375.867 km, while the smallest deviation, 0.01 km, is observed at a distance of 100 km. In contrast, the comparison between the post-reformulation calculation method and Google Earth across all distance and degree variations shows a markedly improved level of accuracy, with differences consistently below 1 km. This indicates that, unlike the pre-reformulation method, whose accuracy was reliable only up to 2000 km, the reformulated approach yields precise results even at greater distances, thereby enhancing the reliability of Qibla direction determination for global applications.

The reason the pre-reformulation deviation formula is inaccurate at distances greater than 2000 km is that the assumption used in creating the Qibla deviation formula in *Mekanika Benda Langit* book is the perspective of a plane triangle. Thus, this formula is only valid when used on a flat plane. As explained above, the shape of the Earth is like a sphere, and even more accurately, an ellipsoid. Therefore, the reformulated Qibla deviation formula is better than the approach of the pre-reformulation formula. This is because the pre-reformulation method employs a plane triangle approach, so the deviation value will only be accurate within a certain distance limit, specifically 2000 km. This contrasts with the post-reformulation formula, which is precise at various distances because it has an approach that more closely resembles the shape of the Earth, i.e., a sphere.

The pattern produced by the method in the *Mekanika Benda Langit* book before reformulation shows an exponential function, where the farther a place is from the Kaaba, the higher its deviation value will be, as seen in graphs 3 and 4. This differs from the pattern produced by the post-reformulation formula, which does not exhibit an exponential function but is shaped like a mountain, with a peak at the 10,000 km distance variable and the smallest values at the nearest (100 km) and farthest (19,860 km) distance variables.

Graphs 3 and 4 show that, after the formula was reformulated, the highest deviation value occurs at a distance of 10,000 km, and the smallest is at a distance of 100 km. If analyzed with a mathematical approach, this result can be explained by the following arc comparison:

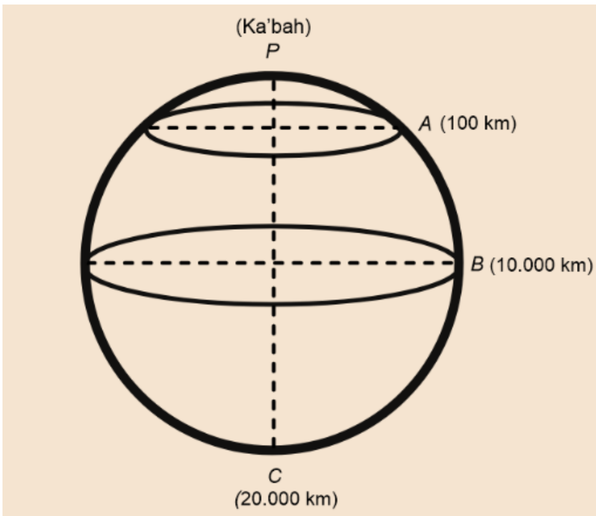



**Figure 7.** The Earth as a sphere

Assuming the Earth is spherical, as illustrated in the figure, point P represents the Kaaba, point A is located 100 km from the Kaaba, point B is 10,000 km away, and point C is 20,000 km away. Each of these locations lies on a circular path corresponding to its distance from the Kaaba. If each circle represents 360°, then the value of a one-degree deviation from the Kaaba can be expressed as the ratio of the arc length to the circle's total circumference. For example, at point B, which is 10,000 km from the Kaaba and lies on the Earth's largest possible circle (the great circle) with a circumference of approximately 40,053 km, the value of a one-degree deviation is calculated as the ratio of the arc length corresponding to one degree to the total circumference.

(Arc length) / (Circumference) = (angle $\theta$) / (angle of one rotation)

Deviation / (Circumference) = (angle $\theta$) / (angle of one rotation)

Deviation = (angle θ) / (angle of one rotation) x circumference

In this case, the distance of 10,000 km from the Kaaba has the largest circumference on Earth (great circle), which is 40,053 km. Thus:

deviation = (1 degree) / (360 degrees) x 40,053

= 111.2583 km

This deviation value corresponds to Table 6, which is 111.258 km. Another example is at a distance of 100 km with a one-degree deviation of 1.74 km, which can be used to find the circumference of the circle at that distance from the Kaaba.

Deviation / (Circumference) = (angle $\theta$) / (angle of one rotation)

1.74 / (Circumference) = (1) / (360 degrees)

Circumference = 1.74 x 360 degrees

= 626.4 km

Thus, the value of the circumference at a distance of 100 km is 626.4 km.

From these two examples, it can be concluded that the Qibla direction deviation value is influenced by the circumference of the circle for each respective distance from the Kaaba, because each place has a different value for the circumference of its circle relative to the Kaaba. The distance of 10,000 km (a quarter of the Earth) has the highest deviation value from the Kaaba because it has the largest circumference on Earth (great circle), which is 40,053 km.

Whereas in the pre-reformulation formula, namely:

(Arc Length) / (Circumference) = (angle $\theta$) / (angle of one rotation)

$(r) / (2\pi * s)$ = (angle $\theta$) / (360 degrees)

$r$ = $(1° * 2\pi * s)$ / (360 degrees)

$r$ = $s * (1° * \pi)$ / (180 degrees)

The value of '*s*' in the circumference formula uses the value of the distance from the location to the Kaaba, not the radius of the circle at that distance. Thus, the pre-reformulation Qibla deviation formula will only be accurate at short distances from the Kaaba, because the value of the distance from the location to the Kaaba is almost the same as the value of the radius of the circle at that distance (see Figure 7).

From my perspective, the root of the inaccuracy of the *Mekanika Benda Langit* book formula lies in its algorithm or calculation method. The *Mekanika Benda Langit* book's formula is based on the assumption of a plane triangle (the ratio of arcs to a plane circle). This assumption, as confirmed by Anugraha, book author, through interviews, is only accurate for very short distances (under 2000 km). However, the author of this study emphasized that this finding does not generalize to all formulas in the *Mekanika Benda Langit* book. Other formulas in the book, such as the distance calculation formula (which uses the ellipsoid assumption), are actually considered accurate. As a solution to this skewness formula problem, I propose a reformulation of the calculation method using a spherical trigonometry approach. I believe that this approach is better and more accurate because the spherical model is closer to the actual shape of the Earth than the flat model.

A limitation of this study is that the reformulated formula still employs a spherical Earth model, which assumes a perfectly round shape, rather than an ellipsoidal model that is geodetically more precise. Nevertheless, the use of the spherical model has proven sufficient, producing a very high level of accuracy, with differences of less than 1 km, in calculating the inclination of the Qibla direction. This research serves as a refinement of previous studies on Qibla inclination calculation. Although it shares methodological similarities with earlier works (such as those by Mulyadi, Somawinata, and Ismail et al.) in applying mathematical approaches to convert angular deviations (in degrees) into linear distances (in kilometers), it introduces a key advancement through the inclusion of accuracy validation. The author identified that many previous studies proposing Qibla deviation or tolerance formulas lacked empirical validation of their computational results. To address this gap, the present study conducted a systematic accuracy assessment by comparing the calculated results with Google Earth data, which is recognized for its high precision because it employs the WGS84 datum, the same geodetic reference system used by GPS.[22]

This finding carries significant implications for Islamic jurisprudence (*fiqh*), particularly concerning the validity of prayer direction (Qibla accuracy). Within *fiqh* discourse, the tolerance limit for Qibla deviation has been widely debated. For instance, Sudibyo argues that the acceptable Qibla deviation tolerance is equivalent to a lateral displacement of 45 km, corresponding to the distance between the Kaaba and the intersection coordinates of the Quba Mosque.[23] To apply such tolerance limits effectively, scholars of Islamic jurisprudence and astronomy require precise calculations that quantify how many kilometers of lateral deviation correspond to a certain angular deviation (in degrees) at a specific geographic location. This study demonstrates that the Qibla deviation formula presented in the book of *Mekanika Benda Langit*, which has been widely referenced in Qibla orientation studies, produces inaccurate results for locations situated more than 2,000 km from the Kaaba. The practical implication is critical: if this inaccurate formula is applied to assess the Qibla orientation of a mosque located far from Mecca, it may lead to an erroneous conclusion that the mosque's orientation exceeds the permissible tolerance limit, even when it actually remains within the acceptable range.

## D. Conclusion

The analysis reveals that the Qibla deviation calculation presented in *Mekanika Benda Langit* book demonstrates significant inaccuracies for locations situated more than 2,000 km from the Kaaba, regardless of the degree of deviation. The resulting deviation values differ substantially from those measured using Google Earth, with discrepancies ranging from 9.12 km to 1,375.867 km. Conversely, the method remains relatively accurate for locations within 2,000 km of the Kaaba, where the difference compared to Google Earth measurements is less than 1 km for one- and four-degree arc variables, except for a distance of 2,000 km with a four-degree variable, which still produces a reasonably accurate deviation of 1.53 km. The inaccuracy for distant locations primarily stems from the fundamental assumption underlying the formula, which models the deviation as an arc comparison on a planar triangle. Such an assumption is valid only when applied to a flat surface. From a geometric perspective, the inaccuracy also arises because the formula uses the distance between the location and the Kaaba as the variable s, instead of the radius of curvature at that specific distance. As a result, the formula yields acceptable accuracy only for short distances, where the location's distance to the Kaaba approximates the radius of the circle at that range.

It is important to note that this limitation applies exclusively to the Qibla deviation formula and not to other formulas in *Mekanika Benda Langit* book, such as those used to determine the

[22] Mohammed et al., "Positional Accuracy Testing of Google Earth."

[23] Muh. Ma'rufin Sudibyo, *Sang Nabi Pun Berputar : Arah Kiblat Dan Tata Cara Pengukurannya* (Tinta Medina, 2011). 85

distance from the Earth's surface to its center or between two points on Earth, which correctly employ an ellipsoidal model. The reformulated approach proposed in this study applies the laws of spherical trigonometry and yields more accurate results across all distance and degree variations. Despite adopting a spherical rather than ellipsoidal model, the reformulated method achieves a deviation difference of less than 1 km compared to Google Earth, thereby demonstrating significantly improved precision and reliability in determining Qibla direction.

## BIBLIOGRAPHY


Abd. Haji Amahoru and Sri Rahmadani Pulu. "Pemetaan Data Astronomi untuk Mengidentifikasi Pergeseran Arah Kiblat Masjid di Pulau Ambon." *JURNAL PENDIDIKAN MIPA* 13, no. 1 (2023): 150–58. https://doi.org/10.37630/jpm.v13i1.848.

Ali, M. Sayuti. *Ilmu Falak*. PT Raja Grafindo Persada, 1997.

Al-Syirazi, Imam. *Al-Muhadzdzab*. Dār al-Fikr, n.d.

An-Nawawi, Abu Zakariya Muhyiddin bin Syaraf. *Al-Majmu' Syarah al-Muhadzdzab*. Translated by Muhammad Najib Al-Muthi'i. Pustaka Azzam, n.d.

Anugraha, Rinto. *Mekanika Benda Langit*. Universitas Gadjah Mada, 2012.

Ardliansyah, Moelki Fahmi. "Korelasi Fikih dan Sains dalam Penentuan Arah Kiblat." *MASLAHAH (Jurnal Hukum Islam Dan Perbankan Syariah)* 8, no. 1 (2017): 13–30.

Bukhari, Abi Abdillah Muhammad bin Ismail bin Ibrahim al-. *Shahih Al-Bukhari*. Dar Ibn al-Haitsam, 2004.

Husna, Amirah Himayah, Aristiono Hamdani, Ckamilatun Nikmah, Givari Ardiansyah, Mohammad Sultan Yusuf Saifullah, and Adi Damanhuri. *ANALISIS ORTHODROM DAN LOXODROM DALAM PENENTUAN ARAH KIBLAT DI TOKYO JEPANG*. 2, no. 2 (2021).

Ismail, Ismail, Dikson T. Yasin, and Zulfiah. "Toleransi Pelencengan Arah Kiblat Di Indonesia Perspektif Ilmu Falak Dan Hukum Islam." *Al-Mizan* 17, no. 1 (2021): 115–38. https://doi.org/10.30603/am.v17i1.2070.

Izzuddin, Ahmad. "Typology Jihatul Ka'bah on Qibla Direction of Mosques in Semarang." *Ulul Albab: Jurnal Studi Dan Penelitian Hukum Islam* 4, no. 1 (2020): 1. https://doi.org/10.30659/jua.v4i1.12186.

Kementerian Agama RI. *Ilmu Falak Praktik*. 2013.

Al-Khairi, Muammar. "Uji Akurasi Citra Google Earth dalam Menentukan Arah Kiblat Masjid di Kecamatan Langsa Timur." Undergraduate Thesis, Universitas Islam Negeri Walisongo, 2022.

Laksana, Agung. "Telaah Matematis Variasi Lebar Arah Kiblat Di Wilayah Indonesia." *El-Falaky* 4, no. 1 (2017): 9–15.

Laksana, Agung, and Muh Rasywan Syarif. "Telaah Matematis Variasi Lebar Arah Kiblat di Wilayah Indonesia." *ELFALAKY* 6, no. 1 (2022): 18–37. https://doi.org/10.24252/ifk.v6i1.29587.

Mujab, Sayful. "Kiblat dalam Prespektif Mazhab-Mazhab Fiqh." *Jurnal Pemikiran Hukum dan Hukum Islam* 5 (2014): 434.

Mulyadi, Achmad. "Akurasi Arah Kiblat Masjid-Masjid di Kabupaten Pamekasan." *Jurnal Penelitian Ilmu Sosial dan Keagamaan Islam* 10, no. 1 (2013): 71–100.

Schumm, Walter R. "How Accurately Could Early (622-900 C.E.) Muslims Determine the Direction of Prayers (Qibla)?" *Religions* 11, no. 3 (2020): 102. https://doi.org/10.3390/rel11030102.

Solikin, Agus. "Pertemuan Rumus Cosinus dan Sinus dengan Haversine dalam Perhitungan Arah Kiblat." *Teorema: Teori dan Riset Matematika* 5, no. 2 (2020): 211. https://doi.org/10.25157/teorema.v5i2.3671.

Sowamita, Yusuf. *ILMU FALAK: Pedoman Lengkap Waktu Shalat, Arah Kiblat, Perbandingan Tarikh, Awal Bulan Qamariyah, dan Hisab Rukyat*. 1st ed. Edited by Monalisa. Rajawali Press, 2020.

Sudibyo, Muh. Ma'rufin. *Sang Nabi Pun Berputar : Arah Kiblat dan Tata Cara Pengukurannya*. Tinta Medina, 2011.

Syarif, Muh Rasywan, and Zulhasari Mustafa. *Analisis Keakurasian Azimuth Bintang sebagai Acuan Penentu Arah Kiblat*. 3, no. 3 (n.d.): 19–35.

Tanjung, Dhiauddin. "Urgensi Kalibrasi Arah Kiblat dalam Penyempurnaan Ibadah Salat." *Al-Manahij: Jurnal Kajian Hukum Islam* 11, no. 1 (2018): 113–32. https://doi.org/10.24090/mnh.v11i1.1273.

Fatmawati, Muhammad Shuhufi, et al. "Rumus Arah Kiblat Saadoeddin Djambek Perspektif Spherical Trigonometry." *Al-Marshad: Jurnal Astronomi Islam dan Ilmu-Ilmu Berkaitan* 6, no. 2 (2020): 149–61. https://doi.org/10.30596/jam.v6i2.5092.

Mustaqim, Riza Afrian. "Analisis Metode Penentuan Arah Kiblat Masjid Agung Baitul Makmur Meulaboh Aceh Barat." *Al-Marshad: Jurnal Astronomi Islam dan Ilmu-Ilmu Berkaitan* 6, no. 2 (2020): 181–94. https://doi.org/10.30596/jam.v6i2.5229.

World Geodetic System 1984 Reference System. "Https://Earth-Info.Nga.Mil/Index.Php?Dir=wgs84&action=wgs84." 2024.

Zen, Fathurin. *Trigonometri*. ALFABETA CV, 2018.

Zomrawi, Mohammed Nagi, Ahmed Ghazi, and Hussam Eldin Mustafa. "Positional Accuracy Testing of Google Earth." *International Journal of Multidisciplinary Sciences and Engineering* 1984 (2013): 6–9.

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