Article

Evaluation of Rashd Al-Qiblah Method Accuracy: Spherical Plane And Ellipsoid Approaches in Qibla Direction Determination

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ABSTRACT

Determination of Qibla direction is an important aspect in the implementation of Muslim worship. One of the methods used is rashd al-qiblah, which is a direct observation based on the shadow of an object when the sun is directly above the Kaaba. However, the use of rashd al-qiblah that considers the shape of the Earth's ellipsoid through Vincenty Theory is still very limited. This study aims to analyze the accuracy of determining the Qibla direction using two geometric approaches, namely the spherical plane and the ellipsoid, and compare it with the results of direct observation using the rashd al-qiblah method. The research location is focused on Banjarmasin, which is geographically qualified to use the rashd al-qiblah method. The results of this study are expected to provide a comprehensive picture of the differences in accuracy between the two calculation methods and the direct observation method. The analysis also aims to evaluate the reliability of the ellipsoid-based method in the context of Qibla direction determination practice. The findings of this study can be an important reference for phalacticians and the general public in choosing the most accurate method for Qibla direction determination.

Keywords: Rashd Al-Qiblah; Vincenty Theory; Ellipsoid

1. Introduction

Currently, there are still many mosques in South Kalimantan whose Qibla direction is not in accordance with the proper direction. A study of the Qibla direction of mosques in Banjarmasin city revealed that of the 40 mosques studied, 50% had very low Qibla direction accuracy (Mashunah & others, 2013). Meanwhile, in Banjar Regency, a similar study showed that out of 40 mosques, 70% had inaccurate Qibla directions (Helmi & Badrian, 2019).

The main problem in Qibla determination is ascertaining the exact direction towards the Kaaba in Makkah. This direction is determined through calculations and measurements from any point or location on the Earth's surface (Khafid, 2013). Calculation is done to determine the direction of the Kaaba from a location, while measurement is the application of the results of these calculations (setting out) on the ground or floor of a building, such as a mosque (Yaqin, 2022).

In the measurement process, the Qibla direction is determined based on the angle of direction and azimuth. The angle measured in Qibla direction measurement is included in the

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horizontal angle category, which is the reference to ensure the Qibla direction accurately. Along with the advancement of science, there are several methods in determining the Qibla direction, such as the spherical plane method, the ellipsoid plane method, and the Qibla shadow method (rashd al-qiblah). These different methods also produce different levels of accuracy. This is because it is related to the calculation system, the astronomical data used, the equipment used and the people.

So far, the determination of the Qibla direction of a place is based on the assumption that the Earth is spherical with a fixed radius. The distance between the center of the Earth to the equator is equal to the distance between the center of the Earth to the poles. The formula for determining the Qibla direction is derived from several spherical trigonometric formulas.

In addition to the assumption of a spherical Earth, in 1975, Vincenty introduced a more accurate approach to the Earth that assumed the shape of ellipsoid. An ellipsoid Earth has an unequal distance between the distance from the center of the Earth to the equator and the distance from the center of the Earth to the poles. The distance from the center of the Earth to the equator is slightly greater than the distance from the center of the Earth to the poles. To calculate the Qibla direction based on this ellipsoid plane Earth reference, the Vincenty formula is introduced (Vincenty, 1975a).

The method of determining the Qibla direction can also utilize the position of heavenly bodies, such as the Sun. The position of the Sun at a time above the Kaaba called yaumu rashd al-qiblah can be used to determine the Qibla direction. This rashd al-qiblah occurs twice a year, namely May 27/28 and July 15/16.

The rashd al-qiblah method is believed to be the most accurate and cheap method, so it is widely used by the public (Thoyfur, 2021). However, it should be noted that at the time of global rashd al-qiblah, the Sun is almost never exactly at the zenith of the Ka'bah. The Sun is only close to the zenith of the Kaaba, sometimes further north or south of the Kaaba's zenith. The Kaaba in Makkah is located at coordinates 21°25'21.00" N and 39°49'34.30" E. Consider the following table:

Table 1. Sun Transit Near the Zenith of the Kaaba

Date	Sun Transit at Kaaba (UT+3)	Declination (d)	Difference d-p	Description
26/05/2020	12.17.48	+21°14'00,18''	-0°11'20',82'	Sun South of the Zenith of the Kaaba
27/05/2020	12.17.55	+21°23'58,85''	-0°01'22',15'	Sun South of the Zenith of the Kaaba
28/05/2020	12.18.02	+21°33'35,28''	+0°08'14',28'	Sun South of the Zenith of the Kaaba
15/07/2020	12.26.44	+21°25'01,26''	-0°00'19',74'	Sun South of the Zenith of the Kaaba
16/07/2020	12.26.49	+21°15'08,77''	-0°10'12',23'	Sun South of the Zenith of the Kaaba
17/07/2020	12.26.54	+21°04'54,66''	-0°20'26',34'	Sun South of the Zenith of the Kaaba

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

From the table above, it can be seen that the declination and geodetic latitude of Kaaba there is a difference between 19.74 seconds to 20 minutes 26.34 seconds of arc. This can reduce the accuracy of the results of determining the Qibla direction. The declinations closest to the geodetic latitude of the Kaaba are May 27 and July 15, 2020. However, if we consider the geocentric latitude of the Kaaba which is 21°17'31.09" U and then compare it with the declination of the Sun, then May 26 and July 16, 2020 are the closest dates.

For local rashd al-qiblah(Faid, Nahwandi, Nawawi, Zaki, & Saadon, 2022), because the declination of the Sun changes in every hour then we can determine when the azimuth of the Sun's shadow is still close to the value of the qibla azimuth of a place(Qulub, 2013). This time will be calculated by considering the shape of the Earth's ellipsoid, using the Earth's geocentric latitude. Until now, the Vincenty raşd al-qiblah Theory that considers the shape of the Earth's ellipsoid has not been widely applied. Therefore, it is necessary to study the method of rashd al-qiblah in Vincenty Theory and its accuracy. The accuracy of this method is then compared with direct observation of Qibla direction with the rashd al-qiblah method (Munfaridah, 2022)..

2. Theoretical Framework

Direction in the perspective of the spherical earth model is the closest distance measured through a great circle centered on a sphere with an orthodrome trajectory. With this understanding, the Qibla direction is the direction indicated by the great circle on the earth's surface that connects the point where prayer is performed with the point of the geographical location of the Kaaba(Azhari, 2007).

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Calculation of Qibla direction is done by using the principle of measuring the spherical triangle with 3 necessary points, namely:

1. point A, located at the Kaaba
2. point B, located at the location where the Qibla direction will be calculated.
3. point C, located at the North pole.

The Qibla direction formula is as follows (Khafid, 2013)

$$\cot B = \frac{\cot b \sin a}{\sin C} - \cos a \cot C$$

or (Anugraha, 2012):

$$\tan B = \frac{\sin C}{\sin a \cot b - \cos a \cos C}$$

Distance to Qibla formula:

$$\sin c = \frac{\sin b}{\sin B} . \sin C \quad \text{and} \quad d = c . R$$

or

$$\cos c = \cos a \cos b + \sin a \sin b \cos C$$

where:

B = Qibla direction of a place, i.e. the angle between the direction to the north pole point and the direction to the Kaaba
a = 90 - φ of the observer; the north polar point minus the latitude of the observer
b = 90 - φ of the Kaaba; the north polar point minus the latitude of the Kaaba
C = λ observer - λ Kaaba|; the absolute price of the difference of two longitudes
c = Distance from a place to the Kaaba
R = The radius of the earth (6371.137 km)
d = Distance from a place to the Kaaba in kilometers

While the direction in the perspective of the ellipsoid-shaped earth model is done using the geodetic calculation method. This method was introduced by Vincenty. The parameters used are defined as follows:

a : length of the major axis of the ellipsoid or radius of the earth at the equator (WGS-84: 6,378,137 meters) (Committee, 1991)
b: length of minor axis of the ellipsoid or radius of the earth at the poles (WGS-84: 6,356,752.3142 meters)
f, flattening = (a - b)/a (WGS-84: 1/298. 257223563)
φ1,φ2 : geodetic latitude coordinates with latitude correction U, defined as
U1 = arctan[(1 - *f*) tanφ1],
U2 = arctan[(1 - *f*) tanφ2]
λ1,λ2: geographic longitude coordinates
L, longitude difference =λ2 -λ1
α1, α2: geodetic azimuth, clockwise from north; forward azimuth and reverse azimuth
α: geodetic azimuth at the equator
s: geodetic distance along the surface of the ellipsoid
The lambda calculation is done iteratively.

- Direct formula (forward direction formula)

It starts by calculating the following:

$$U_1 = \arctan[(1 - f) \tan \phi_1]$$
$$\sigma_1 = \operatorname{arctan2}(\tan U_1, \cos \alpha_1)$$
$$\sin \alpha = \cos U_1 \sin \alpha_1$$
$$u^2 = \cos^2 \alpha \left(\frac{a^2 - b^2}{b^2}\right) = (1 - \sin^2 \alpha) \left(\frac{a^2 - b^2}{b^2}\right)$$
$$A = 1 + \frac{u^2}{16384} \left(4096 + u^2 \left[-768 + u^2 (320 - 175u^2)\right]\right)$$
$$B = \frac{u^2}{1024} \left(256 + u^2 \left[-128 + u^2 \left(74 - 47u^2\right)\right]\right)$$

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Then, using our initial value $\sigma = \frac{s}{bA}$,
Repeat the following equation until there is no significant change in *σ*:

$$2\sigma_m = 2\sigma_1 + \sigma$$

$$\Delta\sigma = B\sin\sigma\left\{\cos(2\sigma_m) + \frac{1}{4}B\left(\cos\sigma\left[-1+2\cos^2(2\sigma_m)\right] - \frac{B}{6}\cos[2\sigma_m]\left[-3+4\sin^2\sigma\right]\left[-3+4\cos^2(2\sigma_m)\right]\right)\right\}$$

$$\sigma = \frac{s}{bA} + \Delta\sigma$$

Once σ is obtained with sufficient accuracy, the evaluation uses:

$$\phi_2 = \operatorname{arctan2}\left(\sin U_1\cos\sigma + \cos U_1\sin\sigma\cos\alpha_1,\ (1-f)\sqrt{\sin^2\alpha + (\sin U_1\sin\sigma - \cos U_1\cos\sigma\cos\alpha_1)^2}\right)$$

$$\lambda = \operatorname{arctan2}(\sin\sigma\sin\alpha_1, \cos U_1\cos\sigma - \sin U_1\sin\sigma\cos\alpha_1)$$

$$C = \frac{f}{16}\cos^2\alpha\left[4 + f\left(4 - 3\cos^2\alpha\right)\right]$$

$$L = \lambda - (1-C)f\sin\alpha\left\{\sigma + C\sin\sigma\left(\cos[2\sigma_m] + C\cos\sigma\left[-1+2\cos^2(2\sigma_m)\right]\right)\right\}$$

$$L_2 = L + L_1$$

$$\alpha_2 = \operatorname{arctan2}(\sin\alpha, -\sin U_1\sin\sigma + \cos U_1\cos\sigma\cos\alpha_1)$$

If the starting point is at the north or south pole, then the first equation cannot be determined. If the starting azimuth is in the east or west, then the second equation cannot be determined. If the standard arctangent atan2 function with 2 arguments is used, then these values are usually handled correctly.

- *Inverse formula* (reverse direction formula)

$\sin\sigma = \sqrt{(\cos U_2 \cdot \sin\lambda)^2 + (\cos U_1 \cdot \sin U_2 - \sin U_1 \cdot \cos U_2 \cdot \cos\lambda)^2}$
$\cos\sigma = \sin U_1 \cdot \sin U_2 + \cos U_1 \cdot \cos U_2 \cdot \cos\lambda$
$\sigma = \operatorname{atan}(\sin\sigma / \cos\sigma)$
$\sin\alpha = \cos U_1 \cdot \cos U_2 \cdot \sin\lambda / \sin\sigma$
$\cos^2\alpha = 1 - \sin^2\alpha$
$\cos 2\sigma_m = \cos\sigma - 2 \cdot \sin U_1 \cdot \sin U_2 / \cos^2\alpha$
$C = f/16 \cdot \cos^2\alpha \cdot [4 + f \cdot (4 - 3 \cdot \cos^2\alpha)]$
$\lambda = L + (1 - C) \cdot f \cdot \sin\alpha \cdot \{\sigma + C \cdot \sin\sigma \cdot [\cos 2\sigma_m + C \cdot \cos\sigma \cdot (-1 + 2 \cdot \cos^2 2\sigma_m)]\}$

When λ has converged to the desired accuracy (10-12 for an accuracy of about 0.06 mm), the other components are given in the formula below:

$u^2 = \cos^2\alpha \cdot (a^2 - b^2)/b^2$
$A = 1 + u^2/16384 \cdot \{4096 + u^2 \cdot [-768 + u^2 \cdot (320 - 175 \cdot u^2)]\}$
$B = u^2/1024 \cdot \{256 + u^2 \cdot [-128 + u^2 \cdot (74 - 47 \cdot u^2)]\}$
$\Delta\sigma = B \cdot \sin\sigma \cdot \{\cos 2\sigma_m + B/4 \cdot [\cos\sigma \cdot (-1 + 2 \cdot \cos^2 2\sigma_m)$
$\quad - B / 6 \cdot \cos 2\sigma_m \cdot (-3 + 4 \cdot \sin^2\sigma) \cdot (-3 + 4 \cdot \cos^2 2\sigma_m)]\}$
$s = b \cdot A \cdot (\sigma - \Delta\sigma)$
$\alpha_1 = \operatorname{atan2}(\cos U_2 \cdot \sin\lambda / \cos U_1 \cdot \sin U_2 - \sin U_1 \cdot \cos U_2 \cdot \cos\lambda)$
$\alpha_2 = \operatorname{atan2}(\cos U_1 \cdot \sin\lambda / -\sin U_1 \cdot \cos U_2 + \cos U_1 \cdot \sin U_2 \cdot \cos\lambda)$

The Rashd al-Qiblah method is a practical approach used to determine the Qibla direction accurately, relying on astronomical observations and mathematical calculations. As the Qibla is an essential component of Islamic worship, its determination requires a precise understanding of geographical, geometrical, and astronomical principles. The Rashd al-Qiblah method has gained prominence due to its integration of traditional and scientific knowledge, making it accessible and reliable for Muslims worldwide (Mahmud, Bahran, Ipansyah, Faridah, & Ruslan, 2023).

Spherical geometry is fundamental in determining the Qibla direction as the Earth is a nearly spherical object. This approach assumes that the Earth's surface can be approximated as a perfect sphere, allowing the use of spherical trigonometry to calculate the shortest path between two points on the Earth's surface—referred to as the great circle distance. This

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geometric model simplifies calculations and has been widely adopted in Qibla determination methods (Sabiq, 2021).

While the spherical model provides practical results, the Earth is not a perfect sphere but an oblate spheroid, slightly flattened at the poles and bulging at the equator. The ellipsoidal approach takes this deviation into account, providing a more accurate representation of the Earth's shape. This model incorporates parameters such as the equatorial and polar radii to refine Qibla calculations, especially over long distances (Putri & Rosyidi, 2024).

The Rashd al-Qiblah method's accuracy depends on the model used. The spherical approach, while simpler, may lead to slight errors due to the Earth's actual shape. Conversely, the ellipsoidal approach, though mathematically more complex, enhances precision by considering the Earth's geodetic characteristics. This comparative analysis is crucial for understanding the trade-offs between simplicity and accuracy in Qibla determination(Munfaridah, 2022).

Geodesy, the science of measuring and understanding the Earth's shape, plays a critical role in Qibla determination. By applying geodetic principles, such as geocentric coordinates and reference ellipsoids, the Rashd al-Qiblah method aligns with modern scientific standards. The use of geodesy ensures that Qibla calculations are both accurate and scientifically robust, meeting the demands of contemporary Islamic practice (Vincenty, 1975b; Wicaksono & others, 2016).

The Rashd al-Qiblah method is also grounded in astronomical principles, particularly the Sun's position during its transit over the Ka'bah. During these moments, Muslims worldwide can verify the Qibla direction by aligning with the Sun's shadow. This celestial event reinforces the Rashd al-Qiblah method's practicality and underscores the interplay between astronomy and Islamic jurisprudence (Khazin, 2004).

Theoretical models for Qibla determination rely heavily on mathematical equations derived from spherical and ellipsoidal geometry. These equations calculate the azimuth angle, which defines the direction of the Qibla from a specific location. The Rashd al-Qiblah method incorporates these calculations to ensure precision, demonstrating the integration of mathematics into religious practice.

The accuracy of the Rashd al-Qiblah method has profound religious significance. Even minor deviations in Qibla direction can affect the validity of prayers. Therefore, this method aims to minimize errors and provide Muslims with confidence in their worship practices. The comparison between spherical and ellipsoidal approaches underscores the commitment to achieving the highest level of accuracy.

In an era of technological advancements, the Rashd al-Qiblah method remains relevant by adapting to modern tools such as GPS and geodetic software. These technologies enhance the precision of Qibla determination, aligning with the theoretical foundations of the method. The integration of traditional and modern approaches reflects the dynamism of Islamic science in addressing contemporary needs(Awalluddin & others, 2018).

The Rashd al-Qiblah method, with its foundations in spherical and ellipsoidal geometry, serves as a robust framework for Qibla determination. By combining geodesy, astronomy, and mathematical precision, this method exemplifies the intersection of science and religion. Its accuracy and adaptability ensure its continued relevance in Islamic practice, offering a comprehensive approach to fulfilling a fundamental aspect of worship (Faid et al., 2022).

In addition to its theoretical foundation, the Rashd al-Qiblah method serves as a practical tool for addressing real-world challenges in Qibla determination. One of the most significant aspects of its application is the reconciliation of traditional Islamic jurisprudence (fiqh) with contemporary scientific methodologies. Historically, Qibla direction was determined using rudimentary tools and local observations, which often led to inconsistencies. However, the integration of spherical and ellipsoidal approaches within the Rashd al-Qiblah method ensures a more unified and precise outcome, aligning with the expectations of modern Islamic communities.

The method's adaptability to various geographic locations further enhances its relevance. By leveraging geodetic data and astronomical principles, the Rashd al-Qiblah method accounts for the curvature of the Earth, the observer's position, and the precise location of the Ka'bah. This adaptability is particularly beneficial for Muslims living in distant regions, where traditional methods may struggle to provide accurate results. The use of ellipsoidal geometry, in particular, reduces errors that can arise from assuming a perfect spherical Earth, thereby offering enhanced reliability for global Qibla determination (Niri, Zaki, & Nor, 2023).

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Moreover, the Rashd al-Qiblah method's reliance on scientific precision does not diminish its spiritual significance. On the contrary, the integration of advanced methodologies into Qibla determination reflects the Islamic tradition of embracing knowledge and innovation. The use of astronomical phenomena, such as the Sun's transit over the Ka'bah, serves as a reminder of the harmony between religion and the natural world, reinforcing the spiritual connection Muslims have with their prayers.

Another critical dimension of the Rashd al-Qiblah method is its role in facilitating consensus among Islamic scholars and practitioners. The ongoing debate between the spherical and ellipsoidal approaches underscores the need for a standardized framework that balances simplicity with accuracy. By analyzing the strengths and limitations of both models, the Rashd al-Qiblah method contributes to a more informed and unified understanding of Qibla determination. This scholarly engagement fosters collaboration and innovation within the field of Islamic science.

The method's practical applications extend to the development of technological solutions, such as Qibla-finding apps and devices. These tools, underpinned by the Rashd al-Qiblah method, provide Muslims with easy access to accurate Qibla directions, enhancing their ability to observe prayers wherever they may be. By embedding spherical and ellipsoidal calculations into user-friendly technologies, the Rashd al-Qiblah method bridges the gap between theoretical knowledge and everyday practice.

Additionally, the method supports educational initiatives aimed at promoting scientific literacy within Muslim communities. By incorporating concepts from geodesy, astronomy, and mathematics into religious education, the Rashd al-Qiblah method encourages a deeper understanding of the principles behind Qibla determination (Munfaridah, 2022). This educational approach empowers Muslims to appreciate the scientific underpinnings of their religious practices, fostering a culture of curiosity and learning.

From a broader perspective, the Rashd al-Qiblah method highlights the interplay between faith and reason in Islamic thought. By emphasizing accuracy and precision, the method exemplifies the Islamic principle of ihsan (excellence), which calls for striving to achieve the best possible outcome in all aspects of life, including acts of worship. This principle is evident in the meticulous calculations and advanced methodologies that underpin the Rashd al-Qiblah approach.

In analyzing the Rashd al-Qiblah method, it is also essential to consider its limitations and areas for further research. While the ellipsoidal approach enhances accuracy, it requires more complex calculations and access to precise geodetic data, which may not always be readily available. Addressing these challenges through advancements in technology and data accessibility can further refine the method and expand its usability.

The Rashd al-Qiblah method represents a dynamic fusion of traditional Islamic knowledge and modern scientific advancements (Hosen & Ghafiruddin, 2018). By bridging the gap between spirituality and technology, it ensures that the Qibla determination process remains relevant and reliable in a rapidly changing world. This integration not only strengthens the spiritual practices of Muslims but also underscores the timeless value of Islamic science in addressing contemporary challenges. The Rashd al-Qiblah method, through its use of spherical and ellipsoidal approaches, demonstrates a commitment to precision, adaptability, and innovation. Its theoretical framework, enriched by geodesy, astronomy, and mathematics, serves as a testament to the enduring relevance of Islamic science in both spiritual and practical domains. As a comprehensive and evolving methodology, the Rashd al-Qiblah method continues to inspire confidence in the observance of prayer while promoting a deeper appreciation of the harmony between faith and reason.

3. Method

This type of research is field research, which is research conducted in the field to explore and obtain data about the accuracy of setting out the Qibla direction of the spherical plane method and ellipsoid with the rashd al-qiblah method (Azhari, 2001). The research location for determining the Qibla direction is in South Kalimantan. While the observation points used for the measurement of rashd al-qiblah are in the area of Syahrazza Muhtadin Banjarbaru Mosque and or UIN Antasari Banjarmasin Campus Mosque.

The equipment used were: GPS receiver, Nikon 102 Theodolite, istiwa stick, and Microsoft Excel software. The data used in this study are data coordinates of the center point of the Kaaba, GPS measurement data of Qibla direction observation points, and measurement of the direction of saar rashd al-qiblah.

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Data collection uses documentation and observation methods. Documentation is done by collecting data and documents related to the problem to be studied, both in the form of written records, calculation results and so on. Observation by observing and taking measurements directly at the observation point (Mahmud et al., 2023).

The coordinates of the Kaaba center used are 21°25' 21.00" N and 39°49' 34.30" E. The calculation of the Qibla direction on the spherical plane is done using the spherical triangle formula and on the ellipsoid plane is done using the Vincenty formula. The outline of the analysis includes, first difference between the results of calculating the Qibla direction in the spherical plane and the ellipsoid plane. In this section, we describe the results of calculating the Qibla direction at the observation point for each reference plane. The results of Qibla direction obtained different values. Second, accuracy of Qibla direction on spherical plane and ellipsoid plane against rashd al-qiblah method

Based on the results of direct observation of the Qibla azimuth in the field during the rashd al-qiblah event, the Qibla azimuth of the observation point will be obtained. The angle of the calculation results based on the spherical plane and the ellipsoid plane is then compared with the angle of Qibla direction observed in the field with the rashd al-qiblah method.

4. Result and Discussion

There are two theoretical approaches that we can use, namely astronomical and geodetic theories.

Table 2: Qibla Azimut of the Spherical Plane Method and Ellipsoid Plane Method

City	Geodetic latitude	Geocentric latitude	Longitude	Qibla Azimut Earth Sphere Method	Qibla Azimut of the Ellipsoid Plane
AMUNTAI	2°25'13,65" S	2°24'15,39" S	115°15'16,91" E	+292°27'05,89"	292°29'20,42"
BANJARBARU	3°27'40,43" S	3°26'17,22" S	114°49'27,95" E	+292°43'29,38"	292°45'29,76"
BANJARMASIN	3°19'08,02" S	3°17'48,21" S	114°35'28,60" E	+292°43'45,61"	292°45'46,98"
BARABAI	2°34'55,70" S	2°33'53,55" S	115°22'57,60" E	+292°28'05,78"	292°30'18,78"
BATULICIN	3°25'23,89" S	3°24'01,58" S	116°00'18,78" E	+292°32'58,49"	292°35'03,19"
KANDANGAN	2°47'11,30" S	2°46'04,25" S	115°16'05,90" E	+292°31'29,23"	292°33'39,34"
KOTABARU	3°14'30,01" S	3°13'12,05" S	116°13'35,40" E	+292°29'08,32"	292°31'16,04"
MARABAHAN	2°59'04,38" S	2°57'52,58" S	114°46'29,48" E	+292°37'58,65"	292°40'04,69"
MARTAPURA	3°24'17,93" S	3°22'56,06" S	114°50'54,44" E	+292°42'35,12"	292°44'36,26"
PARINGIN	2°21'12,86" S	2°20'16,20" S	115°28'05,99" E	+292°24'39,46"	292°26'55,56"
PELAIHARI	3°47'57,85" S	3°46'26,55" S	114°45'51,58" E	+292°48'11,18"	292°50'07,22"
RANTAU	2°55'48,68" S	2°54'38,18" S	115°09'29,20" E	+292°34'08,02"	292°36'16,00"
TANJUNG	2°10'53,20" S	2°10'00,68" S	115°26'22,38" E	+292°22'45,89"	292°25'03,99"

Sources: Modified from Anugraha (2012) and T. D. Jastrzębski (2012), retrieved from https://github.com/tdjastrzebski/Vincenty-Excel (accessed on Nov 3, 2019)

Local rashd *al-qiblah* on May 27, 2020 for Cities/Regencies in South Kalimantan using the theory of spherical trigonometry.

Table 2, The Qibla azimuth calculated using the Spherical Plane Method (Earth Sphere) and the Ellipsoid Plane Method for various cities in South Kalimantan. The table highlights key differences in geodetic and geocentric latitude, with geodetic latitude representing GPS-based positions and geocentric latitude accounting for the Earth's spherical shape. The Qibla azimuth is calculated using two approaches: the Spherical Plane Method, which assumes the Earth as a perfect sphere, and the Ellipsoid Plane Method, which is more accurate as it considers the Earth's slight flattening at the poles.

The comparison shows slight differences between the Qibla azimuth values produced by both methods, with the Ellipsoid Plane Method generally providing more precise results. These differences, though small, can impact the accuracy of Qibla direction in mosque construction and other religious structures. Given its higher precision, the Ellipsoid Plane Method is recommended for determining the Qibla direction accurately. Overall, the study affirms that Qibla calculations based on the ellipsoid model are more geodetically accurate than those relying on the simpler spherical Earth model.

Table 3 presents the local Rashd al-Qiblah time for various cities in South Kalimantan based on the Spherical Plane Method. The table lists the geodetic latitude of each city alongside the specific local time when the Rashd al-Qiblah occurs. This time represents the moment when the Sun's position aligns with the Qibla direction, allowing for a direct verification of the Qibla without additional calculations.

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Table 3. Local Rashd al-Qiblah Based on the Spherical Plane Method

City	Geodetic latitude	Local Rash al-Qiblah
AMUNTAI	2°25'13,65" S	17.20.18,30
BANJARBARU	3°27'40,43" S	17.20.07,67
BANJARMASIN	3°19'08,02" S	17.20.07,77
BARABAI	2°34'55,70" S	17.20.17,40
BATULICIN	3°25'23,89" S	17.20.12,88
KANDANGAN	2°47'11,30" S	17.20.14,99
KOTABARU	3°14'30,01" S	17.20.15,42
MARABAHAN	2°59'04,38" S	17.20.11,09
MARTAPURA	3°24'17,93" S	17.20.08,18
PARINGIN	2°21'12,86" S	17.20.20,06
PELAIHARI	3°47'57,85" S	17.20.05,09
RANTAU	2°55'48,68" S	17.20.13,24
TANJUNG	2°10'53,20" S	17.20.21,67

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

The data shows slight variations in Rashd al-Qiblah times across different locations, influenced by each city's latitude. Cities positioned further south generally experience the event slightly earlier or later compared to those located further north. This method, which assumes a perfectly spherical Earth, provides a practical approach for determining the Qibla direction, although it may have minor inaccuracies compared to the Ellipsoid Plane Method. Despite this, the local Rashd al-Qiblah remains a widely used and accessible reference for verifying the Qibla direction with observational methods.

Table 4 presents the Qibla azimuth values calculated using the Spherical Plane Method without transforming the sample coordinates to a plane. The table includes the geodetic latitude, longitude, and the resulting Qibla azimuth for various cities in South Kalimantan. This method assumes a perfectly spherical Earth and does not account for the ellipsoidal shape, which may introduce minor deviations in Qibla direction calculations.

Table 4. Qibla Azimut of the Spherical Plane Method whose Sample Coordinates are Not Transformed to the Plane

City	Geodetic Latitude	Longitude	Qibla Azimut Earth Sphere Method
AMUNTAI	2°25'13,65" S	115°15'16,91" E	292°35'15,19"
BANJARBARU	3°27'40,43" S	114°49'27,95" E	292°51'42,41"
BANJARMASIN	3°19'08,02" S	114°35'28,60" E	292°51'58,86"
BARABAI	2°34'55,70" S	115°22'57,60" E	292°36'15,24"
BATULICIN	3°25'23,89" S	116°00'18,78" E	292°41'08,58"
KANDANGAN	2°47'11,30" S	115°16'05,90" E	292°39'39,49"
KOTABARU	3°14'30,01" S	116°13'35,40" E	292°37'17,51"
MARABAHAN	2°59'04,38" S	114°46'29,48" E	292°46'10,58"
MARTAPURA	3°24'17,93" S	114°50'54,44" E	292°50'47,95"
PARINGIN	2°21'12,86" S	115°28'05,99" E	292°32'48,11"
PELAIHARI	3°47'57,85" S	114°45'51,58" E	292°56'25,16"
RANTAU	2°55'48,68" S	115°09'29,20" E	292°42'18,91"
TANJUNG	2°10'53,20" S	115°26'22,38" E	292°30'54,11"

Sources: Modified from Anugraha (2012)

The results show variations in Qibla azimuth across different locations, influenced by each city's geographical position. Cities with greater longitudinal differences tend to exhibit slight shifts in their azimuth values. Although the Spherical Plane Method provides a straightforward approach to determining the Qibla direction, its accuracy may be slightly lower compared to methods that consider the Earth's ellipsoidal shape. These differences highlight the importance of choosing an appropriate calculation model, especially for applications requiring high precision in Qibla direction alignment.

Table 5 compares the Qibla azimuth values obtained using the Spherical Plane Method (with geodetic latitude) and the Ellipsoid Plane Method for various cities in South Kalimantan. The table highlights the differences in Qibla azimuth between the two methods, showing that the Ellipsoid Plane Method generally produces slightly lower azimuth values than the Spherical Plane Method. The differences range from approximately 5'50" to 6'18", indicating that the assumption of a perfectly spherical Earth leads to minor inaccuracies when determining the Qibla direction.

These discrepancies arise because the Ellipsoid Plane Method accounts for the Earth's actual shape, which is slightly flattened at the poles rather than a perfect sphere. While the differences may seem small, they can be significant when applied to mosque alignment and

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other religious structures requiring precise Qibla direction. The results suggest that the Ellipsoid Plane Method provides a more accurate representation of Qibla direction, making it a preferred approach for applications demanding higher precision.

Table 5. Comparison of Qibla Azimut of the Spherical Plane Method whose Sample Coordinates are Not Transformed to the Spherical Plane and the Ellipsoid Plane Method

City	Qibla Azimut of the Spherical Earth Method with Geodetic Latitude	Qibla Azimut of the Ellipsoid Plane	Qibla Azimut Difference
AMUNTAI	292°35'15,19"	292°29'20,42"	0°05'54,76"
BANJARBARU	292°51'42,41"	292°45'29,76"	0°06'12,65"
BANJARMASIN	292°51'58,86"	292°45'46,98"	0°06'11,88"
BARABAI	292°36'15,24"	292°30'18,78"	0°05'56,46"
BATULICIN	292°41'08,58"	292°35'03,19"	0°06'05,40"
KANDANGAN	292°39'39,49"	292°33'39,34"	0°06'00,15"
KOTABARU	292°37'17,51"	292°31'16,04"	0°06'01,47"
MARABAHAN	292°46'10,58"	292°40'04,69"	0°06'05,90"
MARTAPURA	292°50'47,95"	292°44'36,26"	0°06'11,69"
PARINGIN	292°32'48,11"	292°26'55,56"	0°05'52,55"
PELAIHARI	292°56'25,16"	292°50'07,22"	0°06'17,94"
RANTAU	292°42'18,91"	292°36'16,00"	0°06'02,91"
TANJUNG	292°30'54,11"	292°25'03,99"	0°05'50,12"

Sources: Modified from Anugraha (2012) and T. D. Jastrzębski (2012), retrieved from https://github.com/tdjastrzebski/Vincenty-Excel (accessed on Nov 3, 2019)

From this research, it is known that the *rashd al-qiblah* method in spherical trigonometry theory uses geocentric latitude and geocentric declination data. Geocentric latitude is latitude data taken with the assumption of the earth as a sphere. The latitude data taken from GPS is geodetic data, so it must first be converted into geocentric latitude. While the declination data in the Ephemeris table, from the observations made it is known that the data is geodetic data. The *rashd al-qiblah* method in Vincenty's theory uses geodetic latitude and declination data. The data is inputted in the Qibla direction formula and *rashd al-qiblah* ellipsoid plane method. In the calculation of *raşd al-qiblah* method can be determined also based on the spherical plane method with the ellipsoid plane method. The calculation of *raşd al-qiblah* is generated from the calculation of the qibla azimuth of the two methods.

4.1. Global *rashd al-qiblah*

The global *rashd al-qiblah* for 2020 is obtained by taking into account the Sun's declination values throughout the year that have values equal to or close to the latitude of the Kaaba. The declination values that are close to the latitude of the Kaaba are May 26-28, 2020 and July 15-17, 2020.

After these dates are known, the time when the Sun transits the coordinates of Kaaba is calculated based on local time. The transit time is then converted into Indonesian time (WIB/WITA/WIT).

Table 6. Estimates of Global Rashd al-Qiblah in 2020

Date	Sun Transit at Kaaba (UT+3)	Declination (d)	Difference d-p	Description
26/05/2020	12.17.48	+21°14'00,18"	-0°11'20',82'	Sun South of the Zenith of the Kaaba
27/05/2020	12.17.55	+21°23'58,85"	-0°01'22',15'	Sun South of the Zenith of the Kaaba
28/05/2020	12.18.02	+21°33'35,28"	+0°08'14',28'	Sun North of the Zenith of the Kaaba
15/07/2020	12.26.44	+21°25'01,26"	-0°00'19',74'	Sun South of the Zenith of the Kaaba
16/07/2020	12.26.49	+21°15'08,77"	-0°10'12',23'	Sun South of the Zenith of the Kaaba

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

The table above shows that the declination of the sun at the time of transit in Makkah is not at the zenith of the Kaaba, but sometimes it is inclined to the north and sometimes to the south of the Kaaba on its journey. The position of the sun is not at the latitude (p) of the Kaaba which is at 21°25'21.00" N. However, it can be taken that the Sun is closest to the zenith, which has the smallest d-p difference, namely May 27 and July 17, 2020.

The following is a comparison of the time of global *Raşd al-qiblah* based on the two methods for calculations on May 27 and July 15, 2020 for the coordinates of the Syahrazza Muhtadin Mosque Banjarbaru which has a geodetic latitude of 3°27'1.2''S, a geocentric latitude of 3°25'38.25'' S and a longitude of 114°46'44.95'' E place.

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Table 7. Global Rashd al-Qiblah at Syahrazza Muhtadin Mosque Banjarbaru

Date	Method	Global Rashd al-Qiblah (WITA)	Qibla Azimut	Azimut Sun	Difference Qibla-Sun Azimut	Distance Difference (m)
27/05/2020	Metode Bumi Bola	17.17.55	292°43'45,19"	292°50'16,89"	-0°06'31,69"	8.729,36
	Metode Vincenty	17.17.55	292°45'45,56"	292°50'34,08"	-0°04'48,51"	8.685,68
15/07/2020	Metode Bumi Bola	17.26.44	292°43'45,19"	292°51'20,68"	-0°07'35,49"	10.639,41
	Metode Vincenty	17.26.44	292°45'45,56"	292°51'37,87"	-0°05'52,30"	10.605,93

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

From the results of the comparison, it is known that the azimuth of the Sun at the time of global *rashd al-qiblah* does not coincide with the qibla azimuth for the coordinates of the Syahrazza Muhtadin Mosque in Banjarbaru. This can be seen from the difference in azimuth that varies. On May 27, 2020, the smallest difference was 4'48.51" arc for the ellipsoid plane method, while the spherical plane method gave a difference of 6'31.69" arc. Furthermore, on July 15, 2020, the smallest difference was 5'52.30" arc for the Ellipsoid Plane Method. While the Spherical Plane Method gave a difference of 7'35.49" arc.

Based on the analysis using the distance formula, if the Qibla azimuth is taken from the Sun azimuth value, the difference in distance in meters will be produced. On 27 May 2020, the spherical plane method produced a difference in Qibla direction distance that was greater than it should have been by 8,729.36 meters. While on July 15, 2020, the spherical plane method also produced a difference in Qibla direction distance that was greater than it should be as far as 10,639.41 meters.

Thus the determination of Qibla direction based on global *raşd al-qiblah* time shows that the ellipsoid plane method is still better than the spherical plane method.

The inaccuracy of the measurement results of the Qibla azimuth direction between the spherical plane method and the ellipsoid plane method here is more due to the transit position of the Sun which is not exactly at the zenith of Ka'bah so that the value of the Sun's azimuth in a city does not coincide with the Qibla azimuth.

The position of the Sun on May 27, 2020 is not exactly at the zenith of Kaaba but is tilted south by 1'22.15" arc. Similarly, on July 15, 2020, the Sun tilted south by 19.74" arc from the zenith. Because on these two dates the Sun was not found to be at the zenith of the Kaaba, the Sun's azimuth from the global *raşd al-qiblah* time is also not accurate in producing the Qibla direction.

For measurements at the coordinate location of the Syahrazza Muhtadin Mosque in Banjarbaru on May 27 and July 15, 2020, it could not be done because the weather was cloudy and the Sun was covered by clouds.

4.2. Local *Rashd al-qiblah*

The time of local *rashd al-qiblah* based on the two methods for calculations on May 27, 2020 for cities/districts in South Kalimantan is indeed different. This difference is due to the calculation of *rashd al-qiblah* refers to local coordinates.

Table 8. Comparison of Local Rashd al-Qiblah Spherical Plane Method and Ellipsoid Plane Method

City	Rasdh al-Qiblah by Spherical Plane Method (WITA)	Rasdh al-Qiblah with Ellipsoid Plane Method (WITA)	Difference
AMUNTAI	17.21.25,34	17.20.18,30	0.01.07,04
BANJARBARU	17.20.56,55	17.20.07,67	0.00.48,88
BANJARMASIN	17.20.57,46	17.20.07,77	0.00.49,68
BARABAI	17.21.22,42	17.20.17,40	0.01.05,02
BATULICIN	17.21.08,06	17.20.12,88	0.00.55,18
KANDANGAN	17.21.15,93	17.20.14,99	0.01.00,95
KOTABARU	17.21.14,55	17.20.15,42	0.00.59,13
MARABAHAN	17.21.06,33	17.20.11,09	0.00.55,24
MARTAPURA	17.20.57,91	17.20.08,18	0.00.49,73
PARINGIN	17.21.29,68	17.20.20,06	0.01.09,62
PELAIHARI	17.20.49,45	17.20.05,09	0.00.44,36
RANTAU	17.21.11,32	17.20.13,24	0.00.58,08
TANJUNG	17.21.34,34	17.20.21,67	0.01.12,67

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

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Table 8 shows the local *rashd al-qiblah* time on May 27, 2020 calculated based on the Spherical Plane Method and the Ellipsoid Plane Method. The *rashd al-qiblah* time between the Spherical Plane Method and the Ellipsoid Plane Method in each city/district varies greatly. The time difference ranges from 44.36 seconds to 1 minute 12.67 seconds.

Although the time difference is only in seconds and minutes, it is the change in the Sun's azimuth in such a short time that is of concern. The change in the Sun's azimuth as it approaches the meridian pass is faster. The movement within 1 second already produces a significant azimuthal angle let alone up to 1 minute. Therefore, this should be taken into consideration when measuring the Qibla direction.

The following is a comparison of the calculation results using the spherical plane method and the ellipsoid plane method on May 27 and July 16, 2020 for the coordinates of the Syahrazza Muhtadin Banjarbaru Mosque which has a geodetic latitude of 3°27'1.2"S, a geocentric latitude of 3°25'38.25''S and a longitude of 114°46'44.95''T.

Table 9: Local Rashd al-Qiblah at Syahrazza Muhtadin Mosque Banjarbaru

Date	Method	Global Rashd al-Qiblah (WITA)	Qibla Azimut	Azimut of the Sun	Difference Qibla-Sun Azimut	Distance Difference (m)
15/07/2020	Metode Bumi Bola	17.20.57	292°43'45,19"	292°43'45,20"	8.601.039,15	3.178,79
	Metode Vincenty	17.20.08	292°45'45,56"	292°45'45,56"	8.604.217,93	-
15/07/2020	Metode Bumi Bola	17.25.44	292°43'45,19"	292°43'45,19"	8.601.039,15	3.178,79
	Metode Vincenty	17.24.59	292°45'45,56"	292°45'45,56"	8.604.217,93	

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

To prove the accuracy of the local *rashd al-qiblah* of these two methods, it can be done by determining the distance of the observation coordinates to the coordinates of the Kaaba based on the azimuth of the Sun which is the same as the azimuth of the Qibla. This determination uses the help of the distance formula and Vincenty Direct Calculation which can be accessed on the page https://geographiclib.sourceforge.io/scripts/geod-google.html

From the comparison, it is known that the azimuth of the Sun obtained from the time of *rashd al-qiblah* based on spherical plane method has a difference of 3,178.79 m from the point of Kaaba. The direction point of the Sun's azimuth is at coordinates 21°23'30.0" N and 39°50'33.1" E with an Azimut of 278°44'30.4" in the southeast direction of Makkah City. While the ellipsoid plane method results in a distance difference of 0 m and the direction point of the Sun's azimuth is right at the coordinates of Ka'bah, namely 21°25'21.0" N and 39°49'34.3 " E with an azimuth of 278°45'49.4".

Furthermore, the comparison of measurement results using the spherical plane method and the ellipsoid plane method on November 14 and 15, 2020 for the coordinates of the Abdurrahman Ismail Mosque Banjarmasin which has a geodetic latitude of 3°19'55.11''S, a geocentric latitude of 3°18'34.99''S and a longitude of 114°37'04.81''E.

Table 10: Local Rashd al-Qiblah at Abdurrahman Ismail Mosque Banjarmasin

Date	Method	Global Rashd al-Qiblah (WITA)	Qibla Azimut	Sun Azimut	Difference Qibla-Sun Azimut	Distance Difference (m)
15/07/2020	Earth Ball Method	09.12.01	292°43'41,45"	292°43'41,45"	8.579.507,52	3.133,39
	Vincenty Method	09.12.41	292°45'42,75"	292°45'42,75"	8.582.640,91	-
15/07/2020	Spherical Earth Method	09.07.50	292°43'41,45"	292°43'41,45"	8.579.507,52	3.133,39
	Vincenty method	09.08.31	292°45'42,75"	292°45'42,75"	8.582.640,91	

Sources: Modified from NOAA Solar Calculations Day.xls, retrieved from https://gml.noaa.gov/grad/solcalc/calcdetails.html (accessed on Jan 5, 2020)

Table 10 presents the Local Rashd al-Qiblah calculations for Abdurrahman Ismail Mosque in Banjarmasin on November 14 and 15, 2020, using both the Spherical Plane Method (Earth Sphere) and the Ellipsoid Plane Method (Vincenty Method). The table displays the local Rashd al-Qiblah time in WITA (Central Indonesian Time), the calculated Qibla azimuth, the Sun's azimuth at that moment, the distance to the Kaaba, and the difference in distance.

The results show that the Spherical Plane Method produced a Qibla azimuth of 292°43'41.45'' on both dates, with a corresponding Sun azimuth that matched. However, this method resulted in a distance discrepancy of 3,133.39 meters from the actual Qibla direction. In contrast, the Ellipsoid Plane Method produced a slightly adjusted Qibla azimuth of 292°45'42.75'', aligning with the Sun's azimuth and eliminating the distance discrepancy.

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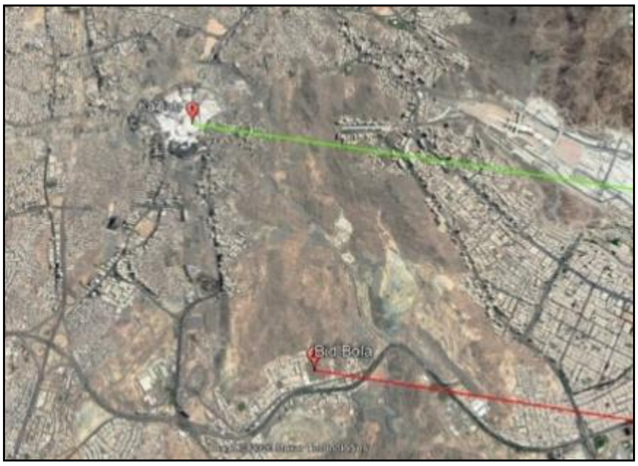
Additionally, the local Rashd al-Qiblah time for the Ellipsoid Plane Method was slightly later than that of the Spherical Plane Method. These findings reaffirm that the Ellipsoid Plane Method provides a more accurate Qibla direction than the Spherical Plane Method. The improved precision is particularly relevant for mosque alignment and other religious practices requiring exact Qibla orientation.

The results of the comparison show that the azimuth of the Sun obtained from the time of *rashd al-qiblah* based on the spherical plane method has a difference of 3,133.39 m from the point of Kaaba. Producing an angle difference of 2'01.30'' or 0.02 cm at a distance of 4.13 meters. The direction point of the Sun's azimuth is at coordinates 21°23'29.0" N and 039°50'32.6" E with an azimuth of 278°41'41.4" in the southeast of Makkah City. Meanwhile, the ellipsoid plane method still produces a distance difference of 0 m and the direction point of the Sun's azimuth is exactly at the coordinates of Kaaba, namely 21°25'21.0" N and 39°49'34.3" E with an azimuth of 278°42'58.6".

Picture 1. The local Rashd al-qiblah result point of the spherical plane method



Sources: Adapted from www.google.com/maps (2020)

5. Conclussion

This research shows that there is a difference in Qibla direction between the spherical plane method and the ellipsoid plane method for the South Kalimantan region. The difference ranges from 1'56.04" to 2'18.10". However, if the sample coordinates are not transformed to the spherical plane, the difference in Qibla direction between the spherical plane method and the ellipsoid plane method is greater, ranging from 5'50.14" to 6'17.95".

The use of global *rashd al-qiblah*, which occurred on May 27 and July 15, 2020, as a reference for determining the Qibla direction shows less accurate results for both the spherical and ellipsoid plane methods. However, the ellipsoid plane method shows a smaller difference than the spherical plane method. At the coordinates of Syahrazz Muhtadin Mosque in Banjarbaru, the ellipsoid plane method produces a difference of 4'48.51" and 5'52.30" arc (equivalent to a distance of 8,685.68 meters and 10,605.93 meters to the southeast of the Kaaba). Meanwhile, the spherical plane method produces a difference of 6'31.69" and 7'35.49" arc (equivalent to a distance of 8,729.36 meters and 10,639.41 meters southeast of the Kaaba).

In contrast, using the local *rashd al-qiblah* as a reference shows more accurate results than the global rashd al-qiblah. In this case, the ellipsoid plane method again shows a smaller difference than the spherical plane method. At the coordinates of the Abdurrahman Ismail Mosque in Banjarmasin, local rashd al-qiblah observations made on November 14 and 15, 2020 with the ellipsoid plane method show the shadow azimuth (opposite the Sun's azimuth) which coincides with the qibla azimuth. While the spherical plane method produces a difference of 2'01.30" arc (or equivalent to a distance of 3,133 meters to the southeast of the Kaaba).

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