The Analysis and Implementation of Haversine Formulas in Determining Qibla Direction by using Sphiral Trigonometry in Indonesia

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Abstract: Muslims are fully obliged to pray five times a day. In carrying out this obligation, facing qibla is a one of the requirements of a valid prayer. However, there are no specific provisions set out in the Qur'an or Hadith which explicitly governs the direction of qibla for each inhabited area. The purpose of this research is to compile and obtain derivations of the haversine formula for calculating the qibla direction which is applied from the locations of Jakarta, Surabaya, and Makassar. The results show that by descending definitions of haversine, rules of cosine in spherical triangles, addition and multiplication rules on trigonometry and the circumference of the spherical triangle, the qibla direction formula from a location at point B is $Hav\ B = \frac{\sin(s-c)\sin(s-a)}{\sin a \sin c}$. B is the coordinate point of the calculated location, c is side length c, a is side length a, and s is the circumference of the spherical triangle. Results of the implementation of qibla direction for the three cities of Jakarta, Surabaya, and Makassar were $65°42'31.27''$,$65°29'10.89''$,and$66°51'53.67''$, respectively.

1 INTRODUCTION

Mathematics is understood to be an abstract and theoretical science. Most people consider it as only containing formulas and is far away and not intersecting with the reality of life. On the other hand, mathematics is the basis of science development (basic of science) and is known as the mother of science because of its various uses. Mathematics also has an important role in worship, as in the case of prayer.

An example of the application of mathematics that relates to prayer is the determination of prayer times and the direction for qibla. Muslims are obliged to pray five times a day. When carrying out this obligation, facing qibla is required as a legal requirement of prayer. In the al-Qur'an, the verses relating to qibla are repeated four times, one being *QS. Al-Baqarah* (2) verse144.

Based on this verse (*QS. Al- Baqarah verse 114*), Muslims only obtain a general provision to perform prayers and that everyone must face qibla. However, no specific provisions are arranged in the al-Qur'an or Hadith that explicitly regulates the direction of qibla for each inhabited area. Therefore, a certain method is needed to determine the direction of qibla as referred in the al-Qur'an.

Muftis and Muslim scholars have conducted particular research related to the determination of the qibla direction as the prayer direction of Muslims in Indonesia. Research was carried out by the Indonesian Mufti Council (known as MUI), the results of the formulation and its provisions was formulated as a fatwa (instructions for Muslims). Precisely in 2010, a fatwa was conveyed to the public stating that the location of qibla was east of Makkah, which is located west of Indonesia. The provisions that were originally expected to facilitate, enlighten, and unite understanding of the people immediately was changed based on facts in the field that the formula caused a number of new problems. Some Muslim communities considered the MUI's fatwa on the determination of qibla direction had ruled out the development of modern technology and science. This was due to the scope of the territory of Indonesia which is very broad, so the determination of the direction of qibla cannot only be based on one particular location. As a response to this matter, MUI made a fatwa revision for the direction of qibla for Muslims in Indonesia, which previously was explained as to only face westward, which was subsequently changed to northwest with varying positions based on the location of each region.

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The determination of the direction of qibla basically discusses the calculation of the direction of two points, from one particular location to the Kabah. Therefore, a certain method was needed to help determine the direction of qibla that was scientifically correct and not just from estimation as had previously been done. A scientific method in mathematics that can be used to help determine the direction of qibla is trigonometry. Trigonometry is a branch of mathematics that studies triangles and its constituent components, including the sides and angles of a triangle.

There have been several studies related to the determination of qibla direction, including by Solikin (2013) who conducted research by using four methods: the sinus cosine formula, auxiliary angle, analoginapier and haversine. The results of the study explained the comparison between the four methods and concluded that the haversine method resulted in more accurate results in the form of coordinate numbers. Another study by Miswanto (2015) discussed the implementation of determining qibla direction by using the haversine method. In these studies, more emphasis was placed on the implementation aspects of the calculation for determination of qibla direction from the formula provided by Miswanto.

Based on the background of the problem above, this paper discusses the application of mathematics in sphiral trigonometry and coordinate systems in determining the direction of qibla in Indonesia, which aims to understand how the process of calculating the direction of qibla is founded.

2 LITERATURE REVIEW

2.1 Qibla Direction

Qibla direction can be determined from any point or place on the surface of the earth by performing calculations and measurements. Therefore, the calculation of qibla direction is basically calculating which direction the Kabah in Mecca is seen from a location on the surface on the earth. All movements of people who are praying - whether during standing, bowing, or prostrating – will always coincide to the direction of the Kabah.

2.2 Sphiral Trigonometry

Ball geometry is also called sphiral trigonometry. The basic principles and concepts of ball geometry that exist can be applied to solve problems such as difficulties in calculating and determining the direction of qibla that applies the rules of spherical triangles.

The rules of the spherical triangle are explained from non-euclid geometry. Non-euclid geometry is one of two specific geometries that is obtained by eliminating the Euclidean parallel postulates, namely the hyperbolic and elliptic geometries. For historical reasons, this term has a much narrower meaning in mathematics that is does in general English. There are many geometries that do not include Euclidean geometry, but only two are referred as non-Euclidean geometries.

The view that appears on the surface of the sky and the earth is in the shape of a ball. Because the earth is predicted to have a round shape, a triangle can be obtained on the surface of the ball.

The haversine formula is defined as follows: (Solikin, 2013)

$$Hav\,\beta = \frac{1}{2}(1 - \cos b) \qquad (1)$$

3 RESEARCH METHOD

3.1 Data

The coordinate data points of the cities in Indonesia that implemented the haversine formula were taken from the Der Gehele Aarde Atlas by PR. JF boss. Niermeyer, JB. Wolters - Groningen. In this paper, the coordinate data points of Jakarta, Surabaya and Makassar were taken as a sample to calculate the qibla direction.

3.2 Data Analysis

Data analysis was carried out by describing various mathematics concepts in order to obtain the formula for determining the direction of qibla, which was then applied to calculate the direction of the qibla in large cities. The steps undertaken to achieve the goal of the research is explained in the following flowcharts in Figure 1:

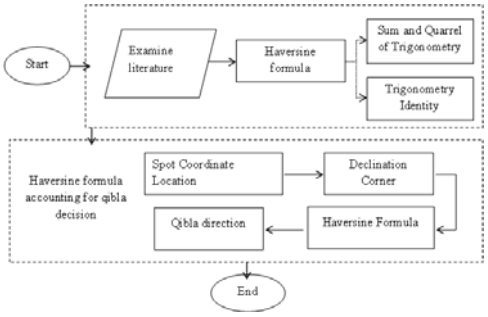

Figure 1: Research flowchart.

Two main processes were carried out in this research to analyze data and obtain results in calculations. The first process was data collection by reviewing appropriate research literature such as books, articles, journals, and previous studies. The second process was calculation of the haversine formula to determine the direction of qibla.

4 RESULTS DAN DISCUSSION

4.1 Analysis of the *Haversine* Formula

Haversine is denoted by "Hav" and is defined by

$$Hav\ \beta = \frac{1}{2}(1 - \cos b) \quad (1)$$

Figure 1 shows that β is the angle formed from the sides of a and c, while the side located in front of point B has a length b. Based on this definition, the following was obtained:

$$\cos b = 1 - 2hav\ \beta \quad (2)$$

By observing Figure 1, the size of $\beta = b$ and B is the point with the angleβ, hence it can be written as:

$$\cos B = 1 - 2hav\ B \quad (3)$$

Based on the equation of sine and cosine in spherical trigonometry, the $cos\,\beta = cos\,a\,cos\,c + sin\,a\,sin\,c\,cos\,B$ equation was obtained, so Equation (4) was obtained by observing the preceding equations.

$$1 - 2\ hav\ \beta = \cos a \cos c + \sin a \sin c - \sin a \sin c\ hav\ \beta \quad (4)$$

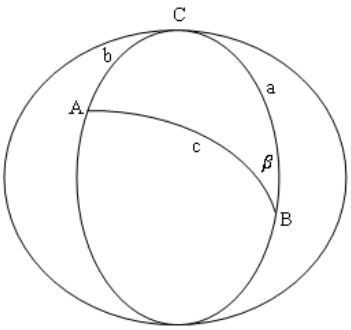

Figure 2: Spot coordinate location.

Because of the $\cos\beta = \cos a \cos c + \sin a \sin c \cos B$ then

$$1 - 2\ hav\ \beta = \cos(a - c) - 2 \sin a \sin c\ \ hav\ B \quad (5)$$

Based on Equation (4), Equation (5) becomes:

$$1 - 2\ hav\ \beta = \cos(a - c) - 2 \sin a \sin c\ \ hav\ B$$

$$hav\ \beta = hav\ (a - c) + \sin a \sin c\ \ hav\ B \quad (6)$$

The calculation of the qibla direction in a place at point B is explained in Figure 3, as follows:

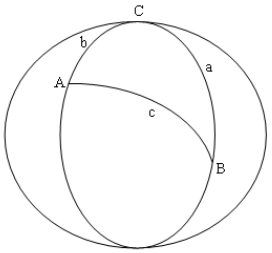

Figure 3: Quantification of location city.

There are three points in Figure 3, namely$A$, B, and C.A, B, and C each representing the location of the Kabah, the location where the direction of qibla will be measured, and the pole of the earth. The Kabah and the location to be measured in this case are at a certain latitude (ϕ) and longitude (λ), denoted by $\phi_A, \phi_B, \lambda_A$, dan λ_B

On the ABC spherical triangle in Figure 3, the corresponding sides appear as a, b, and c. The length of each side of the ball triangle, based on mathematical calculations can be determined by the formula:

$$a = 90° - \phi_B$$
$$b = 90° - \phi_A$$

The value of C is the longitude difference between two locations. In Indonesia the value of C is mathematically written as the difference in longitude with the longitude of the Kabah, which is:

$$C = \lambda_B . - \lambda_A$$

The value of C depends on the position of the place to be measured, as follows (Hambali, 2015). It is noted that the value of $hav\ \beta = (\frac{(1-cos\ b)}{2})$is obtained as:

$$\sin a \sin c\ \ hav\ B = -\frac{1}{2}(\cos b - \cos(a - c)) \quad (7)$$

Equation (7) supposes that $b = \alpha$ and $(a - c) = \beta$, Equation (7) can then be written $sin\,a\ \ sin\,c\ \ hav\ B = \frac{-1(cos\,\alpha - cos\,\beta)}{2}$.

Furthermore, trigonometry is defined in the sum formula by multiplying that $cos\,\alpha - cos\,\beta = -2\ sin\ \frac{(\alpha+\beta)}{2}\ sin\ \frac{(\alpha-\beta)}{2}$ then Equation (7) can be written as:

$$\sin a \sin c\ \ hav\ B = sin\frac{1}{2}(\alpha + \beta) sin\frac{1}{2}(\alpha - \beta)) \quad (8)$$

Furthermore, as previously stated, $b = \alpha$ and $(a - c) = \beta$, it was obtained:

$$\sin a \sin c \ hav\, B = sin\tfrac{1}{2}(a + b - c) sin\tfrac{1}{2}(b + c - a) \quad (9)$$

By observing s, where s is the circumference of the triangle value $s = \frac{(a+b+c)}{2}$, then the value $2s = a + b + c$, so that it is obtained:

$$a + b - c = 2s - 2c = 2(s - c) \quad (10)$$
$$b + c - a = 2s - 2a = 2(s - a) \quad (11)$$

With the example of the s value, the equation (11) becomes$sin\, a\, sin\, c\, hav\, B = sin\,(s - c)\, sin\,(s - a)$. Then we have,

$$hav\, B = \frac{sin(s-c)sin(s-a)}{\sin a \sin c} \quad (12)$$

The last equation is the equation used as the calculation of the qibla direction in a place at point B.

4.2 Implementation of the *Haversine* Formula

The results of accounting of qibla direction from the three cities were: Jakarta $65°42'31.27''$, Surabaya $65°29'10.89''$, dan Makassar $66°51'53.67''$.

The qibla direction was compared to the results of determination calculated by Sriyatin Shadiq Al-Falaky, which has been copied by the Rukyat Reckoning Education and Training in East Java. The two methods have slightly different results because the two differs in determining the starting point of the coordinates of each location by only a few degrees.

5 CONCLUSIONS

Based on the discussion, the conclusion to the calculation of the qibla direction from a place at point B was the use of the equation $Hav\, B = \frac{(sin\,(s-c)\, sin\,(s-a))}{\sin a \sin c}$. Steps were carried out by deriving from the definition, the cosine rules on spherical triangles, addition and multiplication in trigonometry and circumference of the spherical triangle.

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