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Qibla Direction in Various Coordinates in Indonesia using Spherical Trigonometry

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ABSTRACT

Qibla is very important for Muslims. Because facing the Qibla is one of the requirements for performing prayers. As Indonesia is placed far from the Kaaba, the Qibla direction can be determined by spherical trigonometry equations. This article presents the qibla direction of various coordinates in Indonesia by spherical trigonometry. The Qibla direction in Indonesia can be a guide in determining the Qibla direction. The direction is calculated using spherical trigonometry. For the results, to point directly to the Kaaba, the true north direction is very necessary. The true north can be determined using various instruments such as theodolite, gnomon, or mizwala. The qibla azimuth direction in Indonesia was ranged from 289.54° (East Indonesia) to 301.05° (West Indonesia).

I. Introduction

Qibla is something very important for Muslims. It is because the Qibla is one of the requirements for performing prayers. If the prayer being performed does not face the Qibla, then the prayer is categorized as invalid or invalid. Qibla is the direction that every Muslim faces when carrying out worship, especially prayer [1]. Qibla can also mean the Kaaba because Muslims face it when praying [2]. The Kaaba is a building approaching a cube shape located in the center of the city of Mecca [3]. For Muslims in the city of Mecca and its surroundings, the order to face the Qibla is easy to do. However, for Muslims who are far from the city of Mecca, facing the Qibla will be difficult. This can cause problems for Muslims who live in areas far from the city of Mecca [4].

The Kaaba is around 8 thousand to 13 thousand kilometres from Indonesia. If the direction of the Qibla is deviated by one degree, it can cause a very long diversion [2]. Many mosques in Indonesia do not have the Qibla direction towards the Kaaba. It can be caused by two possibilities. The first possibility is that you incorrectly determined the direction of the

Qibla when you first built the mosque. The second possibility is natural factors, namely the movement of the Earth's plates [5]. The methods often used to determine the Qibla direction in Indonesia are determining the west direction as the Qibla direction, aligning it with the road layout, and measuring roughly based on the direction of the Qibla from the nearest mosque [6]. These methods have low accuracy so many mosques do not have the Qibla direction directly towards the Kaaba. The development of determining the Qibla direction can be seen from the measuring instruments and calculation systems used. Currently, there are three types of methods often used to measure the direction of the Qibla, namely using the shadow of the Qibla, using geographic north (true north), and observing when the Sun is directly above the Kaaba [7]. The phenomenon of the Sun directly above the Kaaba occurs because the position of the Sun is always moving from north to south or is known as the apparent annual movement of the Sun [8].

As a place that is quite far from the Kaaba, the direction of the Qibla in Indonesia can be determined using spherical trigonometry mathematical equations. Calculating the Qibla using spherical trigonometry requires three points on the Earth's sphere, namely the point at the North Pole, at the Kaaba, and in the area where you want to find the direction of the Qibla [1]. The direction from one place to another on the earth's surface is shown by the shortest circular arc that connects the two places. Two types of circular arcs can connect two places on the surface of a ball, namely large circles and small circles. The arc with the shortest distance is the arc that passes through the great circle of the Earth's surface [9]. The great circle is the circle of the earth's globe that divides the earth into two equal parts and uses the center of the earth as a reference [10].

II. Method

For example, X is the place that needed to find the Qibla direction which has geographic coordinates, namely latitude (ϕ_X) and longitude (λ_X). The Kaaba has geographic coordinates, namely the latitude of the Kaaba (ϕ_K) and the longitude of the Kaaba (λ_K), and the North Pole is written with C. A spherical triangle can be depicted by connecting the city of X, the Kaaba, and the North Pole on the Earth's surface. The spherical triangle formed is KXC with sides CK, CX, and KX being large circular arcs as seen in Figure 1. To find out the Qibla direction of city X, determine the size of angle X. Angle X can be determined using the spherical triangle formula.

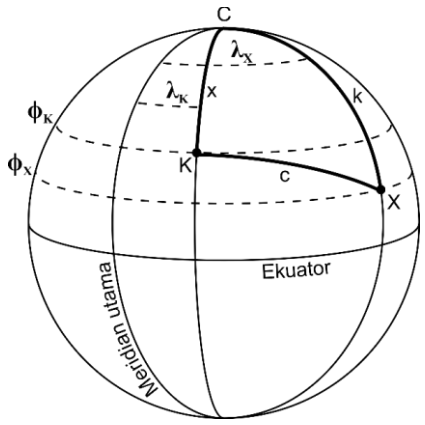

Figure 1. Spherical triangle connecting the X, the Kaaba, and the North Pole

Angle X can be determined by the cosine formula of a spherical triangle.

$$\cos x = \cos c \cos k + \sin c \sin k \cos X$$

$$\cos X = \frac{\cos x - \cos c \cos k}{\sin c \sin k} \quad (1)$$

From equation 1, cosine c and sine c do not yet have values. Then cosine of c substituted by the cosine formula.

$$\cos c = \cos k \cos x + \sin k \sin x \cos C \quad (2)$$

Next, substitute equation 2 with equation 1.

$$\cos X = \frac{\cos x - (\cos k \cos x + \sin k \sin x \cos C)\cos k}{\sin c \sin k}$$

$$\cos X = \frac{\cos x - \cos^2 k \cos x - \sin k \sin x \cos k \cos C}{\sin c \sin k}$$

$$\cos X = \frac{\cos x(1 - \cos^2 k) - \sin k \sin x \cos k \cos C}{\sin c \sin k} \quad (3)$$

From trigonometric identities,

$\sin^2 k + \cos^2 k = 1$, then there is:

$$1 - \cos^2 k = \sin^2 k \quad (4)$$

Then, substitute equation 4 into equation 3, thus obtaining the following equation.

$$\cos X = \frac{\cos x \sin^2 k - \sin k \sin x \cos k \cos C}{\sin c \sin k} \quad (5)$$

Next, substitute sin c using the formula for the sine of a spherical triangle.

$$\frac{\sin c}{\sin C} = \frac{\sin x}{\sin X}$$

$$\sin c = \frac{\sin x \sin C}{\sin X} \quad (6)$$

Then substitute equation 6 into equation 5.

$$\cos X = \frac{\cos x \sin^2 k - \sin k \sin x \cos k \cos C}{\left(\frac{\sin x \sin C}{\sin X}\right) \sin k}$$

$$\cos X = \frac{\cos x \sin^2 k - \sin k \sin x \cos k \cos C}{\frac{\sin x \sin C \sin k}{\sin X}}$$

$$\cos X = \frac{\cos x \sin^2 k - \sin k \sin x \cos k \cos C}{\sin x \sin C \sin k} \sin X$$

$$\frac{\sin X}{\cos X} = \frac{\sin x \sin C \sin k}{\cos x \sin^2 k - \sin k \sin x \cos k \cos C} \quad (7)$$

From trigonometric identities,

$$\tan X = \frac{\sin X}{\cos X} \quad (8)$$

So, equation 7 can be changed to the following equation.

$$\tan X = \frac{\sin k (\sin x \sin C)}{\sin k (\cos x \sin k - \sin x \cos k \cos C)}$$

$$\tan X = \frac{\sin x \sin C}{\cos x \sin k - \sin x \cos k \cos C} \quad (9)$$

From trigonometric identities,

$$\cot x = \frac{\cos x}{\sin x}$$

$$\cos x = \sin x \cot x \quad (10)$$

Next, substitute equation 10 with equation 9.

$$tan\, X = \frac{sin\, x\, sin\, C}{(sin\, x\, cot\, x)\, sin\, k - sin\, x\, cos\, k\, cos\, C} = \frac{sin\, x\, sin\, C}{sin\, x (cot\, x\, sin\, k - cos\, k\, cos\, C)}$$

$$\tan X = \frac{\sin C}{\cot x \sin k - \cos k \cos C} \quad (11)$$

The data from Figure 1 is as follows.

$$k = CX = 90° - \phi_X;\ x = CK = 90° - \phi_K;\ C = \lambda_K - \lambda_X = \Delta\lambda$$

Equation 11 can be changed using trigonometric ratios for related angles to become the following equation.

$$\tan X = \frac{\sin \Delta\lambda}{\cot(90° - \phi_K)\sin(90° - \phi_X) - \cos(90° - \phi_X)\cos\Delta\lambda}$$

$$\tan X = \frac{\sin \Delta\lambda}{\tan\phi_K \cos\phi_X - \sin\phi_X \cos\Delta\lambda}$$

$$\tan X = \frac{\sin \Delta\lambda}{\tan\phi_K \cos\phi_X - \sin\phi_X \cos\Delta\lambda} \quad (12)$$

Where X is the qibla angle of the city you want to find, $\Delta\lambda$ is the difference between the longitude of X and Kaaba, ϕ_K is the latitude of Kaaba, and ϕ_X is the latitude of X. when compass were used to determine the Qibla direction, the Qibla azimuth is the angle calculated from the north point clockwise through the horizon to the projection of the Kaaba. Azimuths 90°, 180°, and 270° indicate east, south, and west directions respectively. The value of X here depends on the denominator and numerator of the right side of the formula tan X. For simplicity, tan X can be written as $\frac{y}{x}$. Therefore, the appropriate angle X value also depends on whether the x and y values are positive or negative. In Ms. Excel, X can be specified with the format atan2 (x;y) [11].

- If x is positive and y is positive, then $AK_X = X$.
- If x is negative and y is positive, then $AK_X = 180° + X$.
- If x is negative and y is negative, then $AK_X = 180° + X$.
- If x is positive and y is negative, then $AK_X = 360° + X$.

III. Results and Discussion

Indonesia has geographic coordinates of 6° N – 11° S and 95° E – 141° E as shown in figure 2. And since Indonesia is Wide, there are three Time Zone that separate the zone. The time zone was needed to know the local time or converted time for determining the sun's ephemeris data when some tools were used.

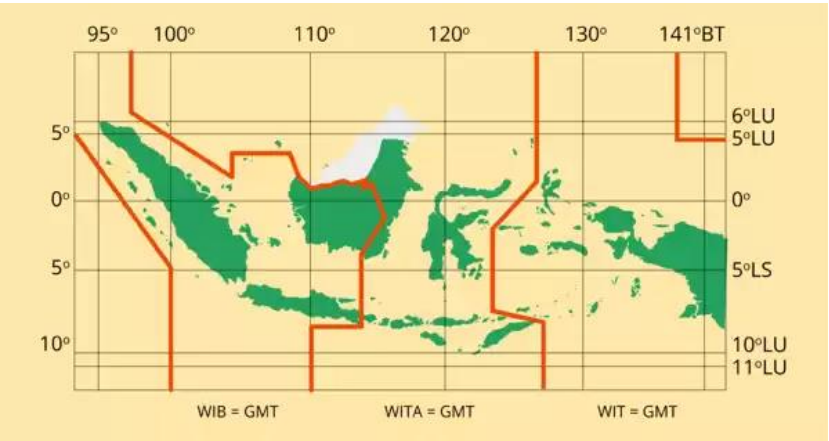

Figure 2. Indonesia Geographic Coordinate and Time zone

The Kaaba has geographic coordinates of 21° 25' 24" N and 39° 49' 39" E. The direction of the Qibla is represented in the numbers on a compass scale with a guide of zero degrees at the North point. Therefore, there are a need to know the true direction of the North. The direction shown by the compass is the direction that refers to magnetic north. It turns out that the direction of magnetic north does not have to be the same as true north. This difference in the north direction is called the magnetic obliquity angle or declination which is also different in each place and always changes throughout the year [1]. True north can be determined by knowing the position of the Sun.

The position of the Sun can be calculated using various instruments, such as a theodolite, gnomon, or mizwala [2]. In determining the Qibla, there are deviation tolerance standards, namely mathematical tolerance, and sociological tolerance. Mathematical tolerance is the limit of tolerance for deviation from the Qibla direction resulting from the construction of a mathematical formula. Sociological tolerance is the limit of tolerance for deviation from the direction of the Qibla which is built based on social construction in producing the direction of the Qibla [12]. The calculated Qibla azimuth for various coordinate in Indonesia using equation (12) can be seen in Tables 1, 2, 3, and 4.

Table 1. Azimuth of regional Qibla in Indonesia from 95° – 106° E

Latitude (°)	Longitude (°)											
	95	96	97	98	99	100	101	102	103	104	105	106
-11	301.05	300.60	300.18	299.76	299.35	298.96	298.57	298.20	297.84	297.49	297.14	296.81
-10	300.61	300.18	299.76	299.36	298.97	298.59	298.22	297.86	297.51	297.17	296.84	296.52
-9	300.15	299.74	299.34	298.95	298.57	298.21	297.85	297.51	297.18	296.85	296.54	296.23
-8	299.69	299.29	298.91	298.53	298.17	297.82	297.48	297.15	296.83	296.52	296.22	295.93
-7	299.21	298.83	298.46	298.10	297.75	297.42	297.09	296.78	296.48	296.18	295.90	295.62
-6	298.73	298.36	298.00	297.66	297.33	297.01	296.70	296.40	296.11	295.83	295.56	295.30
-5	298.23	297.88	297.54	297.21	296.89	296.59	296.30	296.01	295.74	295.47	295.22	294.97
-4	297.71	297.38	297.06	296.75	296.45	296.16	295.88	295.61	295.36	295.11	294.87	294.64
-3	297.19	296.87	296.57	296.27	295.99	295.72	295.46	295.21	294.96	294.73	294.51	294.30
-2	296.66	296.35	296.07	295.79	295.52	295.27	295.02	294.79	294.56	294.35	294.14	293.94
-1	296.11	295.82	295.55	295.29	295.04	294.81	294.58	294.36	294.15	293.95	293.77	293.58
0	295.55	295.28	295.03	294.79	294.56	294.34	294.13	293.93	293.73	293.55	293.38	293.22
1	294.97	294.73	294.49	294.27	294.06	293.85	293.66	293.48	293.31	293.14	292.99	292.84
2	294.39	294.16	293.95	293.74	293.55	293.36	293.19	293.02	292.87	292.72	292.58	292.45
3	293.79	293.59	293.39	293.20	293.03	292.86	292.71	292.56	292.42	292.29	292.17	292.06
4	293.18	293.00	292.82	292.65	292.50	292.35	292.21	292.09	291.97	291.85	291.75	291.66
5	292.56	292.40	292.24	292.09	291.96	291.83	291.71	291.60	291.50	291.41	291.32	291.25
6	291.93	291.79	291.65	291.52	291.41	291.30	291.20	291.11	291.03	290.95	290.89	290.83

Table 2. Regional Qibla azimuth in Indonesia from 107° – 118° E

Latitude (°)	Longitude (°)											
	107	108	109	110	111	112	113	114	115	116	117	118
-11	296.48	296.17	295.86	295.56	295.27	294.98	294.71	294.44	294.18	293.92	293.68	293.43
-10	296.21	295.91	295.62	295.33	295.05	294.78	294.52	294.27	294.02	293.78	293.55	293.32
-9	295.93	295.65	295.37	295.10	294.83	294.58	294.33	294.09	293.86	293.63	293.42	293.20
-8	295.65	295.37	295.11	294.85	294.61	294.37	294.13	293.91	293.69	293.48	293.28	293.08
-7	295.35	295.09	294.85	294.60	294.37	294.15	293.93	293.72	293.51	293.32	293.13	292.95
-6	295.05	294.81	294.57	294.35	294.13	293.92	293.71	293.52	293.33	293.15	292.98	292.81
-5	294.74	294.51	294.29	294.08	293.88	293.68	293.50	293.31	293.14	292.98	292.82	292.67
-4	294.42	294.21	294.00	293.81	293.62	293.44	293.27	293.10	292.95	292.79	292.65	292.51
-3	294.09	293.90	293.71	293.53	293.36	293.19	293.03	292.88	292.74	292.61	292.48	292.36
-2	293.76	293.58	293.40	293.24	293.08	292.93	292.79	292.66	292.53	292.41	292.30	292.19
-1	293.41	293.25	293.09	292.94	292.80	292.67	292.54	292.43	292.31	292.21	292.11	292.02
0	293.06	292.91	292.77	292.64	292.52	292.40	292.29	292.19	292.09	292.00	291.92	291.84
1	292.70	292.57	292.44	292.33	292.22	292.12	292.03	291.94	291.86	291.79	291.72	291.66
2	292.33	292.22	292.11	292.01	291.92	291.83	291.76	291.69	291.62	291.57	291.51	291.47
3	291.95	291.86	291.77	291.68	291.61	291.54	291.48	291.43	291.38	291.34	291.30	291.27
4	291.57	291.49	291.42	291.35	291.29	291.24	291.20	291.16	291.13	291.10	291.08	291.07
5	291.18	291.11	291.06	291.01	290.97	290.93	290.91	290.88	290.87	290.86	290.86	290.86
6	290.78	290.73	290.69	290.66	290.64	290.62	290.61	290.60	290.61	290.61	290.63	290.65

Table 3. Azimuth of regional Qibla in Indonesia from 119° – 130° E

Latitude (°)	Longitude (°)											
	119	120	121	122	123	124	125	126	127	128	129	130
-11	293.20	292.97	292.75	292.54	292.33	292.13	291.93	291.74	291.56	291.38	291.20	291.04
-10	293.10	292.89	292.68	292.48	292.29	292.10	291.92	291.75	291.58	291.41	291.25	291.10
-9	293.00	292.80	292.61	292.42	292.25	292.07	291.91	291.75	291.59	291.44	291.30	291.16
-8	292.89	292.71	292.53	292.36	292.19	292.04	291.88	291.74	291.60	291.46	291.34	291.21
-7	292.77	292.60	292.44	292.29	292.14	291.99	291.86	291.73	291.60	291.48	291.37	291.26
-6	292.65	292.50	292.35	292.21	292.07	291.94	291.82	291.71	291.60	291.49	291.39	291.30
-5	292.52	292.38	292.25	292.12	292.00	291.89	291.78	291.68	291.59	291.50	291.41	291.34
-4	292.38	292.26	292.14	292.03	291.93	291.83	291.74	291.65	291.57	291.50	291.43	291.37
-3	292.24	292.13	292.03	291.93	291.85	291.76	291.68	291.61	291.55	291.49	291.44	291.39
-2	292.09	292.00	291.91	291.83	291.76	291.69	291.63	291.57	291.52	291.48	291.44	291.41
-1	291.94	291.86	291.79	291.72	291.66	291.61	291.56	291.52	291.49	291.46	291.43	291.42
0	291.78	291.71	291.66	291.61	291.56	291.52	291.49	291.47	291.45	291.43	291.43	291.42
1	291.61	291.56	291.52	291.48	291.46	291.43	291.42	291.41	291.40	291.40	291.41	291.42
2	291.43	291.40	291.38	291.36	291.34	291.34	291.33	291.34	291.35	291.37	291.39	291.42
3	291.25	291.24	291.23	291.22	291.22	291.23	291.25	291.27	291.29	291.32	291.36	291.40
4	291.06	291.06	291.07	291.08	291.10	291.12	291.15	291.19	291.23	291.27	291.33	291.39
5	290.87	290.89	290.91	290.93	290.97	291.01	291.05	291.10	291.16	291.22	291.29	291.36
6	290.67	290.70	290.74	290.78	290.83	290.89	290.95	291.01	291.08	291.16	291.24	291.33

Table 4. Azimuth of regional Qibla in Indonesia from 131° – 141° E

Latitude (°)	Longitude (°)										
	131	132	133	134	135	136	137	138	139	140	141
-11	290.87	290.72	290.56	290.42	290.28	290.14	290.01	289.89	289.76	289.65	289.54
-10	290.95	290.81	290.67	290.54	290.42	290.30	290.18	290.07	289.97	289.87	289.78
-9	291.03	290.90	290.78	290.66	290.55	290.45	290.35	290.26	290.17	290.08	290.01
-8	291.10	290.98	290.88	290.78	290.68	290.59	290.51	290.43	290.36	290.29	290.23
-7	291.16	291.06	290.97	290.89	290.81	290.73	290.66	290.60	290.55	290.50	290.45
-6	291.21	291.13	291.06	290.99	290.92	290.87	290.81	290.77	290.73	290.69	290.66
-5	291.26	291.20	291.14	291.08	291.04	290.99	290.96	290.92	290.90	290.88	290.87
-4	291.31	291.26	291.21	291.17	291.14	291.11	291.09	291.08	291.07	291.06	291.07
-3	291.35	291.31	291.28	291.26	291.24	291.23	291.22	291.22	291.23	291.24	291.26
-2	291.38	291.36	291.34	291.34	291.33	291.34	291.35	291.36	291.38	291.41	291.44
-1	291.41	291.40	291.40	291.41	291.42	291.44	291.46	291.50	291.53	291.58	291.62
0	291.43	291.44	291.45	291.47	291.50	291.54	291.58	291.62	291.67	291.73	291.80
1	291.44	291.47	291.50	291.53	291.58	291.63	291.68	291.74	291.81	291.89	291.97
2	291.45	291.49	291.54	291.59	291.65	291.71	291.78	291.86	291.94	292.03	292.13
3	291.45	291.51	291.57	291.64	291.71	291.79	291.88	291.97	292.07	292.17	292.28
4	291.45	291.52	291.60	291.68	291.77	291.86	291.96	292.07	292.18	292.30	292.43
5	291.44	291.53	291.62	291.72	291.82	291.93	292.04	292.17	292.29	292.43	292.57
6	291.43	291.53	291.63	291.75	291.86	291.99	292.12	292.26	292.40	292.55	292.70

From the tables 1,2,3 and 4 above, the qibla azimuth direction for Indonesia ranged from 289.54° from East Indonesia to 301.05° in West Indonesia. This table can help whoever wanted to know their qibla direction in correspondent coordinate so they can make sure whether the prayer facility is correct facing the qibla direction or not.

IV. Conclusion

The Qibla direction of various coordinates in Indonesia can be a guide in determining the Qibla direction. The direction is calculated using spherical trigonometry. For the results to point directly to the Kaaba, the north direction is very necessary. The true north can be determined using various instruments such as theodolite, gnomon, or mizwala. The qibla azimuth direction for Indonesia ranged from 289.54° from East Indonesia to 301.05° in West Indonesia.

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