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The Qibla Direction Problem in Large-Scale Maps and Its Representation with Geodetic Accuracy: The Case of Türkiye

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Abstract

In Islamic societies, knowing the direction of the Qibla is important in the planning of religious areas. In urban plans designed by practitioners where the Qibla direction is not considered, inconsistencies arise among religious areas. These inconsistencies reduce the project areas within the structures and cause loss of space. To address these inconsistencies, plan revisions are required. However, plan revisions extend the construction periods of projects and increase the projected costs. Adding the Qibla direction as a legend to large-scale maps (LSMs) used as base maps in the drawing of urban plans is an option that can be used to eliminate these inconsistencies. In this study, the Qibla direction for all LSMs in Türkiye's national mapping was calculated with geodetic accuracy to eliminate the mentioned inconsistencies. These calculations and the generated visual outputs are presented to users through the Map Qibla Direction Calculation Interface (MQDCI) developed in the MATLAB environment. When any coordinate data or the name of the relevant LSM is entered as input into the developed interface, the Qibla direction value for that map is provided to the user in this study. The developed interface allows the Qibla direction angle to be calculated and presented to the user with geodetic accuracy and instantly, without the need for measurements and calculations performed in the field. Although the developed interface is designed according to the Kaaba, which is the Qibla for Muslims, and Türkiye's geographical boundaries, it is also suitable for other religions in Türkiye or different religions in other countries. For this, it is sufficient to know the national mapping systems of the countries and the geographical coordinates of the Qibla in Christianity and Judaism.

1. Introduction

In Muslim countries, it is important to know the direction of the Qibla for worship practices to be conducted according to religious rules in places such as worship areas (social infrastructure areas), slaughterhouses (municipal service areas), cemetery areas (municipal service areas), and buildings for residential and tourism purposes (working areas) [1-5]. In mosques, facing the Qibla, avoiding positioning beds in residential and tourism facilities so that feet do not point towards the Qibla, ensuring toilets are not oriented towards the Qibla, orienting the deceased's face towards the Qibla in cemeteries, and performing halal slaughtering by turning animals towards the Qibla are important aspects in Islam. All these mentioned structures/areas are social amenities and are shown in master and implementation development plans. In Türkiye, master development plans are drawn on 1/10000 scale maps, and implementation development plans are drawn on 1/1000 scale maps. According to the Large-Scale Map and Map Information Production Regulation (LSMMIPR) valid in Türkiye, the Qibla direction is not marked on development plans, so social amenities cannot be planned according to the Qibla direction. Consequently, the construction and architectural projects for buildings to be constructed on social amenities planned without considering the Qibla direction face the problem of Qibla orientation (Figure 1).

The master development plan is prepared to show urban, social, and technical infrastructure areas and transportation systems. It serves as a reference for the preparation of implementation development plans. If available, it is prepared on approved current maps at a scale of 1/5000 or 1/10000, with the cadastral status included. It is created as a whole with plan notes and a detailed report.

The implementation development plan, on the other hand, is prepared as a whole with plan notes and a detailed report on approved current maps at a scale of 1/1000, with the cadastral status included, in accordance with the principles and basics of the master development plan and includes decisions related to construction and implementation [6]. Although these plans hold an important place for the development and progress of the city, the prolongation of the planning processes negatively affects the residents of the city. Therefore, during the preparation of these plans, it is important to include the Qibla direction as a legend for social amenities where the above-mentioned religious rules are necessary, as per the LSMMIPR regulation.

If the plans are not drawn according to the Qibla direction, there will be area losses in the blocks or parcels designated for social amenities where religious rules are necessary. Consequently, the planned area cannot be fully utilized (Figure 1).

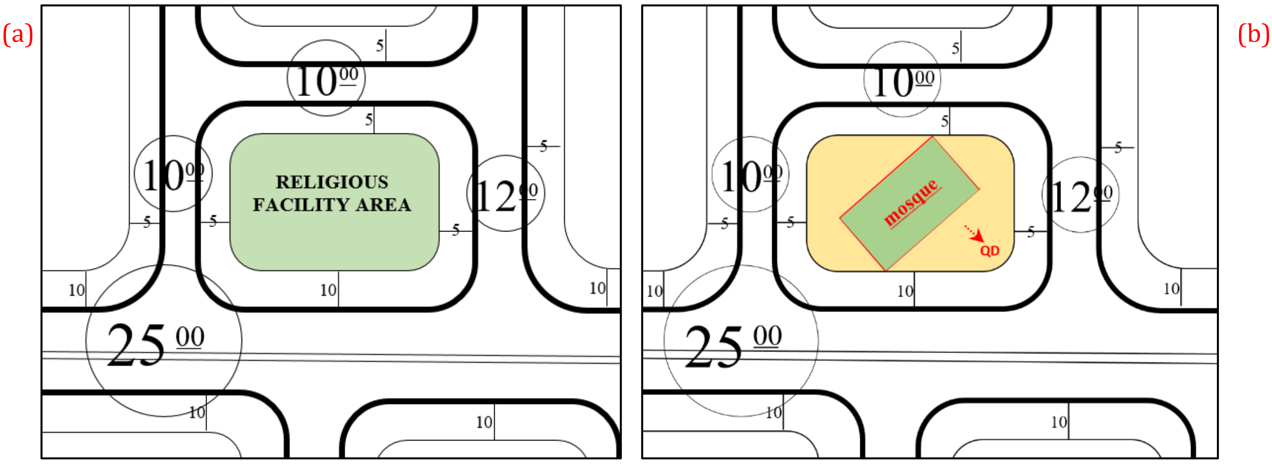

Figure 1. (a) Planned religious facility area, (b) mosque construction area planned according to the qibla direction (QD)

As seen in Figure 1a, the religious facility area is planned according to setback distances (5, 10 m). However, since the Qibla direction is not considered, the area of the mosque built in the religious facility area is reduced by the yellow area as shown in Figure 1b. This situation is valid for all planned areas where the Qibla direction is necessary, and plan changes are made to prevent these area losses. Plan changes are made by altering setback distances or the shape of the zoning block. In the Large-Scale Map and Map Information Production Regulation (LSMMIPR) applied during the drawing of 1/5000 and 1/1000 scale zoning plans prepared in Türkiye to date, the Qibla direction is not specified. Research conducted in Türkiye shows that plan changes are made in nearly 20% of zoning plans where the Qibla direction is not included. Due to this problem, a change was made by the Ministry of Environment, Urbanization and Climate Change with the Regulation on Amendments to the Spatial Plans Production Regulation. The provision "In zoning plan decisions regarding worship areas, criteria such as the Qibla direction required for worship and area size are taken into consideration" was added as Article 8 in June 2024 [6]. However, how this regulation should be implemented has not been presented theoretically.

Taking into account modern technology and scientific capabilities, calculating the Qibla direction with geodetic precision and displaying it on scaled maps is an important issue that should be emphasized. It is possible to find the Qibla azimuth direction on an ellipsoid or sphere with the help of compasses found in widely used smartphone applications today. However, users must consider that these compasses may deviate from the true direction due to the magnetic field in the environment where they are used, and that the north indicated by these compasses is magnetic north. Therefore, necessary corrections must be made by determining the difference between magnetic north and geographic north (magnetic declination). Additionally, the amount of correction required varies with time and location. The magnetic declination at any location today may differ from what it was years ago. According to data published by the National Geophysical Data Center in 2020, the magnetic declination in Türkiye varies between 5° and 7°. Magnetic declination changes with both geographic location and time. For example, it varies between 0° and 2° for the United Kingdom, and between -20° and +20° for the United States. Therefore, Qibla direction applications on smartphones lack geodetic precision. Especially in detailed and acquisition applications involving 1/1000 scale maps, smartphone applications are quite inadequate for achieving cm-level accuracy.

Today, there are also many churches and synagogues belonging to non-Islamic religions that are open for worship. The Qibla direction is important in these religious structures as well. Churches are places of worship for Christians, and synagogues are places of worship for Jews. For Christians, the sacred direction in churches is east, where the sun rises, while for Jews, the Qibla direction is the line connecting the current location to the Temple of Solomon in Jerusalem, which is approximately similar to the Qibla direction for Muslims

[7]. Therefore, determining the Qibla direction and marking it on development plans is an important issue not only for Muslims but also for other religions.

National and international scientific studies regarding problems arising from the absence of the Qibla direction in development plans are summarized below.

There are many studies showing that development plans are inadequate in religious social amenity areas. The first of these is the study by [8], which found that 18 mosques in Mumbai, India, are not aligned with the existing road routes, leading to the mosque buildings appearing disturbingly skewed. It was concluded that this problem arose from not considering the Qibla direction in the development plan. A similar study by [9] was conducted using examples from the social and physical environments of Muslims in North Africa, the Middle East, Europe, and Central Asia. The study explained how urban life could be created with social and environmental variables within the scope of modernization, offering suggestions for city planning, architecture, housing, and environmental planning stages. [10] investigated the spatial distribution of places of worship in the rapidly urbanizing city of Kumasi in Ghana and its impact on sustainable land use planning. [11] presented some recommendations to prevent violations of religious and belief freedom in development plans in the city of Manizales, Colombia. [12] noted that most cities in Iraq serve as religious centers, and development plans are crucial for the sustainability of these cities. [13] found that the geometric shapes of mosques in the city of Yazd, Iran, were built in different architectural styles due to the lack of consideration of the Qibla direction in development plans.

Scientific studies have also been conducted on the arrangement of cemetery areas according to the Qibla direction in development plans. [14] investigated the differences in orientation between the old and new graves in Kefar Saba Cemetery. [15] designed a GPS-based device to eliminate the problems Muslims face when they want to bury a deceased person due to cemetery areas not being planned according to the Qibla direction. [16] analyzed the planning stages and legal regulations in the creation and expansion of municipal cemeteries. [17] stated that the Qibla direction is valid for all religions in cemetery areas and examined the differences in the Qibla directions of old and new cemetery areas in the city of Bengkulu, Indonesia. They concluded that cemetery areas should be planned scientifically.

There are also scientific studies on designing development plans for regions with facilities and hotels within the scope of halal tourism and Islamic medical tourism, taking into account the Qibla direction. [18] emphasized that the accommodation facilities in the cities of Türkiye's Eastern Black Sea Region should be arranged considering the religious sensitivity of Muslim tourists from Arab and Middle Eastern countries. It was noted that considering the Qibla direction in the planning stages of these accommodation places is very important. [19] examined hotels in countries where Islamic tourism is successful. It was emphasized that one of the factors contributing to the success of these hotels in providing good service to Muslim guests is the consideration of the Qibla direction in their planning. [20] researched the aspects that should be considered in the planning of hotels in Antalya, Türkiye, which receives the highest number of tourists.

[21] conducted the first study evaluating hospitals offering Islamic medical tourism services to Muslim tourists, highlighting the need to establish an international Islamic accreditation organization. [22] emphasized in their study the necessity of designing development plans for hospital-designated parcels in Türkiye with the religious sensitivities of Muslim tourists in mind.

When looking at the studies conducted, the importance of considering the Qibla direction in the design phase of development plans for urban areas, religious facility areas, cemetery areas, halal slaughter, halal tourism, and hospital areas for Islamic medical tourism is emphasized. However, incorporating the Qibla direction with geodetic precision into development plans is an application not addressed in the scientific studies conducted. Additionally, it is necessary to distinguish the calculation of the Qibla direction on maps from the Qibla azimuth calculated on an ellipsoid or sphere surface. To date, all calculations have focused on verifying the Qibla azimuth directions of existing mosques. The calculation technique applied in current scientific studies is based on azimuth calculations with geographic coordinates or geocentric three-dimensional coordinates on an ellipsoid or sphere. The purpose of this study is to calculate the Qibla direction on a plane as per the LSMMIPR.

The original contribution of this study is to establish how the Qibla direction should be calculated in the national scale Basic Large-Scale Map (LSM), which serves as a basis for drawing development plans with geodetic precision. The calculation of the Qibla direction is a geodetic calculation method, and only this study provides detailed guidance on how it should be calculated with geodetic precision. Previous studies have focused on calculating the Qibla azimuth on an ellipsoidal surface for verifying the Qibla directions of mosques, but the method for calculating the Qibla direction for LSM has not been established until now. Within this scope, the Qibla directions for all LSM within the geographical boundaries of Türkiye have been calculated and presented to users through a designed interface. This developed interface is designed according to the Qibla direction towards the Kaaba, which is the Qibla for Muslims. However, this interface can easily be adapted not only for other religions in Türkiye but also for countries with different religions outside of Türkiye. For this purpose, it is sufficient to know the geographic coordinates of the Qibla in Christianity and Judaism using the country's national mapping system.

The developed interface provides the Qibla direction belonging to LSM with geodetic precision to users instantly, without any additional computational burden or the need for different geodetic measuring instruments. This interface has been developed to be easily and quickly usable on mobile phones, tablets, laptops, and desktop computers. It was designed using the GUI (Graphical User Interface) in MATLAB 2024a software.

2. Method

2.1. Qibla direction calculation method

Firstly, in the planning and design stages of religious facilities, cemeteries, slaughterhouses, and residential areas on 1:1000 and 1:5000 scale maps, it is necessary to calculate the Qibla azimuth. The Qibla azimuth calculation is a process of determining the azimuth angle on three-dimensional surfaces (sphere or ellipsoid) using a standard Geodetic Basic Problem (Figure 2). To calculate this azimuth value, geographic coordinates are required. In the calculation of the Qibla azimuth, ellipsoidal geodetic basic problem solutions are used, as they are more accurate compared to other traditional and spherical solutions [23-25]

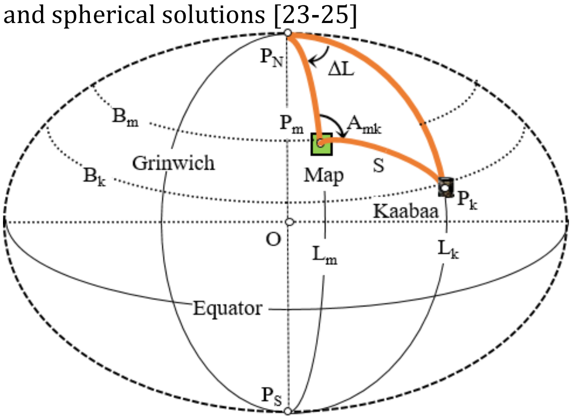

Figure 2. Calculation of qibla azimuth on an ellipsoidal surface

Various methods have been developed for solving geodetic fundamental problems, and the Vincenty method [26] has been used in this study due to its algorithmic clarity, programmability, and applicability for large distances (S > 1000 km) [27]. As alternatives, two other methods [28-29] can also be recommended to users.

In Figure 2, the geographic coordinates of the corner points of the polar triangle, P_N (pole point), P_m (center of the sheet), and P_k (Kaaba), are given by solving the second geodetic fundamental problem (GFP 2) with the ellipsoid azimuth A_{mk} (1).

$$A_{ij} = \arctan((\cos\beta_j \sin\Delta L_{ij})/(\cos\beta_i \sin\beta_j - \sin\beta_i \cos\beta_j \cos\Delta L_{ij}))$$
$$\Delta L_{ij} = L_j - L_i\ , \quad \beta = \arctan(\sqrt{1-e^2}\tan B),\ i = m,\ \ j = k \tag{1}$$

Here, β represents the reduced latitude, e^2 denotes the first eccentricity of the ellipsoid, and ΔL is obtained through iterative steps using equations numbered 2.

$$\Delta\lambda_{(t)} = \Delta L_{ij}\ , \quad t = 0,1,2,3,.....$$
$$\sigma_{ij} = \arcsin\left(\sqrt{(\cos\beta_j \sin\Delta\lambda_{(t)})^2 + (\cos\beta_i \sin\beta_j - \sin\beta_i \cos\beta_j \cos\Delta\lambda_{(t)})^2}\right)$$
$$\alpha_{ij} = \arcsin(\cos\beta_i \cos\beta_j \sin\Delta\lambda_{(t)} / \sin\sigma_{ij}) \tag{2}$$
$$\gamma_{ij} = \cos\sigma_{ij} - (2\sin\beta_i \sin\beta_j / \cos\alpha_{ij}^2)$$
$$c_k = (f/16)\cos\alpha_{ij}^2\left[4 + f(4 - 3\cos\alpha_{ij}^2)\right]$$
$$\Delta\lambda_{(t+1)} = \Delta L_{ij} + (1-c_k)\, f \sin\alpha_{ij}^2\ \left\{\sigma_{ij} + c_k \sin\sigma_{ij}\left[\gamma_{ij} + c_k \cos\sigma_{ij}\left(-1 + 2\gamma_{ij}^2\right)\right]\right\}$$

The iteration process continues until the difference between the current and the previous values, with an initial value of $\Delta\lambda_{(0)} = \Delta L_{ij}$, is within 10^{-12} radians. The Qibla azimuth calculated using equation 1 is on the three-dimensional surface of the ellipsoid. Therefore, it needs to be converted to the two-dimensional Qibla direction seen on maps.

There are two different options for calculating the Qibla direction on a map. One option involves computing it separately from the coordinates of each of the four corners of the map, while the other calculates it from the coordinates of the map's center of gravity (P_m). Choosing the center of gravity for calculating the Qibla direction is more practical as it involves defining only one point on the map. However, this choice should be tested to determine if there is any loss of accuracy in the Qibla direction calculation compared to using the coordinates of the map's corner points. In this context, the aim is to calculate the Qibla direction valid for the entire map. Maps scaled between 1:1000 and 1:10000 are referred to as large-scale maps. The maps used in planning and project design are typically at scales of 1:1000 and 1:5000.

The map sheets are produced in dimensions of 70 cm (width) x 90 cm (height). These dimensions correspond to 700 m x 900 m in the field for a 1:1000 scale map, and 3.5 km x 4.5 km for a 1:5000 scale map. The difference between the map corner points and the map's center of gravity in calculating the Qibla direction is 350 m for a 1:1000 scale map, and 1750 m for a 1:5000 scale map. The impact of this difference on the Qibla direction is provided in Table 1.

Table 1. The impact of selecting the map center of gravity (P_m) over map corners on calculating the qibla direction in Türkiye

1:5000 (1.5'x1.5') scale maps								
P_1 (fixed)		West corner (P_b)	Middle corner (P_o)	East corner (P_d)	Differences			
		$B_b=B_1$ $L_b=L_1$	$B_o=B_1$ $L_o=L_1+45''$	$B_d=B_1$ $L_d=L+1.5'$				
B_1	L_1	A_{1k}	A_{ok}	A_{dk}	$A_{ok}-A_{1k}$ (°)	$A_{dk}-A_{ok}$ (°)	$A_{ok}-A_{1k}$ (')	$A_{dk}-A_{ok}$ (')
42°	26°	146.17065124°	146.19673626°	146.22283107°	0.02608503°	0.02609480°	1.56510163'	1.56568815'
36°	36°	166.00677836°	166.05106795°	166.09537098°	0.04428959°	0.04430302°	2.65737542'	2.65818142'
1000 (≈22.5″x22.5″) scale maps								
P_1		$B_b=B_1$ $L_b=L_1$	$B_o=B_1$ $L_o=L_1+11.25''$	$B_d=B_1$ $L_d=L+22.5''$	Differences			
B_1	L_1	A_{1k}	A_{ok}	A_{dk}	$A_{ok}-A_{1k}$ (°)	$A_{dk}-A_{ok}$ (°)	$A_{ok}-A_{1k}$ (″)	$A_{dk}-A_{ok}$ (″)
42°	26°	146.17065124°	146.17717158°	146.18369253°	0.00652034°	0.00652095°	0.3912″	0.3912″
36°	36°	166.00677836°	166.01784950°	166.02892148°	0.01107114°	0.01107198°	0.6642″	0.6643″

When Table 1 is examined, it can be seen that the differences in Qibla azimuths calculated using the centroids of the sheets for the Qibla direction on the maps are below 3' for 1:5000 scale maps and below 0.7' for 1:1000 scale maps. These differences are so small that they will not affect the boundary values, and they fall within the limits of Mikat and Harem boundaries in Türkiye. Therefore, in the calculation of Qibla direction for the sheets, the centroids of the sheets can be considered in the calculation process.

The term "Mikat," mentioned in the previous paragraph, refers to the points that determine the boundaries where those coming from outside must enter into the state of ihram for performing the pilgrimage or umrah and may not pass without ihram. On the other hand, "Harem" is defined as a region around Mecca where picking plants and hunting animals are prohibited.

According to LSM, in order to calculate the Qibla direction (t_{mk}), the difference between the Qibla azimuth (A_{mk}) and the convergence of the meridian (χ) with the declination reduction (γ) should be taken into account.

$$t_{mk} = A_{mk} - \chi - \gamma \tag{3}$$

The qibla azimuth is the angle measured from true north, which is the meridian. The qibla direction, on the other hand, is the angle measured from grid north, which is the map north, i.e., the x-axis (Figure 3).

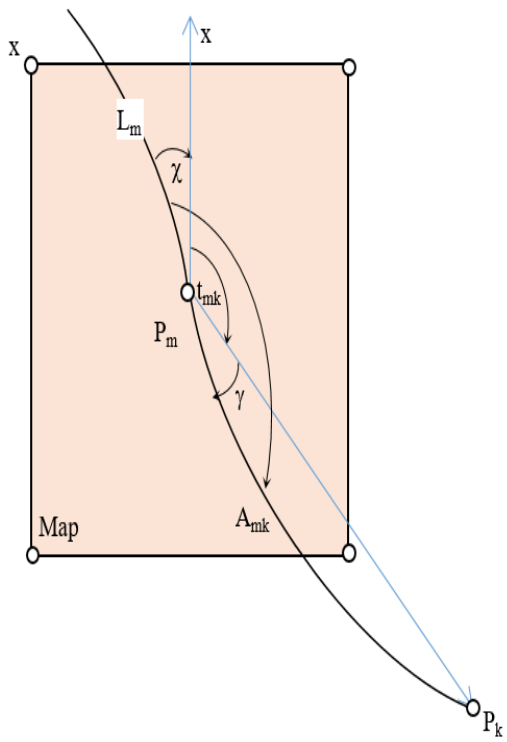

Figure 3. Map qibla direction

The formulas for meridian convergence and grid convergence vary depending on the projection coordinate systems used on maps in different countries. The formulas provided below are given for the UTM (Universal Transversal Mercator) system, which is widely used in Türkiye, Islamic countries, and the majority of the world (Easting, Northing). Meridian convergence increases as it moves away from the central meridian (L_0) for each sheet. Meridian convergence is calculated using the geographic coordinates of the central meridian (L_0) and the map sheet's center of gravity (P_m (B_m; L_m)) [30].

$$
\begin{aligned}
&\chi = t\cos B_m \ell + \frac{t}{3}\cos^3 B_m(1+3\eta^2+2\eta^4)\ell^3 + \frac{t}{15}\cos^5 B_m(2-t^2)\ell^5 + \ldots \\
&\ell = L_m - L_0 \ ,\ \eta^2 = e'^2\cos^2 B_m \quad , \quad t = \tan(B_m) \ , \\
&\gamma = y_m(x_m - x_k)/(2R_m^2), \qquad R_m = a^2/b(1+\eta^2)
\end{aligned} \tag{4}
$$

Here, (x, y) are Gauss-Krüger coordinates obtained from UTM map coordinates (y=Easting-500000; x=Northing). a and b are the semi-major and semi-minor axes of the ellipsoid, respectively.

According to LSMMIPR, in the calculation of the Qibla direction using equations (1), (2), (3), and (4), it is necessary to calculate the geographic coordinates (B_m, L_m) of the map's center of gravity. The coordinates (B_m, L_m) are calculated using the single-variable power series method, derived from the Gauss-Krüger coordinates (x_m, y_m) obtained from the geometric average of the four corners of the map.

$$
\begin{aligned}
B_m &= B_f + B_2 y_m^2 + B_4 y_m^4 + \ldots \\
L_m &= L_0 + B_1 y_m + B_3 y_m^3 + B_5 y_m^5 + \ldots
\end{aligned} \tag{5}
$$

Here, L_0 is the central meridian of the zone. The coefficients bi and the latitude Bf are calculated using equations numbered 6 and 7.

$$
\begin{aligned}
&B_1 = 1/N_f\cos B_f \ ,\ B_2 = t_f\,(-1-\eta_f^2)/(2N_f^2) \\
&B_3 = (-1-2t_f^2-\eta_f^2)/(6N_f^3\cos B_f) \\
&B_4 = t_f\,(5+3t_f^2+6\eta_f^2-6t_f^2\eta_f^2)/(24N_f^4) \\
&B_5 = (5+28t_f^2+24t_f^4)/(120N_f^5\cos B_f) \\
&\eta_f^2 = e'^2\cos^2 B_f \quad , \quad V_f = \sqrt{1+\eta_f^2} \\
&N_f = c/V_f \ ,\ c = a^2/b \ ,\ t_f = \tan B_f
\end{aligned} \tag{6}
$$

$$
\begin{aligned}
&B_f = \sigma + B''\sin 2\sigma + C''\sin 4\sigma + D''\sin 6\sigma + \ldots \ , \qquad G = x_m \quad , \ \sigma = G/A' \\
&A' = \frac{a^2}{b}\left(1 - \frac{3}{4}e'^2 + \frac{45}{64}e'^4 - \frac{175}{256}e'^6 + \frac{11025}{16384}e'^8 + \ldots\right) \\
&B'' = \left(\frac{3}{8}e'^2 - \frac{3}{16}e'^4 + \frac{213}{2048}e'^6 - \frac{255}{4096}e'^8 + \ldots\right) \\
&C'' = \left(\frac{21}{256}e'^4 - \frac{21}{256}e'^6 + \frac{533}{8192}e'^8 + \ldots\right) \\
&D'' = \left(\frac{151}{6144}e'^6 - \frac{453}{12288}e'^8 + \ldots\right)
\end{aligned} \tag{7}
$$

According to LSMMIPR standards, the partitioning of map sheets is done using geographic coordinates for 1:10000 and 1:5000 scale maps, and using 3° UTM (Easting; Northing) coordinates for 1:2000 and 1:1000 scale maps. For this process, the corner points of 1:5000 scale maps need to be calculated in both geographic and 3° UTM coordinates. Therefore, a conversion from geographic coordinates to 3° UTM coordinates is required. Additionally, for 1:10000 scale maps, the calculation of direction reduction (azimuth) in formula (4) also requires this conversion. The conversion from (B; L) to (Easting; Northing) is expressed using single-variable power series as described in equations (8).

$$
\begin{aligned}
&\text{Northing} = G + A_2\ell^2 + A_4\ell^4 + \ldots \\
&\text{Easting} = 500000 + A_1\ell + A_3\ell^3 + A_5\ell^5 + \ldots \ ,\ \ell = L_i - L_0 \\
&A_1 = N\cos B \\
&A_2 = N\cos^2 B\ \ t/2 \\
&A_3 = N\cos^3 B\ \ (1-t^2+\eta^2)/6 \\
&A_4 = N\cos^4 B\ \ t\,(5-t^2+9\eta^2)/24 \\
&A_5 = N\cos^5 B\ \ (5-18t^2+t^4)/120
\end{aligned} \tag{8}
$$

The variables used in the calculation of coefficients Ai are given in equations (6). For the length of the meridian arc G, equations (9) are used [30].

$$G = A'B + B'\sin 2B + C\sin 4B + D'\sin 6B + \ldots$$

$$A' = \frac{a^2}{b}\left(1 - \frac{3}{4}e'^2 + \frac{45}{64}e'^4 - \frac{175}{256}e'^6 + \frac{11025}{16384}e'^8 + \ldots\right)$$

$$B' = \frac{a^2}{b}\left(-\frac{3}{8}e'^2 + \frac{15}{32}e'^4 - \frac{525}{1024}e'^6 + \frac{2205}{4096}e'^8 + \ldots\right) \tag{9}$$

$$C' = \frac{a^2}{b}\left(-\frac{15}{256}e'^4 - \frac{105}{1024}e'^6 + \frac{2205}{16384}e'^8 + \ldots\right)$$

$$D' = \frac{a^2}{b}\left(-\frac{35}{3072}e'^6 + \frac{315}{12288}e'^8 + \ldots\right)$$

2.2. Interface developed for qibla direction calculation (IDQDC)

The interface algorithm developed for IDQDC is provided in Figure 4. This interface, developed within the scope of this study, was created using MATLAB software, which is widely preferred in many engineering applications today, educational programming languages, and scientific studies [31-36]. The conveniences provided to the user by this software are listed in the following sentences in numbered order: (1) It has a library that includes many engineering-based calculation functions. (2) As a result of the use of objects, it has a practical and understandable GUI from a single window. (3) The ability to convert interfaces developed by users into an exe file and thus enabling all users to easily access the developed interfaces without the need for MATLAB software are advantages of this software.

The rapidly advancing Global Navigation Satellite System (GNSS) technology is widely preferred by many users and disciplines, especially for measurement and navigation applications in real-time positioning. GNSS/CORS networks established at international and local scales are frequently used in many countries. In Türkiye, CORS-TR (Continuously Operating Reference Stations-TR) network with Network-Real time kinematic (RTK) structure has been actively used since 2008. In IDQDC, real-time, reliable, accurate, and fast coordinate data obtained from the CORS-TR system can be utilized. In the scope of this study, the developed interface allows defining location information obtained in real-time from GNSS-RTK measurement devices or in office environments. Developed in the MATLAB GUI environment, this interface can be used on smart phones, tablets, laptops, and desktop computers equipped with Wi-Fi and Bluetooth features.

The general features of the interface developed in this study are listed in numbered sentences below: (1) The developed interface allows for different datum selections in calculations. (2) It has the ability to query based on map scale or name (Figure 5). (3) It supports querying based on a coordinate information related to the map (UTM, Geographic, Geocentric, etc.) (Figure 6).

The structure of the algorithm in the developed interface is shown below (Figure 4).

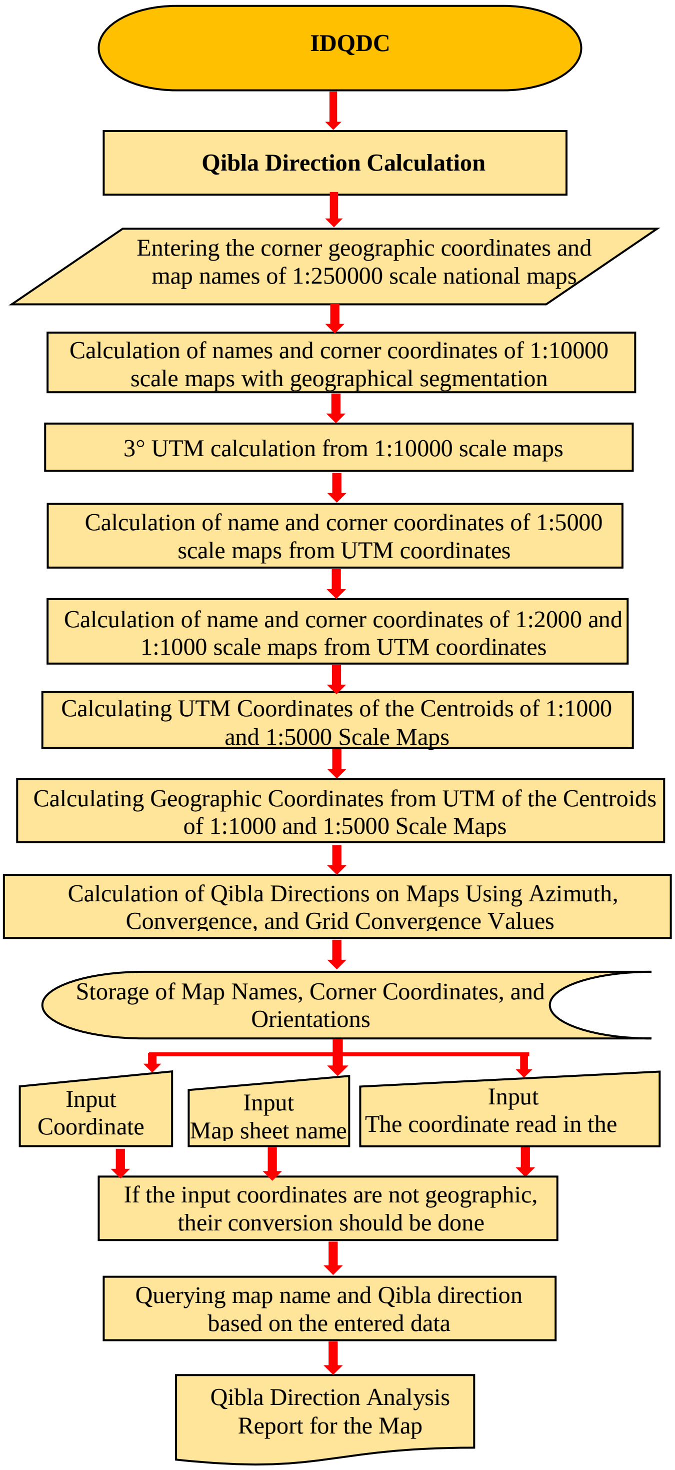

Figure 4. IDQDC algorithm

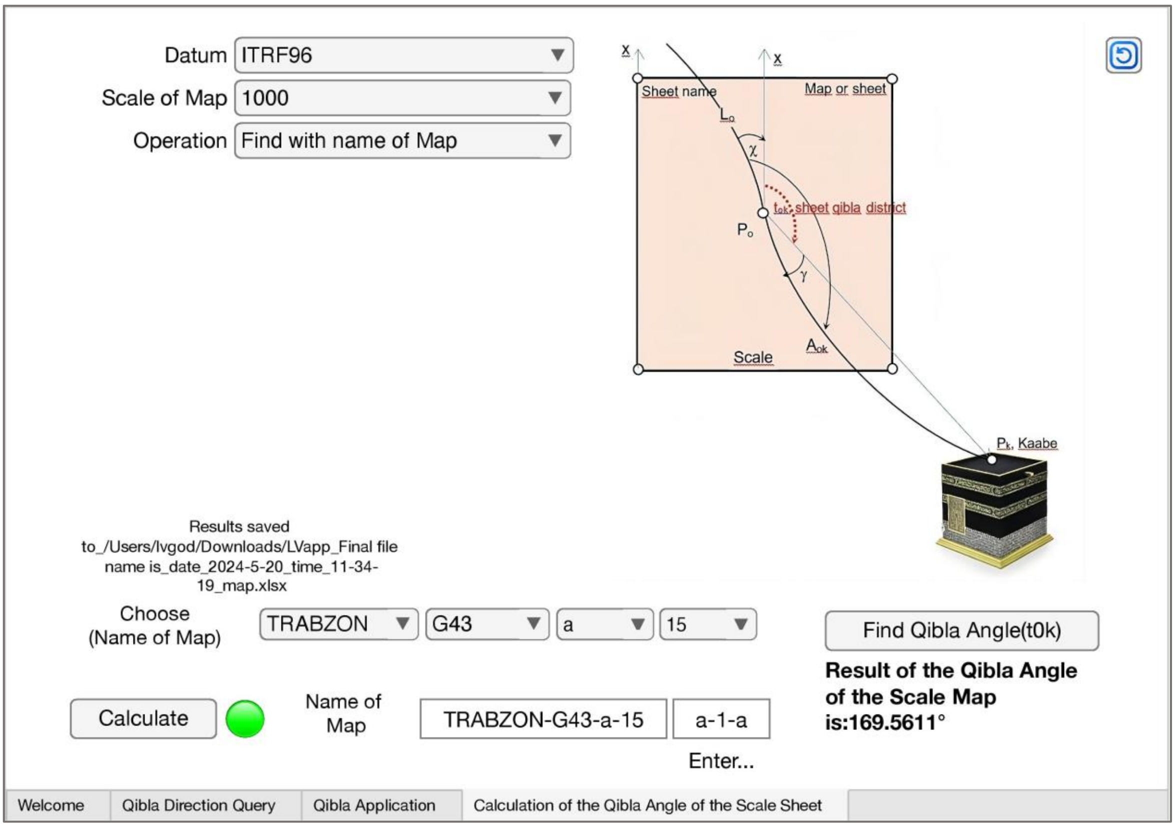

Figure 5. IDQDC - query by map sheet name

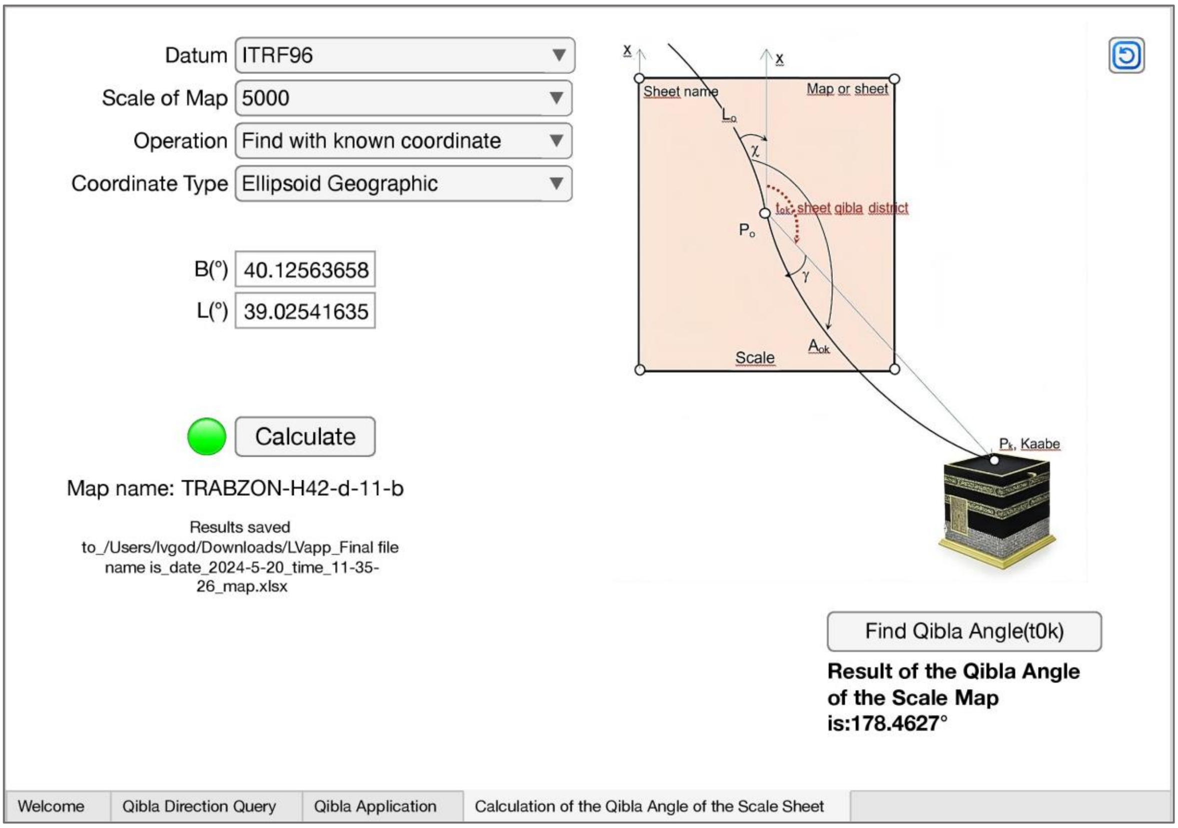

Figure 6. IDQDC - query by coordinates

3. Results

Within the scope of this study, the IDQDC developed was tested according to national mapping scales and map division standards valid within the geographical boundaries of Türkiye. These standards used in Türkiye are in line with international standards, differing only in naming conventions based on provincial names. In Türkiye, large-scale maps (1:1000 - 1:10000) are produced in the UTM (Universal Transversal Mercator) projection based on 3° intervals. Large-scale maps are obtained through geographic division from 1:250000 scale maps to 1:5000 scale maps, while other scale maps are divided using 3° UTM coordinates (Easting; Northing) (Table 2). In the Map Special Signs Classes category and the sheet edge information of large-scale maps, there is no information regarding the direction of the Qibla [6]. Particularly in cadastral maps at a 1:1000 scale, which are essential for engineering projects and planning, as well as standard topographic sheets at 1:1000 and 1:5000 scales, there is no information about the direction of the Qibla.

Table 2. Map division in Türkiye

Scale	Map Dimensions	Map naming	Number of maps	Map coordinates	Map division
1:250000	1° x 1°30′	TRABZON	78	UTM (6°)	Geographical
1:100000	30′ x 30′	TRABZON-G42	468		
1:50000	15′ x 15′	TRABZON-G42-a	1872		
1:25000	7′30“ x 7′30"	TRABZON-G42-a1	7488		
1:10000	3′ x 3′	TRABZON-G42-a-01	46800	UTM (3°)	
1:5000	1′30“ x 1′30"	TRABZON-G42-a-01-a	187200		Geographical and UTM(3°)
1:2000		TRABZON-G42-a-01-a-1	748800		UTM (3°)
1:1000		TRABZON-G42-a-01-a-1-a	2995200		

For the algorithm, it is necessary to first create a data register containing the name of the map sheet, the geographical coordinates of its corners, and the Qibla directions calculated from these coordinates. For this purpose, the geographical coordinates of the names and corners of Türkiye's national map division at a 1:250000 scale are geographically divided into 1:5000 scale maps using the divisions given in Table 2. The 1:5000 scale maps are converted to the 3° UTM system, and the corner coordinates of the 1:2000 and 1:1000 scale maps are determined.

In this context, both geographical and 3° UTM coordinates are obtained using formulas (5), (6), (7), (8), and (9) of LSM. With these coordinates, the Qibla directions in Türkiye according to LSM are calculated using formulas (3) and (4).

Within the scope of this study, for a total of 3987906 maps, of which only the first three national maps are given in Table 3, the maps are respectively:

- Map names
- Central meridians in the 3° UTM system (L_0, in degrees)
- Geographical coordinates of the four corners of the map (B, L in degrees)
- Geographical coordinates of the center of the map (B_m, L_m in degrees)
- 3° UTM coordinates of the center of the map (x_m, y_m in meters)
- 3° UTM coordinates of the four corners of the map (Easting (E), Northing (N) in meters)
- Qibla azimuth of the center of the map (A_{mk}, in degrees)
- Convergence of the center of the map (χ, in degrees)
- Grid declination of the center of the map (γ, in degrees)
- Qibla direction of the center of the map (t_{mk}, in degrees)

The values were calculated and Excel data was generated. For the calculations, the geographical coordinates of the Kaaba were used in the ITRF96 datum, GRS80 ellipsoid (21° 25' 20.9532'' N; 39° 49' 34.3416'' E).

Table 3. Türkiye's national LSM names and map information used for IDQDC

Scale		1:10000		1:5000		1:2000		1:1000	
Map names		EDIRNE-E16-a-01	EDIRNE-E16-a-02	EDIRNE-E16-a-01-a	EDIRNE-E16-a-01-b	EDIRNE-E16-a-01-a-1	EDIRNE-E16-a-01-a-2	EDIRNE-E16-a-01-a-1-a	EDIRNE-E16-a-01-a-1-b
L_0 (°)		27	27	27	27	27	27	27	27
bottom left	B (°)	41.95	41.95	41.975	41.975	41.98750001	41.98750001	41.99375001	41.99375001
	L (°)	26	26.05	26	26.025	26.00000002	26.02500002	26.00000002	26.02500002
top left	B (°)	42	42	42	42	42	42	42	42
	L (°)	26	26.05	26	26.025	26	26.025	26	26.025
bottom right	B (°)	42	42	42	42	42.00000068	42.00000068	42.00000051	42.00000051
	L (°)	26.05	26.1	26.025	26.05	26.01249999	26.03749999	26.00624999	26.03124999
top right	B (°)	41.95	41.95	41.975	41.975	41.98750069	41.98750069	41.99375052	41.99375052
	L (°)	26.05	26.1	26.025	26.05	26.01250001	26.03750001	26.00625001	26.03125001
mid-point	B_m(°)	41.975	41.975	41.9875	41.9875	41.99375052	41.99375052	41.99687530	41.99687530
	L_m(°)	26.025	26.075	26.0125	26.0375	26.00625001	26.03125001	26.00312500	26.02812500
bottom left	E (m)	417083.956	421229.800	417116.365	419188.478	417132.578	419204.285	417140.684	419212.188
	N(m)	4646566.965	4646519.799	4649343.824	4649319.937	4650732.260	4650708.371	4651426.478	4651402.589
top left	E (m)	417148.790	421291.392	417148.790	419220.092	417148.790	419220.092	417148.790	419220.092
	N(m)	4652120.696	4652073.521	4652120.696	4652096.806	4652120.696	4652096.806	4652120.696	4652096.806
bottom right	E (m)	421291.392	425433.988	419220.092	421291.392	418184.441	420255.742	417666.616	419737.917
	N(m)	4652073.521	4652028.766	4652096.806	4652073.521	4652108.751	4652085.164	4652114.723	4652090.985
top right	E (m)	421229.800	425375.638	419188.478	421260.589	418168.431	420240.138	417658.560	419730.064
	N(m)	4646519.799	4646475.053	4649319.937	4649296.654	4650720.316	4650696.730	4651420.506	4651396.768
Map Qibla Angle (°)		146.21218411	146.35680488	146.19225836	146.26452116	146.18229761	146.25454643	146.17731694	146.24955879

The sections shown in Figures 5 and 6 were generated using the interface developed in this study, utilizing the data from Table 3. IDQDC has two types of query capabilities. Queries conducted based on map sheet names or coordinate data are used in calculating the Qibla direction for the respective map sheet. Another convenience provided by the interface developed in this study is the ability for users to query based on coordinate data in their desired projection system. This process eliminates the need for users to perform intensive coordinate transformations and reduces errors resulting from user-based calculations.

As a result of the IDQDC developed in this study, users can quickly calculate the Qibla direction with geodetic accuracy in both field and office environments simply by knowing either the map name or the map's coordinates. IDQDC generates outputs based on data obtained within Türkiye's geographical boundaries, and it can be easily adapted for use in different Muslim countries or countries with different religions. For different Muslim countries, it is sufficient to change the corner coordinates of the initial maps based on the map names and map division. In different religions, the Qibla direction is significant: Churches are places of worship for Christians, and synagogues are places of worship for Jews. For Christians, the sacred direction in churches is towards the east, where the sun rises. For Jews, the Qibla direction is towards the direction that connects their location to the Temple Mount in Jerusalem where the Holy Temple of Solomon once stood. Therefore, in addition to the changes made in IDQDC for different Muslim countries, adjustments to the geographical coordinates of the Qibla direction are also necessary for Christian and Jewish religions. To integrate the Qibla directions calculated with IDQDC into LSM, a legend must be designed. The legends for planning areas where the Qibla direction should be applied in urban plans are shown in Table 4.

Table 4. Türkiye's spatial planning areas requiring qibla direction [6]

Planning area	Legend	Planning area	Legend	Planning area	Legend
Mosque		Municipal service area (slaughterhouse)	BHA	Contiguous construction	B- ...
Musjid		Hostel area	PA	Block construction	BL- ...
Church		Aparthotel area	AO	Health Facility Area	S
Chapel		Hotel area	OTEL	Private Health Facility Area	ÖZEL
Synagogue		Motel area	MOT	Hospital	HAST
Cemetery area		Detached construction	A- ...	Family Health Center	ASM

To ensure that the practitioners take into account the Qibla direction in the plan, an additional legend specifying the Qibla direction needs to be added to the legends provided in Table 4. The new legend to be added to the legends in Table 4 in this study is shown in Figure 7.

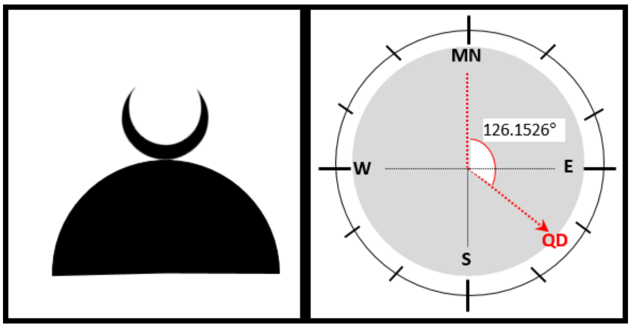

Figure 7. New legend showing the qibla direction (MN:Map North QD:Qibla District)

To plan how to share the total of 3,987,906 Qibla directions provided in Table 3 of the LSM and the proposed legend information in Figure 7 with practitioners, recommendations can be presented to the "Interministerial Board for Coordination and Planning of Mapping Activities (IBCPMA)" responsible for the production of LSM in Türkiye. These recommendations can also be considered for other countries. The recommendations are numbered and listed in the following paragraph: IBCPMA should amend regulations to mandate the inclusion of the Qibla direction legend in LSM. IBCPMA can share the data from Table 3 on their website. IBCPMA should publish the IDQDC developed in this study on their website to make it accessible to all users. Ensure that the IDQDC interface developed in this study is integrated as a plugin module into Computer-Aided Design (CAD) software used for various engineering applications, with recommendations for improving user access.

4. Conclusion and Discussion

In this study, the IDQDC developed enables users to calculate the Qibla direction for 3,987,906 LSM maps within Türkiye's national mapping. The numerical values for some of these LSM Qibla directions are provided in Table 3. The Qibla direction calculation is a geodetic method, and the detailed procedure for its geodetic accuracy is shown in this study. Scientific literature provides studies on Qibla azimuth calculations on an ellipsoidal surface, but there are no existing calculations specifically for LSM Qibla directions. The IDQDC interface developed for users is illustrated in Figures 5 and 6. Figure 7 is proposed for adding Qibla direction information as a legend for LSM maps. IDQDC is designed based on the national mapping criteria of Türkiye and the Qibla direction towards the Kaaba for Muslims. However, IDQDC can easily be adapted for other religions in Türkiye and different countries by knowing the geographic coordinates of the Qibla direction in Christianity and Judaism.

Suggestions have been made to IBCPMA in Türkiye regarding how the Qibla direction legend information for LSM can be shared with practitioners. These suggestions are also suitable for other countries. Moreover, adding a module related to IDQDC in commonly used CAD and geographic information system (GIS) software by practitioners will provide great convenience to users.

In conclusion, IDQDC developed in this study provides users with several conveniences, as numbered below: (1) Practitioners can quickly, reliably, and with geodetic accuracy access the Qibla direction without the need for fieldwork or measurements. (2) With the web publication of the developed interface, users can easily access the Qibla direction via the internet. (3) By entering any coordinate (geographic, geocentric, or UTM) or the name of an LSM, the Qibla direction for that map will be instantly presented to the user. (4) Due to the lack of consideration of the Qibla direction in urban planning, discrepancies arise between the plan and the mosques, slaughterhouses, residences, hotels, and hospital facilities in these buildings. These problems, which cause a decrease in the project area and land loss, will be eliminated by the developed interface. (5) The developed interface will make it widespread to consider the Qibla direction in planning facilities such as religious facilities, cemeteries, slaughterhouses for halal slaughter, residences, hotels for halal tourism, and hospitals for Islamic medical tourism in Islamic communities. (6) Especially for Muslims, who choose from religious sensitivity; halal slaughterhouses, Islamic tourism hotels, and hospitals for medical tourism will be planned accordingly during the preparation of zoning plans. (7) Due to the lack of consideration of the Qibla direction in planning, plan revisions are made, which also increase the construction times of the projects and the cost of the project by re-drawing the project. The developed interface makes it possible to eliminate this problem. (8) The developed interface eliminates calculation errors arising from the calculation of the Qibla direction. (9) It has been seen that it is a guiding way for all religions other than Islam.

Author contributions

Faruk Yildirim: Data curation, Software, Writing-Original draft preparation, Methodology, **Fatih Kadi:** Methodology, Writing-Original draft preparation, Visualization, Writing-Reviewing and Editing, Investigation, **Sakir Levent Sahin:** Software, Visualization, **Bayram Uzun:** Conceptualization, Investigation.

Conflicts of interest

The authors declare no conflicts of interest

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