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Geospatial Modeling of Accessibility and Site Suitability for Primary Health Care Centers in Najaf City, Iraq, through 2034

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Abstract

Primary health care centers (PHCCs) are the most geographically proximate component of an urban health system, yet their effectiveness depends on how well facility locations correspond to population distribution, service reach, road connectivity, and land availability. This study develops a geospatial model that integrates current accessibility, future population requirements, and site suitability for PHCCs in Najaf City, Iraq, through 2034. Official records for 33 main PHCCs, neighborhood boundaries, population estimates, road and land-use layers, high-resolution imagery, and field observations were analyzed in ArcGIS 10.8 and ArcGIS Pro. The methods combined an 800-m Euclidean service buffer, mean center, central feature, standard distance, directional distribution, average nearest neighbor, geometric population projection, and a weighted-overlay GIS multicriteria decision analysis. The centers occupy 78,400 m², averaging 2,376 m² against a local planning standard of 5,000 m². The nearest-neighbor ratio (1.040522; z = 0.337907; p = 0.735434) indicates a statistically random pattern. Accessibility is highly uneven: the share of neighborhood area within an 800-m buffer falls to 4.0% in Al-Salam, 7.41% in Al-Iskan, and 8.14% in Al-Hanana. The 2024 population of 890,187 requires 89 centers, creating a deficit of 56; the projected 2034 population of 1,253,799 raises total normative need to 125 centers. The suitability model generated 42 high-ranking alternatives (scores 8–9), concentrated in Al-Nidaa, Al-Salam, Al-Askari, Al-Mukarrama, Al-Jami'a, and Al-Hussein, within approximately 230,000 m² of candidate land. A phased strategy that prioritizes high-suitability parcels within low-coverage neighborhoods offers a defensible basis for improving spatial equity and planning new PHCC provision through 2034.

Keywords: primary health care centers; spatial accessibility; site suitability; GIS-MCDA; weighted overlay; health-service planning; Najaf City

Introduction

Primary health care centers constitute the first operational contact between residents and the health system. They provide immunization, maternal and child health services, school health, basic diagnosis and treatment, laboratory and pharmaceutical services, and referral to higher levels of care. Their spatial arrangement therefore affects both everyday access and the capacity of hospitals to concentrate on cases that require specialized treatment. International primary health care frameworks emphasize proximity, continuity, equity, and the alignment of service organization with population needs (World Health Organization [WHO] & United Nations Children's Fund [UNICEF], 2020; WHO, 2022).

Geographic accessibility is not equivalent to the simple presence of a facility within an administrative unit. It emerges from the relationship among facility location, population distribution, the distance residents must travel, transport infrastructure, and the scale and capacity of the service. GIS makes it possible to represent these relationships consistently, compare areas, and identify spatial mismatches that may remain hidden in aggregate city-level indicators (Guagliardo, 2004; Apparicio et al., 2008). Euclidean buffers provide a transparent first approximation of service reach, while network or raster travel-time models can refine the estimate where reliable road and impedance information is available (Delamater et al., 2012).

Najaf City has experienced a substantial increase in population and displays marked differences in neighborhood size, density, and connection to the urban road system. The city also receives large numbers of visitors, which creates additional but spatially variable pressure on health services. Existing PHCCs are concentrated mainly in the established urban core, whereas several large or peripheral neighborhoods remain only partly covered. Planning additional centers requires more than calculating a numerical deficit: it requires a reproducible method that connects accessibility gaps to future need and to land parcels capable of supporting new facilities. GIS-based multicriteria decision analysis (GIS-MCDA) offers such a framework by standardizing spatial criteria, assigning explicit weights, and producing a transparent set of candidate locations rather than a single inflexible site (Malczewski, 2006).

Earlier Iraqi geographic research documented uneven health-service efficiency in Najaf and other governorates and demonstrated the value of geomatics for diagnosing spatial variation (Abu Kallal, 2012; Al-Ubaidi, 2013; Al-

Adhari, 2023). The present study advances this line of work by integrating current access gaps, a defined 2034 planning horizon, and parcel-level site suitability within a single decision sequence.

This study therefore reframes the evaluation of PHCCs in Najaf around two connected questions: where access is currently insufficient, and where new centers can be located to address that insufficiency through 2034. The analytical contribution lies in integrating facility-pattern statistics, an 800-m service-reach measure, demographic projection, and weighted site suitability within one planning sequence. The approach is designed to support the Najaf Health Directorate, municipal authorities, and planning agencies in moving from general statements of shortage toward spatially prioritized and technically verifiable interventions.

2. Research Framework

2.1 Research Problem

The central problem is a spatial and planning mismatch between the number, location, and site area of PHCCs on the one hand, and the distribution and projected size of the population on the other. This mismatch produces uneven service reach and leaves parts of several neighborhoods beyond the adopted access threshold. The principal research question is: How can geospatial modeling integrate present accessibility, population need through 2034, and land suitability to identify priority locations for new PHCCs in Najaf City? Subsidiary questions concern the spatial pattern and directional tendency of existing centers, differences among neighborhoods within an 800-m service buffer, the current and projected numerical and land-area deficits, and the location of high-suitability alternatives.

2.2 Research Hypothesis

The study hypothesizes that the current PHCC configuration is not spatially aligned with the distribution and scale of population demand, producing measurable accessibility gaps. It further hypothesizes that integrating low-coverage neighborhoods with a weighted GIS suitability model will identify priority sites that can support a more equitable and phased allocation of new centers through 2034.

2.3 Significance of the Study

Scientifically, the study extends health-service geography in an Iraqi urban context by linking descriptive facility statistics to explicit measures of accessibility and spatial decision support. Practically, it offers a replicable basis for ranking neighborhoods, screening candidate land, coordinating health and municipal decisions, and distinguishing the existing backlog from the additional requirement generated by population increase. This distinction is essential for realistic capital programming and for avoiding the repeated placement of new facilities inside already covered areas.

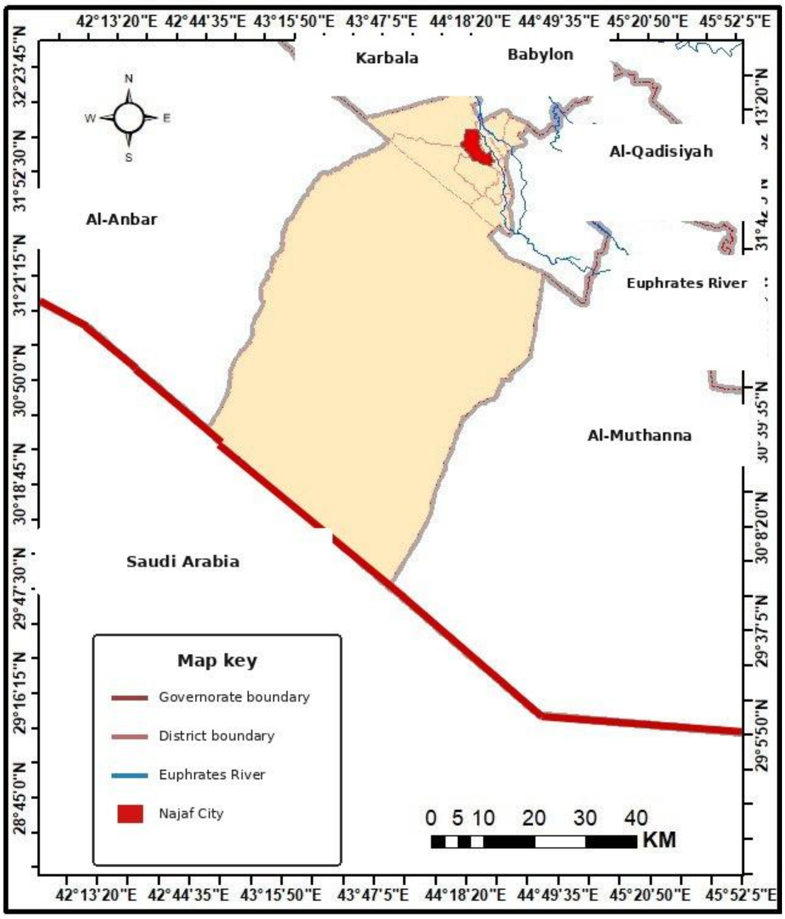
2.4 Objectives

1. Evaluate the current number and site area of the 33 main PHCCs against local population and land-area standards.
2. Measure the spatial configuration, central tendency, dispersion, direction, and nearest-neighbor pattern of existing centers.
3. Assess neighborhood-level accessibility using an 800-m service buffer and identify areas with the weakest coverage.
4. Estimate the additional and cumulative PHCC requirements associated with population change through 2034.
5. Build a weighted GIS-MCDA model to identify candidate sites and rank priority neighborhoods for phased implementation.

3. Study Area

The study covers the municipal boundary of Najaf City in central Iraq. The city is located near 31°59′ N and 44°19′ E and occupies approximately 183.75 km² within the 2012–2035 master plan. It is bordered by Al-Haidariya to the north, Kufa to the east, Al-Hira and Al-Manathira to the south and southwest, and the Bahr Al-Najaf depression toward the west. The present assessment uses the 2024 population base, the 2025 PHCC inventory, and a planning horizon extending through 2034.

Figure 1. Geographic location of Najaf City within Najaf Governorate, Iraq



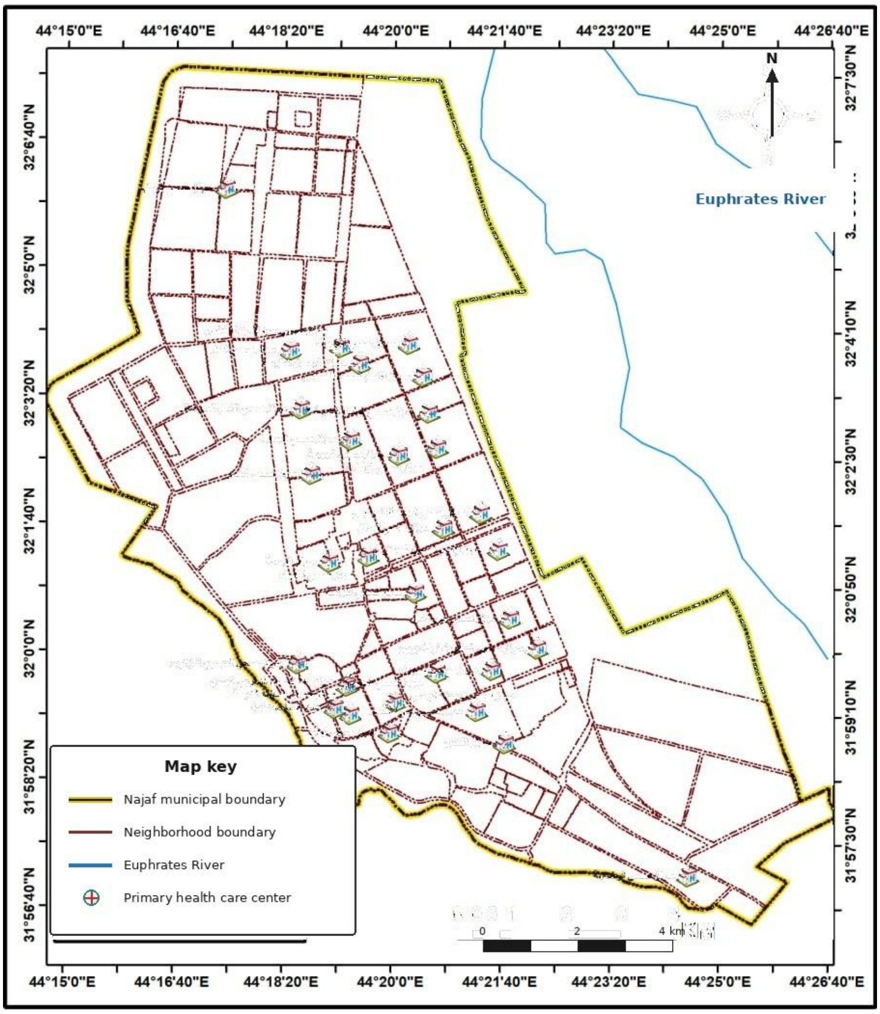
Source: Based on the Republic of Iraq, Ministry of Planning, Central Statistical Organization, administrative map of Najaf Governorate, scale 1:250,000.

4. Materials and Methods

4.1 Sources and Spatial Database

The spatial database combined the 2025 locations and site areas of 33 main PHCCs from the Najaf Health Directorate; 2024 population estimates from the Central Statistical Organization and Najaf Statistics Directorate; neighborhood and municipal boundaries; primary, secondary, and local road layers; residential, health, green, service, and open land uses; high-resolution satellite imagery; and field observations. Layers were georeferenced to a common projected coordinate system and clipped to the municipal boundary. ArcGIS 10.8 was used for descriptive spatial statistics and buffering, while ArcGIS Pro supported raster preprocessing and the suitability model.

Figure 2. Spatial configuration of the main primary health care centers in Najaf City, 2025



Source: Based on the Iraqi Ministry of Health, Najaf Health Directorate, Planning and Health Policies Department, unpublished official records, 2025, and ArcGIS processing. Neighborhood boundaries follow the official municipal layer.

4.2 Planning Benchmarks and Population Projection

Two local benchmarks were applied: one main PHCC per 10,000 residents and a standard site area of 5,000 m² per center (Iraq, Ministry of Construction, Housing, Municipalities and Public Works, 2018). Population was projected geometrically using $P_t = P_0(1 + r)^t$, where P_0 is the 2024 population, r is the annual increase rate (approximately 3.48%), and t is the number of years. The resulting 2034 estimate was used to separate the current facility deficit from the additional requirement attributable to population increase during 2024–2034.

4.3 Spatial-Pattern Measures

The mean center was used to locate the geometric balance point of the facility pattern, whereas the central feature identified the existing PHCC with the smallest aggregate distance to all other centers. Standard distance measured overall dispersion, and the standard deviational ellipse summarized the dominant directional tendency. Average nearest neighbor compared the observed mean interfacility distance with the expectation under complete spatial randomness; its z-score and p-value were used to test statistical significance (Mitchell, 2005; Dawood, 2012). These measures describe the configuration of facilities but do not independently establish whether population access is adequate.

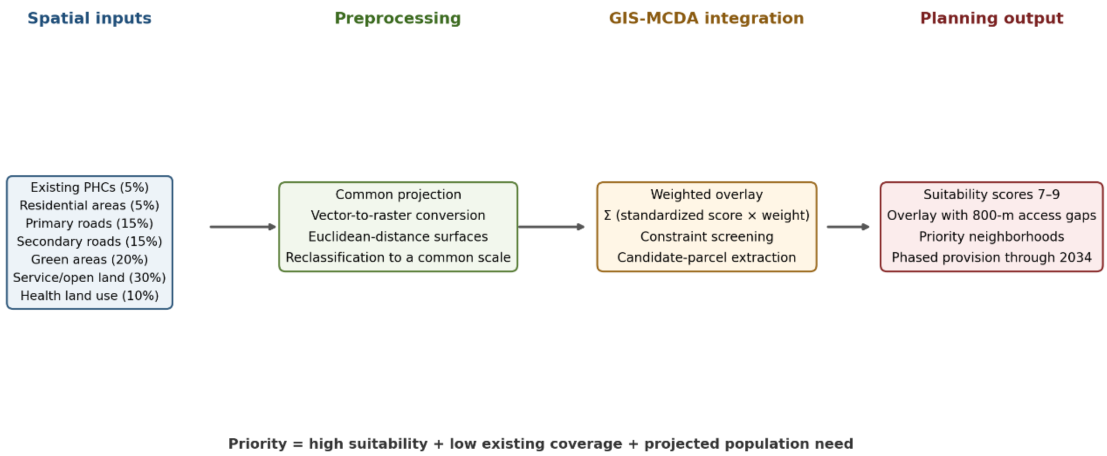
4.4 Accessibility Model

An 800-m Euclidean buffer was generated around each PHCC. For every neighborhood, the analysis calculated the area intersecting at least one buffer and divided it by total neighborhood area. The resulting percentage was interpreted as a comparable indicator of potential spatial coverage. The metric distinguishes between a center merely being located in a neighborhood and the extent to which the neighborhood lies within the adopted planning distance. Because the buffer is based on straight-line distance, it is treated as a screening measure rather than a direct estimate of travel time; network constraints are addressed in the limitations and recommendations.

4.5 GIS-MCDA Site-Suitability Model

Seven spatial criteria were standardized and integrated. The workflow included common projection, conversion of required vector layers to raster, Euclidean-distance calculations, reclassification to a common suitability scale, and weighted overlay. Service and open land received the highest weight (30%) because parcel availability is a prerequisite for implementation. Green areas received 20%, primary roads 15%, secondary roads 15%, health land use 10%, residential areas 5%, and distance from existing PHCCs 5%. The weights sum to 100%. The final raster was converted to candidate polygons and compared with 800-m access gaps, neighborhood need, parcel size, and road connection. GIS-MCDA makes these value judgments explicit, but final implementation still requires ownership, field, and engineering verification (Malczewski, 2006).

Figure 3. GIS-MCDA workflow for accessibility-informed PHCC site suitability



Source: Constructed from the ModelBuilder sequence and criterion weights applied in the thesis using ArcGIS Pro.

Table 1. Criteria and relative weights used in the PHCC site-suitability model

No.	Spatial criterion	Weight (%)
1	Distance from existing PHCCs	5
2	Residential areas	5
3	Access via primary and high-capacity roads	15
4	Access via secondary and local roads	15
5	Green areas	20
6	Service and open land	30
7	Health land use	10
	Total	100

Source: Based on the field survey, satellite imagery, and the geospatial model documented in the thesis.

5. Results

5.1 Existing Provision and Planning Deficits

Najaf City contained 33 main PHCCs in 2025. Their combined site area was 78,400 m², or 2,376 m² per center on average. The largest site, the 15 Sha'ban Training Center, occupied 4,377 m²; Al-Quds followed with 3,696 m², whereas Al-Rasool in Al-Mukarrama was the smallest at 1,880 m². No existing center reached the local 5,000-m² standard. Applying that benchmark to 33 centers yields a required aggregate area of 165,000 m² and a current site-area deficit of 86,600 m². An equal-interval classification placed 25 centers (75.8%) in the small-area category, six (18.2%) in the medium category, and only two (6.0%) in the large category.

The 2024 population of 890,187 implies a normative requirement of 89 centers under the one-per-10,000 benchmark. The gap between this requirement and the 33 existing centers is 56 facilities. The shortage therefore has two linked dimensions: too few centers for the population and insufficient land area at most existing sites. Site-area constraints reduce opportunities for internal expansion, waiting space, parking, supporting services, and future service diversification.

Table 2. Current PHCC provision and planning benchmarks in Najaf City

Indicator	Observed / calculated value	Planning implication
Existing main PHCCs (2025)	33	Current supply base
Combined site area	78,400 m²	Existing land provision
Mean site area	2,376 m²	Below the 5,000-m² benchmark
Required area for 33 centers	165,000 m²	Benchmark × existing centers
Current site-area deficit	86,600 m²	Limits on-site expansion
Population (2024)	890,187	Reference year
Centers required in 2024	89	One center per 10,000 residents
Current numerical deficit	56 centers	Immediate backlog

Source: Based on the Iraqi Ministry of Health, Najaf Health Directorate, 2025; the Iraqi Ministry of Planning, 2024; and national urban and rural housing standards, 2018.

5.2 Central Tendency, Dispersion, and Spatial Pattern

The mean center of the 33 PHCC locations fell in Al-Marhalin neighborhood at X = 437,364.284055 and Y = 3,542,604.949068. The central feature was approximately 970 m to the northwest in Al-Naft. Their proximity indicates a relative concentration around the established central urban belt; however, these points express geometric balance and interfacility position rather than population-weighted access. The standard distance was 5,966.94 m (5.97 km). Twenty-one centers (63.6%) fell within the standard-distance circle, while 12 (36.4%) lay outside it. The directional ellipse extended northwest–southeast at an approximate rotation of 155° and contained 17 centers (51.5%), with 16 (48.5%) outside.

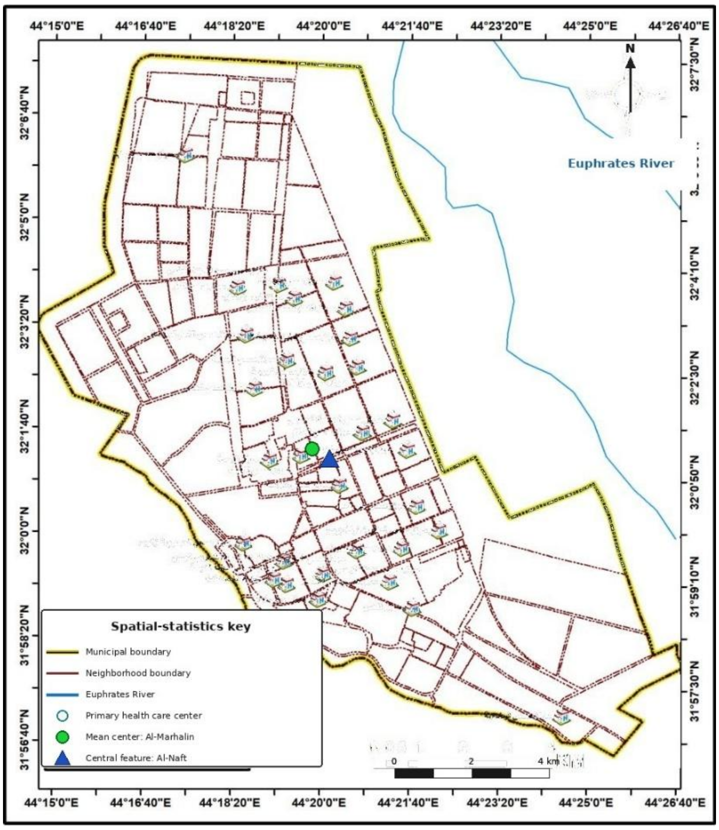
The nearest-neighbor ratio was 1.040522, with $z = 0.337907$ and $p = 0.735434$. Because p exceeds 0.05, the observed pattern cannot be distinguished statistically from spatial randomness. The result does not imply equitable access; rather, it shows that facility locations do not form a significant clustered or regularly spaced pattern. Population distribution, service buffers, roads, and land suitability must therefore be evaluated directly before new sites are selected.

Table 3. Summary of spatial-pattern measures for the main PHCCs

Measure	Result	Spatial interpretation
Mean center	Al-Marhalin	Geometric balance point
Central feature	Al-Naft; 970 m northwest	Most centrally positioned existing center
Standard distance	5.97 km; 21 centers inside	Relative concentration in the central belt
Directional distribution	NW–SE; 155°	Dominant longitudinal tendency
Average nearest neighbor	R = 1.040522; z = 0.337907; p = 0.735434	Statistically random pattern

Source: Based on ArcGIS spatial-statistics outputs documented in the thesis.

Figure 4. Mean center and central feature of the PHCC pattern in Najaf City



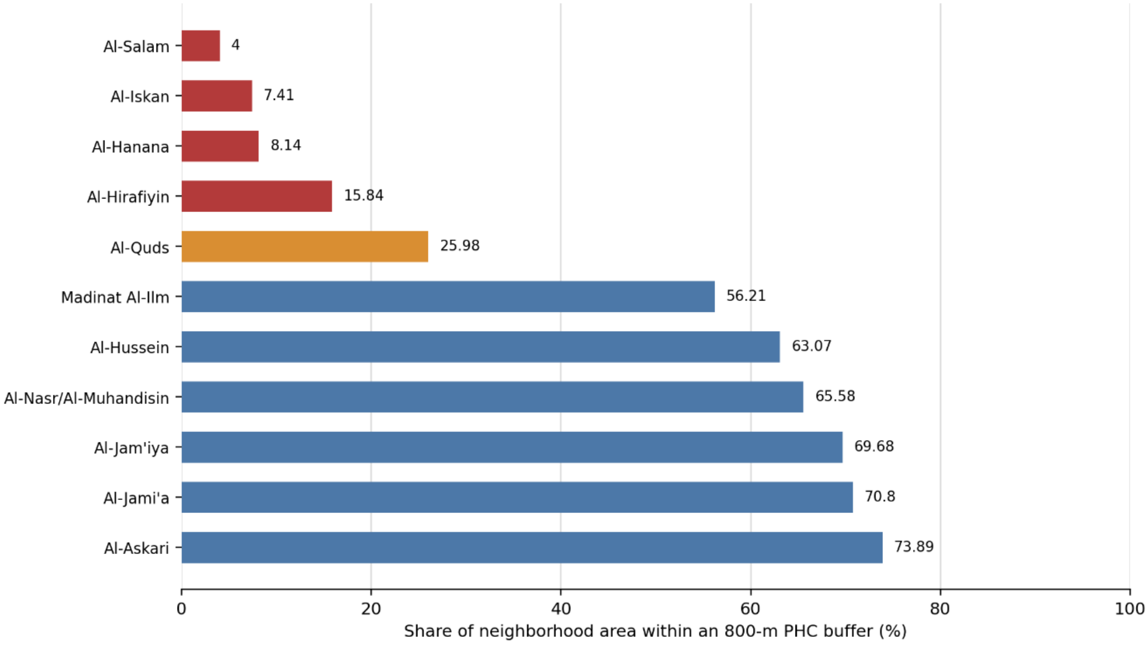
Source: Based on the Iraqi Ministry of Health, Najaf Health Directorate, 2025, high-resolution satellite imagery, and ArcGIS spatial-statistics tools. Neighborhood boundaries follow the official municipal layer.

5.3 Accessibility within the 800-m Service Buffer

Potential accessibility varied sharply among neighborhoods. Al-Salam recorded only 4.0% of its area within an 800-m PHCC buffer, followed by Al-Iskan (7.41%), Al-Hanana (8.14%), Al-Hirafiyin (15.84%), and Al-Quds (25.98%). Mid-range coverage was recorded in Madinat Al-Ilm (56.21%), Al-Hussein (63.07%), Al-Nasr/Al-Muhandisin (65.58%), Al-Jam'iya (69.68%), Al-Jami'a (70.80%), and Al-Askari (73.89%). By contrast, full coverage was attained in Aden, Al-Naft, Al-Marhalin, Al-Karama, Al-Qadisiyah, Al-Shurta, the Old City, and Al-Jadidat, while several other neighborhoods exceeded 90%.

The contrast confirms that citywide center counts conceal localized access deficits. Large neighborhoods can contain a PHCC while most of their territory remains outside the adopted service distance. The lowest-coverage group therefore represents the first screening tier for intervention, subject to population concentration, road access, parcel feasibility, and overlap with existing catchments.

Figure 5. Selected neighborhood coverage within the 800-m PHCC service buffer



Source: Based on the ArcGIS 10.8 buffer analysis of PHCC locations and neighborhood boundaries for Najaf City, 2024–2025.

Table 4. Selected levels of neighborhood coverage within an 800-m PHCC buffer

Neighborhood	Covered area (%)	Coverage level
Al-Salam	4.00	Very low
Al-Iskan	7.41	Very low
Al-Hanana	8.14	Very low
Al-Hirafiyin	15.84	Low
Al-Quds	25.98	Low
Madinat Al-Ilm	56.21	Moderate
Al-Hussein	63.07	Moderate
Al-Nasr/Al-Muhandisin	65.58	Moderate
Al-Jam'iya	69.68	Moderate
Al-Jami'a	70.80	Moderate
Al-Askari	73.89	Moderate

Source: Based on the ArcGIS 10.8 buffer analysis of PHCC locations and neighborhood boundaries for Najaf City, 2024–2025.

5.4 Requirements through 2034

The population is projected to increase from 890,187 in 2024 to 1,253,799 in 2034, an increase of 363,612 residents (40.85%). At one PHCC per 10,000 residents, the increase alone generates a requirement for 36 additional centers and 180,000 m² of site land at 5,000 m² per center. Total normative need reaches approximately 125 centers in 2034. If the existing supply remains fixed at 33, the cumulative shortfall would rise to 92 centers.

Three quantities must remain analytically separate. First, 56 centers constitute the backlog already present in 2024. Second, 36 centers represent the additional requirement associated with population increase during 2024–2034. Third, 92 centers represent the cumulative 2034 gap only if no new centers are delivered. This separation supports phased programming and prevents the projected requirement from being mistaken for the current deficit.

Table 5. Current and projected PHCC requirements through 2034

Year / period	Population	Normative requirement	Existing supply	Deficit
2024	890,187	89 centers	33	56
Increase, 2024–2034	363,612	36 additional centers	—	—
2034	1,253,799	125 centers in total	33 if unchanged	92 cumulative

Source: Based on the Iraqi Ministry of Planning, Central Statistical Organization, Najaf Statistics Directorate, 2024, and national urban and rural housing standards, 2018.

5.5 Site-Suitability Outcomes

The weighted overlay produced final suitability scores ranging from 7 to 9. Score 9 was assigned to 20 alternatives: 17 in Al-Nidaa and three in Al-Salam. Score 8 identified 22 additional alternatives: eight in Al-Nidaa, seven in Al-Askari, two each in Al-Mukarrama, Al-Salam, and Al-Jami'a, and one in Al-Hussein. The combined score 8–9 group therefore contains 42 high-ranking alternatives. The total candidate area across the model was approximately 230,000 m².

Suitability rank alone is not a final implementation order. Al-Nidaa contains the largest number of high-scoring parcels, but citywide spatial equity requires the ranking to be cross-checked against the 800-m access deficit and the distribution of future population. Al-Salam is particularly important because it combines extremely low existing coverage with three score-9 and two score-8 alternatives. Sites in Al-Askari, Al-Mukarrama, Al-Jami'a, and Al-Hussein offer additional options where road access, parcel size, and service overlap are favorable. Ownership, parcel configuration, contamination or hazard conditions, utility connection, and compatibility with municipal plans must be verified before acquisition or construction.

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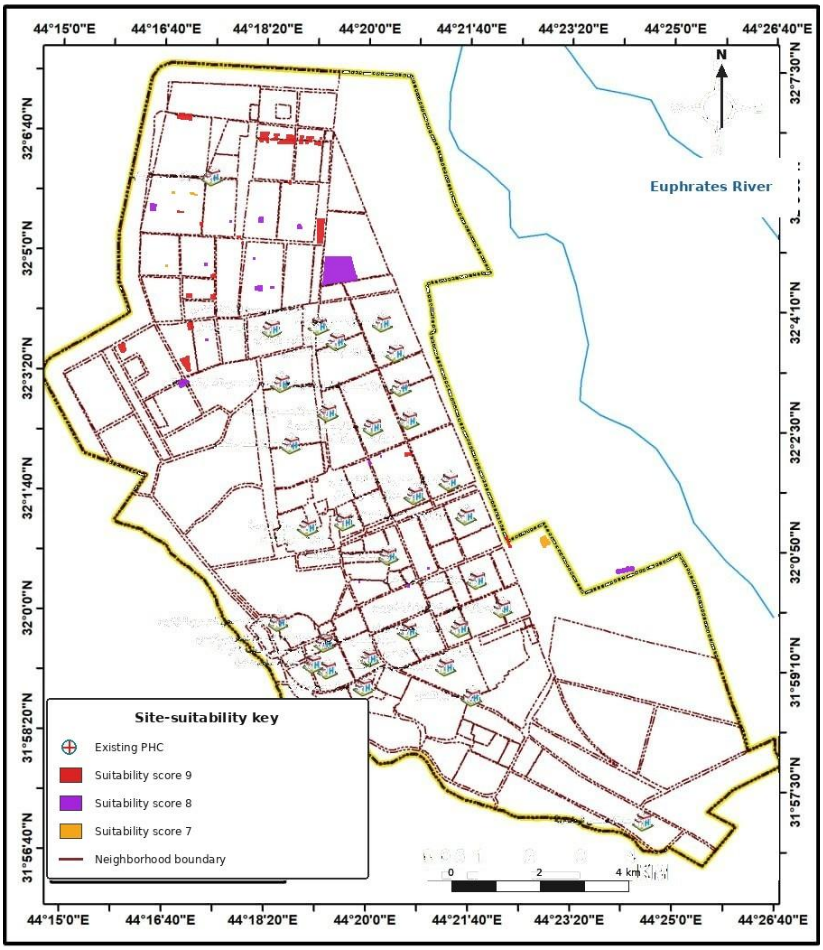
Figure 6. Candidate locations and site-suitability scores for new PHCCs in Najaf City



Source: Based on the Iraqi Ministry of Health, Najaf Health Directorate, 2025; high-resolution satellite imagery; and the ArcGIS 10.8 / ArcGIS Pro suitability model. Candidate-site classes were transferred from the original model output to an English cartographic base.

Table 6. Distribution of high-ranking candidate sites by neighborhood

Suitability score	Neighborhood	Candidate sites
9	Al-Nidaa	17
9	Al-Salam	3
8	Al-Nidaa	8
8	Al-Askari	7
8	Al-Mukarrama	2
8	Al-Salam	2
8	Al-Jami'a	2
8	Al-Hussein	1

Suitability score	Neighborhood	Candidate sites
8–9	Total high-ranking alternatives	42

Source: Based on the weighted-overlay output documented in the thesis.

6. Discussion

The results demonstrate why accessibility and suitability should be treated as a linked planning problem. A numerical standard identifies the scale of shortage but cannot determine where investment should occur. A service buffer identifies poorly covered neighborhoods but cannot establish whether feasible land is available. A suitability model identifies technically promising parcels but can reproduce spatial inequality if high scores are accepted without reference to existing service gaps. Integrating the three components produces a more defensible decision sequence: quantify shortage, locate low-coverage areas, screen feasible parcels, and phase implementation according to population need through 2034.

The random nearest-neighbor result is also substantively important. Statistical randomness does not mean that centers were literally placed without administrative decisions, nor does it imply adequate coverage. It indicates that the configuration lacks a significant tendency toward clustering or regular spacing at the city scale. The very low 800-m coverage recorded in Al-Salam, Al-Iskan, and Al-Hanana confirms that spatial-pattern statistics must be interpreted with population and accessibility measures, consistent with the conceptual distinction between facility distribution and population access in the health-geography literature (Guagliardo, 2004; Apparicio et al., 2008).

The projected 2034 requirement creates a practical sequencing challenge. Approximately 230,000 m² of candidate land is theoretically sufficient to accommodate the 180,000 m² associated with the 36 centers generated by population increase alone. It does not, however, automatically resolve the current backlog of 56 centers, nor does aggregate area guarantee that each parcel meets the 5,000-m² standard. A phased plan should therefore begin with parcels that combine high suitability, low current coverage, and adequate site geometry, while separate programs address undersized existing centers through expansion, replacement, or service reconfiguration.

The adopted 800-m Euclidean buffer offers a transparent and reproducible screening indicator, but actual access is shaped by street connectivity, barriers, congestion, walking conditions, and transport mode. Network travel time would provide a more behaviorally realistic measure where current road speeds and impedance information can be assembled (Delamater et al., 2012). Similarly, weighted overlay is sensitive to criterion definition, score thresholds, and weights. Future implementation should include stakeholder validation and sensitivity testing to determine whether priority areas remain stable under plausible alternative weight sets.

7. Conclusions

1. The 33 main PHCCs occupy 78,400 m² and average 2,376 m², leaving all existing sites below the local 5,000-m² benchmark and producing an aggregate current site-area deficit of 86,600 m².
2. The 2024 population requires 89 centers under the local benchmark, so the city has an immediate deficit of 56 PHCCs before future population needs are considered.
3. The facility pattern is statistically random ($R = 1.040522$; $z = 0.337907$; $p = 0.735434$), with a relative central-belt concentration and a northwest–southeast directional tendency.
4. Accessibility within an 800-m service buffer is highly uneven; Al-Salam, Al-Iskan, Al-Hanana, Al-Hirafiyin, and Al-Quds record the weakest selected coverage levels.
5. The projected 2034 population of 1,253,799 raises total normative need to 125 centers; if supply remains unchanged, the cumulative shortfall would reach 92 centers.
6. The GIS-MCDA model identified 42 high-ranking alternatives with scores of 8–9 in Al-Nidaa, Al-Salam, Al-Askari, Al-Mukarrama, Al-Jami'a, and Al-Hussein, within approximately 230,000 m² of candidate land.
7. Priority should be assigned to high-suitability parcels that also reduce current accessibility deficits; suitability rank should not be treated as a stand-alone construction order.

8. Planning Recommendations

1. Adopt the 800-m accessibility results as an initial prioritization layer and give immediate attention to Al-Salam, Al-Iskan, Al-Hanana, Al-Hirafiyin, and Al-Quds.
2. Implement a phased capital program that distinguishes the 56-center current backlog from the 36 additional centers generated by population increase through 2034.

3. Subject all score 8–9 candidate parcels to ownership, area, utility, environmental, traffic, and engineering verification before final selection.
4. Prioritize parcels that combine high suitability with low existing coverage and minimal overlap with current service buffers.
5. Create a shared and regularly updated geospatial database linking PHCC locations, population, roads, land use, planned development, and parcel status across health and municipal agencies.
6. Complement Euclidean buffers with network-based walking and driving times, including congestion and barrier information, when a routable road dataset becomes available.
7. Conduct a sensitivity analysis of the GIS-MCDA weights and document stakeholder agreement before the model is used for land acquisition or capital budgeting.

9. Study Limitations

The analysis measures potential geographic accessibility rather than actual utilization. It does not model service quality, staffing, opening hours, affordability, referral behavior, or individual travel mode. The 800-m buffer represents straight-line distance and may overestimate effective access where the road network is discontinuous or barriers are present. Population is evaluated at the neighborhood scale rather than as a fine-resolution population surface. Finally, the suitability output is a screening model; legal ownership, parcel geometry, infrastructure, hazards, and construction feasibility require field and administrative verification.

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