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RESEARCH

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Empowering access: unveiling an overall composite spatial accessibility index to healthcare services in Southeastern Iran

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Abstract

Background Access to healthcare is critical for population health; however, geographic barriers persist especially in rural and deprived regions. This study aims to develop an overall composite potential spatial accessibility index to healthcare facilities and services in Sistan and Baluchestan Province in southeast Iran.

Methods This study employed the enhanced two-step floating catchment area (E2SFCA) method to create an overall composite spatial accessibility index for healthcare facilities and services in Sistan and Baluchestan Province, southeast Iran. Spatial accessibility for general practitioners, nursing, dentistry, midwifery, pharmacy, medical laboratory, nutrition, public health, radiology, psychology, environmental health, rural health workers, inpatient hospital beds, and five medical specialty services were calculated. Spatial accessibility scores were normalized from 0 to 1 (no access = 0, low = 0.01 to 0.33, moderate = 0.331 to 0.66, high = 0.661 to 1) and aggregated into overall indices of primary, secondary, and overall healthcare accessibility for each district. Inequality was assessed using the Lorenz curve and Gini coefficient analysis.

Results Low geographic accessibility was found across Sistan and Baluchestan Province, especially in rural areas. Almost 75% of the population had low/no access to overall primary care services within a 30-minute drive time. For secondary care, nearly 45% had low/no access to hospital inpatient beds within a 30-minute drive time, and around 40% had low/no access to specialists within a 60-minute drive time. Just 11.6% of the population had high overall healthcare access. The calculated Gini coefficient of 0.517 for the overall spatial accessibility index to healthcare services in Sistan and Baluchestan Province highlights a highly unequal distribution of healthcare services.

Conclusions This study demonstrates a useful replicable methodology that combines individual service accessibility metrics into an overall spatial healthcare access index. Furthermore, this study provides evidence of major shortfalls in healthcare access across Sistan and Baluchestan Province. Targeted strategies are required to increase the availability and capacity of services in underserved communities. Improving geographic access is key for progressing towards universal coverage and better population health.

Keywords Healthcare Access, 2SFCA, Enhanced 2SFCA, Primary care, Secondary care, Inequality

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Background

Access to healthcare services is a critical determinant of population health and well-being. However, it presents a significant challenge for people living in deprived and low-level access areas [1, 2]. Inequality in access to healthcare is one of the foremost obstacles to achieving the Sustainable Development Goals (SDG) set by the United Nations, which aims to end poverty, protect the planet, and ensure peace and prosperity for all [3, 4]. As part of the agenda for SDG, all countries have committed to achieving Universal Health Coverage (UHC) by 2030 signifying that everyone should have reasonable access to healthcare services without obstacles [5, 6]. Identifying underserved areas with low access to healthcare services can help inform policies and interventions to improve healthcare provision and increase utilization, especially among vulnerable populations like undeserved areas of Iran [7].

Iran's healthcare system is centrally managed by the Ministry of Health and Medical Education (MOHME), which oversees policy-making, planning, regulation, and supervision. The system is structured into three main levels: primary, secondary, and tertiary care. Primary healthcare is delivered through health houses (lowest healthcare unit within the healthcare networks, located in the villages of Iran), rural health centers, and urban health centers, while secondary care is provided by district and provincial hospitals. Tertiary care is offered by teaching hospitals and specialized medical centers. The private sector also plays a significant role, particularly in urban areas, offering a range of medical services through private hospitals, clinics, and diagnostic centers. Additionally, non-governmental organizations (NGOs), charitable foundations, and international agencies contribute to healthcare delivery. Iran has a mixed health insurance system, including public, semi-public, and private schemes, with major providers like the Social Security Organization (SSO) and the Medical Services Insurance Organization (MSIO) [8–10]. Despite progress, challenges such as geographic disparities, a growing burden of non-communicable diseases, and financial constraints persist, prompting ongoing reforms to improve access and efficiency [9].

The Sistan and Baluchestan (SB) Province, the second-largest province in Iran located in the southeast, faces unique challenges. It has a high proportion of rural and deprived residents [11] and exhibits the highest poverty rate, lowest literacy rate, lowest life expectancy, lowest insurance coverage rate, and the highest age-standardized disability-adjusted life year (DALY) rate among all provinces of Iran [12–16]. Additionally, SB has the highest neonatal mortality rate and significant disease burden from unsafe water, sanitation, and road traffic injuries compared to other provinces of Iran [15]. The province also has the lowest social health index rating and access to healthcare in Iran [13, 17, 18]. Specifically, SB is the poorest province with a human development index (HDI) of 0.665 in 2021 [19]. This province has few urban areas, with significant distance between them. Almost half of the population lives in rural areas, which are also widely dispersed. Some villages are located in remote, inaccessible regions. Additionally, approximately 65% of the roads in this province are dirt roads, complicating transportation and access to healthcare services [15, 20]. These challenges underscore the critical importance of spatial access to healthcare.

Access to healthcare is a critical component of healthcare systems globally [21]. Penchansky and Thomas [22] proposed five dimensions affecting access: Accessibility (distance and travel time), Availability (capacity and service supply), Affordability (cost barriers), Acceptability (cultural and provider attitudes), and Accommodation (service organization and delivery) [22–24]. Spatial dimensions like accessibility and availability play critical roles in underserved regions, making their measurement vital for assessing healthcare disparities [24].

Various methodologies have been developed to measure spatial accessibility, evolving from basic metrics like provider-to-population ratios to more sophisticated techniques [25–27]. The gravity-based two-step floating catchment area (2SFCA) method, widely used to analyze accessibility, considers both service supply and demand [25, 26, 28–31]. However, the 2SFCA model has limitations, including the "distance decay" effect, where access declines with increased travel distance [30, 32]. To address this, the enhanced two-step floating catchment area (E2SFCA) method incorporates weighted distance decay factors, offering a more nuanced analysis of spatial accessibility [32, 33]. However, despite these improvements and widespread use, these methods often focus on individual service types without integrating findings into a composite measure, limiting their utility for systemic evaluations, particularly in underserved regions.

As countries strive to achieve universal health coverage, measuring and mapping overall spatial accessibility is critical to reducing healthcare disparities [34]. Existing studies have explored service-specific indices [24, 26, 35, 36] but lack a unified approach that evaluates healthcare accessibility comprehensively. Given that healthcare systems are inherently complex, encompassing diverse services from primary care to specialized treatments [37]. This represents a significant gap in the literature, as an overall composite index would enable a holistic evaluation of healthcare accessibility, facilitating planning and targeted resource allocation [38, 39]. Addressing this gap, the present study introduces a Composite Spatial Accessibility Index (CSAI) that integrates multiple healthcare service types using the E2SFCA method, tailored to the unique geographic and socio-economic context of southeast Iran. This study aims to quantify potential spatial accessibility to healthcare services and calculate a CSAI to inform healthcare planning and policymaking in SB Province.

Methods

This study measured the spatial accessibility to various healthcare services in SB Province, Southeast Iran, including primary care (e.g., general practitioners, nurses, pharmacies) and secondary care (e.g., hospital beds, medical specialists). An overall CSAI was then developed to evaluate healthcare access across the study area. Figure 1 illustrates the methodological process.

Study area

The SB Province covers an area of 181,785 km^2 and has a population of approximately 3 million. The SB Province is the second largest province of the 31 provinces in Iran. Despite its vast land area, the province represents only 3.5% of Iran's total population. Notably, approximately 51.5% of residents inhabit rural regions, while the other 48.5% inhabit urban areas. The province contains 26 counties, 142 districts, and 5,367 villages. The province is bordered by the Gulf of Oman to the south, Pakistan and Afghanistan to the east, Southern Khorasan to the north, and Kerman and Hormozgan to the west (Fig. 2).

Data sources

Three main data sources were used for this study, all sourced for the year 2022 to ensure consistency: (1) population data, (2) road network data, and (3) healthcare facility data.

Population data

Population data include (1) administrative boundaries and divisions, (2) geographical location, and (3) the population of each administrative division. The administrative boundaries and divisions, and geographical location of populations are based on Iran's latest 2022 administrative divisions. These data were validated and updated using the OpenStreetMap website (https://www.openstreetmap.org). The 2016 population census data for each district were obtained from the Statistical Center of Iran

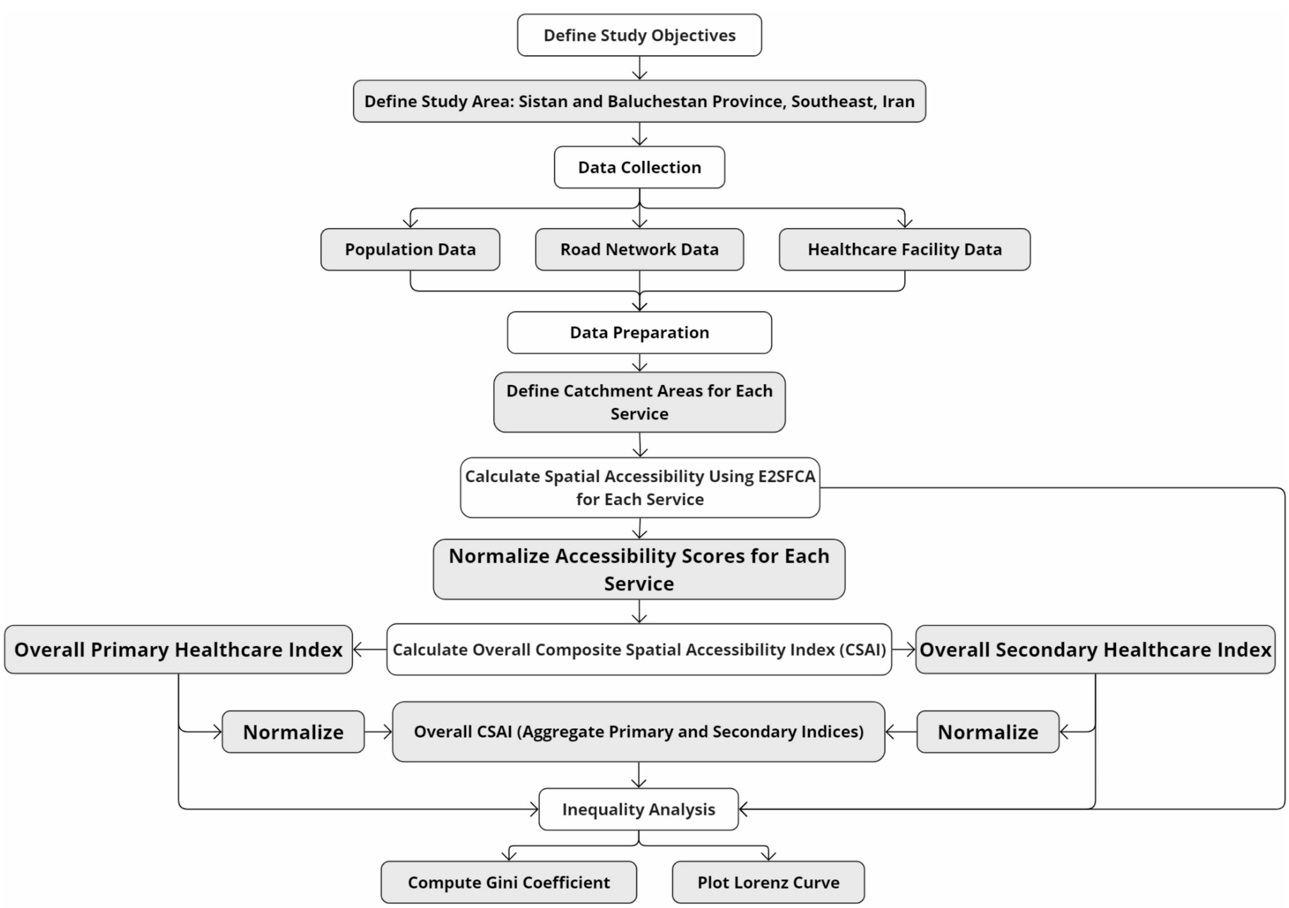

Fig. 1 Methodological workflow for measuring spatial accessibility to healthcare services and developing the Composite Spatial Accessibility Index (CSAI)

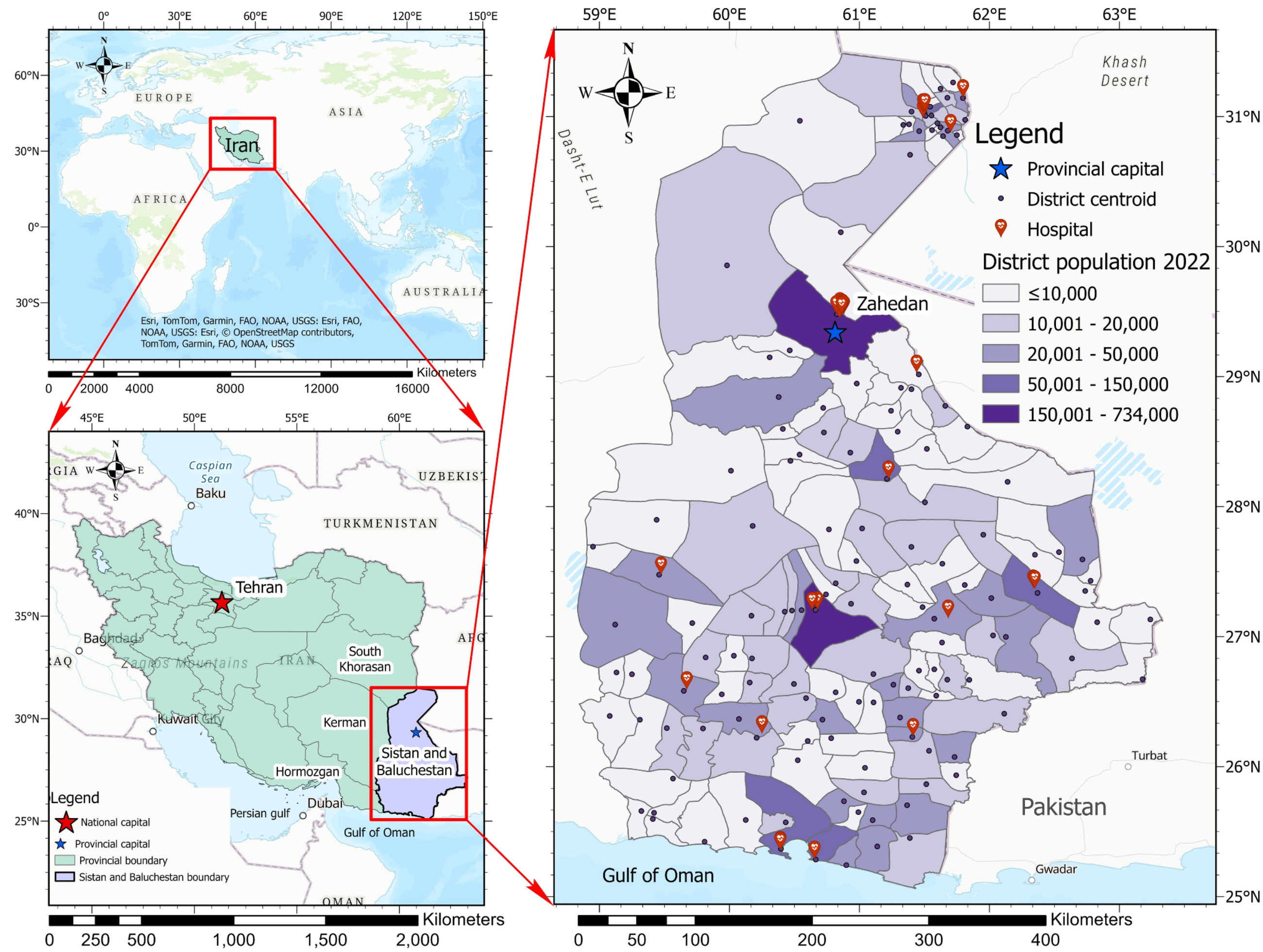

Fig. 2 Location of the study area (Sistan and Baluchestan) and population per district

and projected to 2022 using the mathematical geometric increase method to account for significant population changes in SB Province [20]. The following equation was used:

$$P_{t+n} = P_t(1+r)^n \tag{1}$$

Where:

- $\boldsymbol{P_{t+n}}$ is the projected population in the year 2022.
- $\boldsymbol{P_t}$ is the base year population (2016).
- $\boldsymbol{n}$ is the number of years from the base year to the projection year (6 years).
- $\boldsymbol{r}$ is the population growth rate.

Using Eq. 2, the population growth rate ($\boldsymbol{r}$) was calculated [20].

$$r = \sqrt[n]{\frac{p_{t+n}}{P_t}} - 1 \times 100 \tag{2}$$

Where:

- $\boldsymbol{P_{t+n}}$ is the projected population for counties of SB Province for 2021, as provided by the Statistical Center of Iran.
- P_t is the population of 2016.
- n is the interval between two censuses (5 years).

This method was used for its accuracy in reflecting growth trends over time, providing a reliable estimate of the population distribution in 2022 [20, 40, 41].

Road network data for network analysis

Measuring spatial access entails calculating the automobile travel distance and time between supply locations (healthcare centers) and demand points (population centers) [42]. The World Health Organization recommends travel time over distance for measuring access to healthcare [43]. The service area analysis method was utilized to calculate travel time between supply and demand locations. OpenStreetMap road network data was processed to generate a network dataset, and topology checks fixed any connectivity issues. Speed limits were assigned using Iran's traffic regulations, considering that some roads lacked speed data. Road hierarchy was determined from road type and speed limit to select optimal routes. The road hierarchy and corresponding speed limits are as follows:

- Main roads have a 90 to 120 km/h speed limit outside residential areas and 60 km/h inside.
- Secondary roads have 60 to 90 km/h outside residential areas and 50 km/h inside.
- Tertiary roads have a 40 km/h limit outside residential areas and 20 to 30 km/h inside.
- Limited roads that are inaccessible by car or under construction were not considered when measuring accessibility [20].

Healthcare facility data

The geographical location and capacities of healthcare facilities were sourced from the relevant governmental organization in SB Province. This analysis covered all primary and secondary healthcare facilities, which offer a range of services including general practitioner, nursing care, pharmacies, and specialized treatments (Table 1).

The travel time thresholds were based on Iran's national standards to establish catchment areas for healthcare facilities. These thresholds represent the maximum travel time within which populations are likely to access healthcare services, divided into different zones. These thresholds directly impact Eq. 3 by assigning weights (W_r) to indicate the likelihood of healthcare utilization. Shorter travel times receive higher weights ($W_1 = 1.0$), while longer travel times are given lower weights ($W_3 = 0.22$), reflecting the distance decay effect.

Table 1 provides a summary of the healthcare services, their corresponding travel time thresholds, health levels, capacity measures, and the target populations considered in the analysis.

Spatial analysis

Spatial analysis was conducted in the following steps:

Measuring spatial access using the E2SFCA method for each service

The E2SFCA technique was used to measure spatial accessibility for each healthcare service type listed in Table 1. The E2SFCA involves two key steps [30, 32]:

Step 1 For each healthcare service location ***j***, a catchment area was defined based on the travel time thresholds detailed in Table 1. Within each catchment, the weighted provider-to-population ratio (***Rj***) was calculated using Eq. 3 and a Gaussian distance decay function. The capacity of each healthcare service type used in the analysis is detailed in Table 1.

Table 1 Parameters for Measuring Spatial Accessibility of Healthcare Services in SB Province

R	Service Type	Travel Time Thresholds (Minutes)	Health Level	Capacity	Target Population
1	General Practitioner	0–10, 10–20, 20–30	Primary (1)	Number of general practitioners	Total population
2	Nursing	0–10, 10–20, 20–30	Primary (1)	Number of nurses	Total population
3	Dentistry	0–10, 10–20, 20–30	Primary (1)	Number of dentists	Total population
4	Midwifery	0–10, 10–20, 20–30	Primary (1)	Number of midwives	Women's population
5	Pharmacy	0–10, 10–20, 20–30	Primary (1)	Number of pharmacies	Total population
6	Medical Laboratory	0–10, 10–20, 20–30	Primary (1)	Number of laboratory technicians	Total population
7	Public Health	0–10, 10–20, 20–30	Primary (1)	Public health workers	Total population
8	Nutritionists	0–10, 10–20, 20–30	Primary (1)	Number of nutritionists	Total population
9	Environmental Health Services	0–10, 10–20, 20–30	Primary (1)	Environmental health engineers	Total population
10	Radiology	0–10, 10–20, 20–30	Primary (1)	Number of radiology technicians	Total population
11	Psychologists	0–10, 10–20, 20–30	Primary (1)	Number of psychologists	Total population
12	Rural Health Workers (Behvarz)	0–10, 10–15, 15–20	Primary (1)	Number of Behvarz in village health houses	Village population
13	Hospital	0–10, 10–20, 20–30	Secondary (2)	Inpatient hospital beds	Total population
14	Pediatric	0–20, 20–40, 40–60	Secondary (2)	Number of pediatric specialists	Children's population (≤ 18 years)
15	Gynecologist	0–20, 20–40, 40–60	Secondary (2)	Number of gynecologists	Women's population
16	Cardiologist	0–20, 20–40, 40–60	Secondary (2)	Number of cardiologists	Total population
17	Internal Medicine	0–20, 20–40, 40–60	Secondary (2)	Number of internal medicine specialists	Total population
18	General Surgeon	0–20, 20–40, 40–60	Secondary (2)	Number of general surgeons	Total population

$$R_j = \frac{S_j}{\sum_{k\in}\left\{d_{kj\in D_r}\right\}P_k W_r} \tag{3}$$

Where:

- R_j is the provider-to-population ratio of healthcare center j in the catchment area.
- P_k is the population of the k-th location where the centroid falls within catchment j ($d_{kj} \in D_r$).
- S_j is the capacity of the healthcare center j.
- d_{kj} is the travel time between location k and healthcare center j.
- D_r is the r-th travel-time zone $r \in \{1,2,3\}$ within the catchment.
- W_r is the weight of the r -th travel time zone (W_r = 1.0, 0.68, 0.22).

Step 2 For each population location i, the Rj values were summed across all healthcare facility catchment areas containing that population location (Eq. 4). Distance decay weights were applied again in this step.

$$A_i^F = \sum\nolimits_{j\in\left\{d_{ij}\leqslant d_r\right\}} R_j W_r \tag{4}$$

Where:

- A_i^F is the accessibility index score of the population location i to a certain healthcare service.
- R_j is the provider population ratio of healthcare center j in the catchment area centered at the population location i where the centroid is located (i.e., dkj ∈ Dr).
- d_{ij} is the travel time between i and j.
- W_r represents the distance weights same as step 1.

The centroid in Eq. 4 serves as a reference point for calculating the average travel time to healthcare services. It represents the central point of each selected district or administrative division.

Create an overall index based on the different measured access

To develop a comprehensive measure of healthcare access, the different spatial accessibility indices for various healthcare services were combined into a single index. The steps were:

Normalizing access to each healthcare service To calculate the overall index of accessibility to primary (level 1) and secondary (level 2) healthcare services, first, all the calculated accessibility values were normalized between 0 and 1 using the Min-Max normalization method (Eq. 5). The purpose of data normalization is to convert them to a common and comparable scale. This is because the level of access to each health service is calculated based on different criteria [44].

$$A_{i\,norm} = \frac{A_i - A_{\min}}{A_{\max} - A_{\min}} \tag{5}$$

Where:

- $A_{i\,norm}$ is the normalized accessibility value.
- A_i is the value of one accessibility score in a location i.
- A_{min} is the minimum accessibility value.
- A_{max} is the maximum accessibility value.

Calculating overall CSAI of primary and secondary healthcare services After normalizing different accesses, the accessibility index to primary and secondary healthcare services for each district is separately calculated using the following Equation:

$$D_l = \sum A_{i\,norm} \tag{6}$$

Where:

- $A_{i\,norm}$ is the normalized accessibility value for each district.
- D_l is the overall CSAI score of the primary (l =1), and secondary (l =2) healthcare services.

Calculating overall CSAI The normalized indices of access to primary and secondary healthcare services were summed to calculate the overall healthcare access index for each population location (Eq. 7).

$$A_{Overall} = \sum D_l \tag{7}$$

Where:

- $A_{Overall}$ is the overall CSAI value for each district.
- D_l is the overall CSAI score of the primary (l =1), and secondary (l =2) healthcare services.

This overall CSAI provides a single metric combining the accessibility of primary and secondary healthcare services. A higher index value indicates a location has good access to the full range of healthcare providers necessary for basic healthcare services. The index can identify underserved areas and guide policies to improve access and equity.

The accessibility scores for rural health workers (called: Behvarz) were not incorporated into the overall CSAI for SB Province, as Behvarzes only provide limited primary care services in rural villages and do not contribute meaningfully to access to the wider healthcare system.

Classification of calculated and normalized accessibility scores

The calculated and normalized accessibility scores were classified into four categories to aid interpretation:

1) No access (Index value of 0);
2) Low access (Index value between 0.01 and 0.33);
3) Moderate access (Index value between 0.331 and 0.66); and.
4) High access (Index value between 0.661 and 1).

This classification system allows the results for different healthcare service types to be more easily compared and understood.

Inequality using the lorenz curve and gini coefficient

The Lorenz curve and Gini coefficient are widely used measures to evaluate inequality that allow standardized comparisons across various metrics, such as income or in this case, healthcare accessibility [7, 45–47]. The Lorenz curve and Gini coefficient were used to assess inequality in the spatial distribution of healthcare access across SB Province. The Lorenz curve plots the cumulative proportion of the population (x-axis) against the cumulative proportion of healthcare accessibility (y-axis) for each district, ordered from lowest to highest access. The line of equality represents perfectly equal access across the population and curves further from this line indicate greater inequality. The Gini index quantifies the level of inequality, with 0 representing perfect equality and 1 indicating maximum inequality [46, 47]. Lorenz curves and Gini indices were calculated for all primary, and secondary healthcare services, and also for overall primary and secondary healthcare services as well as for overall healthcare access based on the measured spatial accessibility indices.

Computing requirements and software

The data were prepared and analyzed using Microsoft Excel® 2021, Python in Visual Studio Code 1.90.2, and spatial analysis was performed using ArcGIS Pro 3.0 software. The analysis was performed on a system featuring an Intel Core i7 processor, 16 GB of RAM, and 1 TB of storage, operating on Windows 11.

Results

The projected population of SB Province in 2022 reached 3,152,294 individuals, with 48.8% living in rural villages and women comprising 49% of the population. The province contains 5,367 villages across 142 districts. Healthcare infrastructure in the province includes 27 hospitals and 281 active primary health centers. Additionally, there are 188 non-active and 983 active health houses (called *Khaneh Behdasht* in Iran) which are staffed by Behvarz (rural health worker) providing basic services in villages.

Sai to primary healthcare services

Figure 3; Table 2 present spatial accessibility results for primary healthcare services in SB. Key findings include:

- **Nutrition Services**: Among all services, nutrition services had the highest proportion of the population with no access, at 39% of the population in 97 out of 142 districts. Low access was reported for 50% in 31 districts, while 11% in 14 districts had moderate to high access within a 30-minute drive time.
- **Radiology Services**: Radiology services had a significant proportion of the population with no access, at 30% of the population in 88 districts. Low access was reported for 33% in 29 districts, while 37% in 25 districts had moderate to high access within a 30-minute drive time.
- **Dentistry Services**: These services were not accessible to 23% of the population in 68 districts. Low access was reported for 32%, while 45% had moderate to high access within a 30-minute drive time.

For all primary care services except for pharmacies, over 50% of the population had low or no spatial access. Moderate access was observed for 3–56% of the population depending on the specific service. High accessibility within reasonable travel times was limited, with only 0.5–12% of the population having such access to each primary care service.

For rural populations served by Behvarzes in the heath house, 6% had no access in 820 out of 5,367 villages. However, the vast majority (89%) had only low access based on travel time thresholds. Just 23 villages (0.5%) had high access to a Behvarz (Table 2).

SAI to secondary healthcare services

Figure 4 and Table 3 show the results for spatial accessibility to secondary healthcare services.

The services with the largest populations having no access were hospital beds (30% of the population in 87 districts within a 30-minute drive time) and cardiologists (23% in 63 districts within a 60-minute drive time). For all specialist services, almost 40% of the population

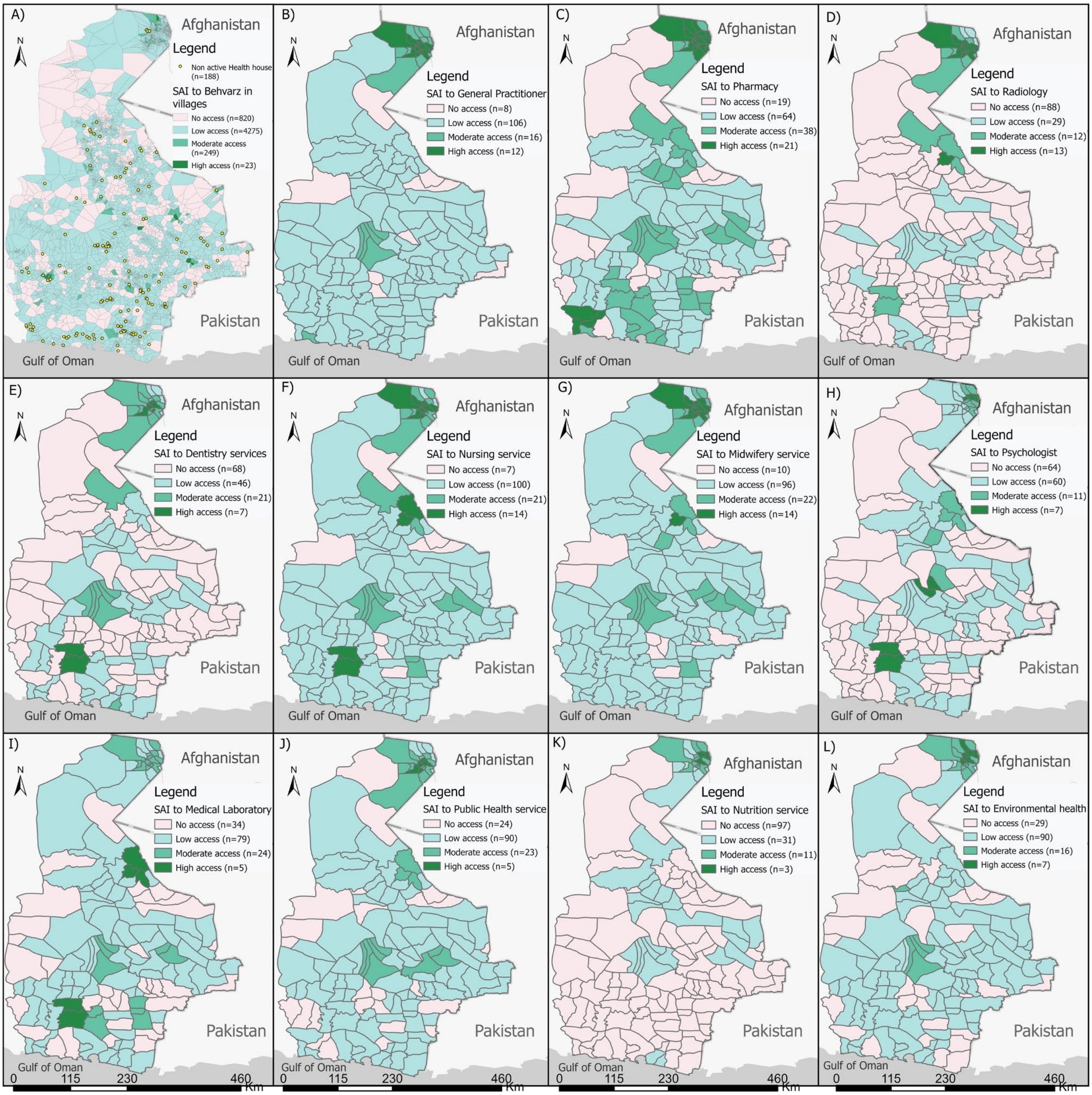

Fig. 3 Spatial accessibility index (SAI) to primary healthcare service in Sistan and Baluchestan Province in Iran. The numbers in the legend of this figure represent the number of districts whose accessibility index falls within that class of SAI. (**A**) displays the SAI of the village's population to rural health workers at the Heath House within a 20-minute drive time displayed in the Thiessen polygon created based on the village point. (**B-L**) displays the SAI to General Practitioners, Pharmacy, Radiology, Dentistry, Midwifery, Psychologist, Medical Laboratory, Public Health, Environmental health service, and Nutrition services within a 30-minute drive time based on district administrative divisions

had low or no spatial access. Moderate access was present for 17–45% of the population depending on service. High access was limited to just 9–38% of the population, depending on the specific secondary care service (Fig. 4; Table 3).

Overall CSAI

The overall CSAI combining primary and secondary services is shown in Fig. 5, and Table 4.

In SB Province, only four districts, constituting 0.4% of the total population, lack access to primary healthcare services within a 30-minute drive. In contrast, 44 districts, encompassing 15.2% of the population, are without access to secondary healthcare services. A

Table 2 Results of spatial accessibility index for different primary healthcare services in Sistan and Baluchestan Province in Iran

R	Type of healthcare service	No access		Low access		Moderate access		High access	
		Population (%)	ND*	Population (%)	ND	Population (%)	ND	Population (%)	ND
1	General Practitioner	55,689 (2%)	8	2,441,283 (77%)	106	341,212 (11%)	16	314,110 (10%)	12
2	Pharmacy	136,925 (4%)	19	860,657 (28%)	64	1,767,559 (56%)	38	387,153 (12%)	21
3	Dentistry service	722,976 (23%)	68	1,005,202 (32%)	46	1,176,427 (37%)	21	247,689 (8%)	7
4	Medical laboratory services	292,831 (9%)	34	2,140,674 (68%)	79	648,556 (21%)	24	70,233 (2%)	5
5	Nutrition service	1,226,888 (39%)	97	1,590,213 (50%)	31	287,642 (9%)	11	47,551 (2%)	3
6	Public health service	191,479 (6%)	24	2,260,875 (72%)	90	503,488 (16%)	23	196,452 (6%)	5
7	Nursing service	46,422 (1%)	7	1,504,494 (49%)	100	1,272,940 (40%)	21	328,438 (10%)	14
8	Midwifery service	58,077 (2%)	10	2,230,076 (71%)	96	528,584 (16%)	22	335,557 (11%)	14
9	Environmental health service	293,873 (9%)	29	2,248,963 (71%)	90	392,832 (13%)	16	216,626 (7%)	7
10	Radiology	952,362 (30%)	88	1,031,138 (33%)	29	845,389 (27%)	12	323,405 (10%)	13
11	Psychologist	654,790 (21%)	64	2,301,819 (73%)	60	99,991 (3%)	11	95,694 (3%)	7
12	Behvarz in villages	96,630 (6%)	820	1,370,066 (89%)	4275	66,776 (4.5%)	249	3,711 (0.5%)	23

*ND: Number of districts whose accessibility index falls within that class of spatial accessibility index (SAI)

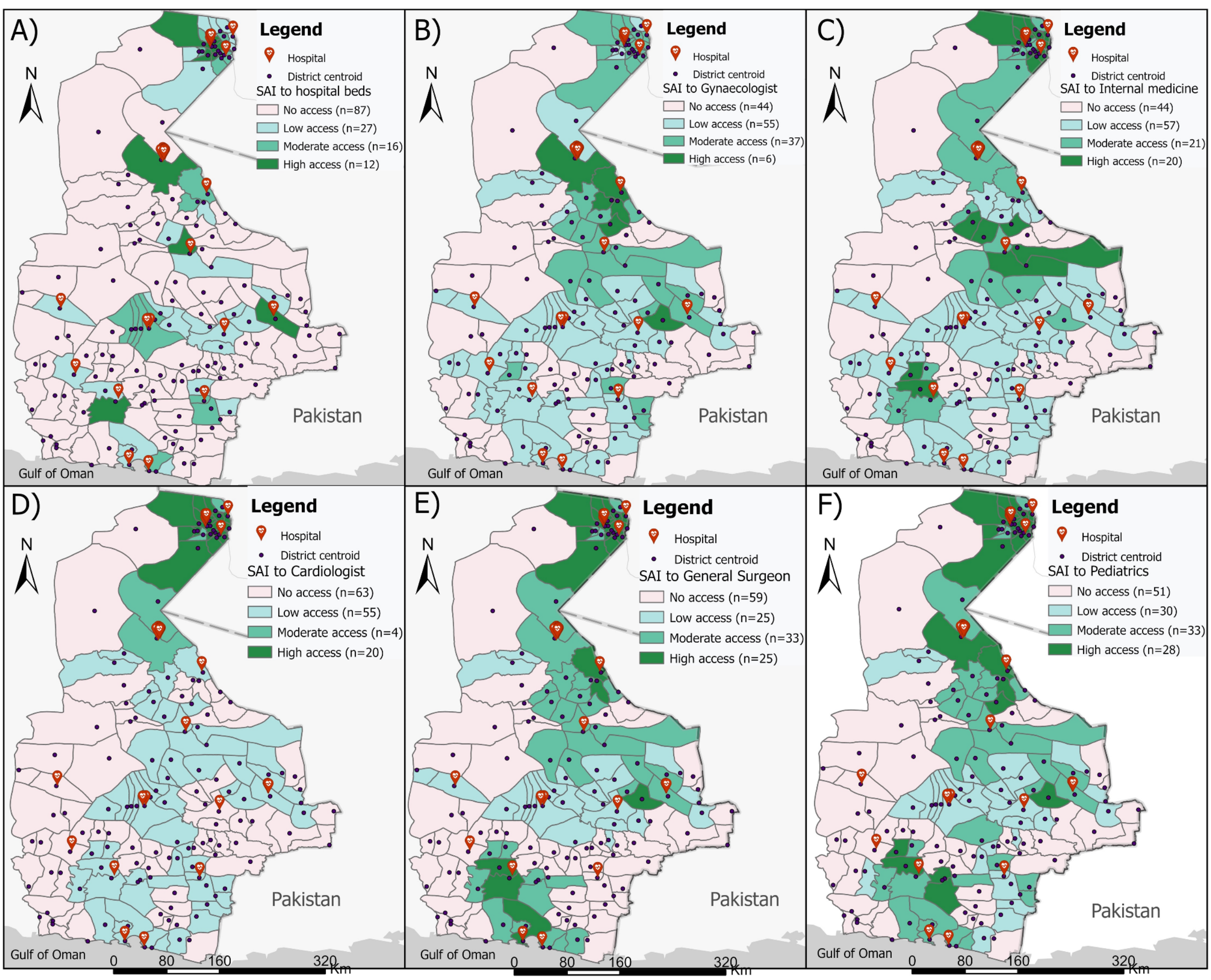

Fig. 4 Spatial accessibility index (SAI) to secondary healthcare services in Sistan and Baluchestan Province in Iran. (**A**) demonstrate the SAI to inpatient hospital beds in a 30-minute drive time. (**B-F**) present the SAI of access to five important medical specialists (Gynaecologist, Internal medicine, General Surgeon, Cardiologist, and Pediatrics) in SB Province within a 60-minute drive time

Table 3 Results of spatial accessibility index to different secondary healthcare services in Sistan and Baluchestan Province

R	Type of healthcare service	No access		Low access		Moderate access		High access	
		Population (%)	ND*	Population (%)	ND	Population (%)	ND	Population (%)	ND
1	Pediatrics	260,567 (18%)	51	275,043 (19%)	30	361,898 (25%)	33	550,085 (38%)	28
2	Gynaecologist	225,465 (15%)	44	541,119 (35%)	55	384,828 (25%)	37	392,756 (25%)	6
3	Internal medicine	478,514 (15%)	44	1,234,792 (39%)	57	1,160,437 (37%)	21	278,551 (9%)	20
4	General Surgeon	733,781 (23%)	59	483,550 (15%)	25	1,408,669 (45%)	33	526,294 (17%)	25
5	Cardiologist	722,516 (23%)	63	1,288,438 (41%)	55	770,685 (24%)	4	370,655 (12%)	20
6	Inpatient hospital beds	938,399 (30%)	87	506,641 (16%)	27	541,807 (17%)	16	1,165,447 (37%)	12

*ND: Number of districts whose accessibility index falls within that class of spatial accessibility index (SAI)

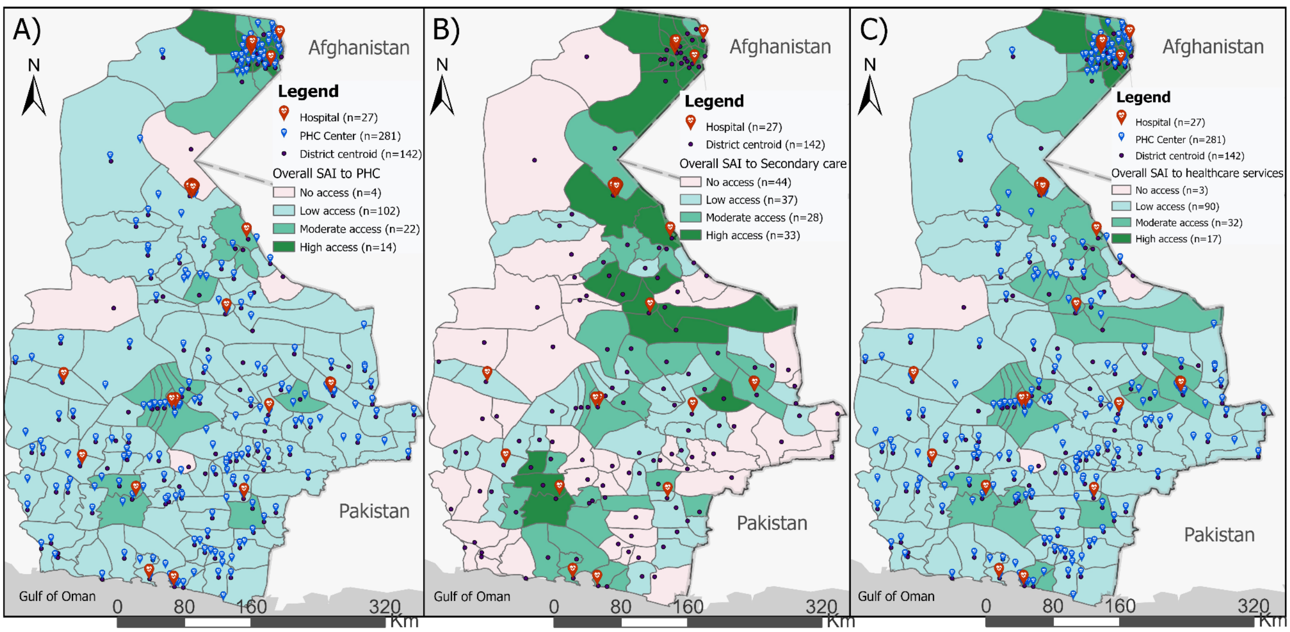

Fig. 5 The Composite Spatial Accessibility Index (CSAI) for primary, secondary, and overall healthcare CSAI in Sistan and Baluchestan Province in Iran. (**A**) displays the aggregation of SAI for different primary healthcare services. (**B**) presents the aggregation of SAI for various secondary healthcare services. (**C**) displays the aggregation of SAI to both primary and secondary healthcare services

Table 4 The results of overall composite spatial accessibility index (CSAI) to primary, secondary, and overall healthcare CSAI in Sistan and Baluchestan Province in Iran

R	Type of healthcare service	No access		Low access		Moderate access		High access	
		Population (%)	ND*	Population (%)	ND	Population (%)	ND	Population (%)	ND
1	Overall CSAI** to primary healthcare services	13,876 (0.4%)	4	2,350,659 (74.6%)	102	438,519 (13.9%)	22	349,240 (11.1%)	14
2	Overall CSAI to secondary healthcare services	478,514 (15.2%)	44	487,185 (15.5%)	37	825,142 (26.2%)	28	1,361,453 (43.1%)	33
3	Overall CSAI to healthcare services	7,050 (0.2%)	3	1,174,174 (37.2%)	90	1,606,773 (51%)	32	364,297 (11.6%)	17

*ND: Number of districts whose accessibility index falls within that class of spatial accessibility index

**CSAI: Composite Spatial Accessibility Index

substantial 74.6% of the population across 102 districts had low access to primary healthcare, while 15.5% in 37 districts have similarly low access to secondary healthcare. The overall CSAI, which combines both primary and secondary services, indicates that around one-third of the population (37.2% in 90 districts) had low overall healthcare access. Meanwhile, 51% has moderate overall access, and only 11.6% in 17 districts enjoy high spatial access to the full range of primary and secondary healthcare services necessary for basic health needs (Fig. 5; Table 4).

Inequality in healthcare access in SB province

The Lorenz curve and Gini coefficient analysis, as presented in Fig. 6 reveal high inequality in the spatial distribution of various healthcare services across SB province. For primary care services, the greatest disparities are observed in nutrition (Gini = 0.842), radiology (Gini = 0.759), and dentistry (Gini = 0.712) (Fig. 6A).

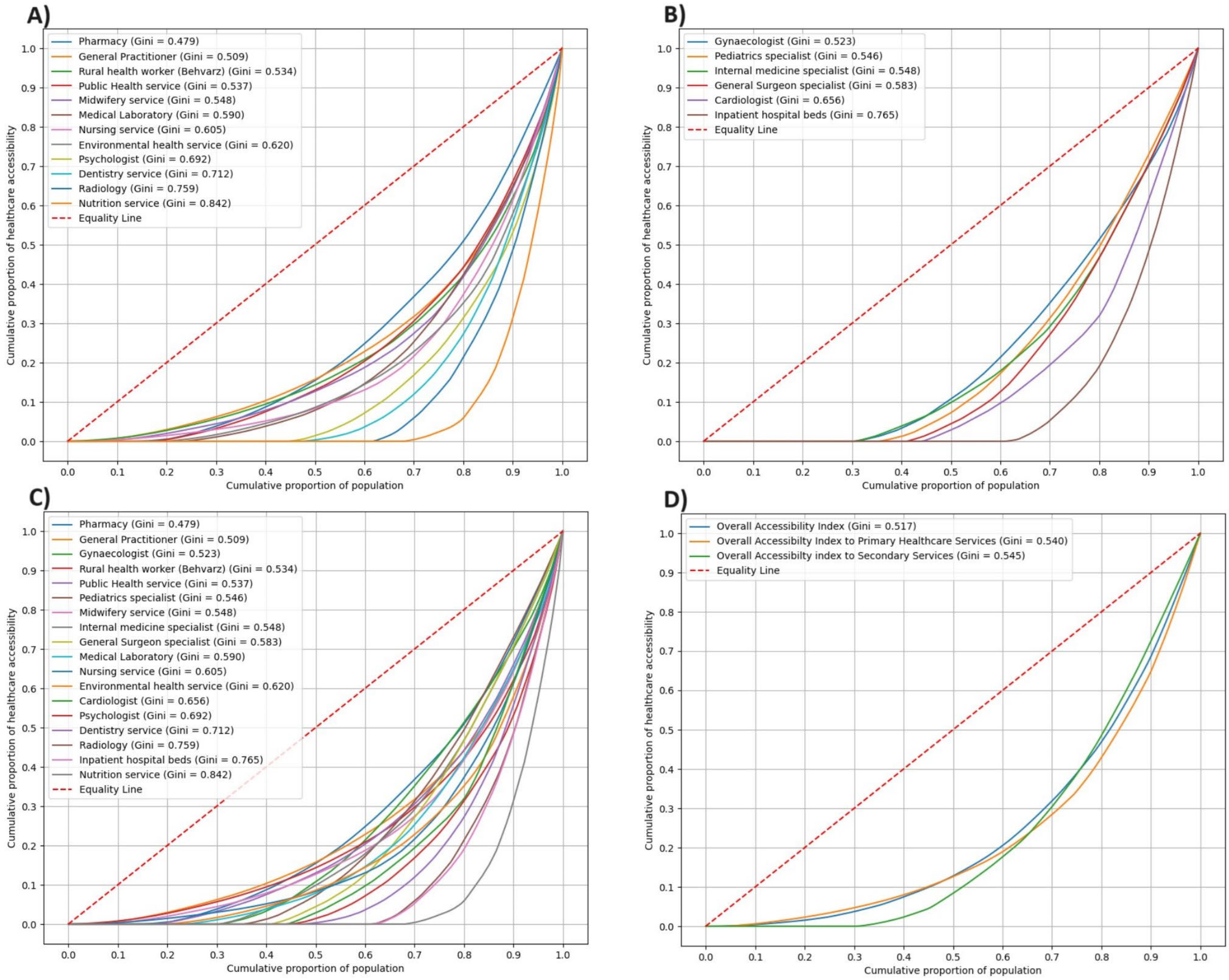

Fig. 6 Lorenz curves depicting inequality in spatial accessibility to healthcare services in Sistan and Baluchestan Province in Iran. (**A**) Lorenz curves for different types of primary healthcare services. (**B**) Lorenz curves for different types of secondary healthcare services. (**C**) Lorenz curves of primary and secondary care services. (**D**) Lorenz curve for overall spatial accessibility index

Among secondary care services, the most unequal distribution is seen for inpatient hospital beds (Gini = 0.765) and access to cardiologists (Gini = 0.656) (Fig. 6B). Comparing all primary and secondary services, nutrition, inpatient hospital beds, radiology, and dentistry stand out as the most unequally distributed healthcare resources in the province (Fig. 6C). Overall, secondary healthcare services (Gini = 0.545) exhibited slightly higher inequality in spatial distribution compared to primary care services (Gini = 0.540) within SB Province (Fig. 6D). The Gini index of the overall CSAI to healthcare services in SB Province was calculated to be 0.517.

Discussion

In this study, we developed a CSAI that aggregates measures of access to multiple healthcare service types into a single metric. This index simplifies the comparison of overall healthcare accessibility across different regions. Given the complexity of healthcare systems, which encompass a wide array of services from primary care to specialized medical treatments and hospital facilities, a composite index offers a more comprehensive and integrative method to assess spatial accessibility than individual indices for each service type. The methodology proposed here offers flexibility for further research in including or excluding specific accessibility indices, based on their study goals and context providing a robust tool for evaluating and comparing healthcare access at a systems level in different countries. The straightforward and transparent methodology, making it easily replicable in other countries by utilizing census data and the geographical locations of healthcare centers, along with following the methodology presented in this study.

Healthcare systems are inherently complex, encompassing diverse services from primary care to specialized treatments [37]. Aggregating accessibility scores into an overall CSAI allows for holistic assessments of healthcare access across a region. Such an approach facilitates comparisons between regions, identifies underserved communities, and optimizes resource allocation [7, 48]. By summarizing spatial accessibility, CSAI supports evidence-based decision-making and the design of targeted interventions for vulnerable populations.

This study provides a detailed evaluation of SAI to primary and secondary healthcare services across SB Province in Iran. The findings highlight notable geographical disparities, underscoring severe challenges in accessing healthcare in this economically disadvantaged and predominantly rural area. The results indicate alarmingly low levels of healthcare access for a substantial portion of SB Province's population. For all primary care services except pharmacy, over 50% of the population had low or no access within reasonable travel times. For secondary care, approximately 40% had low or no access to medical specialists and hospital beds. Almost 75% of the population had low or no access to overall primary care services within a 30-minute drive time. Combining both primary and secondary services, only 11.6% of the population had high spatial access, highlighting major deficiencies in healthcare accessibility across the province. These findings are consistent with previous research that identifies SB Province as underserved, characterized by inadequate infrastructure and high poverty rates [13, 14]. The study by Farzadfar et al. [15] illustrates that SB Province has the worst health profile among all provinces in Iran. In 2019, it had the lowest life expectancy at birth, highest age-standardized death rates, highest neonatal mortality rates, highest age-standardized DALY rates, and the highest DALY rates attributable to unsafe water sources, sanitation, and road traffic injuries. Additionally, SB exhibits substantial health inequalities relative to the national average on measures ranging from infectious diseases to neonatal disorders to environmental risks. Given its low life expectancy, high communicable and non-communicable disease rates, and inadequate environmental conditions, SB could be considered the least healthy province in Iran [15]. These issues are compounded by financial constraints and limited health insurance coverage, which exacerbate geographic barriers, particularly for disadvantaged populations [12, 14, 17].

Among individual primary care services, the most concerning gaps were in nutrition and dental care, with nearly 40% and 23% of the population respectively had no geographic access to these services. This lack of access negatively impacts the prevention and management of nutritional deficiencies and oral health outcomes, leading to conditions such as rampant decay in children, advanced periodontal disease, and the potential for abscesses in adults [49, 50]. Furthermore, about 30% of the SB Province's population faces a lack of access to medical radiology services within a 30-minute drive time. This issue is particularly significant as SB Province holds the highest incidence of road traffic injuries among all Iranian provinces [15]. Furthermore, over half of the population had low accessibility to general practitioners and midwifery services, which are critical for basic healthcare needs [51–53].

The nursing service achieved the highest coverage at the district level within a 30-minute drive time, while the Behvarz worker program achieved the highest coverage among primary services for the rural population in SB Province within a 20-minute drive time. However, the majority of rural populations still had low potential geographic access to Behvarz workers within their village. While Behvarz workers provide essential basic care, their limited training and scope mean they cannot fully substitute for more comprehensive primary and secondary care [54].

In secondary care, access to inpatient hospital beds and cardiologists also faced notable accessibility issues. 30% of the population had no access to hospital beds within 30 min, indicating insufficient bed capacity and maldistribution. One quarter lacked access to cardiologists within 60 min, limiting treatment options for cardiovascular emergencies. Significant travel distances reduce the utilization of hospital services and are associated with worse health outcomes [20, 55, 56]. Enhancing the availability of hospitals and secondary healthcare, along with ensuring suitable entry to primary health services, has the potential to decrease rates of infant and maternal mortality [57, 58] and improve outcomes for emergencies [59]. This can also lead to heightened utilization of healthcare services, particularly among those with chronic conditions [60]. Improving spatial access to secondary care notably enhances healthcare outcomes and overall quality of life, especially for economically disadvantaged individuals with restricted incomes [2].

Analysis of the Lorenz curves and Gini indices reveals a highly unequal distribution of healthcare resources across SB Province. First, both primary and secondary healthcare services exhibit high levels of inequality, with secondary services showing even greater overall inequality (Gini coefficient 0.545 vs. 0.540). This aligns with previous studies indicating secondary and hospital care are more unevenly distributed than primary care [45]. Services such as nutrition, radiology, and dentistry at the primary care level, and inpatient hospital beds and cardiovascular specialists at the secondary care level, are among the most unequally distributed. The results of Mojiri and Ahmadi's study [61] showed that the medical specialists and inpatient hospital beds had the highest rates of unequal access, while, physicians and laboratories had the lowest rates. The spatial inequality in these basic healthcare resources highlights major gaps in healthcare access for certain populations within the province.

The overall CSAI for the province has a Gini coefficient of 0.517 indicating a moderately high level of inequality suggesting that many residents across the province likely lack adequate healthcare access. Targeting resources and facilities to address these types of geographic inequities could help improve population health equity. Equitable distribution of healthcare resources in geographically dispersed areas, like SB Province, can improve healthcare indicators, especially in regions with socio-economic challenges [2, 57, 59, 60]. Urgent strategies are needed to expand healthcare access in identified underserved districts. Increasing capacity and availability of primary and secondary services should be prioritized in underserved districts identified by this analysis. Establishing more rural healthcare centers and outreach services could improve local access to primary care, while strategically locating additional hospital beds and specialist providers can shorten travel distances.

To improve healthcare access in underserved regions, governments should develop scholarship programs and career advancement incentives aimed at recruiting and retaining local health professionals willing to work in their communities in the long term. Furthermore, transportation assistance programs may also help patients reach distant facilities. Beyond infrastructure, boosting health insurance and financial protection will be critical to transforming potential access into realized utilization and better outcomes [62].

The CSAI presented in this study effectively evaluates the overall geographic accessibility of healthcare services. However, several critical factors were not considered, which may influence realized access. These include non-spatial barriers such as affordability, acceptability, and accommodation [63]. Additionally, transportation challenges remain a key limitation, as poor infrastructure in rural and remote areas restricts physical access despite spatial proximity. Furthermore, access maybe influenced by the health protection schemes that available to the population, with disparities in insurance coverage affecting individuals' ability to access care. The combined impact of these geographic and systemic factors exacerbates healthcare disparities, particularly for vulnerable populations in rural and underserved areas [64, 65]. Future studies could explore targeted strategies to address these challenges and improve healthcare accessibility in underserved regions. One area of investigation could focus on the impact of expanding health insurance coverage to reduce financial barriers, particularly for low-income populations. Another potential avenue for research is the effectiveness of initiatives aimed at attracting and retaining healthcare professionals in underserved areas, such as offering financial incentives, scholarships, and professional development opportunities, to address workforce shortages. Additionally, future research could examine the role of improved transportation infrastructure and subsidized patient transport services in mitigating access issues for remote populations. Telehealth services represent another promising area of study, particularly their potential to provide virtual consultations and specialist care that bypass geographic barriers. Finally, further investigation is warranted into the benefits of cultural competency training for healthcare providers to ensure services are acceptable and responsive to the diverse needs of the population [21, 65–67]. By exploring these measures, future research could provide valuable insights into other components of healthcare access beyond spatial access, which was the focus of this study. These studies could help identify additional strategies to further reduce inequities and promote more equitable access to healthcare services in SB Province.

Strengths and limitations

This study provided a comprehensive evaluation of potential spatial accessibility across diverse primary and commonly needed secondary healthcare services using the robust E2SFCA method. The E2SFCA method is widely regarded for its ability to effectively measure spatial accessibility by incorporating both the supply and demand of healthcare services within defined catchment areas. Combining the accessibility scores into an overall composite index represents a novel method for identifying gaps and monitoring improvements in healthcare access over time. This comprehensive index allows for a holistic view of healthcare accessibility, offering insights into where interventions may be most needed.

Additionally, the use of normalization and discrete categories for mapping greatly enhanced the visualization and identification of underserved communities requiring targeted access improvements. By normalizing the data, we compared the geographic distribution of access across various service types that were originally measured using different parameters. Dividing this normalized scale into four distinct categories (no access, low, moderate, and high access) provided a clear and actionable framework for policymakers and healthcare planners. These categories assigned a semantic meaning that clearly denotes actionable thresholds, making the findings more accessible and practical for decision-making.

Several limitations should be noted when interpreting the findings of this study. First, the analysis exclusively focused on geographic accessibility based on travel impedance without considering non-spatial barriers such as affordability and cultural acceptability or healthcare quality. Access to healthcare is multifactorial, involving spatial, socio-demographic, and cultural aspects, this study specifically addresses the spatial accessibility of healthcare services. While geographic accessibility is a crucial component, incorporating non-spatial factors in future research could provide a more holistic understanding of healthcare access.

Second, healthcare quality, which may significantly impact the utilization of accessible services, was not considered in this study. Access to healthcare does not guarantee the quality of services received, and poor quality can deter individuals from seeking care even if services are geographically accessible.

Third, the results depict potential rather than realized access. This means that while healthcare services might be geographically accessible, actual usage patterns were not examined. Surveying actual healthcare usage could reveal if transportation difficulties or other barriers translate to foregone care.

Fourth, the study only assessed and compared healthcare accessibility within SB Province. The results do not enable benchmarking district access levels against national standards across Iran. Therefore, areas rated as having "high" access for the province may still exhibit poor geographic access when compared on a national scale. Caution is required when generalizing the findings more broadly or using them to advocate for resources relative to other Iranian provinces. Further national-level studies are needed for appropriate context about SB's healthcare access gaps compared to the rest of Iran.

Fifth, this study did not associate the accessibility findings with health indicators. While identifying areas with poor healthcare access is crucial, linking these findings to health outcomes could provide stronger evidence for targeted interventions. Further research could explore if underserved districts exhibit worse population health metrics, thereby strengthening the case for resource allocation.

Sixth, possibility of potential biases regarding data sources. The accuracy of the population data relies on the reliability of the census and updates from OpenStreetMap, which may contain discrepancies or inaccuracies, particularly in remote or rural areas. The mathematical geometric increase method used to project the 2016 population data to 2022 may introduce biases if actual population growth deviates from the projected trend. Furthermore, the road network data from OpenStreetMap may have limitations in completeness and accuracy, affecting travel time calculations and accessibility scores. The healthcare facility data, sourced from governmental records, may not capture all private or informal providers and may not reflect real-time changes or temporary closures, potentially leading to underestimation or overestimation of healthcare accessibility. These factors collectively highlight the need for cautious interpretation of the spatial accessibility indices and underscore the importance of considering potential biases in future research.

Finally, the study focused on common essential primary and secondary health services required universally. While this approach covers a broad range of major health needs, incorporating accessibility for additional specialized secondary and tertiary care could enrich the analysis and potentially alter the overall access index, especially for the provincial capital area where these services are concentrated. However, scores for other districts would likely remain unchanged. Including more specialized services in future studies could provide a more comprehensive measure of healthcare access across all levels of care.

Conclusion

This study demonstrates a useful replicable methodology that combines individual service accessibility metrics into an overall spatial healthcare access index for assessing and comparing healthcare access across different regions. Therefore, through using robust GIS-based methods, this study offers compelling evidence of alarmingly low and inequitable geographic accessibility to healthcare across SB Province. The lack of access is most severe for secondary care services, such as hospital beds and specialists, but is also inadequate for nearly all primary care services.

The analysis using Lorenz curve and Gini coefficient further underscores the highly unequal distribution of healthcare services across the province. Secondary care, along with nutrition and dental services, shows the greatest disparities in accessibility. The findings are important as Iran strives to achieve universal health coverage and meet its sustainable development goals. The severe and inequitable access to healthcare services identified in this study indicates a pressing need for targeted interventions. Urgent strategies are needed to expand healthcare availability and capacity in the districts with the poorest access identified in this study.

Abbreviations

SB	Sistan and Baluchestan
SDG	Sustainable Development Goals
UHC	Universal Health Coverage
GIS	Geographic Information System
2SFCA	Two-Step Floating Catchment Area
E2SFCA	Enhanced Two-Step Floating Catchment Area
SAI	Spatial Accessibility Index
CSAI	Composite Spatial Accessibility Index
HDI	Human Development Index
DALY	Disability-Adjusted Life Year
ND	Number of districts
PHC	Primary Health Care

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Author contributions
MT, BK, and AR designed the study. MT and BK supervised the project. AR and NS collected the data, and prepared data for analysis. AR, MT, and SH analyzed and interpreted data. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Approval for this study was obtained from the Research Ethics Committees of Mashhad University of Medical Sciences (ID: IR.MUMS.REC.1400.272).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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