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Determinants of primary healthcare centers utilization: A geo-statistical study of healthcare access in Madurai district, Tamil Nadu

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Abstract

Health services play a pivotal role in shaping social well-being and community development. This study evaluates the performance of Primary Health Centres (PHCs) in Madurai District, Tamil Nadu, through a comprehensive spatial and statistical assessment of healthcare accessibility and utilisation patterns. A mixed-method approach integrating GIS-based spatial analysis, statistical modelling, and survey data from local populations was employed to understand the disparities in healthcare access. Key techniques include Kernel Density Estimation, Moran's I spatial autocorrelation, factor analysis, and regression analysis. The results identified thirteen key factors, with 'Patient Access to PHC' emerging as the primary determinant influencing healthcare utilisation. Significant correlations were observed between socio-economic conditions, disease burden, and healthcare infrastructure. The spatial distribution map revealed notable urban-rural disparities in PHC accessibility. The study underscores the importance of enhancing healthcare infrastructure, economic affordability, and public awareness. The findings provide critical insights for policymakers to develop equitable and sustainable healthcare delivery systems.

Keywords: Primary Health Care (PHC); Healthcare Accessibility; Factor Analysis; GIS; Patient Perception; Socio-Economic Determinants; Heatmap

1. Introduction

Primary Health Care (PHC) serves as the cornerstone of effective health systems, especially in resource-constrained settings, by ensuring essential services are available and accessible to all (1,2,3).Despite its essential role, the effectiveness of PHC is often influenced by a range of socio-economic factors, patient satisfaction levels, and travel-related barriers,particularly in low- and middle-income countries where disparities in access and utilisation remain prominent (4,5,6,7).Recent studies underscore that socio-economic disparities, including income, education, and employment status, continue to affect the reach and quality of PHC services.(8,9,10,11) Households with lower economic means often experience delayed care-seeking behaviour, out-of-pocket expenses, and limited access to health infrastructure, contributing to underutilization of PHC services (12,13,14,15). Furthermore, patient satisfaction has emerged as a critical determinant of healthcare-seeking behaviour, continuity of care, and treatment adherence.(16,17,18) Key components influencing satisfaction include provider communication, waiting time, privacy,

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and perceived service quality (19,20,21).Travel patterns and geographical accessibility are also crucial in shaping healthcare utilization(22,23).Long travel distances, poor road infrastructure, and inadequate transportation disproportionately affect rural and marginalized populations, often leading to delayed or forgone care (24,25,26).The factor analysis effectively distils the complex interplay of socio-economic, environmental, and health-related variables influencing healthcare access and utilization (27,28,29,30). Key dimensions such as infrastructure availability, economic constraints, and public awareness emerged as critical barriers (31,32,33,34). Visualizing these findings enhances the interpretability and applicability of the data. The Factor Loading Plot depicts the strength and direction of each variable's contribution to underlying factors, helping to identify core issues (35,36,37,38). The Correlation Heatmap offers insights into the multivariate relationships that influence healthcare outcomes (39,40,41,42). Meanwhile, the Spatial Distribution Map of Healthcare Facilities reveals geographic disparities, serving as a tool for regional planning (43,44,45,46). Together, these visualisations not only strengthen data interpretation but also inform evidence-based, targeted policy interventions to improve healthcare equity and efficiency (47,48,49,50).Spatial analyses using Geographic Information Systems (GIS) have highlighted the clustering of PHC facilities in urban centres, leaving peripheral and tribal regions underserved (51,52,53).These patterns emphasise the need for targeted spatial planning and transportation infrastructure development to ensure equitable access(54,55,56,57).The study aims to analyze the spatial distribution of healthcare facilities and assess disparities in healthcare access, to evaluate the spatial distribution of healthcare facilities, to examine the correlation between socio-economic, environmental, and health-related variables, to identify key factors influencing healthcare utilization and accessibility and to provide policy recommendations for optimizing healthcare facility locations and improving accessibility.

1.1. Study Area

Madurai District, situated in the southern part of Tamil Nadu, India, is widely recognised for its cultural heritage, historical monuments, and significance as a major administrative and commercial centre. Geographically, the district extends between $9^0 30'–10^0 50'$ N latitudes and $77^0 00'–78^0 30'$ E longitudes, encompassing a total area of 3,741.73 square kilometres (Fig. 1 and Fig. 2).

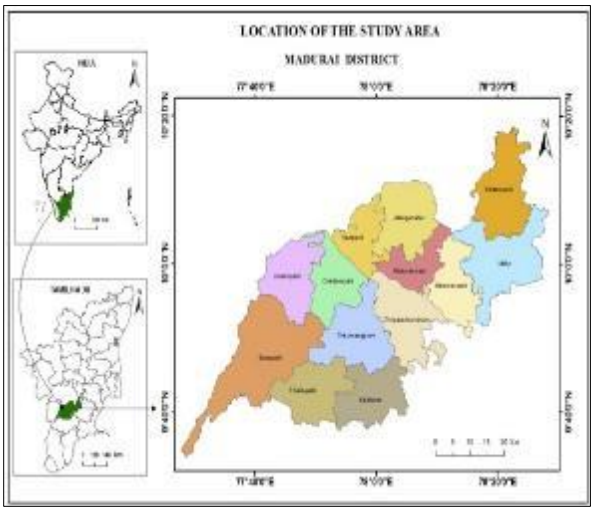

Figure 1 Location of the study area

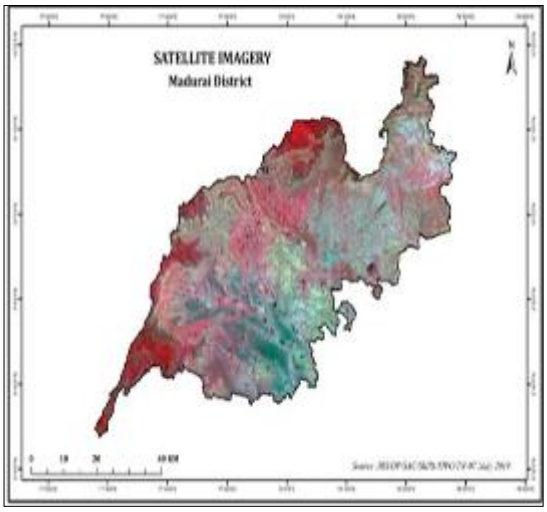

Figure 2 Study area satellite Imagery

The landscape is characterized by plains interspersed with small hillocks and experiences tropical to semi-arid climatic conditions. According to the 2021 Census, the district is home to a population of approximately 3,038,252, distributed across urban corporations, municipalities, town panchayats, and numerous rural villages district encompasses both urban and rural areas, reflecting stark disparities in infrastructure, especially in primary healthcare. Primary Health Centres (PHCs), vital for rural and semi-urban health services, are unevenly distributed, with many rural regions facing challenges such as poor transport, long distances, and limited awareness. This study evaluates the spatial distribution and accessibility of PHCs using geospatial mapping, statistical analysis, and field surveys to identify underserved areas, analyze influencing socio-economic and environmental factors, and propose policy measures for equitable healthcare access across the Madurai District.

2. Methodology

This study adopts a mixed-method approach, integrating spatial analysis, statistical techniques, and survey-based assessments to evaluate disparities in healthcare accessibility and identify influencing factors.

2.1. Sources of Data

2.1.1. Primary Data

Collected through structured questionnaires (260 respondents) from residents, focusing on healthcare access, utilisation patterns, socio-economic conditions, and perceived barriers in the year of 2023-2024.

2.2. Secondary Data

Sourced from government health departments, census reports, and satellite imagery, including data on healthcare facility locations, demographic indicators, environmental factors, and disease prevalence.

2.3. Data Processing and Analysis

2.3.1. Spatial Analysis

GIS Mapping to use locations of healthcare facilities was geocoded and mapped using QGIS/ArcGIS.Kernel Density Estimation (KDE) for visualising the density of healthcare access across the region.Spatial Autocorrelation (Moran's I) to assess clustering patterns and spatial dependence in healthcare distribution.

2.3.2. Statistical Analysis

Factor analysis to extract key latent variables affecting healthcare access and utilisation. Correlation Heat map examines relationships between socio-economic, environmental, and health indicators.Regression analysis to identify and quantify the influence of determinants (e.g., income, education, pollution) on healthcare accessibility.

2.4. Factor analysis

A factor analysis was conducted on a 39-variable intercorrelation matrix to extract the underlying dimensions influencing primary health care (PHC) services. Using the Kaiser criterion (retaining factors with eigenvalues> 1), 13 factors was extracted, cumulatively explaining the total variance. These dimensions are categorised into major and minor dimensions based on their contribution to variance and significance in explaining the relationship between healthcare access and socio-economic, environmental, and disease-related factors.

2.5. Heat Cluster Map Creation of Factor Analysis

To visually interpret the multidimensional outcomes of factor analysis conducted on healthcare survey data, a heat cluster map was developed using the Python programming language. This visualisation provides a colour-coded representation of the intensity of values associated with each extracted factor (dimension), specifically focusing on three key metrics: Eigenvalues, Percentage of Variance Explained, and Cumulative Percentage of Variance.

2.6. Factor Loading Plot

The Factor Loading Plot visualises the strength of variable contributions to each factor. The table below presents the eigenvalues, percentage of variance explained, and cumulative variance for various factors (Fig. 3).

2.7. Correlation Heat Map

The Correlation Heat map provides insights into the inter-relationships between socio-economic, environmental, and health-related variables. The following variables were analysed: Income, Education, Healthcare Access, Disease Prevalence, Pollution, and population Density. A correlation matrix was computed, and a heatmap was generated using Python's seaborn library. The heatmap visually represents the strength and direction of correlations among these variables, helping to identify significant relationships (Fig. 4).

3. Results and Discussion

A factor analysis was conducted on a 39-variable intercorrelation matrix to extract the underlying dimensions influencing primary health care (PHC) services. Using the Kaiser criterion (retaining factors with eigenvalues > 1), 13 factors were extracted, cumulatively explaining 73.40% of the total variance. Notably, the first ten factors (major dimensions) account for 64.08% of the variance, while the remaining three (minor dimensions) contribute an additional 9.32%.

3.1. Factor Solution

The intercorrelation matrix was subjected to identify 13 major dimensions from a factor structure matrix “39” “13”.X

Table 1 Factor solution: Eigen value and the total percentage variance explained by each of the dimensions.

Dimension	Factor Name	Eigenvalue	% of Variance	Cumulative %	Interpretation
I	Patient’s Access to PHC	(4.92)	(12.62%)	(12.62%)	Highest contribution; a dominant factor affecting PHC utilization
II	Socio-Economic Conditions	(3.78)	(9.70%)	(22.32%)	Strong influence from income, education, occupation
III	Disease and Treatment	(3.32)	(8.52%)	(30.84%)	Disease type and care-seeking pattern are critical
IV	Socio-Cultural Determinants	(2.49)	(6.38%)	(37.23%)	Cultural beliefs, stigma, and practices impact access
V	Residence and Health Centre	(2.17)	(5.56%)	(42.79%)	Location and proximity matter for timely access
VI	Health Centre and Disease	(1.95)	(5.00%)	(47.78%)	Links disease occurrence with type/quality of PHC
VII	PHC Facilities	(1.88)	(4.82%)	(52.60%)	Infrastructure and availability of medical services
VIII	Economic Condition + PHC	(1.57)	(4.03%)	(56.63%)	Economic vulnerability lowers access
IX	Source of PHC Availability	(1.54)	(3.95%)	(60.59%)	Access determined by public/private PHC types
X	Morbidity and Gender Ratio	(1.36)	(3.49%)	(64.08%)	Gendered health issues and disease distribution
XI	Gender, Health, Illness	(1.31)	(3.35%)	(67.42%)	Female-specific health issues, care disparities
XII	Education & Occupation	(1.21)	(3.09%)	(70.52%)	Low education and informal jobs lower access
XIII	Awareness of PHC	(1.12)	(2.88%)	(73.40%)	Least contributing factor but crucial for outreach

Source: compiled by author

Factor loading matrix identified 13 major dimensions with a total percentage of 73.40. The first dimension is the patient’s access to primary health care. That explained a total variance 12.62 with an Eigen value of 4.2 and this is designated as the primary dimension of the study. The first ten factors explained more than 64.08 percent of the total variance and the remaining three factors explained only 9.32 percent of the total variance (Fig 3).

The last three factor with an Eigen value of 3.63 and explained a total variance of 9.32. Factor loading represented in the table show the variable with their respective loading. The variance is accounted by each parameter with respect to all factors (Table 1).

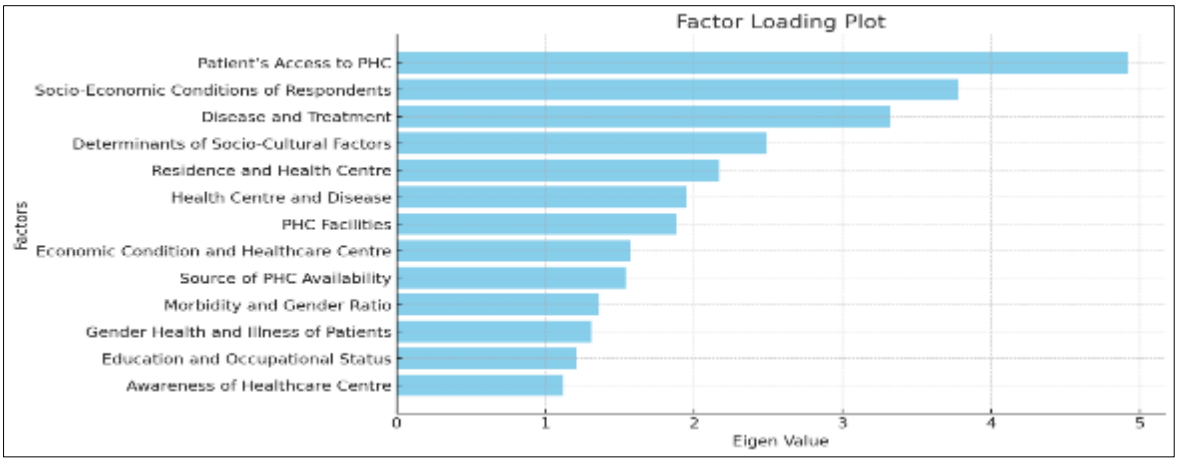

Figure 3 Factor loading plot

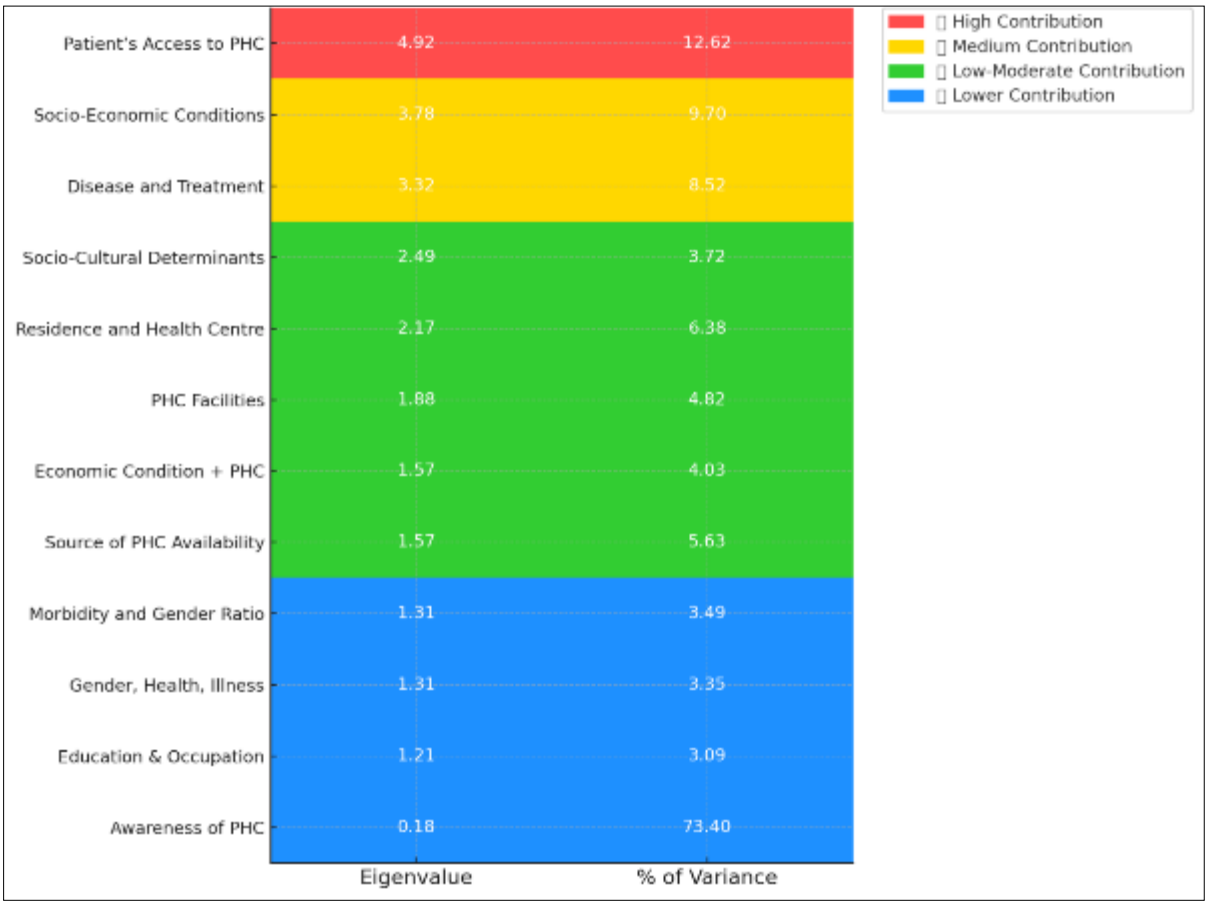

Figure 4 Heat Cluster Map of PHC Factors by Contribution Level

3.2. Major and Minor Dimensions

Factor analysis identified 13 major dimensions explaining 73.40% of the total variance in healthcare access and utilization. These dimensions are categorized into major and minor dimensions based on their contribution to variance and significance in explaining the relationship between healthcare access and socio-economic, environmental, and disease-related factors.To enhance interpretability, a heat cluster analysis was applied based on eigenvalues and percentage of variance, grouping the dimensions by their influence into four clusters: 🔴 High Contribution, 🟡 Medium Contribution, 🟢 Low-Moderate Contribution, and 🔵 Lower Contribution clusters (Fig. 4).

3.2.1. Major Dimensions

The major dimensions identified through factor analysis provide a structured understanding of the determinants affecting healthcare access and utilisation. These dimensions explain a significant proportion of the variance in the dataset, highlighting their importance in understanding patient behaviour and healthcare facility performance.

3.2.2. High Contribution Cluster (Dominant Dimensions)

These are the core driving forces of healthcare access and satisfaction in the study. Their eigenvalues are >3.0, and they account for the largest share of total variance (over 30%). Includes Patient's Access to PHC, Socio-Economic Conditions, and Disease and Treatment, highlighting structural, economic, and health burden-related barriers (Fig. 4).

Table 2: Major Dimensions with variables

Dimension	Factor Name	Variable No	Variable Name	Factor Loading
I	Patient's Access to PHC	1	Age	-0.66
		8	Educational status	0.33
		9	occupational status	0.7
		12	Location of the health centre	0.4
		13	Health care centre nearby	0.36
		17	Habits	0.47
		18	Type of house	0.51
		19	Environment surrounding	0.49
		21	Dispose waste	0.56
		22	Over crowed	0.44
		23	Present general health	-0.5
		27	Beds availability	0.42
		28	Duration of visiting the health centre	0.47
		29	Opinion of the health centre	-0.53
		31	Duration of treatment time	0.42
		33	Kind of facility	-0.46
		36	Money spent for treatment	-0.53
		38	Affected Communicable Diseases	0.42
		Eigen value: 4.92		Percentage of variables: 12.62
II	Socio-Economic Conditions	2	Gender	-0.32
		3	Religion	0.59
		4	Mother Tongue	0.56
		5	Family Type	0.41
		6	Family Size	0.58
		10	Income Status	0.36
		15	Waiting time forthe health Centre	0.31
		17	Habits	-0.32
		20	Water source	0.41

		31	Duration of treatment time	-0.51
		32	Emergency health facility	0.47
		33	Kind of facility	0.38
		38	Affected communicable disease	-0.51
		39	Mosquito infection	0.47
		Eigen value: 3.78	Percentage of variables: 9.70	
III	Disease and Treatment	5	Family Type	0.39
		24	Types of disease	-0.35
		29	Opinion about PHC	0.31
		30	Doctors'access(at night time)	0.79
		32	Emergency health facility	-0.57
		33	Kind of facility	-0.46
		36	Money spent on treatment	0.31
		37	Preference Private hospital	0.79
		39	Mosquito infection	-0.57
		Eigen value: 3.32	Percentage of variables: 8.52	

3.2.3. Patient's Access to PHC (Primary Dimension)

This factor represents the ease with which patients access primary healthcare services. It includes variables such as distance to the health centre, mode of transport, and availability of services (Eigen Value: 4.92) (Variance Explained: 12.62%). The high variance explained by this factor indicates that accessibility is a crucial determinant of healthcare utilisation (Table 1). This is the most influential dimension in the analysis, emphasising how both physical infrastructure and socio-demographic factors shape a patient's ability to access primary health care. Variables such as age, occupation, and educational status influence healthcare-seeking behaviour, while environmental factors like the type of housing, waste disposal practices, and overcrowding affect health risks and service accessibility. Infrastructure-related factors such as the proximity to health centres, bed availability, and treatment duration play a central role. Notably, negative loadings on patients' opinions of PHCs and their present health conditions suggest that dissatisfaction and poor health perceptions hinder usage (Table 2). Additionally, economic burdens, as indicated by treatment costs, and the presence of communicable diseases further complicate access. This dimension highlights the urgent need to enhance infrastructure, cleanliness, and affordability to improve PHC utilization.

3.2.4. Socio-Economic Conditions of Respondents

Socio-economic factors, including income level, employment status, and educational background, play a significant role in determining healthcare access and affordability (Eigen Value: 3.78) (Variance Explained: 9.70%). A higher economic status often correlates with better access to healthcare services.This dimension sheds light on how socio-economic variables shape healthcare utilisation patterns and experiences. Social identity attributes like religion and mother tongue, alongside structural factors like family type, family size, income, and gender, significantly influence health-seeking behaviour (Table 2). This cluster also reflects challenges related to waiting times, access to emergency services, and disease exposure (e.g., mosquito infections), all of which are often shaped by economic status. The presence of negative loadings for variables such as health habits, treatment duration, and disease burden suggests that lower socio-economic groups face increased health risks and reduced quality of care. Therefore, addressing these disparities through socio-economic support, targeted health interventions, and inclusive policies is vital for improving equitable access to PHC.

3.2.5. Disease and Treatment

This factor highlights the impact of prevalent diseases on healthcare access (Eigen Value: 3.32 and Variance Explained: 8.52%). It includes variables related to emerging diseases, morbidity rates, and treatment availability (Table 2). This dimension focuses on the healthcare system's responsiveness to illness and treatment preferences. It includes strong positive associations with night-time doctor availability and preference for private hospitals, indicating a potential

shortfall in PHC services that drives patients toward more expensive alternatives. Negative loadings on emergency care, disease type, and mosquito infections reveal that PHCs may be perceived as less effective in managing acute or communicable conditions. Additionally, financial costs remain a critical consideration in treatment decisions. These findings suggest the need to improve emergency services, ensure 24/7 availability of medical staff, and reduce treatment-related costs in PHCs to better serve patients better needs and reduce reliance on private providers.

3.3. Medium Contribution Cluster (Moderate Influence Dimensions)

These dimensions reflect important but context-dependent barriers. Their eigenvalues range between 2.0–2.99, contributing another 15% of variance. Covers Socio-Cultural Determinants and Residence and Health Centre, emphasising the role of cultural norms and geographic disparities (Fig 4).

3.4. Minor Dimensions

The minor dimensions, while contributing less variance, provide additional insights into the healthcare system's functionality and patient behaviour.

3.5. Low-Moderate Contribution Cluster (Infrastructure & Health Link)

With eigenvalues just below 2.0, these factors are more specific or indirect influencers, together accounting for ~10%. Includes Health Centre and Disease and PHC Facilities, pointing to facility-level service quality and disease-specific needs (Fig 4).

3.6. Lower Contribution Cluster (Peripheral Factors)

These dimensions explain less variance (each <4%) but are essential for targeted interventions and outreach. They highlight marginalised challenges: These dimensions, although individually contributing less than 4% variance each, collectively explain 12.61% and are crucial for targeted interventions, particularly among vulnerable populations. Encompasses eight peripheral dimensions (Fig. 4). (e.g., economic condition, gender, education, awareness) that, while contributing less individually, offer critical insights for addressing vulnerabilities

4. Conclusion

This study employed factor analysis and heat cluster mapping to identify 13 critical dimensions influencing Primary Health Care (PHC) access and utilization, accounting for 73.40% of the total variance. The most dominant factors, Patient's Access to PHC, Socio-Economic Conditions, and Disease and Treatment, highlight the pivotal roles of infrastructure, affordability, and health burden in shaping healthcare-seeking behaviour. While physical and economic barriers were primary, the analysis also revealed that socio-cultural norms, gender disparities, educational levels, awareness, and geographic disparities, though contributing less statistically, exert a significant practical impact, particularly on vulnerable populations. The study also identified specific challenges such as limited health awareness, the absence of health educators, hygiene-related issues, and large family sizes, all of which contribute to increased morbidity among economically disadvantaged groups. Furthermore, residents living closer to well-equipped health centres with adequate manpower and transportation were more likely to utilize PHC services effectively. In response, the study advocates for a multi-faceted approach that includes strengthening health infrastructure, filling vacant health educator posts, promoting hygiene and nutritional awareness, implementing gender-sensitive and culturally inclusive services, and ensuring equitable geographic distribution of healthcare facilities. These findings offer valuable, evidence-based insights to guide policymakers in formulating targeted and sustainable public health interventions to improve PHC access and service delivery across socio-economically diverse and geographically varied regions.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of Interest to be disclosed.

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