

Spatial Equity and Locational Performance of Primary Health Centres (PHC's) in Ri-Bhoi District, Meghalaya

V. Saravanabavan¹; Gigilinda Marpna²; C. Vinothini³

¹Department of Geography, School of Human and Environmental Sciences, North Eastern Hill University, Shillong, Meghalaya, India

²Department of Geography, School of Human and Environmental Sciences, North Eastern Hill University, Shillong, Meghalaya, India

³Department of Geography, School of Earth and Atmospheric Sciences, Madurai Kamaraj University, Madurai, Tamilnadu, India

Publication Date: 2026/09/25

Abstract: This study evaluates the spatial equity, locational efficiency, and service performance of Primary Health Centres (PHCs) in Ri Bhoi District, Meghalaya. Utilizing a dual-analytical approach, Geographic Information System (GIS) tools and Nearest Neighbour Analysis (NNA) were applied to examine the spatial distribution of the district's health facilities, while a multi-criteria Z-score standardisation was employed to evaluate the clinical and operational performance of five selected PHCs (Byrnihat, Umden, Marngar, Mawhati, and Kyrдем) across 12 infrastructure indicators. To capture the user perspective, a household survey of 100 respondents was conducted to assess physical and financial accessibility. The NNA yielded a Nearest Neighbour Ratio (Rn) of 1.81, indicating a statistically significant uniform (dispersed) spatial arrangement of health facilities designed to maximize territorial coverage. However, significant regional imbalances were observed between the sparse, isolated western region and the denser eastern health network. Z-score standardisation revealed major performance disparities. Byrnihat PHC emerged as the top-performing centre (Composite Z-Score: +9.13), characterised by a strong clinical workforce and high patient utilization. Conversely, Umden PHC ranked lowest (Composite Z-Score: -3.67), constrained by severe staffing shortages and service underutilization despite high bed capacity (12). This study highlights the need for targeted infrastructural upgrades, manpower redistribution, and the integration of GIS spatial analytical models into decentralised healthcare planning to ensure equitable and efficient healthcare delivery.

Keywords: Spatial Distribution, Nearest Neighbour Analysis, Z-Score Standardisation, Healthcare Accessibility.

How to Cite: V. Saravanabavan; Gigilinda Marpna; C. Vinothini (2026) Spatial Equity and Locational Performance of Primary Health Centres (PHC's) in Ri-Bhoi District, Meghalaya. *International Journal of Innovative Science and Research Technology*, 11(9), 1365-1377. <https://doi.org/10.38124/ijisrt/26sep468>

I. INTRODUCTION

Primary Health Centres (PHCs) constitute an important component of primary healthcare delivery, particularly in rural and geographically dispersed regions (1,2). They provide essential preventive, promotive, curative and referral services and serve as an important link between rural communities and higher-level healthcare institutions (3-5). The effectiveness of a primary healthcare network, however, depends not only on the number of facilities available but also on their geographical distribution, human resources, infrastructure and service capacity (6-8). Consequently, examining the spatial organization and relative performance of PHCs is important for understanding the adequacy of primary healthcare provision (9,10). The location of healthcare facilities has a direct spatial dimension because the distribution of PHCs determines the

geographical spread of primary healthcare services (11-13). When facilities are concentrated in particular areas, some settlements may have greater access to healthcare while geographically isolated communities may have fewer nearby facilities (14,15). In contrast, a relatively dispersed network may provide wider territorial coverage. Therefore, identifying the spatial pattern of PHCs is an important first step in evaluating the organization of primary healthcare services (16-18).

Geographical Information System (GIS) and spatial statistical techniques provide effective approaches for examining the distribution of healthcare facilities (19,20). Among these techniques, Nearest Neighbour Analysis (NNA) is particularly useful for analysing the spatial arrangement of point-based facilities (21-23). NNA compares the observed average distance between each

facility and its nearest neighbouring facility with the expected distance under a random spatial distribution. However, the spatial distribution of facilities alone does not provide a complete assessment of healthcare provision. A PHC may occupy an important geographical location but differ substantially from another PHC in terms of staffing, infrastructure, bed strength, patient utilization and population coverage (24-26). Consequently, spatial distribution and facility performance represent two distinct but complementary dimensions of healthcare planning. An assessment based only on facility locations may therefore overlook important differences in the functional capacity of individual PHCs (27,28).

Healthcare facilities are characterized by multiple indicators measured in different units and scales (29,30). For example, the number of doctors and nurses represents human-resource availability, beds represent physical capacity, while inpatient and outpatient attendance reflect service utilization^(31,32,33). Direct comparison of these variables is difficult because of their different measurement scales. Z-score standardization converts the indicators into a common statistical scale by expressing each value in relation to the mean and standard deviation of the selected PHCs(31-34). The magnitude of the Z-score indicates the degree to which a PHC differs from the group average (35-37). By combining the standardized scores of multiple indicators, a composite standardized performance score can be developed to compare the overall relative performance of selected PHCs (38-40). This approach enables differences in human resources, infrastructure, service utilization and geographical coverage to be examined simultaneously (41-43). The integration of NNA and Z-score analysis is particularly valuable because the two methods address different analytical questions (44-46). A dispersed spatial pattern does not necessarily mean that all facilities have comparable levels of healthcare capacity. Similarly, a facility with strong service indicators may serve a geographically extensive area (47,48). Combining the two approaches therefore provides a more comprehensive assessment of the spatial and functional characteristics of the PHC network (49-50).

Existing assessments of healthcare facilities often emphasize either geographical distribution or service characteristics independently. Such approaches may provide only a partial understanding of the healthcare network. A facility-location analysis can identify spatial concentration or dispersion but cannot explain differences in institutional capacity. Conversely, facility-level performance analysis may identify stronger and weaker centres without

considering their geographical position within the wider healthcare network (51,52). An integrated spatial-statistical approach can overcome this limitation by linking the geographical structure of the PHC network with the relative performance of individual facilities (53). Differences in institutional resources and service characteristics may persist even where healthcare facilities are broadly distributed across the district. By integrating spatial distribution analysis with standardized facility-level assessment, the study seeks to identify both the spatial structure of the PHC network and variations in the relative performance of individual centres (54).

The spatial separation of settlements and healthcare facilities can influence the organization of primary healthcare services. At the same time, differences in staffing, infrastructure and service utilization among PHCs may produce variations in their functional capacity. Examining both the spatial pattern and facility-level performance is therefore necessary to understand the overall structure of primary healthcare provision in the district. The present study therefore focuses on the spatial distribution and locational performance of Primary Health Centres in Ri-Bhoi District, Meghalaya, with particular emphasis on Nearest Neighbour Analysis and Z-score standardization. NNA is used to determine the overall spatial pattern and nearest-neighbour relationships of PHCs, while Z-score analysis is employed to assess the relative performance of selected PHCs using indicators of staffing, infrastructure, service utilization and village coverage. Accessibility characteristics are considered as a supplementary component rather than the primary analytical focus.

➤ Objectives

- To analyse the spatial distribution patterns of Primary Health Centres (PHCs) in Ri Bhoi District.
- To evaluate the locational efficiency, capacity variations, and physical accessibility of selected PHCs in Ri Bhoi District.

➤ Study Area

Geographically, Ri Bhoi District is positioned between the latitudes of 25°15' N and 26°15' N and longitudes of 91°45' E and 92°15' E. It covers an area of approximately 2,448 square kilometres, making it one of the most geographically diverse and strategically important districts of Meghalaya (Figure 1).

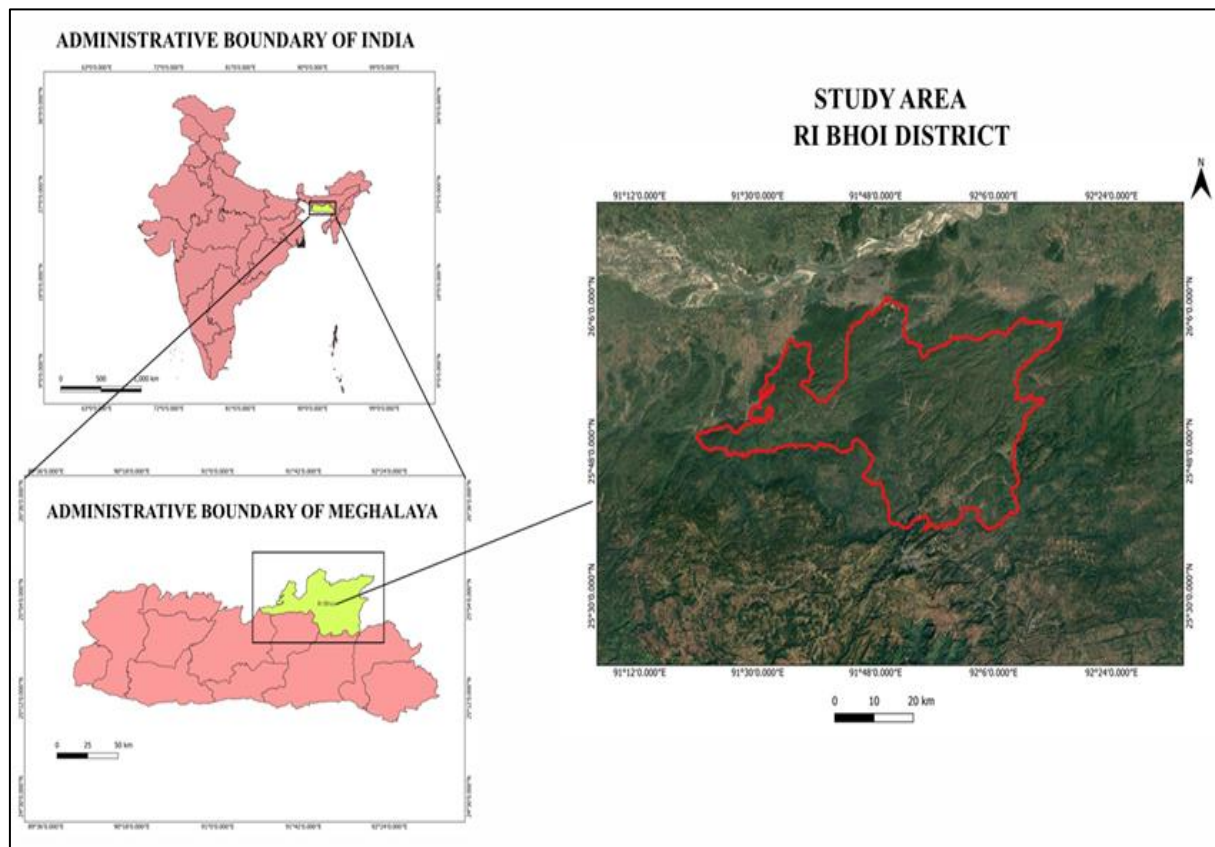


Fig 1 Location of the Study Area

II. METHODOLOGY

This study utilizes a robust, mixed-methods spatial and statistical approach to analyse health facility distribution and capacity. To assess physical accessibility and user satisfaction, a structured household survey was administered to 100 random respondents residing within the active catchment basins of five selected PHCs: Byrnihat PHC, Umden PHC, Marngar PHC, Mawhati PHC, and Kyrדם PHC. The analytical framework consists of three sequential components: spatial nearest-neighbour mapping, primary household surveys, and multivariate Z-score standardization. Spatial analysis of all nine Primary Health Centres (PHCs) in the district was conducted using Geographic Information System (GIS) tools

The Nearest Neighbour Ratio (Rn) is mathematically formulated as:

$$Rn = 2D\sqrt{n/A}$$

Where 'D' is the observed average distance between each PHC and its nearest clinical neighbour, 'n' is the total number of PHCs (n = 6 major operational entries mapped for spatial distance), and 'a' is the total geographical area of the study area (a = 2,448 km²).

The individual Z-scores were computed using the formula: $Z = (X - \mu) / \sigma$

Where X is the raw indicator value, μ is the sample mean, and σ is the standard deviation. A Composite Z-Score for each PHC was subsequently calculated by summing the Z-scores across all 12 indicators to establish a definitive locational and service efficiency ranking.

III. RESULTS AND DISCUSSION

➤ Location of Selected PHCs in Ri Bhoi District

The selected Primary Health Centres are spatially distributed across in Ri Bhoi District. There are five PHCs namely Byrnihat PHC, Umden PHC, Marngar PHC, Mawhati PHC, and Kyrדם PHC were selected for the present study in Ri Bhoi District, Meghalaya. From Figure 2, among the selected PHCs, Byrnihat PHC is situated in the northern part of the district, while Umden PHC is located in the north-eastern region. Marngar PHC occupies a central position, whereas Mawhati PHC and Kyrדם PHC are located in the eastern and southern parts of the district respectively.

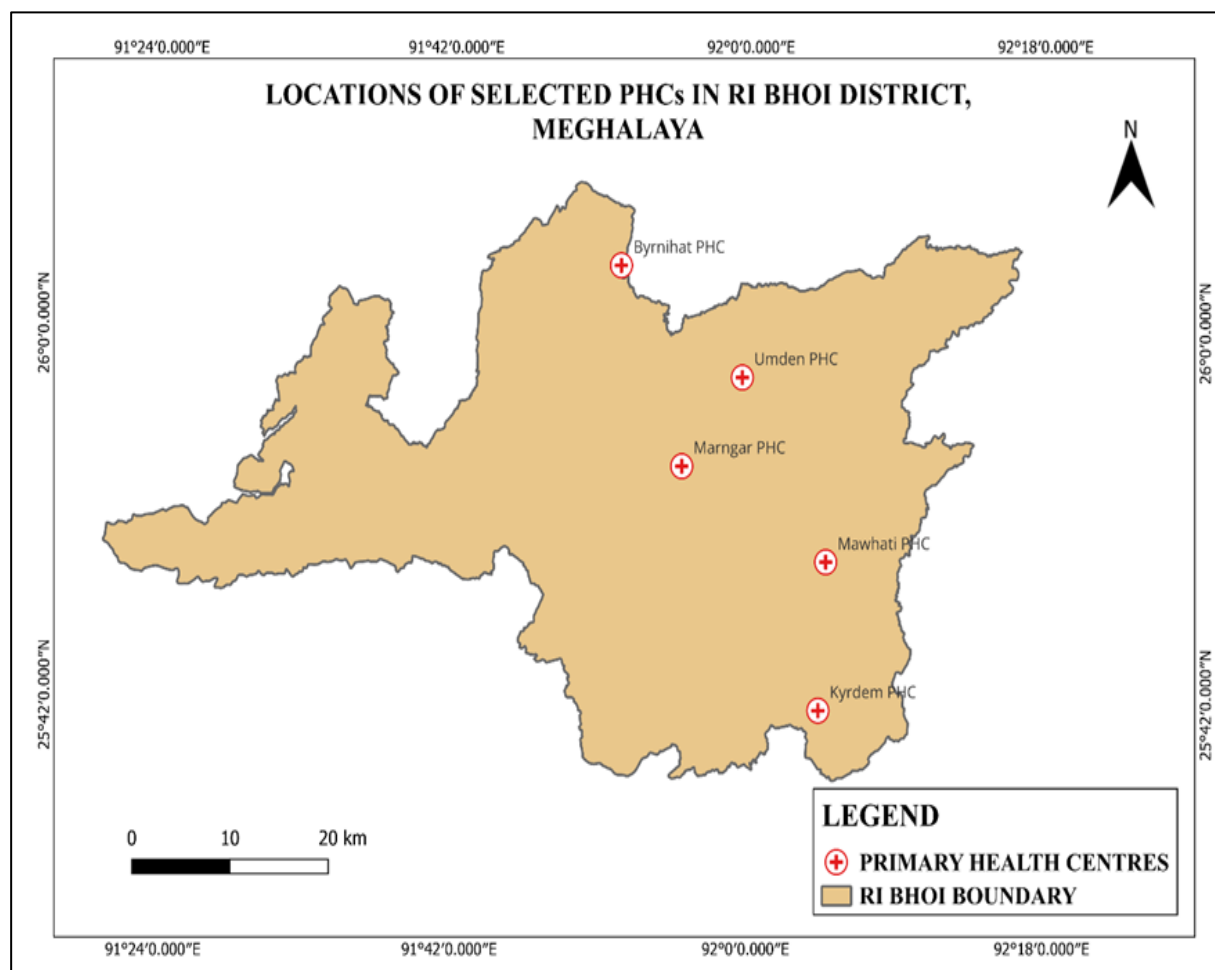


Fig 2 Location of Selected Primary Health Centres in Ri Bhoi District

➤ *Spatial Distribution and Nearest Neighbour Analysis*

The spatial arrangement of healthcare facilities determines the territorial efficiency and equity of public health delivery. To evaluate the spacing of PHCs in Ri Bhoi

District, the geographical distance between each facility and its nearest operational neighbour was calculated using GIS tools (Figure 4). Table 1 details these spatial relationships.

Table 1 Distance Matrix Between Primary Health Centres (PHCs) in Ri Bhoi District

Sl. No.	PHC Name	Nearest PHC	Distance (in km)
1	Kyrdem PHC	Mawlasnai PHC	9.03
2	Mawlasnai PHC	Mawhati PHC	11.25
3	Marngar PHC	Umden PHC	10.13
4	Umden PHC	Umtra PHC	14.65
5	Umtra PHC	Marmain PHC	12.82
6	Byrnihat PHC	Warmawsaw PHC	32.03
-	Total Distance	All Connections	89.91
-	Average Distance (D)	-	15.00

Applying the Nearest Neighbour Analysis formula with an average distance (D) of 15.0 km, a total mapped count (n) of 6, and a district area (a) of 2,448 km², the

resulting Nearest Neighbour Ratio (Rn) is 1.81. To interpret this spatial statistic, the value was compared against the standard Randomness Index ranges shown in Table 2.

Table 2 Randomness Index Interpretation Ranges

Randomness Index Range	Distribution Type	Spatial Interpretation
0.00 – 0.50	Clustered	High concentration of facilities in a specific area with significant overlap.
0.60 – 1.50	Random	Facilities are distributed without a coordinated geographical plan.
1.60 – 2.15	Uniform / Dispersed	Facilities are strategically spaced to maximize geographical coverage.

Table 3 Consolidated Socio-Demographic, Accessibility and PHC Service Profile of Survey Rspndents.

Variables	Category	Frequency/ Response	Percentage (%)
Age Composition	1–15 years	2	2
	16–30 years	27	27
	31–45 years	42	42
	46–60 years	29	29
	>60 years	0	0
	Total	100	100
Gender Composition	Male	38	38
	Female	62	62
	Total	100	100
Occupational Structure	Primary sector	54	54
	Secondary sector	15	15
	Tertiary sector	31	31
	Total	100	100
Household Size	1–2 members	0	0
	2–4 members	5	5
	4–6 members	43	43
	>7 members	52	52
	Total	100	100
Distance to Nearest PHC	<1 km	39	39
	1–3 km	15	15
	3–5 km	26	26
	>5 km	20	20
	Total	100	100
Travel Time to PHC	<15 minutes	39	39
	15–30 minutes	36	36
	30–45 minutes	16	16
	>45 minutes	9	9
	Total	100	100
Mode of Transportation	Walking	12	12
	Two-wheeler	0	0
	Private vehicle	31	31
	Public transport	57	57
	Total	100	100
Transport Cost per Visit	No cost (walkers)	12	12
	Low cost (₹10–₹20)	20	20
	Moderate cost (₹20–₹50)	38	38
	High cost (>₹50)	30	30
	Total	100	100
Road Accessibility	Easily accessible	94	94
	Not easily accessible	6	6
	Total	100	100
Road Condition	Good	68	68
	Moderate	32	32
	Poor	0	0
	Total	100	100
Waiting Time	<30 minutes	2	2
	30 minutes–1 hour	19	19
	1–2 hours	51	51
	>2 hours	28	28
	Total	100	100
PHC Service Availability	Free essential medicines	Yes	100
	Free essential medicines	No	0
	Doctor availability	Yes	98
	Doctor availability	No	2
	Emergency service (24/7)	Yes	47
	Emergency service (24/7)	No	53

PHC Location and Coverage	Convenient PHC location	Yes	100
	Effective coverage of surrounding villages	Yes	100

The Rn score of 1.81 falls squarely within the 'Uniform / Dispersed' range (1.6 to 2.15). This statistically confirms a dispersed distribution pattern. This uniform arrangement suggests that health infrastructure in Ri Bhoi

District has been designed to maximize physical coverage, reduce territorial overlap, and provide distinct geographical catchments. However, this district-wide dispersed pattern masks major micro-regional variations.

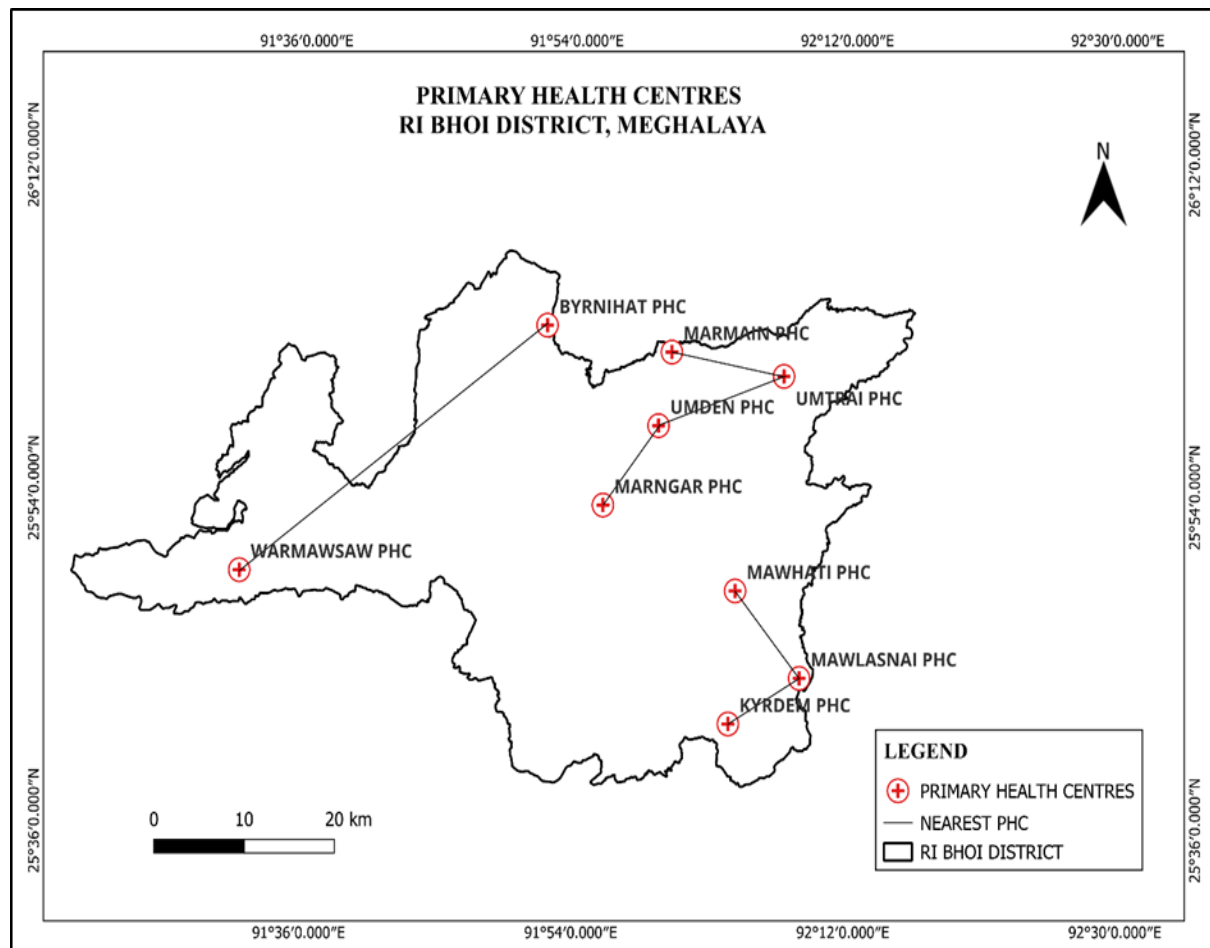


Fig 3 Nearest Distance in Between PHCs in Ri Bhoi District

A clear spatial imbalance exists between the western and eastern sectors. The western portion is extremely sparse, with Warmawsaw PHC isolated at a considerable distance (32.03 km from Byrnihat PHC), resulting in massive service areas and physical accessibility challenges. Conversely, the eastern and south-eastern regions exhibit a dense, well-connected health network consisting of KyrDEM, Mawlasnai, Mawhati, Marmain, and Umtrai PHCs, driven by higher population density and superior road connectivity.

➤ Socio-Economic Profile of Surveyed Respondents

To understand the demographic characteristics of the primary users of public health facilities, a household survey of 100 respondents was executed across the active catchment zones of the five selected PHCs. Demographics heavily influence healthcare-seeking behaviour and clinic utilization (Table 3).

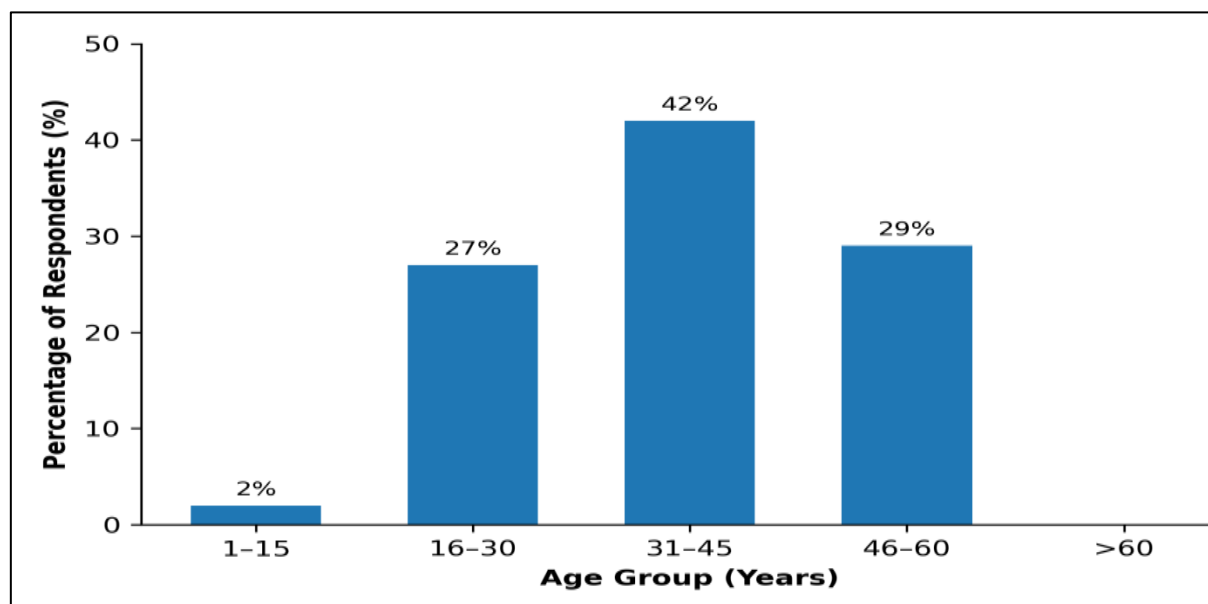


Fig 4 Visual Distribution of Respondent Age Composition

The demographic profile reveals several key characteristics. The majority of respondents fall into the highly active 31–45 years age bracket (42%), indicating that the survey reflects the perspectives of primary household decision-makers (Figure 4). Female respondents comprise a clear majority (62%), highlighting the central role of women as primary users of maternal, neonatal, and paediatric healthcare services at PHCs (Figure 6). In terms of livelihoods, 54% are engaged in the primary agricultural sector, indicating a low-income profile with limited access to expensive private clinics (Figure 7). Furthermore, 52% of respondents belong to large households with more than 7 members (Figure 8). Large families significantly increase the demand on PHCs, highlighting the importance of robust public facilities in rural areas.

➤ Workforce, Physical Infrastructure, and Service Capacities

To evaluate clinical capacity, physical and administrative infrastructure records were compiled for the five selected PHCs, shown in Table 5.

Clinical capacity varies widely. Byrnihat PHC holds the strongest workforce (7 doctors, 5 nurses, 2 lab technicians, and 5 ANMs) and covers the largest territory (117 villages), recording high patient volumes (2,685 IPD and 18,490 OPD cases). Conversely, Mawhati PHC manages the highest OPD volume (27,135 cases) with only 2 doctors and 3 nurses, reflecting a high workload. Umden PHC has the largest inpatient capacity (12 beds and 6 nurses) but is severely underutilized (only 308 IPD cases), pointing to underlying clinical and equipment limitations.

➤ Z-Score Multi-Criteria Standardization Analysis

To standardize these variables, a Z-score transformation was performed. Standardizing the 12 indicators onto a common scale (where positive represents above-average performance and negative represents below-average) enables objective comparison, as shown in Table 5.

Table 5 Standardized Z-Scores Across 12 Operational and Clinical Indicators

PHC Name	Dr.	NS	G4	LT	IPD	OPD	Ph.	ANM	Vac.	HV	Beds	Villages
Marngar	-0.64	-0.35	0.61	-0.73	-0.54	-1.22	-0.45	0.35	-0.73	0.45	0.27	0.02
Byrnihat	1.64	0.53	-0.92	1.10	1.73	0.41	1.79	1.23	1.10	0.45	-1.55	1.64
Umden	-0.64	1.40	-0.92	-0.73	-0.72	-0.39	-0.45	0.35	-0.73	-1.79	1.19	-0.25
Mawhati	-0.64	-1.23	-0.15	1.10	-0.46	1.46	-0.45	-0.53	1.10	0.45	-0.18	-0.36
Kyrdem	0.27	-0.35	1.38	-0.73	0.00	-0.25	-0.45	-1.40	-0.73	0.45	0.27	-1.05

Key: Dr. = Doctors, NS = Nurses, G4 = Grade-IV Staff, LT = Lab Technicians, IPD = Inpatient Annual Attendance, OPD = Outpatient Annual Attendance, Ph. = Pharmacists, ANM = Auxiliary Nurse Midwives, Vac. = Vaccinators, HV = Lady Health Visitors, Beds = Total Beds, Villages = Number of Villages Covered.

➤ Individual Locational Performance

- Marngar PHC: Marngar PHC exhibits below-average performance across most clinical metrics. Positive scores are observed only for Grade-IV support staff (+0.61), ANMs (+0.35), beds (+0.27), and villages served

(+0.02). Conversely, severe negative scores in patient utilization (OPD: -1.22; IPD: -0.54) and core clinical personnel (Doctors: -0.64; Nurses: -0.35) indicate substantial underutilization and staffing gaps relative to its physical capacity (Figure 11).



Fig 5 Mapped Z-Score Profile for Marngar PHC

- Byrnihat PHC: Byrnihat PHC holds the strongest overall performance profile. It records high positive Z-scores across core clinical personnel (Doctors: +1.64; Lab Technicians: +1.10; Pharmacist: +1.79; ANMs: +1.23) and patient utilization (IPD: +1.73; OPD: +0.41), along

with extensive geographical coverage (Villages: +1.64). Its only negative scores occur in Grade-IV staff (-0.92) and bed capacity (-1.55), confirming its status as a highly efficient regional health hub (Figure 5).

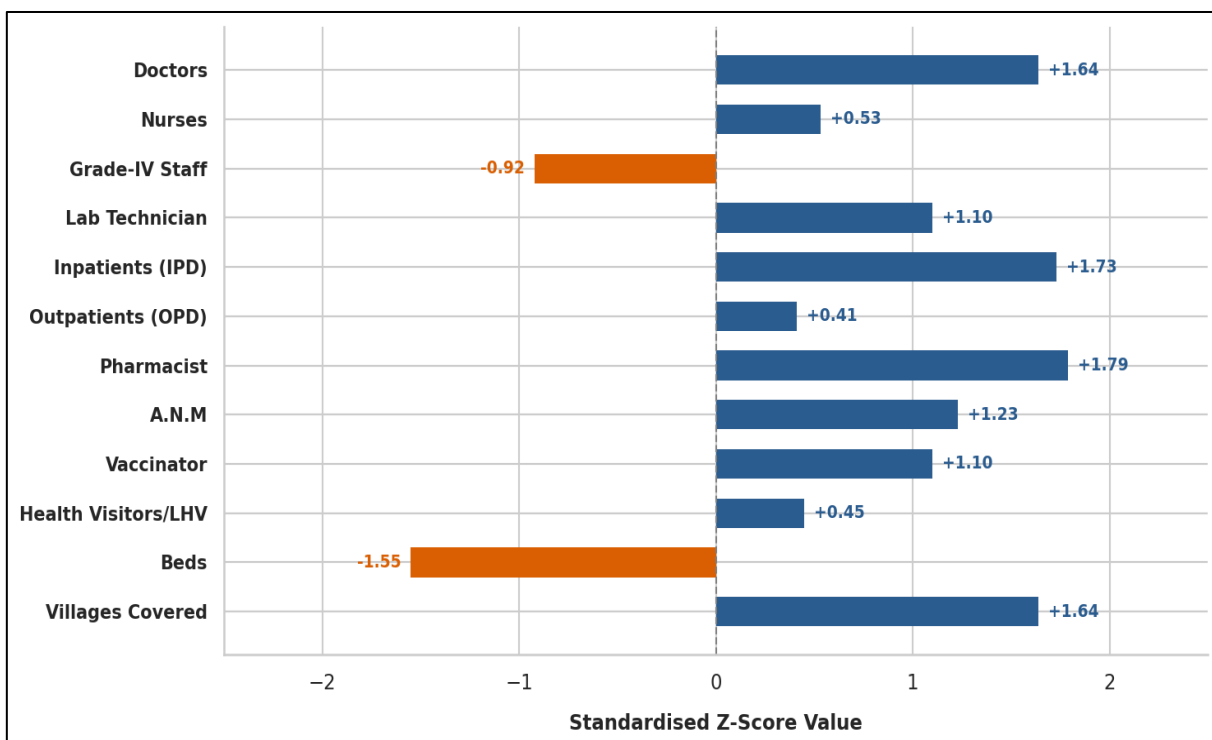


Fig 6, Mapped Z-Score Profile for Byrnihat PHC

- Umden PHC: Umden PHC presents a highly uneven profile. It records strong positive scores for nursing staff (+1.40) and bed capacity (+1.19), indicating solid inpatient capacity. However, negative scores across most

other indicators, including doctors (-0.64), IPD utilization (-0.72), and lady health visitors (-1.79), point to severe clinical and outreach gaps that limit its overall effectiveness (Figure 6).

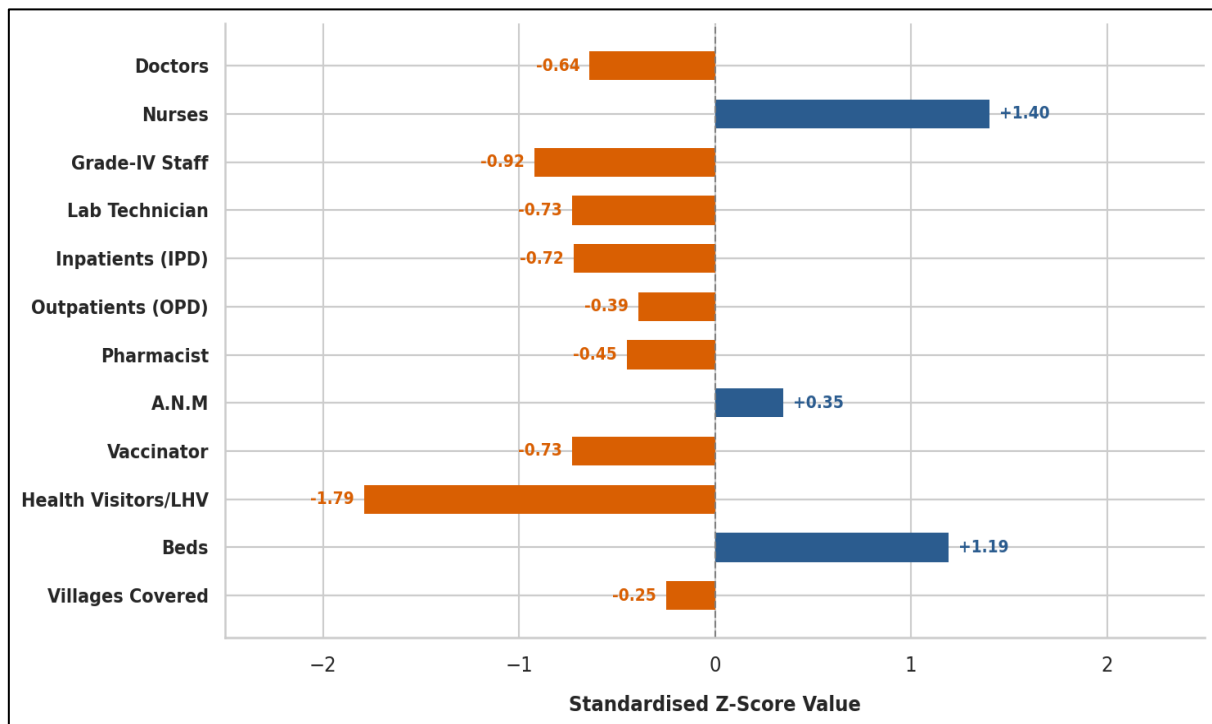


Fig 7 Mapped Z-Score Profile for Umden PHC

- Mawhati PHC: Mawhati PHC manages a high workload. It records the highest positive score for outpatient utilization (OPD: +1.46) and strong technical support (Lab Tech: +1.10; Vaccinators: +1.10). However,

negative scores in core staffing (Doctors: -0.64; Nurses: -1.23; Pharmacists: -0.45; ANMs: -0.53) indicate a critical clinical shortage relative to its high patient volume (Figure 8).

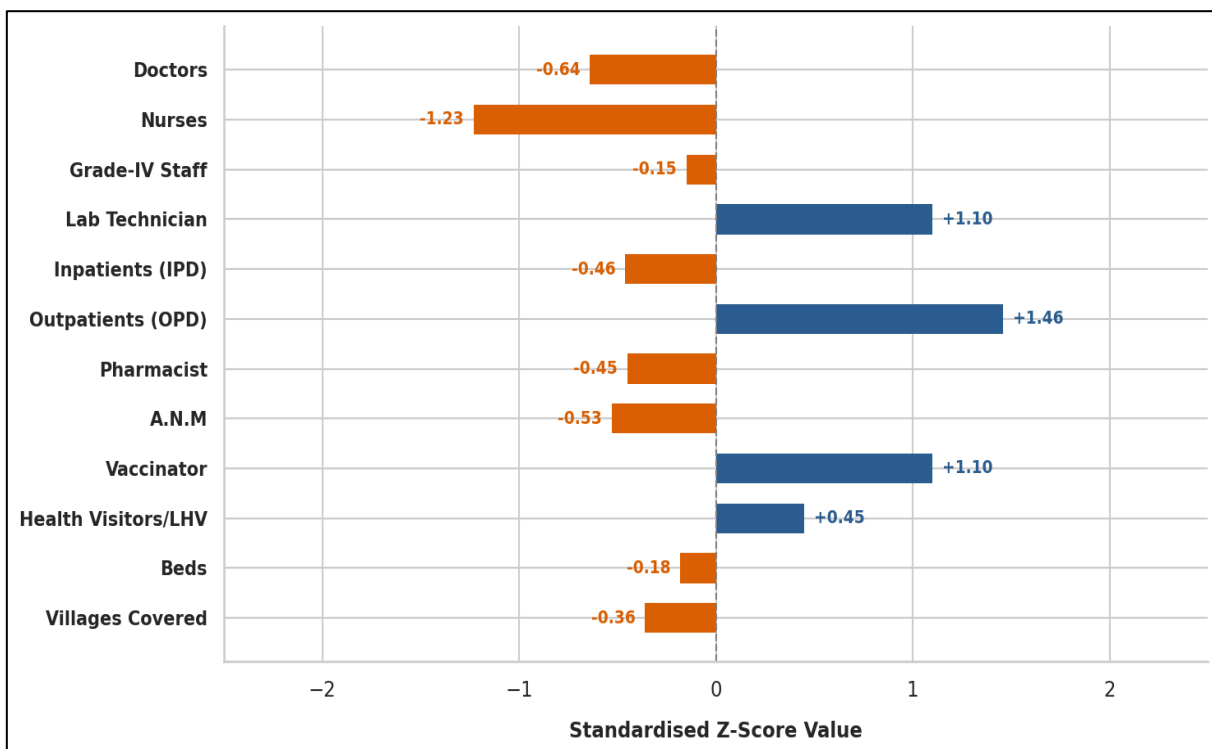


Fig 8 Mapped Z-Score Profile for Mawhati PHC

- Kyrдем PHC: Kyrдем PHC shows moderate, balanced performance. It records positive scores for supportive staff (Grade-IV: +1.38; Doctors: +0.27; Beds: +0.27; LHV: +0.45). However, negative scores in nursing (-

0.35) and territorial coverage (Villages: -1.05) indicate that while its internal capacity is stable, its geographical reach is limited (Figure 9).

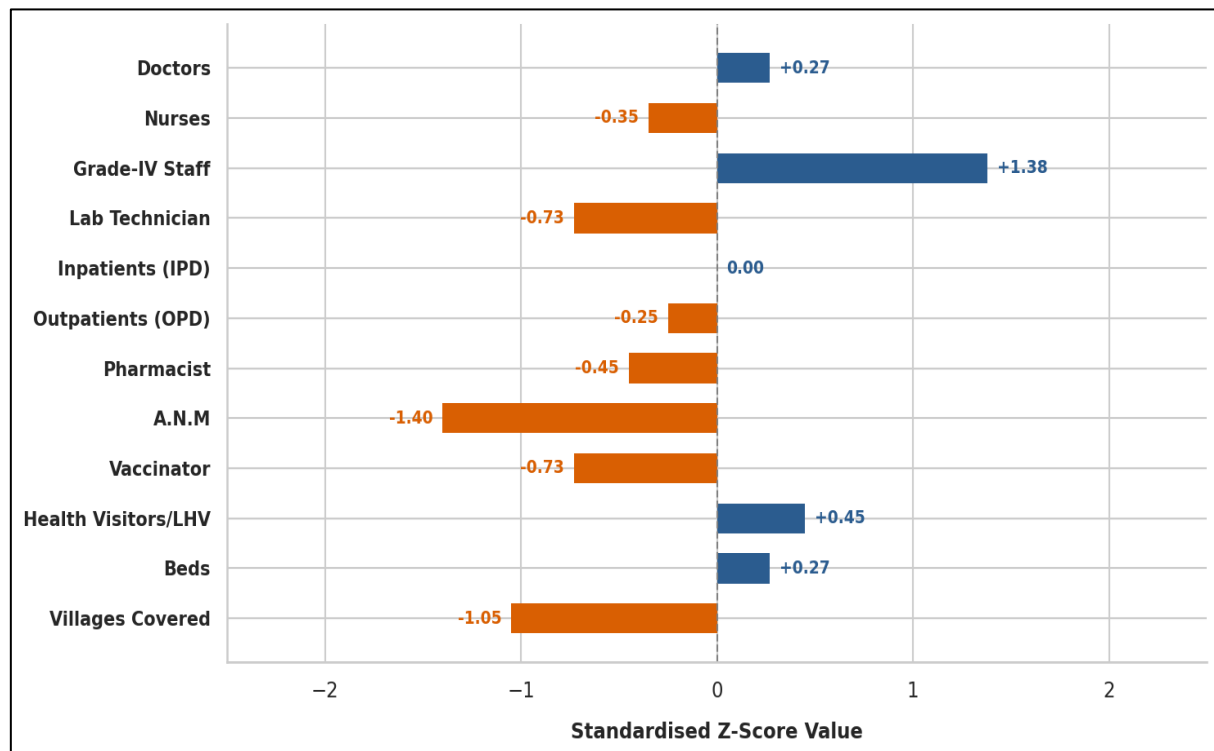


Fig 9 Mapped Z-Score Profile for Kyrдем PHC

➤ *Definitive Facility Rankings Using Composite Z-Scores*

By summing the standardized Z-scores across all 12 indicators, a Composite Z-Score was calculated to establish

a definitive locational and service efficiency ranking for each PHC, as detailed in Table 6.

Table 6 Composite Z-Score Rankings of the Selected PHCs

Performance Rank	Primary Health Centre(PHC)	Composite Z-Score	Performance Classification
1	Byrnihat PHC	+9.13	High Efficiency / Superior Performance
2	Mawhati PHC	+0.10	Moderate Efficiency / Adequate Utilization
3	Kyrдем PHC	/-2.60	Sub-Average / Localized Coverage
4	Marngar PHC	-2.96	Low Efficiency / Underutilized Capacity
5	Umden PHC	-3.67	Lowest Efficiency / Severe Resource Constraints

The composite rankings confirm significant performance disparities. Byrnihat PHC ranks first (+9.13), functioning as a highly efficient regional health hub with strong resources and utilization. Mawhati PHC ranks second (+0.10), representing a highly utilized, under-staffed facility. In contrast, Kyrдем (-2.60), Marngar (-2.96), and Umden (-3.67) PHCs perform below average, reflecting severe resource constraints, service underutilization, or limited geographical reach, and highlighting the need for targeted infrastructural intervention.

IV. CONCLUSION

The integration of GIS spatial analytical models, household accessibility surveys, and multivariate standardized performance indices provides a comprehensive evaluation of Primary Health Centres in Ri Bhoi District, Meghalaya. The Nearest Neighbour Analysis statistically confirms a uniform, dispersed spatial distribution ($R_n = 1.81$), indicating a coordinated planning effort to maximize territorial coverage. However, significant geographical

imbalances persist between the dense eastern network and the isolated western borderlands, creating localized accessibility barriers. Furthermore, physical accessibility does not guarantee operational efficiency. While 75% of users can reach a PHC within 30 minutes, significant service gaps exist, notably a widespread lack of emergency care (53% unavailable) and long waiting times (79% exceeding one hour). The Z-score analysis highlights these disparities, showing a stark contrast between highly efficient centres like Byrnihat (+9.13) and severely constrained facilities like Umden (-3.67). To resolve these inequities and establish a balanced primary healthcare system, the following targeted policy recommendations are proposed: Establish new clinical entries, mobile clinic routes, and community sub-centres in the underserved western region (specifically targeting the isolated catchment areas of Warmawsaw PHC) to reduce excessive travel distances. Redistribute personnel from resource-rich centers (like Byrnihat) to highly utilized, understaffed facilities (such as Mawhati) to improve staff-to-patient ratios and reduce waiting times. Equip all low-performing and moderately rated PHCs (specifically Umden

and Marngar) with emergency trauma wards, basic laboratory diagnostic equipment, and 24/7 obstetric facilities to expand rural healthcare options. Develop a dynamic, GIS-based administrative platform to continuously track patient volumes, waiting times, and staffing levels, allowing for responsive, data-driven healthcare planning in Meghalaya.

- Ethical Approval: The study was conducted following institutional ethical guidelines. Informed consent was obtained from all participants prior to data collection.
- Conflict of Interest: The authors declare no conflict of interest.
- Funding: No external funding was received for this study.

REFERENCES

- [1]. Saravanabavan, V., Vinothini, C., & Rose, R. S. (2023). Spatial distribution of primary health care centre and socio economic conditions of patients in Madurai district. *International Journal of Geography, Geology and Environment*, 5(2), 192-198.
- [2]. Vinothini, C., Suja Rose, R. S., & Saravanabavan, V. (2024). Assessment of primary health care accessibility and patients' perception in Madurai district: a geo-medical study. *GeoJournal*, 89(5), 211. <https://doi.org/10.1007/s10708-024-11208-1>
- [3]. Saravanabavan, V., Vinothini, C., & SujaRose, R. S. (2024). Transport accessibility and efficiency of PHC location in Kanyakumari district, Tamil Nadu. *International Journal of Science and Research Archive*, 11(2), 1342-1351. <https://doi.org/10.30574/ijisra.2024.11.2.0605>
- [4]. Saravanabavan, V.; Naphibanroi Wankhar, C. Vinothini (2026) Healthcare Accessibility in Primary Health Centers of East Khasi Hills District, Meghalaya: Spatial Analytical Approach. *International Journal of Science and Research Archive* 20 (3), 001-017. <https://doi.org/10.30574/ijisra.2026.20.3.1670>
- [5]. Vinothini, C., Suja Rose, R. S., Saravanabavan, V., & Vadivel, S. (2025). Factors influencing healthcare accessibility in Madurai District: A spatial and factor analytical approach. *International Journal of Engineering Development and Research*, 13(3), 20-30. www.ijedr.org
- [6]. Vinothini, C., & Saravanabavan, V. (2023). Determinants of health care facilities and patients 'accessibility to PHC in Madurai district. *International Journal of Geography, Geology, and Environment*, 5(2), 17-22.
- [7]. Rahamath Nisha, R., V. Saravanabavan, R. Sureskumar (2021) Effects of Population Density and Air Pollution on Covid -19 Morbidity and Mortality in India Using GIS. *International Journal of Contemporary Medical Research* 8 (8), H1-H11. DOI: <http://dx.doi.org/10.21276/ijcmr.2021.8.8.8>
- [8]. Sheheersha, S. K., & Saravanabavan, V. (2021). Geo-Medical Analysis of Telemedicine Based Mobile Tele-Ophthalmology Screening For Cataract Cases in Thiruvananthapuram District, Kerala, India. *IOSR Journal Of Humanities And Social Science*, 26(10), 1-7. <http://DOI:10.9790/0837-2610070107>
- [9]. Saravanabavan, V., Reejo, R. J., Neethidevi, A., & Jayashree, R. (2006). Travel and health care utilization pattern of patients in Vadipatti panchayat union: A micro level study using GIS. *Journal of Deccan Geographer*, 44(2), 97-108.
- [10]. Saravanabavan, V., Nongspung, C., Vinothini, C., & Vadivel, S. (2025). Healthcare Accessibility in East Khasi Hills, Meghalaya, India: Age, Gender, and Socioeconomic Barriers to Primary Health Centre Access. *Asian Journal of Geographical Research*, 8(3), 488-505. <https://doi.org/10.9734/ajgr/2025/v8i3313>
- [11]. Saravanabavan, V., Emayavaramban, V., Thangamani, V., Manonmani, I. K., Rose, R. S., Balaji, D., ... & Vinothini, C. (2023). Spatial variation of covid-19 morbidity status and identification of risk zone in Tamil Nadu (India) during first wave. *GeoJournal*, 88(2), 1341-1354. <https://doi.org/10.1007/s10708-022-10680-x>
- [12]. Vinothini, C., Suja Rose, R. S., & Saravanabavan, V. (2024). Geospatial analysis of communicable diseases in Madurai district. *International Journal of Humanities Social Science, and Management*, 4(3), 1145-1153.
- [13]. Sudharsan, R., & Saravanabavan, V. (2019). Availability and Utilization of Primary Healthcare Centre in Thanjavur District, Tamilnadu. *International Journal of Scientific Research in Science and Technology*, 6(4), 288-297. <https://doi.org/10.32628/IJSRST196451>
- [14]. Saravanabavan, V., Reshma, C. U., & Preethi, S. (2021). Determinants of reproductive health in working women in Thrissur district, Kerala. *GeoJournal*, 86(1), 239-253. <https://doi.org/10.1007/s10708-019-10051-z>
- [15]. Saravanabavan, V., Vinothini, C., Suja Rose, R. S., & Balaji, D. (2025). A Geo-Chemical Study of Water Pollution Due to the Tanning Industry: A Case Study of Dindigul District, Tamilnadu, India. In *Groundwater Resource Management Planning Strategies: A Geospatial Approach: Volume 1* (pp. 651-683). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-88870-0_25
- [16]. Vinothini, C., Rose, R. S., & Saravanabavan, V. (2024). Spatial distribution and female travel behavior: Enhancing primary health care services in Madurai District. *International Journal of Engineering applied Sciences and Technology*, 9(05), 2455-2143.
- [17]. Reshma CU, SK Sheheersha, V Saravanabavan (2014) Enhancing The Quality And Accessibility Of Geographic Learning Through Modern Instructional Strategies In The School: Its Implications And Opportunities. *IOSR Journal of Research & Method in Education (IOSR-JRME)* Volume 4, Issue 3 Ver. II (May-Jun. 2014), PP 25-30
- [18]. Umasankar, R. V., & Saravanabavan, V. (2024). Geospatial analysis of health care resource allocation

- in Karur District: Insights from GIS. *Shodhkosh: Journal of Visual and Performing Arts*, 5(1), 646-655.
- [19]. Sheheersha, S. K., & Saravanabavan, V. (2015). An analysis of the role of sunayanam mobile ophthalmology unit for preventing blindness among rural poor in Thiruvantahapuram district. *Geospatial Technologies for Resource Evaluation and Management*, 412-414.
- [20]. Nemcha Mate, T. , Saravanabavan, V., & Vinothini, C. (2025). Consumption of Areca Nut and its Socioeconomic and Health Impacts in Shillong, Meghalaya-A Geographical Analysis. *International Journal of Research Publication and Reviews*, 6(11), 899-909.<https://doi.org/10.55248/gengpi.06.1125.3842>
- [21]. Saravanabavan V ,MekyrshanborThabab , C. Vinothini(2026) Assessment of Patient Satisfaction with Primary Health Centre Services in Eastern West Khasi Hills District , Meghalaya: A Z - Score Analysis.*International Journal of Research Publication and Reviews* 7 (7), 3478-3488
- [22]. Saravabavan, V., Ganesan, J., Vinothini, C., & Balaji, D. (2026). The Impact of BMI on the Health Status of Tea Plantation Workers in the Nilgiris, Tamil Nadu, India. *Journal of Complementary and Alternative Medical Research*, 27(2), 59-74. DOI: <https://doi.org/10.9734/jocamr/2026/v27i2741>
- [23]. Vinothini, C., Saravanabavan, V., & Suja Rose, R. S. (2025). Travel behaviour of child patients and health care accessibility of PHC in Madurai District, Tamilnadu. *International Research Journal of Education and Technology*, 7(02), 283-295
- [24]. Saravanabavan, V., Balaji, D., Reshma, C. U., Sheheersha, S. K., Sudharsan, R., Vimala Vinnarasi, J., ... & Balasubramani, K. (2021). Urban disease ecology and its spatial variation of Chikungunya in Madurai City, Tamilnadu, India: a geo-medical study. *GeoJournal*, 86(5), 2335-2350. <https://doi.org/10.1007/s10708-020-10192-6>
- [25]. Saravanabavan, V. (1996). Bicycles and health-a geo medical study of Madurai city. In *Velo Australis and Velo-City'96*, International Bicycle Conference, 1996, Fremantle, Western Australia.
- [26]. Chakraborty, S., & Singh, V. (2025). Spatial inequality in primary health services: Evidence from India using GIS and accessibility indices. *GeoJournal of Health and Place*, 85, 102789. <https://doi.org/10.1016/j.healthplace.2025.102789>
- [27]. Ali, M. A., Verma, R., & Dey, S. (2025). Measuring patient satisfaction in primary care: A cross-sectional analysis of service quality indicators in South Asia. *International Journal of Health Planning and Management*, 40(1), 12–24. <https://doi.org/10.1002/hpm.3765>
- [28]. Saravanabavan, V., Thabab, M., & Vinothini, C. (2026). Age-wise travel patterns and utilization of primary health Centres in Eastern West Khasi Hills District, Meghalaya: A GIS-Based Analysis.*International Journal of Science and Research Archive* 20 (02), 192–205. <https://doi.org/10.30574/ijisra.2026.20.2.1600>
- [29]. Radhakrishnan, R., & Vaithialingam, S. (2023). Exploring the suitability of groundwater for domestic water quality and irrigation purpose in Dindigul district, Tamil Nadu. In *Surface and groundwater resources development and management in semi-arid region: strategies and solutions for sustainable water management* (pp. 253-277). Cham: Springer International Publishing.https://doi.org/10.1007/978-3-031-29394-8_14
- [30]. Eswari, S., Saravanabavan, V., Vinothini, C., & Balaji, D. (2025). Mother and Child Health Care In Madurai District: A Structural Equation Modelling Approach. *The Indian Geographical Journal*, 100(1), 39-54.
- [31]. Saravanabavan, V., Cajee, L., Sangma, M. C., & Vinothini, C. (2025). Spatial Distribution and Service Coverage Analysis of Primary Health Centres in South West Garo Hills District, Meghalaya, India. *Asian Journal of Geographical Research*, 8(4), 389-400.<https://doi.org/10.9734/ajgr/2025/v8i4344>
- [32]. Saravanabavan, V., & Vinothini, C. (2026). Assessment Of Healthcare Performance: Knowledge, Attitude, Behavioral Characteristics of Patients and Spatial Distribution of PHC's In Sepahijala District, Tripura, India. *IRE Journals*, 9(11), 97-108.DOI: <https://doi.org/10.64388/IREV9I11-1717261>
- [33]. Vinothini, C., & Saravanabavan, V. (2022). Spatial Distribution of Emerging Diseases in Madurai District: A Geo Medical Study. *International Journal of Innovative Science and Research Technology*, 7(6), 2456-2165.
- [34]. Vinothini, C., Saravanabavan, V., & Emayavaramban, V. (2022). Location Accessibility of PHC and Health care travel performance in Madurai District. *International Journal of Innovative Science and Research Technology*, 7(12), 2456-2165.
- [35]. Rahamath Nisha R, V.Saravanabavan, C.Vinothini(2026) Rural-Urban Variation in Dengue Vector Breedings Dynamics in Madurai District, TamilNadu,India: A Geo-Medical Study,*Asian Journal of Geographical Research* 9 (3), 345-367 .<https://doi.org/10.9734/ajgr/2026/v9i3433>
- [36]. Saravanabavan, V., Eswari, S., Vimala Vinnarasi, J., Ganesan, J., & Sudharsan, R. (2020). Spatial temporal variation of leptospirosis disease in Madurai city–Medicogeographical analysis. *International Journal of Geography, Geology and Environment*, 2(1), 21-7.
- [37]. Saravanabavan, V., & Shanmuganandan, S. (1994). Geo-Medical analysis of Leprosy patients in Tamilnadu. *The Indian Geographical Journal*, 69(2), 135-139.
- [38]. Saravanabavan, V., & Shanmuganandan, S. (1996). Pattern of leprosy treatment and health care situation in Tamil Nadu. *Annals of the National Association of Geographers, India*, 16(2), 25-35.
- [39]. Rahman, F., & Bose, A. (2024). Travel time to primary care facilities and health outcomes: A geospatial study in Eastern India. *Journal of Transport & Health*, 30, 101462. <https://doi.org/10.1016/j.jth.2024.101462>

- [40]. Kruk, M. E., & Freedman, L. P. (2008). Assessing health system performance in developing countries: A review of the literature. *Health Policy*, 85(3), 263–276. <https://doi.org/10.1016/j.healthpol.2007.09.003>
- [41]. Saravanabavan, V., Debbarma, K., & Vinothini, C. (2025). Primary health care access and socio-economic conditions of the patients in Sepahijala District, Tripura. *International Journal of Science and Research Archive*, 6(1), 295-305. Doi :10.55248/gengpi.6.0125.0207
- [42]. Vinothini, C., Saravanabavan, V., & Rose, R. S. (2024). Travel patterns of adult patients to primary health centers in Madurai district: A public health perspective. *International Journal of Science and Research Archive*, 13(1), 141-149. <https://doi.org/10.30574/ijisra.2024.13.1.1605>
- [43]. Vinothini, C., Suja, R. R., Saravanabavan, V., & Vadivel, S. (2026). Determinants of healthcare access and patient satisfaction in rural and semi-urban Madurai district, India: A geo-medical analysis using structural equation modeling. *Annals of Nursing*, 4(1), 17-33. <https://doi.org/10.5937/annnur4-66903>
- [44]. Mukherjee, S., & Sarkar, S. (2020). Socio-economic determinants of healthcare access in rural India: Implications for spatial planning. *Social Science & Medicine*, 250, 112864.
- [45]. Khatun, F., & Sinha, R. (2018). GIS-driven policy recommendations for healthcare infrastructure improvement in northeast India. *Indian Journal of Medical and Health Research*, 42(3), 327-336.
- [46]. Vinothini, C., Suja Rose, R.S & Saravanabavan, V. (2025) Patients' Perception and Health care Accessibility of Primary Health care centre in Madurai District-A Geo-Medical Study. December 2025. *Annals of the National Association Of Geographers India* 45(2):233-249 DOI:10.32381/ATNAGI.2025.45.02.8
- [47]. Sengnang S Mark, V.Saravanabavan, C.Vinothini (2026) Perception of Health Tourism in enhancing the quality of life of the Garo community: A case study of Daribokgre village, East Garo Hills, Meghalaya. *International Journal of Research Publication and Reviews* 7 (3), 3469-3477. <https://doi.org/10.55248/gengpi.07.0326.20635>
- [48]. Ramphila A Shatsang., Saravanabavan, V., & Vinothini, C. (2025). Health and Socio-Economic Analysis of Adolescent Drug Abuse in Ukhrul District, Manipur. *International Journal of Research Publication and Reviews*, 6(10), 2479-2488. DOI: <https://doi.org/10.55248/gengpi.6.1025.3641>
- [49]. Danyon DameshwaJyrwa ,V Saravanabavan, LaitpharlangCajee ,C Vinothini (2025) Spatial analysis and efficiency of healthcare delivery system in Meghalaya State, India: A 'Z' Score Approach *International Journal of Science and Research Archive* ,15 (01), 1312-1324. <https://doi.org/10.30574/ijisra.2025.15.1.1148>
- [50]. Sharma, M., & Jain, A. K. (2019). Spatial patterns of primary healthcare facilities and accessibility in India: A GIS-based approach. *Journal of Health and Place*, 58, 102218.
- [51]. Adekunle, A., et al. (2020). Health care accessibility and policy challenges in developing countries. *International Journal of Health Planning and Management*, 35(2), 292-302.
- [52]. Sharma, R., & Thakur, R. (2021). Policy recommendations for equitable distribution of health facilities in rural India. *Journal of Health Policy and Planning*, 36(7), 1024-1035.
- [53]. World Health Organization. (2008). *Primary health care: Now more than ever*. Geneva: WHO.
- [54]. Kumar, P., & Sharma, R. (2016). Distribution of health services in India: An analysis of primary health centers. *Journal of Public Health and Epidemiology*, 8(3), 76-84