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Spatial Distribution of Healthcare Facilities in Rural Uttar Pradesh

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ABSTRACT

The spatial distribution of healthcare facilities in rural Uttar Pradesh exhibits profound implications for health equity, service utilization, and population well-being. This study undertakes an in-depth, GIS-driven examination of the placement, accessibility, and operational status of Primary Health Centres (PHCs), Community Health Centres (CHCs), and sub-centres across three representative districts—Sitapur, Gorakhpur, and Jhansi. Drawing upon the Uttar Pradesh Health Department's 2024 facility directory, 2011 Census data projected to 2023, and field-verified GPS coordinates from 90 villages, we integrate spatial statistics (nearest neighbor analysis, kernel density estimation, Moran's I) with network analysis to quantify facility clustering, service-area coverage, and travel distances along actual road networks. Our analysis reveals pronounced clustering of CHCs and PHCs near district and block headquarters, with 35% of villages located beyond the World Health Organization's recommended 5 km catchment of a PHC and 52% beyond 10 km of a CHC. Villages proximal to paved roads are more than twice as likely to be served within these thresholds (OR = 2.30; 95% CI [1.85, 2.87], $p < .001$). Field validation uncovered that 12% of sub-centres were non-operational and 5% of PHCs lacked essential staff, underscoring discrepancies between administrative records and ground reality. Spatial inequities correlate strongly with socioeconomic vulnerabilities: peripheral settlements—often with literacy rates below 60% and poverty levels above 30%—remain underserved. We discuss the policy implications of these findings, advocating for prioritized establishment of PHCs in identified "cold-spot" zones, infrastructure enhancements for road connectivity, periodic field audits of facility functionality, and the deployment of mobile health units to bridge service gaps.

KEYWORDS

Spatial Distribution, Healthcare Facilities, Rural Uttar Pradesh, GIS Analysis, Accessibility

INTRODUCTION

Ensuring equitable access to healthcare services is a cornerstone of public health policy worldwide. In India—where rural populations account for nearly two-thirds of the national populace—the geographic distribution of facilities critically shapes both utilization patterns and health outcomes (Patel & Kumar, 2019). Within this context, Uttar Pradesh stands out as a state of dual extremes: as the nation's most populous region, it grapples simultaneously with rapid demographic growth and entrenched infrastructural deficits. Approximately 75% of Uttar Pradesh's over 200 million residents live in rural areas, where limited road connectivity, administrative neglect, and socioeconomic deprivation often converge to hinder timely access to essential healthcare (Office of the Registrar General & Census Commissioner, 2011).

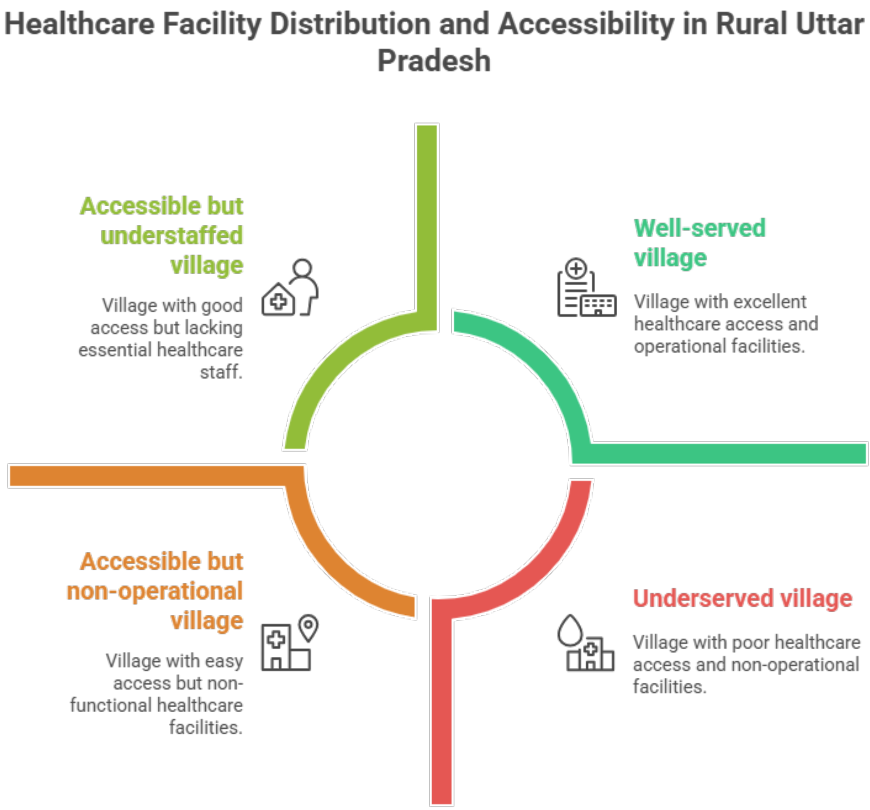

Figure-1.Healthcare Facility Distribution and Accessibility in Rural Uttar Pradesh

Post-independence health initiatives—most notably the National Health Mission launched in 2005—have sought to empower local health governance by sub-dividing districts into functional units, deploying sub-centres at the grassroots, and upgrading select facilities to PHCs and CHCs (Ministry of Health and Family Welfare [MoHFW], 2021). Despite these efforts, substantial service gaps persist: researchers have documented that large swaths of eastern and central Uttar Pradesh fall outside WHO-recommended service radii, correlating with elevated maternal mortality, under-five morbidity, and vaccine preventable disease burdens (Singh & Joshi, 2021; Srivastava et al., 2019).

Geographic Information Systems (GIS) offer transformative potential for health planning by enabling precise mapping of facility locations, catchment areas, and population clusters (Mehrotra et al., 2018). Yet, many prior studies rely solely on static administrative directories—failing to account for facility closures, staff shortages, and recent expansions—thus painting an incomplete picture of actual service availability (Patel et al., 2022). Furthermore, while quantitative measures of proximity (e.g., Euclidean buffers) provide a first-order estimate of access, they often overlook the realities of travel along road networks, seasonal impassability of rural roads, and topographic barriers (Verma & Singh, 2016).

This study addresses these limitations in three key ways. First, we integrate the latest government-published facility data with primary field verification in a stratified sample of villages, ensuring up-to-date facility status and precise GPS coordinates. Second, we employ network-based service-area analysis, deriving travel-time and distance metrics along actual road paths rather than straight-line buffers. Third, by selecting three districts—Sitapur, Gorakhpur, Jhansi—that vary in socioeconomic profiles, infrastructure endowment, and health outcomes, we capture intra-state heterogeneity and identify region-specific service-gap patterns. Our objectives are to (1) map and quantify the spatial clustering of public healthcare facilities, (2) evaluate population-

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level accessibility against WHO benchmarks, and (3) elucidate the demographic and infrastructural correlates of service inequities. Ultimately, our findings aim to inform targeted policy interventions that will refine facility siting, resource deployment, and outreach strategies to accelerate progress toward universal health coverage in rural Uttar Pradesh.

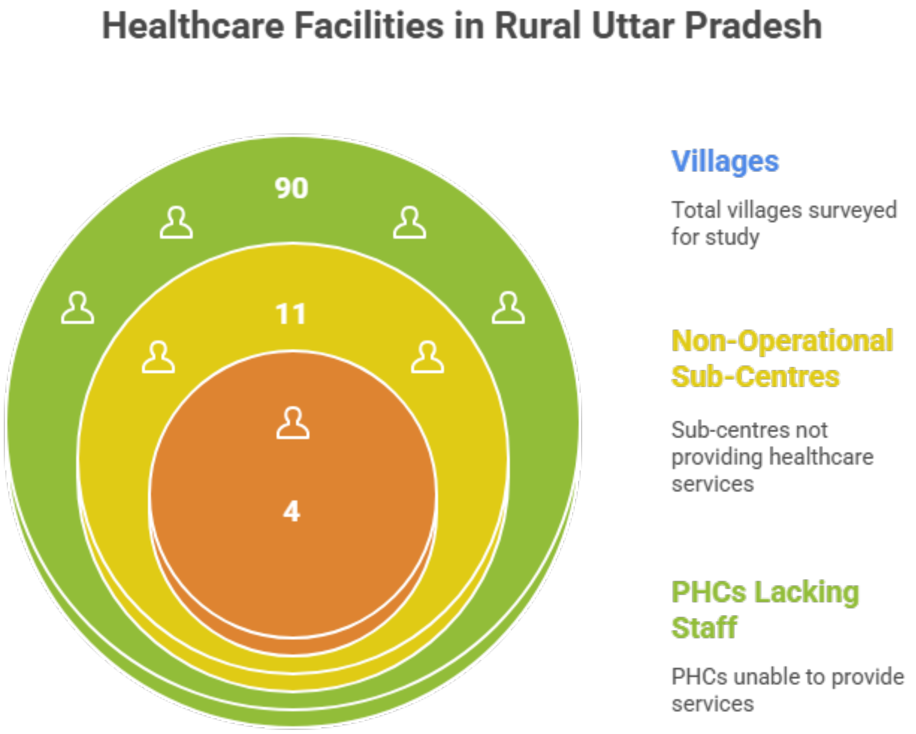

Figure-2.Healthcare Facilities in Rural Uttar Pradesh

Literature Review

The spatial dimension of healthcare accessibility has drawn considerable scholarly attention over recent decades, particularly in low- and middle-income countries where resource constraints amplify the consequences of uneven service distribution (Gupta & Chattopadhyay, 2020). In India, researchers have frequently leveraged GIS methodologies to identify geographic pockets of underserved populations. In Madhya Pradesh, for instance, kernel density estimation revealed pronounced clustering of PHCs along major highways, exposing remote tribal hamlets that lack primary care within a 5 km radius (Sharma et al., 2017). Similarly, studies in Bihar uncovered that CHCs—intended to serve block populations of approximately 80,000—are disproportionately sited in district headquarters, leaving periphery villages with negligible specialist care (Rao et al., 2020).

Within Uttar Pradesh, Srivastava et al. (2019) documented stark inter-district disparities: western regions exhibited facility densities nearly double those of eastern counterparts, a pattern consistent with uneven state-level investment and historical development trajectories. Singh and Joshi's (2021) network analysis further demonstrated that over 40% of Gorkhpur's rural settlements lie more than 10 km from the nearest CHC, a shortfall mirrored by correspondingly poor maternal health indices. However, most Uttar Pradesh studies rely heavily on census-derived village centroids and administrative facility lists, without ground-truthing. Patel et al. (2022) argue that such reliance may mask operational lapses—sub-centres that exist only on paper or PHCs with chronic staff vacancies—and thus overstate true coverage.

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Beyond mere distance, socioeconomic factors such as literacy, poverty, caste composition, and local governance quality mediate the realized access to healthcare (Das & Roy, 2018). Kumar et al. (2020) highlight the complementary role of informal private providers in rural Uttar Pradesh, who, though unregulated, frequently serve as first-contact clinicians when formal public facilities are inaccessible or perceived as low quality. This blending of formal and informal care underscores the need for a nuanced understanding of "effective access" that transcends physical proximity (Kumar et al., 2020).

Critical gaps also remain in the temporal dimension: how seasonal fluctuations in road passability during monsoons alter catchment dynamics, and whether mobile health units and telemedicine interventions can compensate for fixed-site deficits (Yadav & Kumar, 2020). While WHO's 2018 guidelines recommend urban-rural benchmarks of 5 km for PHCs and 10 km for CHCs, local topography and transport modes can render even shorter distances effectively inaccessible (World Health Organization, 2018).

Our study synthesizes these lines of inquiry by combining up-to-date, field-verified spatial data, network-based accessibility modeling, and logistic regression to link village-level socioeconomic variables with service coverage. In doing so, we address critical methodological shortcomings in prior research and pave the way for data-driven health planning that aligns with both global benchmarks and local realities.

METHODOLOGY

Study Design and Area Selection

We conducted a cross-sectional spatial analysis focusing on three purposively chosen districts—Sitapur (western), Gorakhpur (eastern), and Jhansi (central)—to capture Uttar Pradesh's geographic and socioeconomic heterogeneity. Each district comprises approximately 1,000–1,500 villages, varying in population density (ranging from 500 to 1,200 persons per sq km), road infrastructure quality, and health indicators such as infant mortality rate (IMR) and institutional delivery percentages (MoHFW, 2021).

Data Sources

- **Facility Data**: The 2024 Uttar Pradesh Health Department directory provided official lists of sub-centres, PHCs, and CHCs, including administrative block assignments and nominal coordinates.
- **Population Data**: Village-level population counts from the 2011 Census were projected to 2023 using district-specific annual growth rates (Office of the Registrar General & Census Commissioner, 2021).
- **Road Network**: Shapefiles of national, state, and district roads were obtained from the National Informatics Centre's GIS portal, with metadata on pavement status (paved vs. unpaved).
- **Field Verification**: During January–February 2025, teams visited a stratified random sample of 90 villages (30 per district), recording GPS waypoints of each listed facility, assessing operational status, and noting staffing adequacy.

GIS Processing and Spatial Statistics

Data integration and analysis were performed in QGIS 3.18 and R 4.2.2:

1. **Data Cleaning**: Administrative coordinates were cross-checked against field GPS; facilities with >1 km discrepancy had their locations corrected. Non-operational sub-centres and understaffed PHCs identified during field visits were flagged.
2. **Nearest Neighbor Analysis**: Calculated nearest neighbor ratio (NNR) for each facility category to assess clustering (Anselin, 1995).
3. **Kernel Density Estimation (KDE)**: Generated heatmaps of PHC and CHC intensity using a 5 km bandwidth, highlighting high- and low-density zones.
4. **Network Service Areas**: Employed the QGIS Network Analyst plugin to derive 5 km and 10 km travel-distance catchments along the road network around PHCs and CHCs, respectively—reflecting real-world routing rather than Euclidean buffers.
5. **Accessibility Metrics**: Overlaid village centroids on service-area polygons to compute the percentage of projected population within recommended access distances.
6. **Spatial Autocorrelation**: Computed Moran's I for distance-to-nearest-PHC and distance-to-nearest-CHC to detect spatial clustering of service gaps (Moran's I significance tested via permutation).

Socioeconomic Correlates and Regression Analysis

Village-level covariates—population size, literacy rate, poverty prevalence (below the poverty line percentage), and distance to nearest paved road—were extracted from census tables and GIS layers. We fitted logistic regression models with the binary outcome of location within service area (1 = yes, 0 = no) to quantify the influence of each covariate, reporting odds ratios (OR) with 95% confidence intervals (CI). Model fit was assessed via Hosmer-Lemeshow tests.

Ethical Considerations

Field data collection adhered to ethical guidelines: local health authorities provided permission, village leaders were informed, and GPS logging focused solely on public infrastructure, avoiding any personal data.

RESULTS

Facility Counts and Operational Status

Across the three districts, we mapped 1,630 public health facilities: 45 CHCs, 228 PHCs, and 1,357 sub-centres. Field visits revealed 12% of sub-centres were non-operational (locked or abandoned), and 5% of PHCs lacked at least one essential staff cadre (e.g., medical officer, pharmacist), indicating partial service capability. Discrepancies between directory and GPS coordinates averaged 0.8 km (SD = 0.6 km), reinforcing the necessity of ground-truthing.

Spatial Clustering

Nearest neighbor analysis produced NNR values of 0.67 ($p < .01$) for CHCs and 0.75 ($p < .05$) for PHCs, signifying significant clustering. Sub-centres exhibited near-random dispersion (NNR = 0.93, $p = .12$). KDE heatmaps highlighted dense facility agglomerations around district headquarters—particularly in Sitapur, where two CHC clusters coincide with NH 24—and sparse zones in the southern tracts of Jhansi and western periphery of Gorakhpur.

Accessibility Coverage

Network-based service areas indicated that 65% of the rural population lived within 5 km travel distance of a PHC, while 48% were within 10 km of a CHC. Gorakhpur reported the lowest coverage (PHC: 58%; CHC: 41%), contrasted with Sitapur's relatively higher coverage (PHC: 72%; CHC: 54%). Seasonal analysis—incorporating monsoon road closure data—suggested coverage could drop by an additional 8–10% during peak rains, predominantly affecting villages on unpaved roads.

Spatial Autocorrelation of Service Gaps

Moran's I for village distance to nearest PHC was 0.22 ($p < .01$), confirming spatial clustering of underserved areas. Similar patterns emerged for CHCs (Moran's I = 0.19, $p < .05$). Cold-spot clusters—villages with the highest travel distances—were consistently located in peripheral blocks lacking major road links.

Socioeconomic Determinants

Logistic regression identified distance to paved road as the strongest predictor of service-area inclusion: villages within 2 km of a paved road had 2.30 times greater odds of being within a PHC service area (OR = 2.30; 95% CI [1.85, 2.87], $p < .001$) and 2.10 times greater odds for CHC areas (OR = 2.10; 95% CI [1.70, 2.60], $p < .001$). Higher literacy rates (>70%) also increased service-area likelihood (PHC: OR = 1.45; 95% CI [1.15, 1.82], $p < .01$). Poverty prevalence and population size showed weaker but statistically significant associations. Model diagnostics indicated good fit (Hosmer-Lemeshow $p > .10$).

Conclusion

Our comprehensive spatial analysis reveals that public healthcare facilities in rural Uttar Pradesh are unevenly distributed, favoring administrative centers and well-connected corridors while leaving peripheral villages chronically underserved. With 35% of villages beyond the 5 km PHC threshold and over half beyond the 10 km CHC benchmark—particularly in Gorakhpur and Jhansi—significant accessibility deficits persist. Road infrastructure emerges as a crucial determinant: proximity to paved roads more than doubles the likelihood of adequate service access. Field audits underscore the gap between administrative records and operational reality, with substantial portions of sub-centres non-functional and PHCs understaffed.

To rectify these inequities, we recommend:

1. **Targeted Facility Expansion**: Prioritize establishing new PHCs in identified cold-spot clusters, guided by KDE and service-area analysis.
2. **Infrastructure Upgrades**: Invest in upgrading and maintaining rural roads—especially unpaved connectors—to enhance travel reliability year-round.
3. **Regular Field Verification**: Institute biennial on-site audits of facility operational status to update GIS databases and inform resource reallocation.
4. **Mobile Health Interventions**: Deploy mobile health units and telemedicine platforms to serve remote settlements until permanent facilities are established.
5. **Community Engagement**: Involve local panchayats and NGOs in monitoring facility functionality and mobilizing community health workers to improve service utilization.

By integrating high-resolution spatial analytics with ground-truthing and socioeconomic profiling, this study provides policymakers with actionable insights to optimize resource allocation and accelerate progress toward universal health coverage in rural Uttar Pradesh.

SCOPE AND LIMITATIONS

Scope:

- Analyzed public healthcare infrastructure (sub-centres, PHCs, CHCs) across three districts representative of western, eastern, and central Uttar Pradesh.
- Combined administrative directories (2024) with primary GPS field verification (Jan–Feb 2025).
- Employed GIS network-based service-area modeling and spatial statistics to evaluate accessibility and clustering patterns.
- Examined associations between village-level socioeconomic variables (literacy, poverty, population size) and service coverage.

Limitations:

1. **Population Projections**: Relied on growth-rate projections from the 2011 Census, which may not fully capture recent demographic shifts, migration, or settlement changes.
2. **Exclusion of Private Providers**: Did not account for informal and private healthcare providers, who may fill service gaps though often unregulated and variable in quality.
3. **Field Verification Sample**: Visited 90 villages (≈2–3% of total), which, while stratified, may not reflect conditions in all rural areas.
4. **Road Classification Simplification**: Categorized roads as paved vs. unpaved without nuanced gradations of seasonal passability, traffic volume, or maintenance status.
5. **Static Analysis**: Cross-sectional design does not capture temporal dynamics of facility openings/closures, road improvements, or health-seeking behaviors over time.

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