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Disease Hot Spot Mapping for Healthcare Access Inequity in Rural West Bengal (India)

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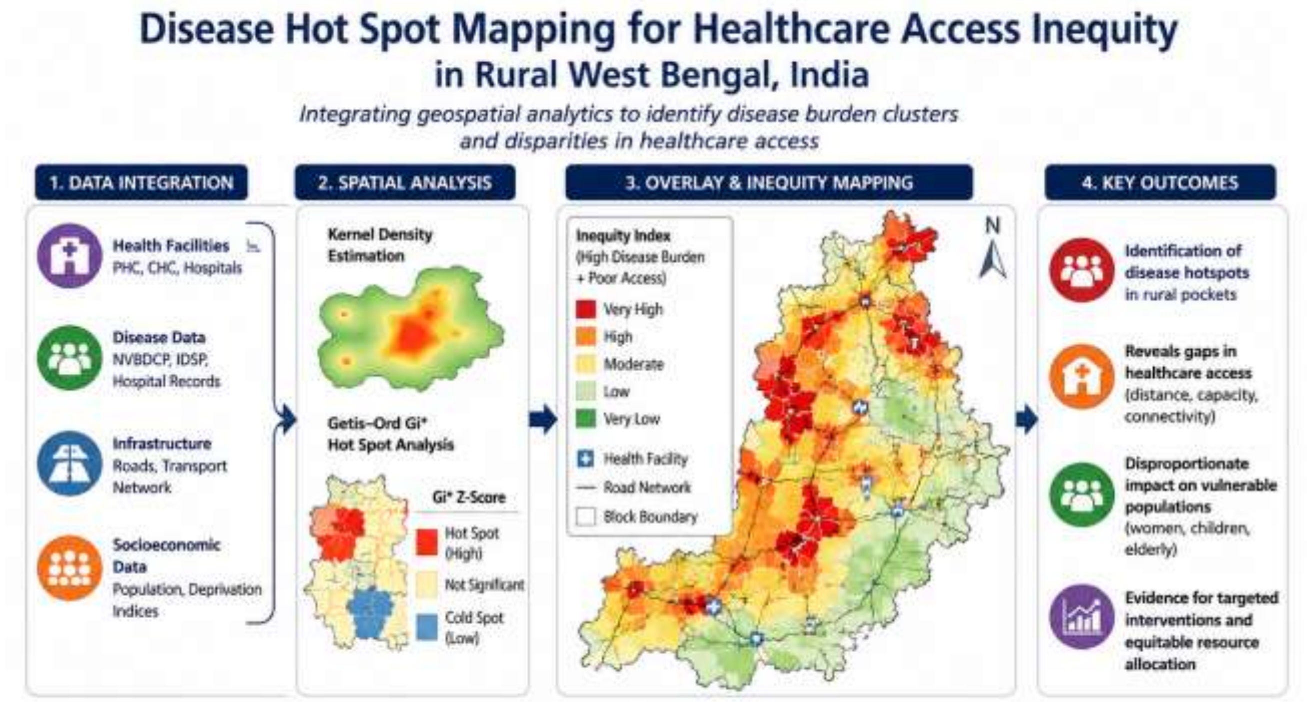
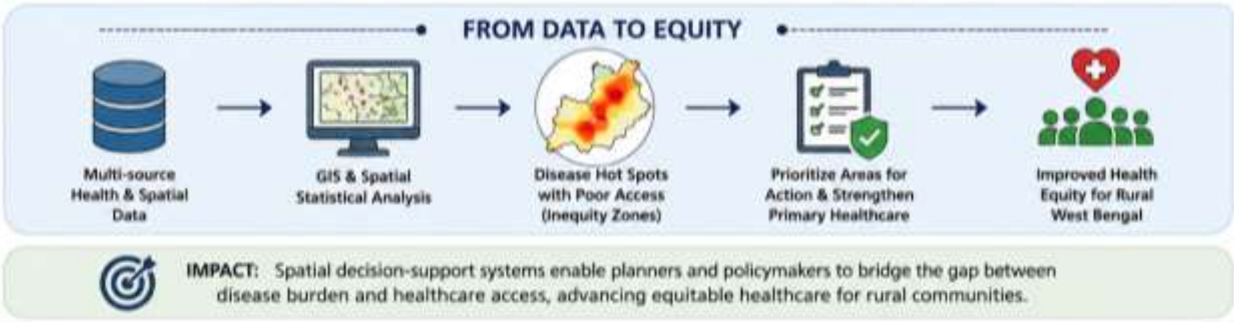
Abstract

Disease hot spot mapping is an essential spatial epidemiological approach for identifying healthcare access inequities in rural West Bengal, India. This study aims to integrate geospatial analytics with public health indicators to delineate disease burden clusters and assess their association with disparities in healthcare availability and utilization. Secondary health data on communicable and non-communicable diseases were combined with geo-coded information on healthcare facilities, transportation networks, population density, and socioeconomic deprivation indices. Spatial statistical techniques, including Getis–Ord Gi* hot spot analysis and kernel density estimation, were employed to identify high-risk disease clusters at the block and village levels. The findings reveal pronounced disease hot spots in geographically isolated and socioeconomically disadvantaged rural pockets, characterized by limited proximity to primary health centers, poor road connectivity, and shortages of skilled health personnel. These inequities disproportionately affect vulnerable populations, including women, children, and the elderly. The study highlights the critical role of spatial decision-support systems in evidence-based health planning and resource allocation. By visualizing mismatches between disease burden and healthcare access, disease hot spot mapping provides actionable insights for targeted interventions, strengthening primary healthcare infrastructure, and advancing equitable healthcare delivery in rural West Bengal.





Graphical Abstract: Spatial Disease Hotspot Mapping for Healthcare Access Inequity in Rural West Bengal: The figure is illustrating geospatial disease hotspot analysis, healthcare accessibility gaps, and inequity mapping to support evidence-based public health planning in rural West Bengal.

Keywords: Disease Hotspot Mapping,Healthcare Access Inequity,Spatial Epidemiology,Rural Healthcare,Geographic Information System (GIS)

1) Context & Problem Definition

Healthcare access inequity in rural West Bengal arises from uneven distribution of health infrastructure, services and disease burden across space and population groups. Key inequities include (Figure1):

- *Spatial distribution of facilities:* Many rural settlements are farther from Primary Health Centres (PHCs) and Community Health Centres (CHCs) — often >5 km from the nearest facility in hotspot rural pockets. (1)
- *Resource and staff shortfalls:* Declining specialist availability (e.g., OB-GYN at CHCs) disproportionately affects marginalized and tribal communities. (2)
- *Socioeconomic gradients:* Poorer districts show lower healthcare quality and accessibility indices. (3)

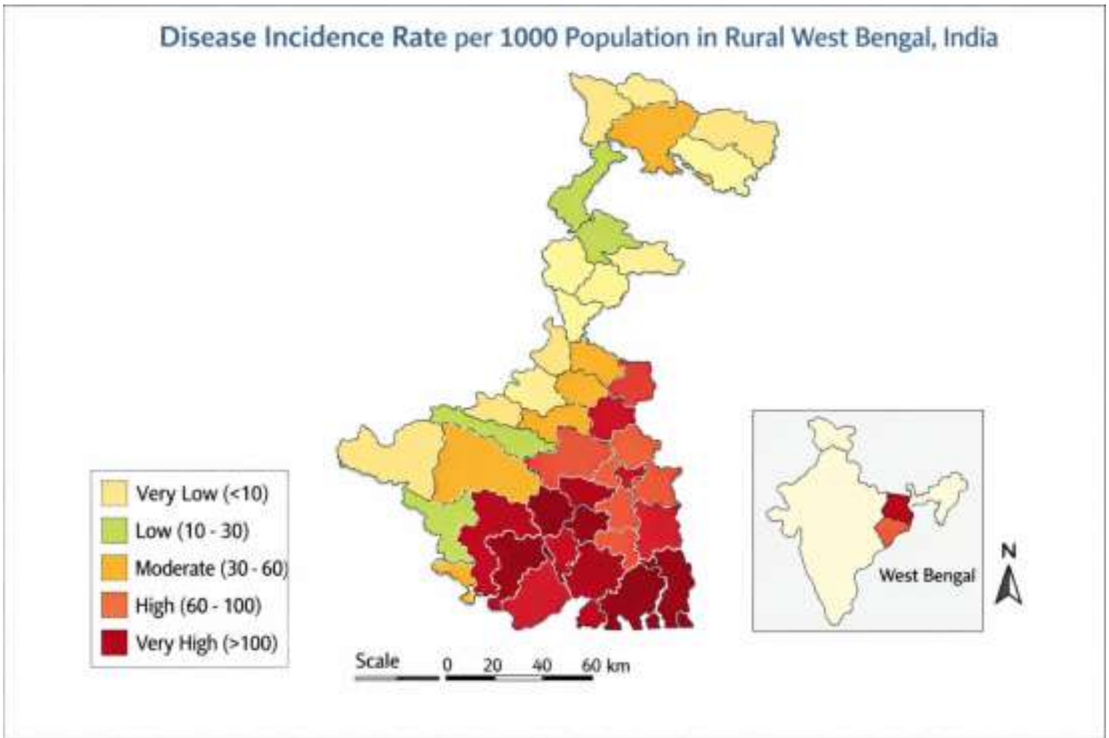


Figure1: Disease Incidence Rate per 1000 population in Rural west Bengal, India

Disease hot spot mapping is used to spatially identify clusters of elevated disease incidence (Figure1) and overlay these with healthcare access metrics to reveal inequities.

2) Spatial Data & Indicators

Disease hotspot mapping requires integrating multiple datasets:

A. Epidemiological data

- Case counts (e.g., vector-borne diseases like dengue, malaria).
- Disease surveillance data (NVBDCP, IDSP, hospital records).
- Serotype or pathogen-specific data (e.g., dengue NS1 positives). (4)

B. Healthcare Access Metrics

- **Facility density & proximity:** distance to nearest PHC/CHC, travel time to care centers(1)
- **Service capacity & quality:** operating capacity of facilities; availability of specialists/nurses. (2)
- **Socio-demographic indicators:** socioeconomic status, education, age, gender. (3)

C. Geospatial Layers

- Administrative boundaries (village/CD Block/district).
- Road/transport network.
- Population density and settlement clusters(5).

3) GIS & Hotspot Analysis Techniques

Hotspot mapping combines GIS with spatial statistics. Common techniques used in public health in West Bengal or comparable contexts (6):

A. Kernel Density Estimation (KDE)

- Converts point cases to a continuous surface to show areas with higher event concentration(7).

B. Getis-Ord Gi*

Identifies *statistically significant clusters* of high (hotspot) or low (coldspot) disease incidence. Used in dengue analyses in West Bengal. (4)

C. Local Indicators of Spatial Association (LISA)

- Detects spatial autocorrelation — identifying local clusters of high/low values relative to neighbors (e.g., disease rates or healthcare indices). Common in spatial epidemiology workflows (8).

D. Multivariate Composite Indices

- Composite access indices (availability, affordability, amenity) mapped across districts highlight healthcare service inequities. (3)

E. Overlay & Suitability Models

- Combine disease hot spots with access metrics to identify *dual burden zones* (high disease + poor access) (9).

4) Case Examples Relevant to West Bengal

Disease hotspot mapping and spatial healthcare analysis have increasingly been utilized in West Bengal to identify inequities in healthcare access, understand disease distribution patterns, and guide evidence-based public health interventions. Several notable examples from the region demonstrate the practical application of Geographic Information Systems (GIS), spatial epidemiology, and hotspot cluster analysis in addressing healthcare disparities (Figure2).

Dengue Hotspot Mapping

Dengue fever remains one of the most significant vector-borne public health concerns in West Bengal, particularly in densely populated urban and peri-urban areas. Spatial and hotspot cluster analyses using advanced GIS-based techniques such as Getis–Ord Gi* statistics, heatmaps, and Kernel Density Estimation (KDE) have been applied extensively to dengue surveillance data across the state. These analyses have enabled researchers and public health authorities to identify statistically significant endemic and outbreak zones with high disease concentration. Evidence suggests that Kolkata and its surrounding districts consistently function as major dengue hotspots due to rapid urbanization, high population density, inadequate sanitation, and climatic conditions favorable for mosquito breeding (4).

Hotspot mapping has facilitated early identification of high-risk transmission zones, thereby supporting targeted vector control measures, improved disease surveillance, and optimized allocation of healthcare resources. Temporal and spatial analysis of dengue outbreaks further helps policymakers understand seasonal variations and prioritize preventive interventions in vulnerable regions. Such GIS-driven approaches have proven valuable in strengthening outbreak preparedness and reducing disease transmission risk within highly affected communities (4).

Healthcare Access Disparity Mapping

Healthcare accessibility across West Bengal demonstrates significant regional disparities influenced by socioeconomic status, geographic remoteness, and uneven distribution of healthcare infrastructure. A multivariate healthcare quality and accessibility index developed for the state revealed persistent inequities between districts. Northern and western districts such as Puruliya, Maldah, Uttar Dinajpur, Dakshin Dinajpur, Jalpaiguri, and Cooch Behar were identified as having comparatively lower healthcare accessibility and poorer healthcare quality indicators (3).

These disparities are attributed to inadequate availability of healthcare facilities, shortages of trained healthcare professionals, poor transportation connectivity, and limited diagnostic and referral services. Spatial mapping of these inequities has provided critical insights into the relationship between socioeconomic deprivation and healthcare utilization patterns. Vulnerable populations residing in remote rural areas often face delayed access to essential health services, contributing to higher morbidity and poorer health outcomes.

GIS-based healthcare disparity mapping enables policymakers to visualize underserved regions and prioritize targeted interventions such as establishment of additional healthcare centers, strengthening referral systems, deployment of specialist healthcare personnel, and improving transportation networks. Consequently, spatial analysis serves as an important decision-support mechanism for promoting equitable healthcare access across geographically disadvantaged populations (3).

Rural Infrastructure Spatial Analysis

Spatial analysis of rural healthcare infrastructure in districts such as Bardhaman and Murshidabad has highlighted substantial variation in facility distribution, functionality, and accessibility. Mapping studies demonstrate that healthcare infrastructure availability is closely associated with settlement proximity, road connectivity, and population density. Many rural settlements remain located far from Primary Health Centres (PHCs) and Community Health Centres (CHCs), resulting in reduced healthcare utilization and delayed treatment-seeking behavior (1).

Infrastructure mapping has also identified pockets of poor healthcare access where inadequate facility functionality, limited medical equipment, and shortages of healthcare personnel significantly affect service delivery. These spatial disparities disproportionately impact vulnerable populations including women, children, elderly individuals, and economically marginalized communities.

The findings emphasize the importance of integrating spatial planning into rural healthcare policy development. GIS-based infrastructure assessments support location-specific planning, optimization of healthcare resource allocation, and identification of priority regions requiring infrastructure strengthening. Such analyses contribute substantially toward improving healthcare accessibility and advancing equitable healthcare delivery in rural West Bengal (1).

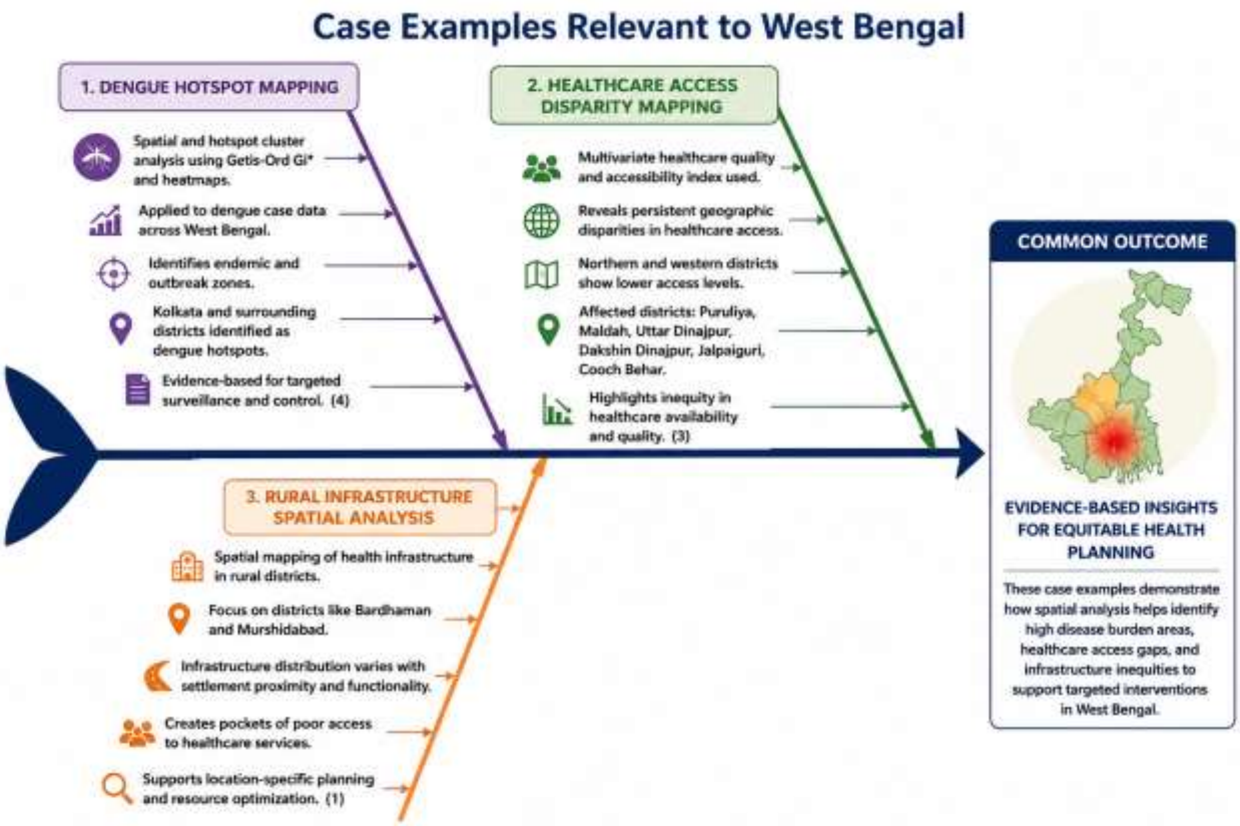


Figure 2: Fishbone Analysis of Spatial Healthcare Inequities and Disease Hotspots in West Bengal: The diagram illustrating dengue hotspots, healthcare disparities, and rural infrastructure gaps contributing to inequitable healthcare access and disease burden across rural West Bengal.

5)Analytical Workflow

The analytical workflow for disease hotspot mapping and healthcare access inequity assessment in rural West Bengal involves a systematic integration of epidemiological, geospatial, and socioeconomic datasets to generate evidence-based spatial insights for public health planning(Figure 3).

Step 1: Data Preparation

The first stage involves comprehensive data collection and preprocessing. Disease incidence data are gathered from surveillance systems, hospital records, Integrated Disease Surveillance Programme (IDSP), and vector-borne disease databases. Simultaneously, geocoded information on healthcare facilities such as Primary Health Centres (PHCs), Community Health Centres (CHCs), and hospitals is compiled. Socioeconomic variables including census indicators, National Sample Survey (NSS) data, literacy rates, income levels, and local demographic surveys are incorporated to understand social determinants influencing healthcare accessibility and disease burden (10). Administrative boundaries, transportation networks, and population distribution layers are also integrated into a GIS platform to establish a unified geodatabase.

Step 2: Disease Hotspot Detection

Spatial statistical methods are then applied to identify significant disease clusters. Techniques such as Getis–Ord Gi* hotspot analysis and Local Indicators of Spatial Association (LISA) help detect statistically significant areas of elevated or reduced disease incidence. These methods identify spatial autocorrelation and reveal localized disease concentration patterns. Where longitudinal datasets are available, temporal validation of hotspot persistence is performed to examine seasonal or recurrent outbreak trends and improve predictive accuracy (11,12,13).

Step 3: Healthcare Access Surface Modeling

The third phase focuses on modeling healthcare accessibility. Accessibility surfaces are generated using travel distance and travel-time analyses to estimate population proximity to healthcare facilities. Geographic barriers, transportation networks, and settlement density are considered while calculating accessibility measures. In addition, service capacity indices are derived based on staffing availability, functional readiness, bed strength, specialist availability, and infrastructural adequacy of healthcare facilities to evaluate healthcare delivery potential (14).

Step 4: Equity Overlay Analysis

Disease hotspots are subsequently overlaid with healthcare accessibility and service capacity indicators to identify high-burden and low-access regions. This overlay analysis enables identification of vulnerable geographic pockets experiencing dual disadvantages. Wherever possible, demographic segmentation is conducted to assess disparities among women, children, elderly populations, and socioeconomically marginalized groups (15).

Step 5: Visualization and Reporting

Finally, thematic GIS maps are generated at village, Community Development Block (CD Block), and district levels to visually represent disease hotspots and healthcare inequities. Spatial summaries and analytical reports are prepared to support policymakers, healthcare administrators, and planners in evidence-based decision-making and targeted intervention planning (16).

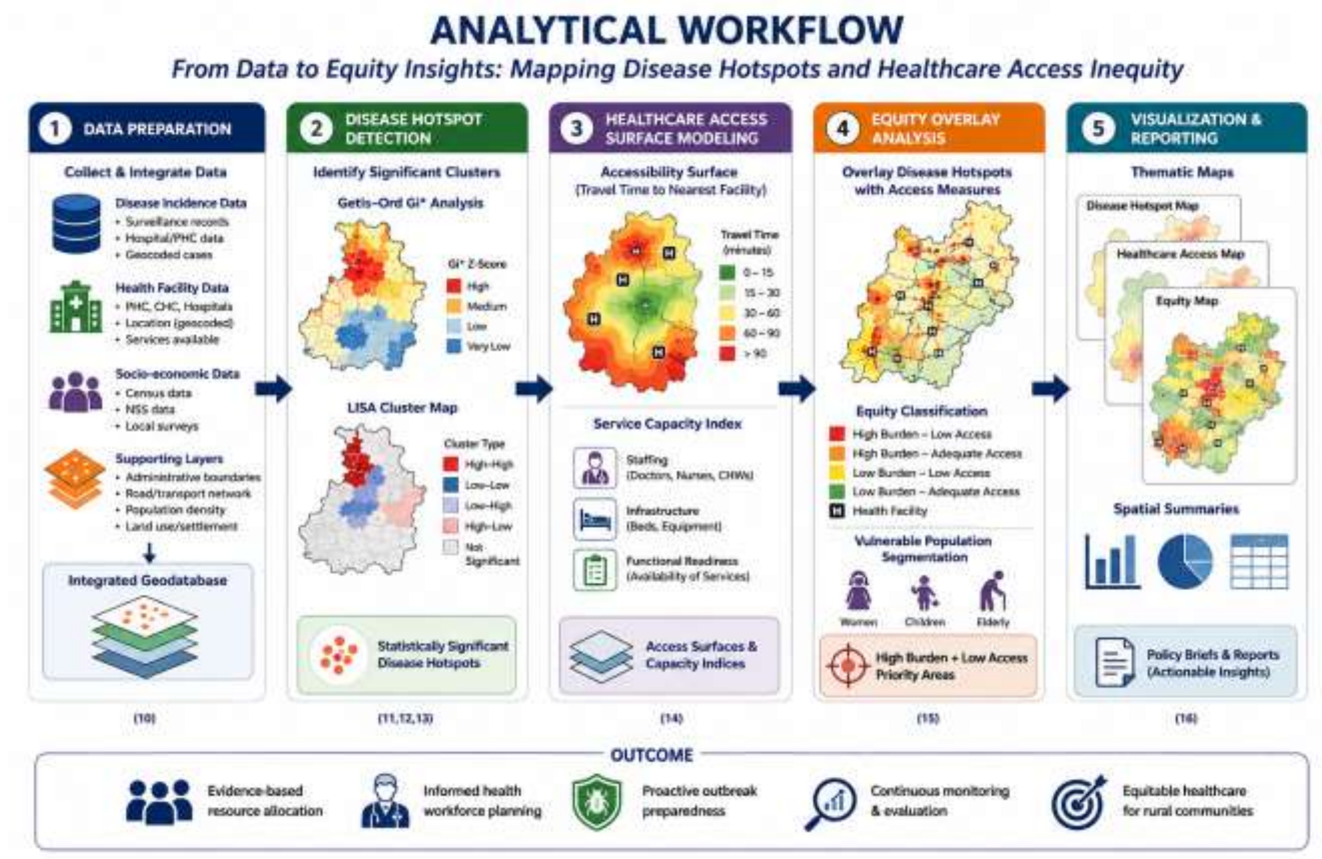


Figure 3: Analytical Workflow for Disease Hotspot Detection and Healthcare Access Inequity Mapping in Rural West Bengal, India : This schematic workflow illustrates data integration, disease hotspot detection, healthcare accessibility modeling, equity overlay analysis, and spatial reporting for evidence-based rural health planning.

6) Policy & Intervention Relevance

Disease hotspot mapping integrated with healthcare access inequity analysis has substantial policy and public health intervention relevance in rural West Bengal. Spatial epidemiological tools provide policymakers with evidence-based insights for identifying underserved populations and geographically vulnerable regions, thereby enabling more efficient and equitable healthcare planning. One of the primary applications is targeted resource allocation, where healthcare authorities can prioritize high-burden geographic clusters for infrastructure development, diagnostic facilities, medical supplies, and preventive healthcare programs. Such prioritization improves distributive efficiency and minimizes regional disparities in healthcare delivery.

Hotspot analysis also supports health workforce planning by identifying areas with shortages of specialists, nurses, and trained healthcare personnel. Deploying healthcare professionals strategically to these identified equity gaps can strengthen rural healthcare systems and improve service accessibility. Furthermore, epidemiological hotspot mapping enhances outbreak preparedness by enabling proactive surveillance, vector control activities, vaccination campaigns, and rapid response interventions in disease-prone regions before outbreaks escalate.

In addition, spatial indicators facilitate monitoring and evaluation of healthcare programs over time by tracking changing disease patterns and healthcare accessibility trends. Continuous geospatial monitoring assists policymakers in assessing intervention effectiveness and modifying strategies based on evolving epidemiological conditions. Thus, GIS-based disease hotspot mapping serves as a powerful decision-support framework for strengthening equitable public health planning and healthcare governance in West Bengal (17).

7) Challenges & Considerations

Despite the growing utility of disease hotspot mapping and geospatial healthcare analysis, several methodological and operational challenges must be considered while interpreting findings and implementing spatial health interventions in rural West Bengal.

One major limitation is data granularity. Rural health data are frequently aggregated at higher administrative units such as districts or blocks rather than at village or household levels. Such aggregation may obscure localized disease clusters and healthcare inequities, thereby limiting the precision of hotspot detection and targeted intervention planning. Inadequate geocoded datasets and inconsistencies in rural health records further complicate accurate spatial analysis.

Another important consideration is temporal alignment of datasets. Disease incidence records, healthcare infrastructure data, and socioeconomic indicators are often collected during different time periods. Variations in data collection timelines can affect the validity of overlay analysis and may lead to inaccurate interpretations of relationships between disease burden and healthcare accessibility. Synchronizing datasets across comparable time frames is therefore essential for reliable spatial epidemiological assessments.

Spatial non-stationarity also presents a significant challenge. Disease distribution patterns, especially for vector-borne illnesses such as dengue and malaria, may vary seasonally due to climatic conditions, rainfall patterns, environmental changes, and human mobility. Consequently, hotspot locations may shift over time, requiring continuous temporal monitoring and dynamic GIS-based surveillance systems.

Finally, healthcare inequity cannot be evaluated solely on the basis of geographic distance from healthcare facilities. Equity dimensions must incorporate broader socioeconomic determinants such as poverty, literacy, gender disparities, transportation affordability, social marginalization, and healthcare-seeking behavior. Integrating these multidimensional indicators is essential for developing comprehensive and context-sensitive public health interventions aimed at reducing healthcare inequities in rural populations.

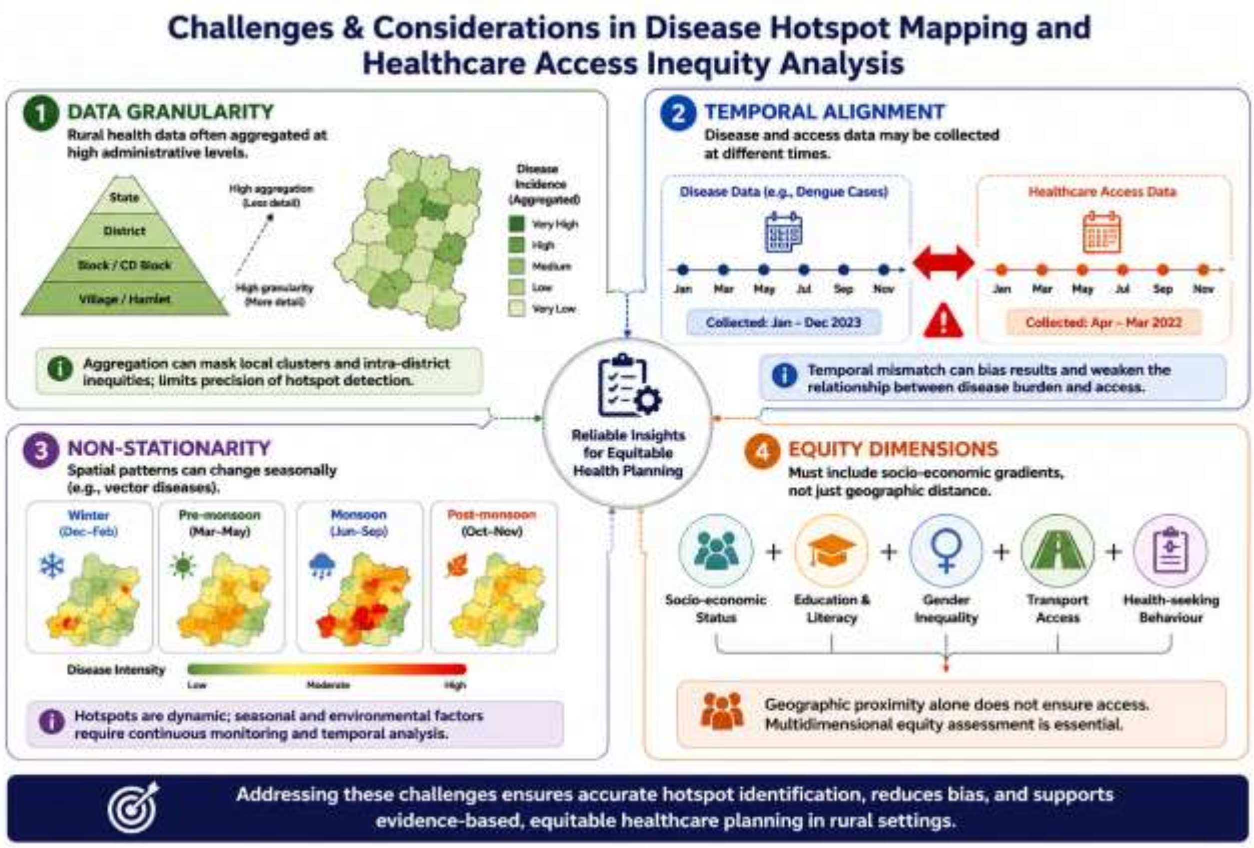


Figure 4: Challenges and Considerations in Disease Hotspot Mapping and Healthcare Access Inequity Analysis : The figure illustrates methodological challenges including data aggregation, temporal mismatch, seasonal spatial variation, and socioeconomic inequities affecting accurate disease hotspot and healthcare access analysis.

8) Conclusion

This study demonstrates the critical utility of disease hot spot mapping as an evidence-based geospatial tool for identifying and addressing healthcare access inequities in rural West Bengal, India. By integrating spatial epidemiological techniques with health service accessibility indicators, the analysis reveals persistent clusters of high disease burden that are spatially coincident with limited availability, affordability, and physical access to healthcare services. These hot spots are predominantly concentrated in geographically remote, socio-economically disadvantaged, and infrastructure-deficient rural districts, underscoring the structural nature of health inequities rather than random spatial variation (18).

The findings highlight that insurance-led schemes such as *Swasthya Sathi*, while substantially expanding financial protection, do not uniformly translate into effective healthcare utilization across space. In several high-burden rural clusters, delayed care-seeking, inadequate referral networks, and sparse empanelled facilities continue to constrain program impact. Disease hot spot mapping thus provides a complementary planning lens that can guide targeted expansion of health infrastructure, mobile health units, transport connectivity, and differential provider empanelment in underserved regions(19).

From a policy perspective, embedding routine geospatial surveillance within state health information systems can strengthen micro-planning, optimize resource allocation, and support equitable universal health coverage. Future research should incorporate temporal hot spot analysis, facility readiness metrics, and social determinants of health to refine intervention prioritization. Overall, spatially explicit disease hot spot mapping emerges as a vital decision-support mechanism for reducing rural health inequities and improving the distributive efficiency of public health programs in West Bengal(20).

9) Data Sources & Tools

- Government disease surveillance (NVBDCP, IDSP).
- Census & Socio-Economic data.
- District health system data (HMIS, Rural Health Statistics).
- Field surveys.

Tools

- QGIS / ArcGIS for spatial analysis.
- R (spdep, sf) or Python (PySAL, GeoPandas) for hotspot statistics.
- Remote sensing for environmental risk predictors.

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