

ORIGINAL ARTICLE

Geospatial Network Analysis of Maternal Healthcare Access and Travel Impedance in South 24 Parganas District, West Bengal

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Abstract

Background: Geographic disparities in access to emergency obstetric care contribute heavily to maternal mortality. Spatial barriers often delay life-saving clinical interventions. **Aims & Objectives:** This study aimed to model the travel network impedance from localized population centers to tertiary and secondary referral health facilities in South 24 Parganas, West Bengal. **Methodology:** A secondary spatial data analysis was conducted for the South 24 Parganas district. The geographical coordinates bounded the region between 21° 29' N to 22° 33' N latitude and 88° 3' E to 89° 5' E longitude. Eight population nodes and five institutional health hubs were mapped. QGIS software v 3.36 was used to calculate travel time matrices using existing road and waterway network vector layers. Bed counts and local population densities served as core attribute variables. **Results:** The calculated travel costs from population nodes to the closest facilities varied significantly across the geographic landscape. The minimum travel impedance recorded was 19.55 minutes. The maximum recorded travel impedance reached 125.15 minutes. Remote deltaic sectors demonstrated extreme transit times to higher-order health facilities. **Conclusion:** Severe spatial constraints restrict healthcare access for maternal populations within remote hubs of South 24 Parganas. Targeted infrastructure investments and strategic placement of emergency obstetric care facilities are crucial to bridge these geographic gaps.

Key Words: Geographic Information Systems, Health Services Accessibility, Maternal Health Services, Maternal Mortality, Travel Time

Key Message: Geospatial network modeling reveals critical gaps and extreme travel-time variation — up to 125 minutes — for maternal populations accessing secondary and tertiary referral health hubs in South 24 Parganas.

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I. INTRODUCTION

Maternal mortality remains a significant global public health concern.¹ Type II delay in reaching an appropriate medical facility is a major driver of preventable maternal deaths.^{2,3} Spatial distance and poor transport infrastructure aggravate these barriers.⁴ This problem is particularly acute in developing countries and rural sub-regions.⁵

The district of South 24 Parganas, with an approximate maternal mortality ratio of 110 per one lakh live births, has unique and complex geographical terrains.⁶ The deltaic region contains massive networks of rivers, creeks, and waterways.⁷ This estuarine terrain hinders the continuous development of standard road infrastructure. Consequently, pregnant women residing in these remote pockets face immense physical challenges during medical emergencies. They must navigate fragmented roads and seasonal river transport systems to reach healthcare facilities.⁸

Traditional administrative planning often overlooks real-world transit layouts.⁹ Straight-line distance measurements do not represent true travel impedance over complex terrains.¹⁰ Geographic Information Systems (GIS) provide advanced tools to address this limitation.⁸ Network analysis techniques calculate precise travel times along actual transport vectors.¹⁰ These models incorporate physical barriers, road classes, and transport speeds.⁹ Thus, spatial modeling offers a realistic assessment of maternal healthcare accessibility.

A detailed evaluation of the existing referral network is highly necessary.⁸ The evidence might allow health administrators to optimize resource distribution.⁵ It also helps in placing emergency obstetric care facilities strategically.³ Therefore, this study was conceptualized to fill the existing gaps in regional transport planning for maternal health. The study aimed to analyze the spatial network accessibility and determine travel time impedance from various population centers to designated secondary and tertiary healthcare hubs in the South 24 Parganas district.

II. MATERIALS AND METHODS

Study Design and Study Area

This study was a secondary data analysis using geospatial modeling techniques. It was conducted for the South 24 Parganas district located in West Bengal, India. The geographic boundaries of the study area extend from 21° 29' N to 22° 33' N latitude and 88° 3' E to 89° 5' E longitude.⁶ This district includes a mix of peri-urban plains and the unique riverine tracts of the Sundarbans delta.⁷ (Figure 1)

Network Nodes and Hubs

The spatial network model incorporated specific geographic points to assess travel friction.⁹ Eight distinct population clusters were selected and designated as origin nodes. These nodes represented major community settlements across the district geography. The selected nodes included Budge Budge, Sonarpur, Jaynagar, Mograhat, Mathurapur, Kulpi, Falta, and Basanti. Five primary institutional health facilities were selected and designated as destination hubs. These hubs included Diamond Harbor Medical College, Baruipur Sub-Divisional Hospital (SDH), Canning Sub-Divisional Hospital (SDH), Sarisha Block Primary Health Centre (BPHC), and Padmahat Block Primary Health Centre (BPHC). (Figure 1)

Study Variables and Data Sources

Multiple spatial and non-spatial variables were integrated into the analysis database. The primary non-spatial attribute was total bed counts at each health facility hub.⁶ Local population numbers within each settled locality node were included as a demand variable. The primary spatial data layers consisted of road networks, navigable waterways, and point locations of health hubs. The secondary spatial layers, transport networks, and demographic variables were sourced from official public domain repositories and institutional health records.

Data Analysis and Spatial Modeling

Spatial network analysis was executed utilizing open-source QGIS software version 3.36. It was used to compile the geographic database and run network simulations. A digital network graph was constructed using the vector

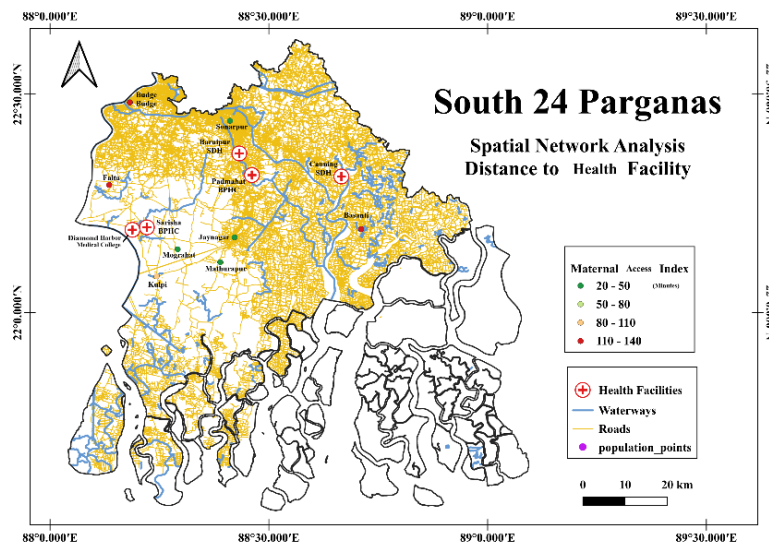


Figure 1: Spatial Network Analysis and Travel Distance to Health Facilities in South 24 Parganas.

road networks and waterway layers. Travel speeds were assigned to different road categories based on standard transport guidelines. Waterway transit parameters were added to represent ferry crossings in deltaic zones.

The Network Analysis toolbox was utilized to run an origin-destination cost matrix.⁹ The algorithm calculated the shortest travel paths along the network vectors.¹⁰ The accumulated travel time in minutes was computed from each of the eight origin nodes to each of the five destination hubs. The mathematical costs accounted for land-water transitions and topological connectivity. The resulting matrix values were mapped to produce a Maternal Access Index layout. The findings were visually represented using a graded colour scheme to indicate variations in transit times across the district.

The accumulated travel time in minutes was computed from each of the eight origin nodes to each of the five destination hubs to establish a comprehensive multi-destination impedance matrix. Subsequently, a secondary proximity filter was applied to isolate and map only the single least time-consuming path from each origin node to its nearest accessible healthcare facility.

Ethical Considerations

This research was based entirely on the analysis of secondary data layers. The dataset did not contain any individual human participant identifiers. No clinical records or personal health information were accessed during the data compilation. Therefore, this study did not require any formal ethical clearance or institutional review board permission.

III. RESULTS

The spatial distribution of health facilities and the travel time categories across South 24 Parganas were mapped systematically. The geographic layout of transport vectors, waterways, and facility catchments is shown in Figure 1.

The network analysis quantified the travel impedance values between all nodes and hubs. The complete matrix of travel times in minutes is presented in Table 1.

The Maternal Access Index is divided into four main travel time tiers. The green points show the shortest travel times between 20 and 50 minutes. The light green points indicate moderate travel times between 50 and 80 minutes. The orange points highlight high travel times between 80 and 110 minutes. The red points mark extreme travel times ranging from 110 to 140 minutes. (Figure 1)

Table 1: Travel Time Impedance Matrix from Population Nodes to Health Hubs (Minutes)

Origin ID	Population Node	Hub 1: Diamond Harbor Medical College	Hub 2: Baruipur SDH	Hub 3: Canning SDH	Hub 4: Sarisha BPHC	Hub 5: Padmahat BPHC
1	Budge Budge	33.83	76.17	125.15	40.75	79.87
2	Sonarpur	25.82	79.17	99.30	19.55	70.77
3	Jaynagar	30.67	93.64	109.15	28.46	80.65
4	Mograhat	75.87	70.16	119.46	82.79	83.29
5	Mathurapur	89.82	19.95	64.32	89.58	33.07
6	Kulpi	54.04	50.57	67.65	47.20	37.58
7	Falta	53.72	64.75	80.27	46.88	51.76
8	Basanti	120.84	77.61	35.19	114.00	69.74

The lowest travel time recorded in the entire network is 19.55 minutes. This minimum time occurs from the origin node 2 to the destination hub 4. The highest travel time recorded in the network is 125.15 minutes. This maximum impedance occurs from origin node 1 to destination hub 3. Origin node 8 shows a low travel time of 35.19 minutes to destination hub 3. However, origin node 8 shows an extreme travel time of 120.84 minutes to destination hub 1. Origin node 4 maintains a travel time above 70 minutes across all five available destination hubs. (Table 1)

The time-optimized spatial network pathway analysis mapped the actual physical transit pathways along the road and waterway infrastructure of the South 24 Parganas district. The multi-destination geographic distribution model highlights a stark regional imbalance. (Figure 2) Figure 2a describes the exhaustive network of all potential spatial paths. The time-optimized pathways in Figure 2b demonstrate that rapid healthcare access remains localized. The most efficient transit routes (under 29 minutes) are heavily restricted to the western and northwestern perimeters, leaving communities adjacent to the southern deltaic networks isolated, facing significantly higher travel times to reach secondary or tertiary clinical infrastructure.

IV. DISCUSSION

The main objective of this study was to analyze spatial network accessibility and determine travel time impedance from population nodes to designated health hubs in South 24 Parganas. The findings showed a wide variation in travel impedance across the district.

Several factors explain the significant differences in travel times. The estuarine geography of South 24 Parganas creates natural obstacles for land transport.⁷ Localities like Basanti are separated from major urban centers by rivers and creeks. Relying on ferry connections increases transit times significantly.⁶ This reliance explains the high travel cost of 120.84 minutes from Basanti to Diamond Harbor Medical College. Conversely, sectors with contiguous highway networks show much lower travel impedance. For example, Sonarpur shows a short travel time of 19.55 minutes to Sarisha BPHC due to better road connectivity. Fragmented infrastructure directly compromises maternal health outcomes.⁵ Long transit times prolong the second delay during obstetric emergencies.² This delay increases the risk of birth complications and maternal mortality.⁴ Pockets facing travel times above 80 minutes require urgent attention. These high-impedance zones leave pregnant women vulnerable when complications arise.⁸

Subsequently, when the network is optimized to model transit strictly to the closest available health facility (Figure 2b), a different

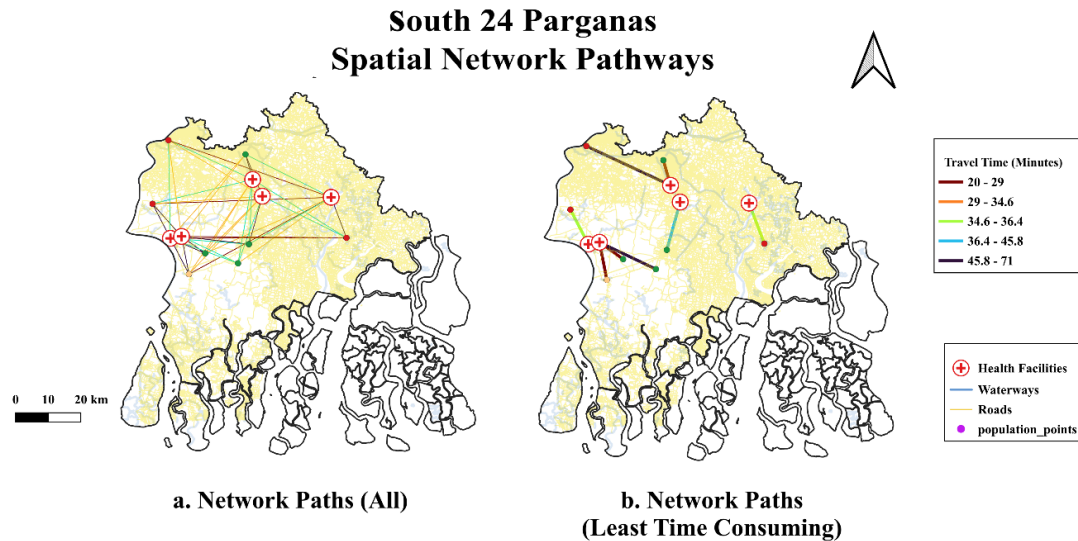


Figure 2: Time-Optimized Spatial Network Path Analysis and Geographic Accessibility Tiers across South 24 Parganas, West Bengal.

layer of spatial inequality emerges. Even under this ideal-case scenario, the safety net is not uniform; while western border populations enjoy highly efficient access within 29 minutes, other northern and sub-deltaic communities still experience localized infrastructure friction and bottlenecks that stretch nearest-facility transit up to 71 minutes. This implies that proximity on a map does not automatically equate to rapid clinical access when the underlying road vectors are fragmented.

This study used actual road and waterway network paths instead of simple straight-line distances. This approach provided a realistic model of travel impedance over difficult deltaic terrain. The dual-model approach of integrating a comprehensive multi-destination matrix alongside a proximity-filtered nearest-hub analysis significantly enhances the accuracy and utility of the geographic model for real-world referral planning.

Thus, localities with travel times exceeding 100 minutes need immediate decentralized care options. Specialized obstetric stabilization units should be set up at riverine transit points. Multi-modal transport networks must be improved. Upgrading ferry services and building bridges will reduce travel friction signif-

icantly. Lastly, future research should incorporate seasonal variables into network models. Analyzing transit variations during heavy monsoons will provide deeper insights. Researchers should also look at how facility capacities affect patient choices. Combining spatial travel costs with clinical quality data will help optimize maternal health planning.

V. CONCLUSION

This study highlights major geographic disparities in maternal healthcare access across South 24 Parganas. Network modeling revealed that travel times to referral hubs range from under 20 minutes to over two hours. The riverine landscape creates significant transit barriers for remote communities. These findings emphasize that straight-line distance models underestimate actual travel barriers. Reducing these spatial inequities requires targeted infrastructure investments and decentralized emergency obstetric facilities. Implementing these spatial adjustments is essential to eliminating transit delays and lowering maternal mortality.

Limitations of the Study

The network analysis assumed static travel

speeds along transport vectors. It did not account for real-time traffic congestion or seasonal weather disruptions. Monsoonal flooding often slows transit speeds or disrupts ferry services completely in the Sundarbans. Furthermore, the model did not include the use of private transport modes or emergency ambulance availability.

Authors' Contribution

All authors contributed substantially to this study, from conceptualization, study design, literature search, data curation and data analysis to manuscript writing and review. All of them are guarantors of this work.

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Conflict of Interest

The authors have no conflicts of interest regarding this work.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors did not use AI at any stage of this study.

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