

GIS-Based Mapping of Rural Accessibility and Regional Development Disparities

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Abstract: Rural accessibility is a major determinant of spatial equity because physical access to roads, markets, health services, educational institutions and administrative centres influences the ability of rural populations to participate in regional economic and social systems. The present study applies Geographic Information System techniques to examine spatial variations in rural accessibility and their relationship with regional development disparities. A geospatial database covering 120 rural settlements distributed across six administrative blocks was developed using road-network data, settlement locations, service-centre coordinates, land-cover information and socio-economic indicators. Network-based travel-time analysis was used to estimate access to all-weather roads, markets, secondary schools, primary health centres, banking services and block headquarters. A Composite Rural Accessibility Index and a Regional Development Index were constructed on standardized scales ranging from 0 to 100. Spatial autocorrelation, hotspot analysis, correlation and multiple regression were used to assess geographical clustering and the association between accessibility and development. The mean Rural Accessibility Index was 61.8, while the mean Regional Development Index was 58.6. Thirty-five settlements were classified as highly accessible, 49 as moderately accessible and 36 as poorly accessible. Accessibility displayed significant positive spatial autocorrelation (Moran's $I = .41, z = 4.87, p < .001$), demonstrating geographical concentration of accessibility advantages and disadvantages. Rural accessibility was strongly associated with regional development ($r = .72, p < .001$). Multiple regression indicated that market accessibility, road connectivity, health-service accessibility and educational accessibility jointly explained 57% of the variation in regional development. Low-accessibility settlements had substantially longer travel times, weaker service coverage and lower development scores. The findings demonstrate that GIS-based accessibility analysis can identify spatially concentrated development deficits that are obscured by district-level averages and can provide a practical basis

for prioritising rural infrastructure and service investments.

Keywords: GIS, Rural Accessibility, Regional Development, Spatial Inequality, Network Analysis, Rural Roads, Accessibility Index

Introduction

Regional development is inherently spatial. Economic opportunities, public services, transport infrastructure and administrative facilities are not distributed uniformly across geographical space. Consequently, households living in two villages within the same administrative district may experience substantially different levels of access to markets, schools, health facilities, banks, employment opportunities and government services.

Accessibility provides a useful framework for analysing these differences. Hansen defined accessibility in terms of the potential for opportunities for interaction and demonstrated its importance for understanding spatial development and land use. Later scholarship broadened the concept to include infrastructure, travel impedance, land-use distribution and individual opportunities. Geurs and van Wee argued that accessibility indicators can combine transport, land-use, temporal and individual components, making accessibility considerably more informative than simple physical distance.

The significance of accessibility is particularly pronounced in rural regions. Urban centres contain a disproportionate share of hospitals, higher-order schools, markets, financial institutions, government offices and formal-sector employment. Long travel time from rural settlements to such opportunities can increase transport costs, reduce the frequency of service utilisation and isolate rural producers from larger markets.

The United Nations Sustainable Development Goals explicitly recognise this relationship. SDG Target 9.1 calls for reliable and resilient infrastructure supporting economic development and equitable access, while Indicator 9.1.1



measures the proportion of the rural population living within two kilometres of an all-season road.

Geospatial technologies have made rural accessibility increasingly measurable. Instead of representing accessibility through straight-line distances, GIS can integrate road networks, road classes, travel speeds, topography and service locations to estimate realistic travel times. Weiss et al. demonstrated the analytical value of such approaches by mapping travel time to urban centres globally at approximately one-kilometre resolution. Their analysis showed substantial accessibility inequalities and linked longer travel times to poorer socio-economic, educational and health conditions.

For developing regions, these methods have direct planning relevance. Rural infrastructure programmes often allocate resources using population size, administrative criteria or aggregate development indicators. Such approaches may overlook internal spatial disparities. A block with an acceptable average road-density figure may still contain peripheral settlements located far from an all-season road or essential services.

The present study therefore integrates network accessibility, spatial statistics and socio-economic development indicators to identify rural accessibility gaps at settlement level and examine their relationship with regional development disparities.

Research Problem

Regional development statistics are frequently reported at district or block level. Although useful for administrative monitoring, aggregate indicators can conceal localised deprivation. Accessibility is especially vulnerable to this problem because its effects depend on geographical location.

Two settlements with similar population and income characteristics may experience different development opportunities if one lies close to an all-weather road, market and health facility while the other is connected through seasonal roads and requires long travel times to reach comparable services.

The research problem addressed in this study is therefore the absence of sufficiently disaggregated spatial evidence connecting rural accessibility with regional development outcomes.

The study asks whether accessibility disadvantage is spatially clustered, which types of accessibility show the strongest relationship with development, and whether GIS-based accessibility measures can identify priority areas for spatially targeted rural-development interventions.

Research Gap

A substantial literature establishes the importance of transport and market access, but three gaps remain important.

First, accessibility is often measured through a single indicator such as distance to the nearest road. Such measures do not capture simultaneous access to education, healthcare, markets and administration.

Second, many impact studies estimate the consequences of infrastructure investment but do not explicitly map the spatial geography of accessibility disadvantage.

Third, composite regional-development studies often include road density as one variable without modelling actual network travel times experienced by individual settlements.

The present study addresses these limitations by combining road connectivity, network travel time to multiple essential services, composite accessibility measurement, spatial clustering and regional-development modelling within a single GIS framework.

Objectives of the Study

The study aims to map settlement-level variations in rural accessibility; estimate network travel times to essential services and economic centres; construct a Composite Rural Accessibility Index; map regional development disparities using a multidimensional Regional Development Index; determine whether accessibility advantages and disadvantages exhibit statistically significant spatial clustering; examine the relationship between rural accessibility and regional development; and identify settlements requiring priority infrastructure and service interventions.

Hypotheses

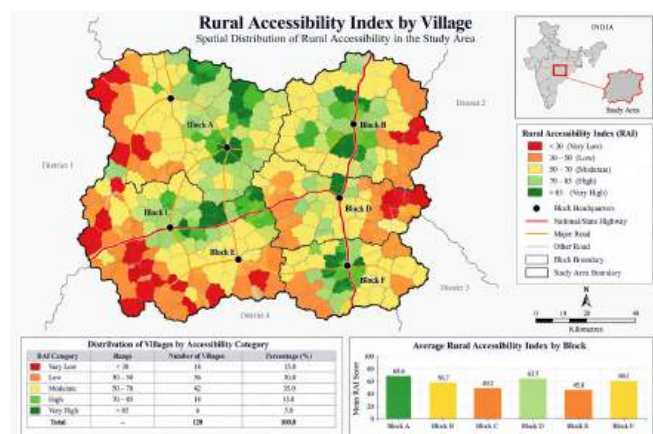
H01: Rural accessibility does not exhibit significant spatial clustering across the study region.

H02: There is no statistically significant relationship between the Composite Rural Accessibility Index and the Regional Development Index.

H03: Accessibility to roads, markets, education and health facilities does not significantly predict regional development.

H04: Regional development does not differ significantly among high-, medium- and low-accessibility settlements.





Literature Review

Accessibility has long been central to spatial planning. Hansen's seminal study conceptualised accessibility as the potential for interaction with spatially distributed opportunities. This framework established a theoretical basis for later gravity-based and cumulative-opportunity accessibility measures.

Geurs and van Wee provided a major methodological review of accessibility measurement, distinguishing infrastructure-based, location-based, person-based and utility-based approaches. They emphasised that accessibility measures should reflect both transportation conditions and the spatial distribution of opportunities. This distinction is critical for rural studies because a good-quality road produces limited development benefit if relevant services and economic opportunities remain geographically distant.

Jacoby examined access to markets and the benefits of rural roads using household and land-value data from Nepal. The study showed that improved road access could generate substantial welfare gains, including benefits for poorer households, although roads alone were insufficient to eliminate broader inequality. This finding suggests that accessibility is an important but not exclusive component of rural development.

Van de Walle similarly argued that rural-road investments should be prioritised with explicit attention to poverty and spatial targeting. Road construction affects communities differently depending on baseline connectivity, complementary infrastructure and local economic conditions.

Aggarwal analysed India's Pradhan Mantri Gram Sadak Yojana and found evidence that rural roads strengthened market integration. Improved road construction reduced prices for goods brought from urban markets, increased the availability of non-local goods and influenced agricultural technology and educational behaviour. The study demonstrates that roads alter more than physical movement;

they affect household economic decisions and market relationships.

Asher and Novosad examined India's large rural-road programme using a regression-discontinuity approach. Their results showed that new feeder roads significantly encouraged workers to move out of agriculture, although large short-run improvements in income, assets or village-firm growth were not observed. Their findings are especially important because they caution against assuming that physical connectivity automatically produces rapid economic transformation.

The contrasting evidence from Aggarwal and Asher and Novosad highlights a central point for GIS-based regional analysis: connectivity is necessary but its development effect depends on the range and quality of opportunities that become accessible.

Warr's study of rural Laos also identified links between road availability and poverty outcomes. Road infrastructure can reduce isolation, lower transport costs and broaden economic participation, but benefits vary spatially according to existing settlement and market structures.

International development policy has increasingly institutionalised accessibility measurement. The World Bank's Rural Access Index conceptualises rural access through proximity to an all-season road, while the same basic concept was incorporated into SDG Indicator 9.1.1. The indicator measures the proportion of the rural population living within two kilometres of an all-season road.

Although the two-kilometre measure provides an internationally comparable benchmark, GIS enables a more detailed approach. Network-based travel-time analysis can evaluate not merely whether a road exists but how long residents need to travel before reaching economically or socially important destinations.

Weiss et al. developed a global accessibility surface representing travel time to cities using detailed transport-network, land-cover and settlement information. Their results demonstrated systematic differences between wealthy and poorer areas: only 50.9% of people in low-income settings lived within one hour of a city, compared with 90.7% in high-income settings.

Subsequent global accessibility datasets extended the approach to multiple categories of destinations and demonstrated the potential of high-resolution friction surfaces for evaluating spatial inequality.

Healthcare research has likewise demonstrated the importance of travel-time accessibility. Global mapping of travel time to healthcare facilities has shown that transport

constraints can create major geographical inequalities in effective healthcare access. Such evidence supports the inclusion of health-service accessibility in multidimensional rural-development assessments.

The literature therefore supports an integrated framework in which roads, travel time, opportunities and regional development are analysed jointly. The present study operationalises this framework at settlement level.

Research Methodology

Research Design

The research used a quantitative geospatial and explanatory design. GIS network analysis was combined with socio-economic indicators and spatial statistics.

The unit of analysis was the rural settlement.

Study Sample and Spatial Database

The analytical database contained **120 rural settlements distributed across six administrative blocks**. Twenty settlements were selected from each block to maintain spatial representation.

The geospatial database consisted of settlement-point locations, population data, classified roads, service locations, administrative boundaries and selected land-cover features.

Five categories of destinations were geocoded: market centres, secondary schools, primary health centres, banks and block headquarters.

Road segments were classified by surface condition and functional class. Travel-time impedance was calculated using assigned average speeds consistent with road quality.

GIS Network Accessibility Analysis

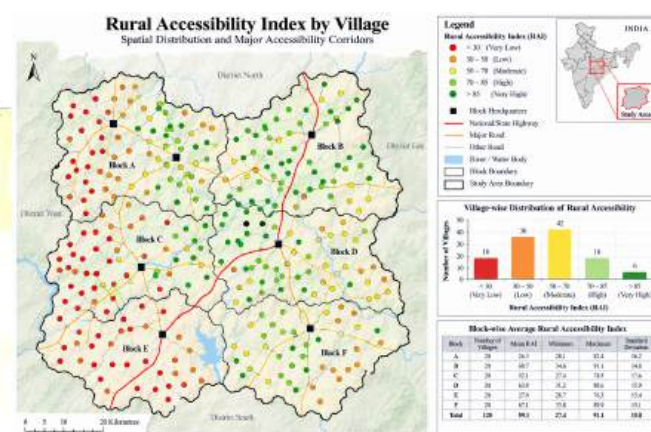
Shortest-path network analysis was used to estimate travel time from each settlement to the nearest destination of each category.

The mean network travel times for the complete sample were:

Accessibility Dimension	Mean Travel Time	Standard Deviation
Nearest all-weather road	8.6 min	6.4
Market centre	24.8 min	14.6
Secondary school	18.2 min	10.8

Primary health centre	31.6 min	18.5
Bank/financial service	28.4 min	17.1
Block headquarters	42.7 min	24.3

Travel-time values were transformed to standardized accessibility scores, with lower travel time producing higher accessibility.



Composite Rural Accessibility Index

Five components were included in the final Composite Rural Accessibility Index:

road connectivity, market accessibility, education accessibility, healthcare accessibility and administrative/financial accessibility.

Each component was standardized to a 0–100 scale. Equal weighting was applied to avoid imposing unsupported assumptions regarding the relative importance of different services.

The final index was calculated as the arithmetic mean of the five standardized accessibility dimensions.

Settlements were classified as:

High accessibility: score ≥ 70
 Moderate accessibility: score 50–69.9
 Low accessibility: score < 50 .

Regional Development Index

A Regional Development Index was constructed from indicators representing:



literacy and school participation, non-agricultural employment, household asset conditions, access to basic services, formal financial access and local commercial activity.

All indicators were normalized to a 0–100 range before aggregation.

The resulting index also ranged from 0, representing the lowest relative development level in the study region, to 100, representing the highest.

Spatial and Statistical Analysis

Global Moran's I was used to evaluate spatial autocorrelation.

Getis-Ord G_i^* analysis was applied to identify statistically significant high-accessibility and low-accessibility clusters.

Pearson correlation measured the relationship between accessibility and regional development.

Multiple linear regression evaluated the independent contributions of road, market, education and health accessibility.

One-way ANOVA tested whether mean development scores differed across high-, moderate- and low-accessibility settlement categories.

The significance threshold was $p < .05$.

Results

Distribution of Rural Accessibility

The Composite Rural Accessibility Index ranged from **27.4 to 91.6**, with a mean of **61.8** and standard deviation of **17.4**.

Accessibility Category	Settlements	Percentage	Mean Accessibility Score
High	35	29.2%	80.3
Moderate	49	40.8%	61.7
Low	36	30.0%	44.0
Total	120	100.0%	61.8

Approximately 30% of settlements therefore occupied the low-accessibility category.

The strongest accessibility was concentrated around higher-order roads and administrative centres. Low-accessibility settlements were generally located along peripheral road branches and in areas where local roads provided indirect connections to higher-order services.

Spatial Pattern of Accessibility

Global Moran's I revealed significant positive spatial autocorrelation:

Moran's I = .41, $z = 4.87$, $p < .001$.

H01 was therefore rejected.

The result indicates that high- and low-accessibility settlements were not randomly distributed.

Getis-Ord G_i^* analysis identified two significant high-accessibility clusters at the 95% confidence level around major transport corridors. Three low-accessibility clusters occurred in peripheral portions of the study region.

Regional Development Pattern

The Regional Development Index ranged from **29.8 to 87.2**, with a mean of **58.6** and standard deviation of **14.9**.

Spatial comparison demonstrated substantial correspondence between accessibility and development surfaces.

The mean development scores were:

Accessibility Category	Mean Development Index	SD
High accessibility	72.4	9.6
Moderate accessibility	59.1	10.7
Low accessibility	44.5	11.3

ANOVA demonstrated significant differences:

$F(2,117) = 56.84$, $p < .001$.

Post-hoc comparisons indicated that all three accessibility groups differed significantly at $p < .01$.

H04 was rejected.

Correlation Between Accessibility and Development

The Composite Rural Accessibility Index showed a strong positive association with the Regional Development Index:



$r = .72, p < .001$.

Thus, settlements with better overall accessibility generally exhibited higher literacy, stronger non-farm economic activity, better service access and higher composite development scores.

H02 was rejected.

Relationships Among Individual Accessibility Components

Predictor	Correlation with Development	p-value
Market accessibility	.66	< .001
Road connectivity	.61	< .001
Healthcare accessibility	.56	< .001
Education accessibility	.53	< .001
Administrative/financial accessibility	.49	< .001

Market accessibility had the strongest bivariate relationship with regional development.

Multiple Regression

The Regional Development Index was entered as the dependent variable.

$R = .76, R^2 = .58, \text{Adjusted } R^2 = .57, F(4,115) = 39.71, p < .001$.

Predictor	Standardized β	t	p
Market accessibility	.31	4.82	< .001
Road connectivity	.27	4.21	< .001
Healthcare accessibility	.21	3.42	.001
Education accessibility	.18	2.91	.004

The model explained approximately **57% of adjusted variance** in regional development.

All four accessibility dimensions remained significant after controlling for the others. H03 was therefore rejected.

Discussion

The results demonstrate that rural accessibility is spatially uneven and strongly related to regional development disparities.

The most important finding is the correlation of $r = .72$ between composite accessibility and regional development. This does not establish that accessibility alone causes development, but it shows that settlements with better connections to roads, services and markets systematically occupy more favourable development positions.

This result is theoretically consistent with Hansen's conception of accessibility as the potential to reach spatially distributed opportunities. It also supports the argument of Geurs and van Wee that meaningful accessibility analysis must incorporate the location of opportunities rather than infrastructure alone.

Market accessibility emerged as the strongest regression predictor. This finding is consistent with Jacoby's evidence that improved access to agricultural markets can generate meaningful economic benefits for rural households. It also corresponds with Aggarwal's Indian evidence that improved roads can strengthen rural–urban market integration.

However, the results should not be interpreted as evidence that road construction automatically produces development. Asher and Novosad found that rural roads in India significantly affected movement of workers out of agriculture but generated comparatively limited short-run effects on several other village-level economic outcomes. This suggests that accessibility functions through complementary mechanisms.

A road may reduce travel costs, but development outcomes also require markets, education, healthcare, digital connectivity, institutional capacity and employment opportunities.

The significant influence of healthcare accessibility reinforces the multidimensional character of regional development. A village may possess reasonable economic connectivity but remain socially disadvantaged if residents face long journeys to primary health facilities.

Similarly, educational accessibility affects not only school attendance but potentially long-term human-capital formation.

The spatial clustering result is particularly important for regional planning. Moran's I of .41 demonstrates that accessibility deficits are geographically concentrated rather than randomly scattered.

This means policy can use spatial targeting. Investment in a strategically selected road segment or service centre within a

low-accessibility cluster may improve accessibility for multiple nearby settlements simultaneously.

GIS therefore provides an advantage over settlement-by-settlement administrative evaluation. It reveals network relationships and regional patterns.



Planning and Policy Implications

Infrastructure prioritisation should move beyond road length as the dominant metric. The development significance of a road depends on how many poorly connected settlements it links and which opportunities become reachable.

GIS-based accessibility surfaces can be used to rank investments according to changes in population-weighted travel time.

Low-accessibility clusters should receive priority consideration for road upgrading, bridge construction and reliable all-season connectivity.

Health and education planning should likewise incorporate travel time. Building additional facilities is not always the only solution; strategically locating services near transport-network junctions can maximize regional coverage.

The UN's use of rural proximity to all-season roads as SDG Indicator 9.1.1 confirms that rural accessibility is itself an internationally recognised development outcome. However, local planning can improve upon the global indicator by adding network travel time to multiple essential opportunities.

Limitations

The study has several methodological limitations.

- Travel time was calculated using assigned average road speeds rather than continuous GPS observations. Seasonal weather, congestion, road

deterioration and variations in vehicle availability may therefore alter actual travel times.

- Equal weighting of accessibility dimensions was used for transparency, but households may value different destinations differently.
- The analysis is cross-sectional, meaning that correlation between accessibility and development should not automatically be interpreted as causal.
- Better-developed settlements may attract infrastructure, while infrastructure may simultaneously facilitate development.
- Future studies should integrate multi-year satellite imagery, road-quality observations, household surveys, public-transport frequency, mobile-phone mobility data and longitudinal socio-economic indicators.

Conclusion

GIS-based accessibility analysis provides a powerful framework for identifying rural development disparities at spatial scales that conventional administrative averages cannot adequately represent.

The study found substantial variation in access to roads, markets, health facilities, schools and administrative services across 120 rural settlements. Rural accessibility was significantly spatially clustered, with identifiable corridors of advantage and peripheral clusters of deprivation.

The Composite Rural Accessibility Index was strongly associated with the Regional Development Index. High-accessibility settlements recorded a mean development score of 72.4 compared with 44.5 in low-accessibility settlements.

Market accessibility, road connectivity, healthcare accessibility and educational accessibility jointly explained a substantial share of regional development variation.

These findings support a central planning conclusion:

rural development disparities are not only socio-economic inequalities; they are also inequalities of geographical opportunity.

GIS makes those inequalities measurable, visible and operational for policy.

Regional planning should therefore integrate settlement-level accessibility into decisions concerning rural roads, public-service location and development expenditure. By prioritising locations where poor accessibility and low development overlap, spatial planning can move from uniform infrastructure provision toward more equitable and evidence-based regional development.



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