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RESEARCH ARTICLE

A Spatial Analysis of Road Density and Socio- Economic Development in Rudrapur City: A GIS Based Analysis

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Abstract
Transportation plays a pivotal role in shaping the political, economic, and social well-being of any region by enhancing accessibility and connectivity. The present study examines the spatial relationship between road density and the level of socio-economic development across 40 municipal wards of Rudrapur City, Uttarakhand. Using high-resolution satellite imagery from Google Earth, the city's road network was digitized and categorized into major and minor roads in QGIS v.3.16 software. Ward-wise Road density was calculated per square kilometre and per thousand population based on digitized road network data, while socio-economic development was assessed using nine demographic and infrastructural indicators through a composite Z-score index. The analysis reveals marked intra-urban disparities in both road density and socio-economic development across the city's 40 municipal wards. Central wards exhibit moderate to high road density, whereas peripheral and industrial wards show lower density but relatively higher per capita road availability. Correlation analysis indicates a significant positive relationship between road density and population density, while significant negative relationships are observed with street lighting and drainage length, reflecting uneven infrastructure provisioning. Other socio-economic variables show weak or insignificant associations with road density. The findings highlight that increased road density alone does not ensure balanced socio-economic development and underscore the need for integrated urban infrastructure planning. The study demonstrates the usefulness of GIS-based spatial analysis in identifying infrastructural inequalities and supporting sustainable urban development strategies in rapidly growing medium-sized cities.

Keywords: Road density; level of Development; composite z score; correlation analysis; GIS

Introduction

Transport plays a vital role in ensuring the political, economic, and social well-being of any society. It has often been described as the lifeblood of civilization, as it provides the fundamental means through which different parts of society are physically and economically connected. According to Ali and Magalmani (2006), transportation serves as the foundation for a nation's overall development, influencing agriculture, industry, trade, administration, and defense. It not only supports the economic structure but also transforms the social

outlook of a community. In this sense, if agriculture and industry represent the body and bones of a national organism, transport and communication can rightly be considered its nerves. A well-developed road network fosters economic, social, and cultural integration within a region. Roads enhance accessibility, reduce travel time, and facilitate the movement of goods and people, which are essential for sustainable regional development (Banerjee, 2025). The development of transport infrastructure is closely linked to spatial and socio-economic transformations, as it determines patterns of settlement, trade, and industrial expansion (Banister & Berechman, 2001; Li, et al., 2025). Improved connectivity helps integrate remote and underdeveloped areas into broader economic systems, thereby promoting equity and inclusive growth. Planned development aims to ensure optimal conditions and opportunities for all segments of society. As Das (1999) highlighted, development is a multi-dimensional phenomenon, encompassing factors such as economic growth, education, healthcare, modernization, gender equality, nutrition, housing, equitable distribution of goods and services, and access to communication. In this context, transport development acts as a catalyst that supports and accelerates improvements across these dimensions. The interdependence between road transport and socio-economic development is well established. A robust road network not only facilitates mobility but also contributes to enhancing productivity, market accessibility, and the overall quality of life (Tchoffo, et al.,2024). Studies have shown that regions with higher road density tend to experience faster economic growth, better access to social services, and improved employment opportunities (Ardila, 2016). Therefore, road connectivity is often viewed as a harbinger of regional development, particularly in remote or backward areas, as it enables the effective utilization of local resources and promotes social inclusion. The use of Geographic Information Systems (GIS) has transformed the way spatial relationships between infrastructure and socio-economic conditions are analyzed. GIS enables the integration of spatial and statistical datasets, facilitating the visualization of complex interactions between variables (Longley et al., 2015; Talpur et al., 2024). Nijagunappa et al. (2007) demonstrated how GIS-assisted mapping of road networks and social indicators in Dehradun helped identify regions needing infrastructure investment. Such approaches are instrumental for sustainable urban management, particularly in medium-sized and rapidly urbanizing cities like Rudrapur. While previous studies have extensively analyzed transportation's role in regional development, few have focused specifically on the intra-urban relationship between road density and ward-level socio-economic development using GIS techniques in small and medium cities of Uttarakhand. Existing literature primarily emphasizes metropolitan regions, leaving limited insight into emerging industrial hubs such as Rudrapur, where industrial expansion (through SIDCUL) has drastically altered urban morphology and infrastructure patterns. This study bridges this gap by employing spatial analysis and statistical correlation to examine how variations in road density correspond with socio-economic indicators across Rudrapur's 40 municipal wards.

The present study is conducted in Rudrapur City, which serves as the administrative headquarters of the Udham Singh Nagar district in the state of Uttarakhand, India. Rudrapur gained the status of district headquarters when Udham Singh Nagar was carved out of the Nainital district on 30 September 1995. Later, with the enactment of the Uttar Pradesh Reorganisation Act, 2000, passed by the Parliament of India on 9 November 2000, Rudrapur became an integral part of Uttarakhand, the 27th state of the Republic of India (District Udham Singh Nagar, 2024). Geographically, Rudrapur is situated in the fertile Terai region of the Himalayan foothills, known for its agricultural productivity and emerging industrial growth. The city covers an area of approximately 55.2 km², lying between 28°55′ to 29°04′ North latitude and 79°22′ to 79°27′ East longitude (Kaur, 2025). The Kalyani River flows through the city, traversing its industrial zone and contributing to the area's agricultural and industrial activities (Kaur & Punera, 2023). The city's terrain is largely flat and alluvial, making it suitable for both agriculture and urban expansion. Administratively, Rudrapur is divided into 40 municipal wards (following the 2018 delimitation), with a total population of 175,723, as recorded in Census 2011. Over the past two

decades, Rudrapur has transformed from a small agricultural settlement into a rapidly developing urban and industrial hub, primarily due to the establishment of the Integrated Industrial Estate (IIE) under the State Infrastructure and Industrial Development Corporation of Uttarakhand Ltd. (SIDCUL) (Kaur, 2022). The city now serves as a major centre for manufacturing, trade, and services, attracting significant in-migration and urban expansion.

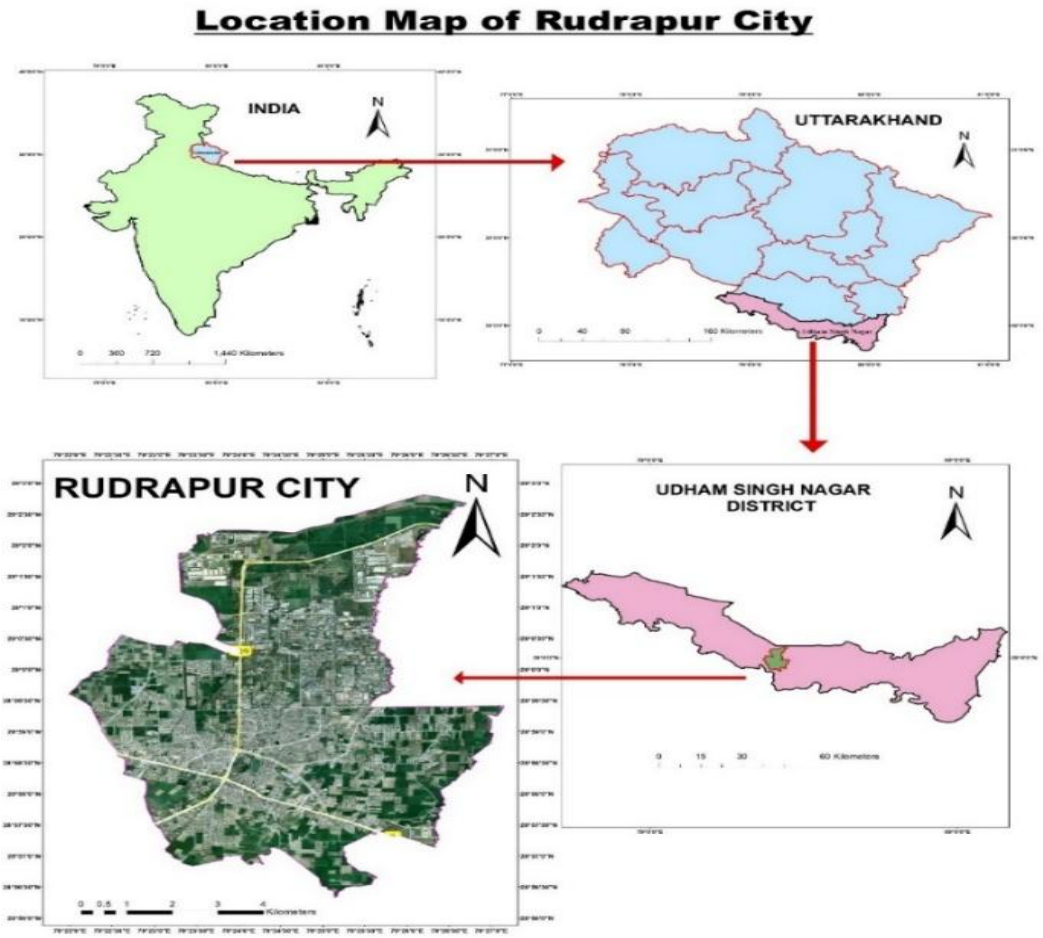


Figure 1: Locality map of Rudrapur City drawn in QGIS software
Source: Drawn by author.

Literature Review

In India, Reddy and Reddy (2012) found that road connectivity has a strong positive correlation with district-level economic development and employment generation. A seminal regional-scale analysis by Khan and Shamshad (2012) on West Bengal revealed a strong positive association between road density and indicators such as education, healthcare, urbanization, industrialization, and infrastructure availability. Their findings highlight pronounced spatial variations, where districts with higher road density exhibited medium to high levels of development, while centrally located districts with sparse road networks lagged behind, underscoring the role of transport infrastructure in uneven regional growth. Rao and Sharma (2019) used GIS techniques to examine

road density in Hyderabad and revealed that high-density areas correspond with zones of higher economic activity and population concentration. Similarly, Mishra and Kumar (2020) analyzed road infrastructure in Patna using QGIS and found that the peripheral wards had lower road density and limited access to urban services, reflecting an uneven pattern of urban expansion. Singh (2018) examined road density variations in Lucknow city and concluded that road density is positively associated with the distribution of educational and health facilities. Geographic Information System (GIS)-based studies by Zhang et al. (2019) in China and Adepoju et al. (2020) in Nigeria also highlighted how spatial mapping of roads can identify infrastructural deficiencies and guide equitable planning decisions. Such spatial analyses are vital in understanding urban disparities and designing sustainable mobility systems. Nijagunappa et al. (2007) successfully mapped the road network of Dehradun City using satellite imagery, highlighting its effectiveness in analyzing road connectivity, spatial distribution, and functional characteristics of urban transport systems. Tchoffo et al. (2024), using a computable general equilibrium (CGE) model in Cameroon, demonstrated that investments in road transport infrastructure generate positive externalities by mitigating inward–immiserizing growth, enhancing productivity, and strengthening regional economic resilience. Their work emphasizes that transport infrastructure is not merely a facilitator of growth but a corrective mechanism for structural economic imbalances, particularly in developing economies. Talpur et al. (2024) employed GIS techniques to measure pedestrian accessibility to bus stops in Hyderabad, Pakistan, revealing significant intra-urban inequalities in access to public transport. Their study illustrates how spatial metrics derived from GIS can inform sustainable transport planning and alleviate urban traffic and mobility challenges. Gadekar (2025) conducted a detailed spatial analysis of road density and network patterns in Ahilyanagar District, Maharashtra, using GIS and statistical techniques such as mean and standard deviation. The study classified road density into four categories—very low, low, moderate, and high—revealing significant intra-district disparities in transportation infrastructure. While tehsils such as Shrirampur exhibited high road density, others, particularly along state highways, showed comparatively low connectivity. The findings highlight the uneven development of road infrastructure across administrative units and demonstrate the effectiveness of GIS in identifying spatial patterns of transport accessibility.

Methodology

The present study adopts a GIS-based spatial analytical framework to examine the relationship between road density and socio-economic development in Rudrapur City. High-resolution satellite imagery obtained from Google Earth (2022) was used to prepare the base map of the study area. The imagery was geo-referenced in QGIS version 3.16 using standard coordinate transformation techniques to ensure spatial accuracy. An official ward boundary map of Rudrapur Municipal Corporation (RMC) was digitized and overlaid onto the base map as a separate vector layer. Administratively, Rudrapur City is divided into 40 municipal wards, which were adopted as the primary spatial units of analysis (Figure 1). The road network of Rudrapur City was digitized manually from the geo-referenced Google Earth imagery. Digitization refers to the process of converting real-world linear features into vector format to enable spatial measurement and analysis within a GIS environment. To capture functional variations in connectivity, the road network was classified into two categories: i) Major roads – comprising national and state highways. ii) Minor roads – including arterial, sub-arterial, and local streets connecting residential, commercial, and industrial areas. The total road length within each ward was calculated using GIS spatial analysis tools. Road density was then computed using two standardized measures: (i) road length per square kilometre and (ii) road length per 1,000 population, to account for both spatial extent and population pressure. The resulting ward-wise road density maps were generated using open-source GIS software (Figure 2).

Socio-economic data were compiled from multiple secondary government sources, including the Rudrapur Municipal Corporation, Chief Medical Officer's Office, Block Education Office, and the District Statistical Handbook. To assess ward-level development, nine socio-economic indicators were selected, representing key dimensions of demography, education, health infrastructure, and basic urban services (Table 4). A standard z score was developed to determine the overall level of development in each ward with the help of given formula;

$$Zi = \frac{Xi - X}{SD}$$

Where,

Zi= Standard score for the ith observation,

Xi=Original value of the observation,

X=Mean for all the values of X, and

SD=Standard deviation of X (Gallardo et al., 2012 & Miezah, K. et.al, 2015; Kaur et al., 2023)

Further, composite score was also calculated as;

$$CS = \sum Zij/N$$

Where, CS stands for composite score.

N refers to the number of variables.

$\sum Zij$ indicates Z-Scores of all variables i in ward j. (Kaur et al., 2022)

To explore the relationship between road density and socio-economic development, Karl Pearson's coefficient of correlation (r) was computed using the formula:

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}}$$

Here, x represents road density, and y represents the socio-economic indicators. Microsoft Excel software was used for statistical analysis to determine the strength and significance of these relationships. QGIS was employed to visualize spatial disparities in road density and socio-economic development across the 40 wards. Maps were generated to highlight areas of high and low road density and levels of development, facilitating a spatial understanding of intra-urban inequalities.

Results and Discussions

The spatial distribution of roads within the Rudrapur Municipal Corporation (Figure 2) illustrates a clear pattern of major and minor road networks across the city, revealing marked intra-urban variations in accessibility and infrastructure development. Considerable differences are observed in ward-wise total road length and road density, reflecting uneven levels of urban growth and functional land use, a pattern commonly noted in GIS-based road network studies (Nijagunappa et al., 2007; Gadekar, 2025). As presented in Table 1 (Appendix), wards such as Sidcul (104.47 km), Fulsunga (70.45 km), and Bigwarha (59.73 km) exhibit extensive road networks, largely attributable to industrial expansion and peripheral development. In contrast, wards including Ajad Nagar (2.61 km), Transit Camp East (3.84 km), and Kherha Southern (2.70 km) record comparatively shorter road lengths, reflecting smaller ward areas, higher population concentration, or relatively underdeveloped transport infrastructure. Similar spatial disparities between industrial–peripheral zones and older residential wards have been documented in earlier urban road density analyses (Gadekar, 2025).

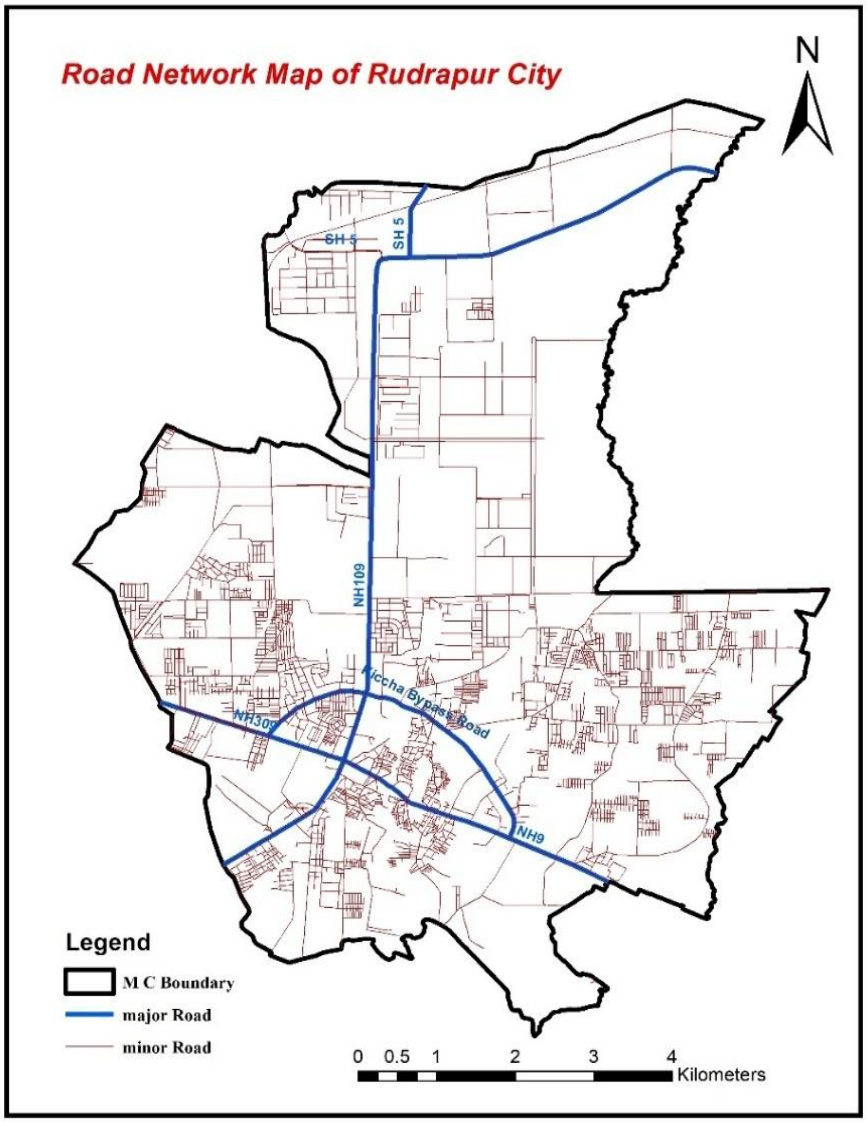


Figure 2: Road Network map of Rudrapur city.
Source: drawn by author using QGIS software

Based on road density per square kilometre (Table 2), Rudrapur City exhibits marked spatial variations in the distribution of its road network. Rampura Middle ward records a very high road density (about 155 km/km²), reflecting a highly compact and well-connected internal road system within the city's central core. Nearly 21 wards—including Awas Vikas West, Shiv Nagar, Vivek Nagar, and Raja Colony—fall within the moderate road density category (27–65 km/km²), representing relatively well-developed and accessible urban zones. In contrast, seven wards such as Fulsunga, Sidcul, Bigwarha, Bhurarani, Fajalpur Mahraula, Aadarsh Colony Ghas Mandi, and Transit Camp East exhibit very low road density (5–14 km/km²) and are largely located in the peripheral parts of the city. Such spatial disparities in road density reflect uneven levels of infrastructural development and accessibility, a pattern also observed in earlier studies linking road density with stages of regional development (Khan & Shamshad, 2012).

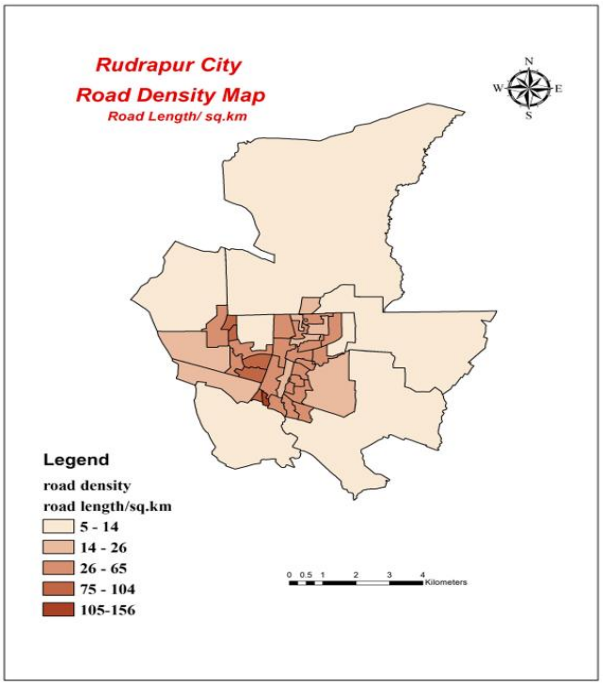
Table 2: Rudrapur city: Level of Road Density/km²

Category	Density	No. of wards	Name of wards
Very low	5-14	7	Aadarsh Colony Ghas Mandi, Bhurarani, Bigwarha, Fajalpur Mahraula, Fulsunga / Fulsungi, Sidcul, Transit Camp East
Low	14-26	6	Bhutbangla northeast, Industrial Area, Ajad Nagar, Alliance Colony, Seergotia, Transit camps Western
Moderate	27-65	21	Aadarsh Colony SRA, Awas Vikas east, Awas Vikas west, Bhadaipura, Bhutbangla West South, D1 D2, Dudia Nagar, Jagatpura, Kalyani View / Ravindranagar, Kherha Middle, Kherha North, Kherha Southern, Mukerjeenagar, Paharganj, Raja Colony / Takurnagar, Rampura East, Sanjay Nagar, Shiv Nagar, Singh Colony, Transit Camp Central, Vivek Nagar,
High	66-104	5	Aadarsh Indra Colony, Gandhi Colony, Indra Colony, Main Market, Rampura Western
Very high	105-156	1	Rampura Middle

Source: data computed by author

The spatial pattern (Figure 3) indicates that the central wards have medium to high road density, while peripheral wards remain less developed in terms of road infrastructure.

a. Road Density per sq. km.



b. Road Density per thousand Persons

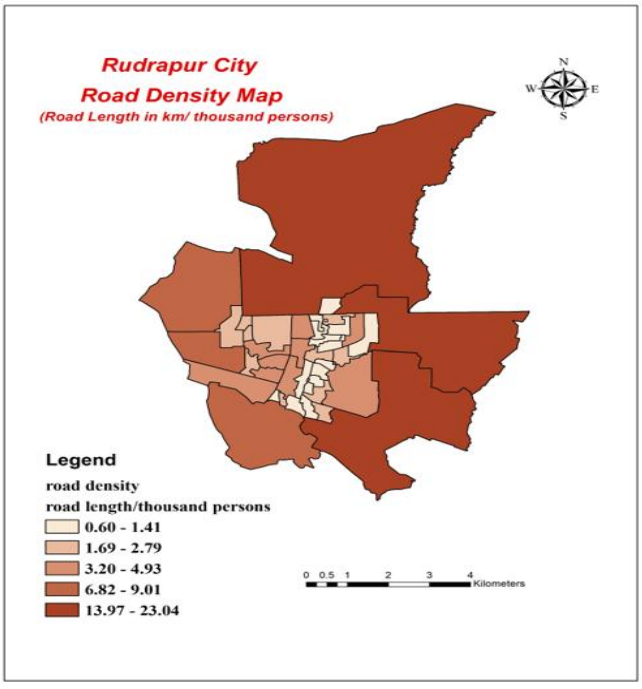


Figure 3: Spatial Distribution of Road Density in Rudrapur City
Source: Drawn by author using QGIS software

The population-adjusted measure of road availability (Table 3) further highlights inequality in accessibility. Wards such as Bigwarha (13.97), Fulsunga (16.93), and Sidcul (23.04) demonstrate very high road density per thousand persons, reflecting relatively lower population pressure and better connectivity. In contrast, 13 wards—

including Ajad Nagar, Kherha Middle, Kherha North, Sanjay Nagar, Rampura East, and Transit Camp East—show very low road density per thousand persons (0.6–1.41 km), implying higher population concentration and limited road infrastructure. This imbalance highlights a critical urban planning concern, as the city's periphery has better road availability per capita than the densely populated central areas.

Table 3: Rudrapur city: Level of Road Density/thousand Person

Category	Density	No. of wards	Name of wards
Very low	0.60-1.41	13	Ajad Nagar, Awas Vikas east, Bhutbangla northeast, Kherha Middle, Kherha North, Kherha Southern, Paharganj, Rampura East, Rampura Western, Sanjay Nagar, Shiv Nagar, Transit Camp East, Transit camps Western,
Low	1.69-2.79	12	Aadarsh Colony Ghas Mandi, Aadarsh Colony SRA, Aadarsh Indra Colony, Bhadaipura, Dudia Nagar, Indra Colony, Jagatpura, Mukerjeenagar, Raja Colony / Takurnagar, Rampura Middle, Singh Colony, Vivek Nagar,
Moderate	3.20-4.93	9	Awas Vikas west, Bhutbangla West South, D1, D2, Gandhi Colony, Industrial Area, Kalyani View / Ravindrangar, Main Market, Seergotia, Transit Camp Central,
High	6.82-9.01	3	Alliance Colony, Bhurarani, Fajalpur Mahraula,
Very high	13.97-23.04	3	Bigwarha, Fulsunga / Fulsungi, Sidcul,

Source: data computed by author

Spatial Analysis of Socio- Economic Development

Nine socio-economic indicators were selected to assess intra-urban disparities in Rudrapur (Table 4). The selected indicators represent demographic composition, access to social infrastructure, and basic urban services, commonly used in urban development studies. The ward-wise composite z scores were calculated (Table 5), and wards were grouped into five levels of development (Table 6).

Table 4. Indicators of socio-economic development

Variables	Definition of variables	Direction for Development
X1	Total population	Negative (higher pressure)
X2	population density	Negative
X3	Total no. of street lights	Positive
X4	Numbers of secondary and hr. sec. schools per thousand people	Positive
X5	Numbers of govt. hospitals per thousand people	Positive
X6	Numbers of private hospitals per thousand people	Positive
X7	Numbers of recreational facilities (parks, shopping malls, hotel & restaurants etc.)	Positive
X8	Drains length in km	Positive
X9	Numbers of dustbin per thousand people	Positive

Each indicator was standardized using Z-score normalization to remove scale effects and allow comparability before aggregation

Table 5. Ward wise Composite Z- Score of Socio- Economic Indicators

S.No.	Ward Name	X1	X2	X3	X4	X5	X6	X7	X8	X9	composite z score
1	Fulsunga / Fulsungi	-0.76	-1.18	3.53	0.70	-0.33	0.20	0.13	2.64	0.65	0.62
2	Transit Camp East	-0.19	-0.72	0.12	0.11	2.92	-0.67	0.43	0.20	1.07	0.36
3	Transit Camp Central	-1.62	-0.52	-0.27	1.69	-0.33	-0.21	-0.31	0.82	0.01	-0.08
4	Transit camp Western	-1.32	-0.11	-0.53	1.32	-0.33	-0.67	-0.46	0.18	0.80	-0.12
5	Mukerjeenagar	0.74	0.31	-0.46	-0.75	-0.33	-0.67	-0.46	-0.19	0.96	-0.09
6	Jagatpura	-0.08	-0.42	-0.45	0.01	-0.33	-0.26	-0.46	-0.08	0.12	-0.22
7	Ajad Nagar	-0.19	0.53	0.03	0.12	-0.33	-0.67	-0.31	0.11	0.48	-0.03
8	Vivek Nagar	-1.91	-0.13	-0.38	2.05	-0.33	-0.67	-0.61	-0.63	0.11	-0.28
9	Shiv Nagar	-1.00	0.18	-0.02	0.96	-0.33	-0.67	-0.61	0.09	-0.50	-0.21
10	Raja Colony / Takurnagar	-0.20	-0.04	-0.60	0.13	-0.33	-0.26	-0.61	0.14	1.29	-0.05
11	Sanjay Nagar	1.40	1.67	-0.77	-1.29	-0.33	-0.30	-0.31	-0.35	-0.01	-0.03
12	Industrial Area	1.26	-1.06	0.45	-1.18	-0.33	-0.30	-0.31	0.41	0.19	-0.10
13	Dudia Nagar	0.42	-0.06	-0.60	-0.46	-0.33	-0.67	-0.61	-0.60	-0.91	-0.42
14	Bhadaipura	-0.15	0.05	-0.28	0.07	-0.33	-0.26	-0.46	-0.24	-1.37	-0.33
15	Paharganj	0.14	0.27	-0.30	-0.20	-0.33	-0.67	-0.61	0.34	-0.91	-0.25
16	Bigwarha	-0.38	-1.19	2.44	0.31	-0.33	1.44	-0.61	2.54	0.54	0.53
17	Kherha Southern	-2.54	1.57	-0.65	2.90	-0.33	-0.67	-0.01	-0.95	-1.52	-0.24
18	Kherha Middle	-0.78	1.16	-0.55	0.73	3.06	-0.67	-0.31	-0.98	-1.89	-0.03
19	Kherha North	0.26	0.47	-0.59	-0.31	-0.33	-0.67	1.32	-0.50	-0.58	-0.10
20	Bhutbangla northeast	0.29	-0.10	0.15	-0.34	-0.33	-0.67	2.22	-0.16	-0.62	0.05
21	Bhutbangla West South	-1.19	-0.68	-0.67	1.18	-0.33	0.67	-0.46	-0.84	-0.49	-0.31
22	Rampura East	-0.70	0.14	0.26	0.64	-0.33	-0.67	-0.61	-0.83	-0.50	-0.29
23	Rampura Middle	-0.91	2.78	-0.70	0.86	3.09	-0.67	-0.61	0.34	-0.65	0.39
24	Rampura Western	-0.87	2.53	-0.78	0.82	-0.33	-0.67	-0.61	-0.73	0.03	-0.07
25	Fajalpur Mahraula	0.91	-1.15	0.40	-0.89	-0.33	-0.67	-0.61	3.61	0.72	0.22
26	Seergotia	1.52	-0.99	0.35	-1.38	-0.33	0.07	-0.16	0.54	0.25	-0.02
27	Gandhi Colony	1.18	-0.14	-0.61	-1.11	-0.33	0.09	0.43	-0.31	-0.17	-0.11
28	Main Market	-0.14	-0.25	-0.19	0.07	-0.33	1.41	2.96	-0.78	-0.06	0.30
29	Aadarsh Colony SRA	1.21	0.12	-0.40	-1.14	-0.33	-0.67	-0.01	-0.62	-0.64	-0.28
30	D1, D2	-0.28	-0.47	-0.34	0.20	-0.33	1.85	1.77	-0.44	0.09	0.23
31	Alliance Colony	1.81	-1.02	-0.24	-1.61	-0.33	1.52	-0.31	0.66	1.33	0.20
32	Bhurarani	-0.63	-1.16	3.20	0.57	-0.33	0.62	-0.61	1.08	0.90	0.40
33	Singh Colony	0.69	-0.73	0.31	-0.70	-0.33	0.11	-0.61	-0.04	1.54	0.03
34	Indra Colony	-0.27	1.55	-0.54	0.20	-0.33	-0.25	-0.61	-0.65	-0.14	-0.12
35	Aadarsh Indra Colony	1.26	1.10	-0.57	-1.18	-0.33	-0.67	-0.61	-0.39	-0.01	-0.16
36	Aadarsh Colony Ghas Mandi	0.93	-0.91	-0.33	-0.91	-0.33	3.58	0.58	-0.68	1.09	0.34
37	Kalyani View / Ravindranagar	0.82	-0.33	-0.42	-0.81	-0.33	0.49	-0.01	-0.41	1.60	0.07
38	Awas Vikas west	0.70	-0.46	0.02	-0.71	-0.33	2.47	3.56	-0.83	0.20	0.51
39	Awas Vikas east	0.10	0.57	-0.63	-0.17	-0.33	0.14	-0.31	-0.49	0.54	-0.06
40	SIDCUL	0.46	-1.20	1.61	-0.49	2.77	-0.67	-0.16	-0.99	-3.51	-0.24

Source: data computed by author. Calculation is based on census 2011, block education department 2021, municipal corporation office 2021, chief medical office 2021.

Table 6 illustrates the ward-wise pattern of socio-economic development in Rudrapur City , based on a composite Z-score index constructed from selected demographic, social, and infrastructural indicators. The composite scores were grouped into five categories—very low, low, medium, high, and very high levels of development—to systematically capture spatial inequalities and variations among the 40 municipal wards. The classification reveals pronounced inter-ward disparities, reflecting unequal access to urban infrastructure and socio-economic opportunities within the city.

Figure 4 spatially visualizes these development levels through a composite Z-score map, where varying shades depict the intensity of socio-economic development across wards. Wards categorized under very high and high levels of development are predominantly concentrated in centrally located and relatively well-planned areas, characterized by better infrastructure, services, and connectivity. In contrast, wards (*Dudia Nagar, Bhadaipura, Rampura East, Jagatpura, Kherha Southern, Shiv Nagar,* and *Sidcul)* exhibiting low and very low levels of development are largely clustered in peripheral, industrial, and transitional zones, where infrastructure provision and service accessibility remain comparatively limited.

The spatial pattern evident in Figure 4 underscores the existence of significant intra-urban disparities in Rudrapur City and highlights the uneven nature of urban development driven by differential planning priorities, industrial expansion, and infrastructural investment.

Table 6. Level of Development in Rudrapur City, 2021

Category	Composite z score	No. of ward	Ward name
Very low	-0.42 – -0.21	11	Dudia Nagar, Bhadaipura, Bhutbangla West South, Rampura East, Vivek Nagar, Aadarsh Colony SRA, Paharganj. Kherha Southern, Sidcul, Jagatpura, Shiv Nagar
Low	-0.20 – -0.050	11	Aadarsh Indra Colony, Transit camps Western, Indra Colony, Gandhi Colony, Industrial Area, Kherha North, Mukerjeenagar, Transit Camp Central, Rampura Western, Awas Vikas east, Raja Colony / Takurnagar
Medium	-0.049– 0.070	7	Ajad Nagar, Sanjay Nagar, Kherha Middle, Seergotia, Singh Colony, Bhutbangla northeast, Kalyani View / Ravindranagar
High	0.071 – 0.40	8	Alliance Colony, Fajalpur Mahraula, D1, D2, Main Market, Aadarsh Colny Ghas Mandi, Transit Camp East, Rampura Middle, Bhurarani
Very high	0.41 – 0.62	3	Awas Vikas west, Bigwarha, Fulsunga / Fulsungi

Source: based on table 5

Correlation between Road Density and Selected Variables of Development

The Pearson's correlation analysis (Table 7) was performed to examine the relationship between road density (km^2) and selected socio-economic variables. The results indicate that road density exhibits a statistically significant positive correlation with population density ($r = 0.586$, $p < 0.05$). This suggests that wards with higher road density per km^2 tend to be more densely populated. The coefficient of determination ($r^2 = 0.343$) implies that approximately 34.3% of the variation in population density can be explained by variations in road density, highlighting the close linkage between transportation infrastructure and urban concentration. In contrast, road density shows a statistically significant negative correlation with the total number of street lights ($r = –0.556$, $p < 0.05$). This inverse relationship indicates that areas with higher road density do not necessarily possess a

proportional increase in street lighting infrastructure. The r^2 value of 0.310 suggests that about 31.0% of the variation in street lighting distribution is associated with changes in road density. This finding points towards uneven infrastructure provisioning and possibly reflects unplanned or rapid road expansion without corresponding upgrades in public amenities. Similarly, a significant negative correlation is observed between road density and drain length ($r = –0.496$, $p < 0.05$). The r^2 value (0.246) indicates that nearly 24.6% of the variation in drainage length is explained by road density. This suggests that drainage infrastructure has not expanded in proportion to road development, raising concerns regarding urban sustainability and flood vulnerability in highly road-dense wards. Other variables, including total population, educational institutions, healthcare facilities, recreational facilities, and waste management infrastructure, show weak and statistically insignificant relationships ($p > 0.05$) with road density. Overall, the findings indicate that while road density is closely linked to population concentration, it does not uniformly translate into improved access to urban amenities, reflecting uneven patterns of urban development in Rudrapur City.

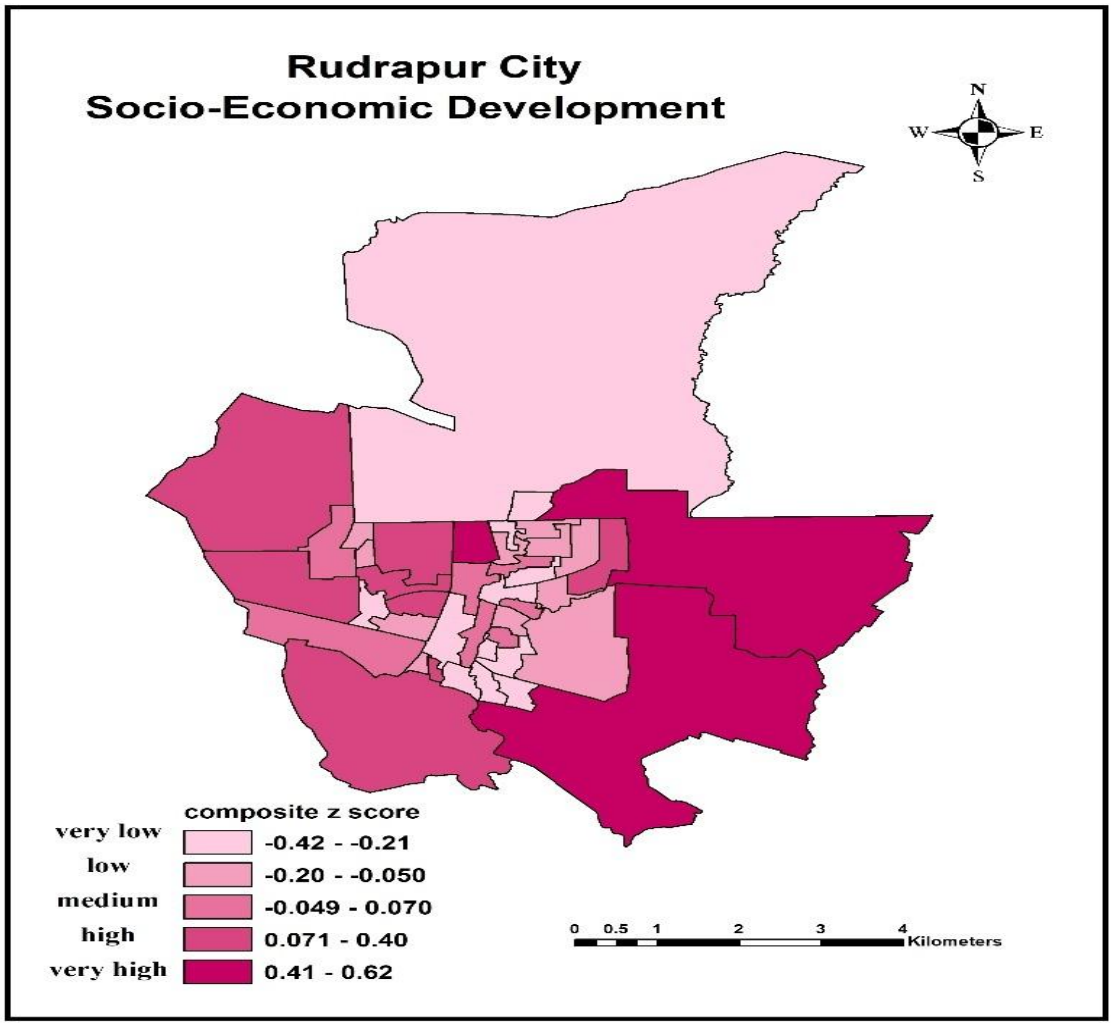


Figure 4. Level of Socio- Economic Development,2021
Source: drawn by author in QGIS software.

Table 7: Correlation of Road Density/ km² area with selected variables.

S.No	variables	r	r^2	p-value	Significance level
1	Total population	0.039	0.002	0.812	Not Significant
2	population density	0.586	0.343	0.00007	*Significant
3	Total no. of street lights	–0.556	0.310	0.00019	*Significant
4	Numbers of secondary and hr. sec. schools per thousand people	–0.036	0.001	0.824	Not Significant
5	Numbers of govt. hospitals per thousand people	–0.154	0.024	0.344	Not Significant
6	Numbers of private hospitals per thousand people	–0.008	0.000	0.959	Not Significant
7	Numbers of recreational facilities	0.202	0.041	0.212	Not Significant
8	Drains length in km	–0.496	0.246	0.00113	*Significant
9	Numbers of dustbin per thousand people	-0.093	0.009	0.568	Not Significant

Source: Calculation is based on census 2011, block education department 2021, municipal corporation, chief medical office 2021. Data Calculated in Excel by author.

*Correlation is significant at p- value < 0.05 level.

Conclusions

The present study reveals pronounced intra-urban disparities in road infrastructure and socio-economic development across the municipal wards of Rudrapur City. GIS-based spatial analysis shows that central wards generally possess higher road density, while peripheral and industrial wards exhibit lower density but relatively better per capita road availability due to lower population pressure. The composite socio-economic development index further highlights uneven development, with only a few wards attaining very high development status and a large number remaining in low and very low categories. Correlation analysis confirms that road density is significantly associated with population density, reinforcing the role of transportation infrastructure in shaping urban form and concentration. However, the observed negative relationship between road density and essential amenities such as street lighting and drainage infrastructure indicates that road expansion has not been accompanied by proportionate improvements in supporting urban services. This imbalance reflects fragmented and uneven infrastructure provisioning, raising concerns regarding sustainability, safety, and service equity.

Overall, the findings reaffirm that transportation infrastructure is not merely a physical component of urban growth but a fundamental determinant of socio-economic equity and inclusivity. Enhanced road connectivity facilitates efficient mobility, improves access to education and healthcare, and supports economic diversification. Therefore, integrated urban planning strategies emphasizing balanced infrastructure investment across all wards are essential for achieving sustainable and inclusive development in Rudrapur City. Future urban policies should prioritize improving road connectivity in low-density and underdeveloped wards, strengthening coordination between municipal authorities and industrial agencies, and ensuring equitable access to public facilities. Such measures are crucial for reducing intra-urban disparities and for transforming Rudrapur into a resilient, well-connected, and socially inclusive urban centre in Uttarakhand.

Limitations of the Study

Despite providing valuable insights into the relationship between road density and socio-economic development in Rudrapur City, the present study has certain limitations. First, the analysis relies primarily on secondary data sources, including Census 2011 and departmental records from 2021. Although these sources are authoritative, the time lag between datasets may not fully capture recent demographic changes and rapid urban growth, particularly in industrial and peripheral wards. Second, the socio-economic development index is based on a limited set of nine indicators. While these indicators represent key demographic and infrastructural dimensions, other important factors such as household income, employment structure, housing quality, public transport availability, and environmental conditions could not be included due to data constraints. Finally, the ward-level analysis, though suitable for intra-urban comparison, may mask micro-level variations within wards. Future studies using finer spatial units such as neighbourhoods or census blocks, along with primary surveys and longitudinal data, would provide a more nuanced understanding of urban infrastructure and socio-economic dynamics.

Declaration statement

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Consent to participate: N/A

Consent for publication: All authors consent to publication.

Data Availability: The data used in this study were obtained from official government sources, including the Rudrapur Municipal Corporation, Chief Medical Officer's Office, Block Education Office, and District Statistical Handbook. Spatial data were derived from Google Earth imagery and processed using QGIS v.3.16.

Author's Contribution: Dr. Sonu Kaur conceptualized the study, conducted the GIS and statistical analyses, prepared the maps, interpreted the results, and wrote and reviewed the manuscript.
Dr. Anjali Punera provided guidance in the preparation of the manuscript, while Dr. Abhilasha Kannaujia contributed to the literature review and assisted in editing the manuscript.

Appendix:

Table 1: Ward Wise Length and Density of Roads in Rudrapur City.

S.no.	Ward_Name	Total Road length (in km)	Road length/ sq.km	Road length/ thousand person
1	Fulsunga / Fulsungi	70.45	11.07	16.93
2	Transit Camp East	3.84	8.52	0.88
3	Transit Camp Central	12.46	42.82	3.2
4	Transit camp Western	4.37	23.4	1.09
5	Mukerjeenagar	9.16	58.56	1.98
6	Jagatpura	4.81	16.88	1.1
7	Ajad Nagar	2.61	20.35	0.6
8	Vivek Nagar	6.9	38.01	1.81
9	Shiv Nagar	5.5	36.52	1.34
10	Raja Colony / Takurnagar	8.05	42.21	1.85
11	Sanjay Nagar	5.42	62.88	1.12
12	Industrial Area	23.43	14.47	4.89
13	Dudia Nagar	9.37	46.57	2.07
14	Bhadaipura	7.42	41.95	1.7
15	Paharganj	6.24	40.38	1.4
16	Bigwarha	59.73	8.04	13.97
17	Kherha Southern	2.7	40.45	0.74
18	Kherha Middle	4.36	48.3	1.05
19	Kherha North	6.1	44.5	1.36
20	Bhutbangla northeast	4.05	19.43	0.9
21	Bhutbangla West South	19.85	50.82	4.93
22	Rampura East	5.68	35.77	1.36
23	Rampura Middle	8.27	155.73	2.01
24	Rampura Western	4.66	82.10	1.12
25	Fajalpur Mahraula	38.33	9.86	8.19
26	Seergotia	22.88	20.89	4.7
27	Gandhi Colony	17.14	75.27	3.6
28	Main Market	20.08	86.48	4.61
29	Aadarsh Colony SRA	8.06	43.61	1.69
30	D1, D2	16.85	56.8	3.91
31	Alliance Colony	33.77	25.9	6.81
32	Bhurarani	37.81	9.33	9
33	Singh Colony	12.86	26.28	2.79
34	Indra Colony	8.31	103.5	1.92
35	Aadarsh Indra Colony	9.88	92.78	2.06

	Aadarsh Colony			
36	Ghas Mandi	8.65	10.97	1.84
	Kalyani View /			
37	Ravindranagar	15.87	58.72	3.41
38	Awas Vikas west	20.37	64.92	4.41
39	Awas Vikas east	5.43	42.35	1.22
40	SIDCUL	104.47	5.01	23.04

Source: Road network digitized from Google Earth high-resolution imagery (2022). Ward-wise road length and road density (per sq. km and per thousand population) were calculated using population data from Census of India (2011)

References

Adepoju, A. O., Aina, Y. A., & Bello, M. O. (2020). Spatial analysis of road network and accessibility in Ibadan, Nigeria using GIS. *Transportation Research Procedia*, 45, 192–201.

Ali, S., & Magalmani, M. (2006). India's infrastructure development: special reference to road transportation. In Rao, C. N. (Ed.), *Rural development in India* (pp. 199–207). Serial Publications, New Delhi.

Ardila-Gomez, A., & Ortegon-Sanchez, A. (2016). *Sustainable urban transport financing: From the sidewalk to the subway—Capital, operations, and maintenance financing*. World Bank.

Banerjee, I., Bajaj, A., & Saha, A. (2025). Sustainable transportation infrastructure in Indian cities of different size-class: towards a research and policy agenda. *Papers in Applied Geography*, *11*(2), 210–228. https://doi.org/10.1080/23754931.2024.2414458.

Banister, D., & Berechman, Y. (2001). Transport investment and the promotion of economic growth. *Journal of Transport Geography*, 9(3), 209–218. https://doi.org/10.1016/S0966-6923(01)00013-8

Das, N. (1999). *Socio-economic development in India: A regional analysis*. Rawat Publications, New Delhi.

District Udham Singh Nagar, Government of India. (n.d.). *About district*. https://usnagar.nic.in/about-district/

Gadekar, D. J. (2025). A GIS-based identification of spatial analysis of road density and understanding the pattern of road network in Ahilyanagar District of Maharashtra State, India. Asian Journal of Geographical Research, 8(3), 34–48. https://doi.org/10.9734/ajgr/2025/v8i3274

Gallardo et al., (2012). Analysis of collection systems for sorted household waste in Spain. Waste management, Elsevier. Volume 32, Issue 9, Pages 1623-1633. https://doi.org/10.1016/j.wasman.2012.04.006.

Kaur, S. (2025). Seasonal dynamics and interrelationships of land surface temperature, normalized difference built-up index and normalized difference vegetation index in Rudrapur City using remote sensing. In Achari, A., Bhatia, H., Nagrath, A., Rane, N. L., & Pande, C. B. (Eds.), *Environmentally Sustainable and Socially Resilient Urban Development and Management*. Springer, Cham. https://doi.org/10.1007/978-3-031-92850-5_41

Kaur, S., & Punera, A. (2023). Enhancing municipal solid waste management in rapidly urbanizing areas: a case study of Rudrapur City, India. *Journal of Environmental Science and Economics*, 2(4), 1–13. https://doi.org/10.56556/jescae.v2i4.616

Kaur, S., et al. (2022). Urban infrastructural development: an assessment of disparities in Rudrapur City using GIS. *IOSR Journal of Humanities and Social Science (IOSR-JHSS)*, 27(11), 17–26.

Khan, J. H., & Shamshad. (2012). Road density and levels of development in West Bengal. *Indian Streams Research Journal,* 1, 1–10. ISSN 2230-7850.

Li, J., Ma, Y., Li, L., & Hou, Y. (2025). Study on the Correlation Between Transportation Development and Urban Expansion in China from the Perspective of Spatio-Temporal Heterogeneity. *Land*, *14*(12), 2326. https://doi.org/10.3390/land14122326.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Systems and Science* (4th ed.). Wiley.

Miezah, K. et.al, (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste management, Elsevier. Volume 46, December 2015, Pages 15-27. https://doi.org/10.1016/j.wasman.2015.09.009.

Mishra, S., & Kumar, V. (2020). GIS-based assessment of road density and urban development in Patna city. *Journal of Urban and Regional Studies*, 12(2), 44–56.

Nijagunappa, R., Shekhar, S., Gurugnanam, B., et al. (2007). *Road network analysis of Dehradun City using high-resolution satellite data and GIS*. Journal of the Indian Society of Remote Sensing, 35, 267–274. https://doi.org/10.1007/BF03013494

Rao, P., & Sharma, S. (2019). Spatial analysis of road density and accessibility using GIS: A case study of Hyderabad city. *Journal of Infrastructure Development*, 11(1), 51–68.

Reddy, G. S., & Reddy, P. (2012). Road transport and regional development: An inter-district analysis in India. *Indian Journal of Regional Science*, 44(2), 89–100.

Singh, R., & Singh, V. (2017). GIS-based analysis of transport accessibility in Varanasi city. *Indian Journal of Geography and Environment*, 19, 102–111.

Talpur, M. A. H., Khahro, S. H., Abro, S., et al. (2024). *Measuring GIS-based pedestrian accessibility to bus stops: A sustainable approach to ease urban traffic problems at Hyderabad, Pakistan*. Discover Cities, 1, Article 28. https://doi.org/10.1007/s44327-024-00031-5

Tchoffo, R. N., Dounya, C. M., Mouafo, P. T., & Tchio, S. S. (2024). *Contribution of road transport infrastructure in mitigating the inward–immiserizing growth in Cameroon: An externality approach in computable general equilibrium analysis*. Sustainable Futures, 8, 100298. https://doi.org/10.1016/j.sftr.2024.100298

Zhang, Y., Zhao, J., & Li, X. (2019). Spatial variation in road network density and urban development in Chinese cities. *Cities*, 90, 272–283.