Density Analysis of Venues and Clustering of DMRC Stations

Kanishka Thakur [a], Ritika Mehra [a,*] [0000-0002-2785-5856], Rakesh Arya [a] [0000-0003-2436-3060], Tanupriya Choudhury [b]

[a] Dev Bhoomi Uttarakhand University, Dehradun, UK, India

kanishkathakur100@gmail.com, riti.arora@gmail.com, rakesh arya1980@gmail.com

[b] Symbiosis Institute of Technology, Symbiosis International (Deemed University), Pune, Maharashtra, India

tanupriya.choudhury@sitpune.edu.in

Abstract. The Delhi Metro is a vital transportation network in India, but little is known about the characteristics and density of venues surrounding its stations. This study employs various techniques, including distance measurement, KDE analysis, and clustering, to explore these areas. Seven main venue groups are considered, revealing diverse densities across metro lines. The New Delhi district exhibits the highest venue density, while commercial venues are more common near the stations. Venue density increases further from the stations, and the presence of venues varies with distance. City centers have concentrated venues related to places, institutions, and nightlife, while shopping and food venues extend to suburban areas. Six distinct clusters are identified, each with unique characteristics catering to diverse needs. This research provides valuable insights for residents, visitors, and urban planners, facilitating informed decision-making and enhancing accessibility and amenities in Delhi's urban landscape.

Keywords: Cluster analysis, KDE, station area, TOD, spatial analysis, venue density.

1. Introduction

1.1 Impact of Metro Stations

Transit-Oriented Development (TOD) emphasizes living near transportation facilities and reducing dependence on driving. TOD places significant importance on stations within transportation systems as pivotal points that connect different modes of transportation, enabling

seamless movement and transportation between places (Aboul-Atta & Elmaraghy, 2022). The presence of venue categories surrounding these stations plays a significant role in meeting the diverse needs of users. This literature review explores the relationship between metro stations, influence zones, venue categories, clustering patterns, hotspot areas, and the suitability of metro lines for different needs.

The clustering of venues near metro stations offers several advantages. One of the most common benefits is high footfall (Deng & Li, 2023) (Zhao et al., 2013) (Zeng & Lin, 2016). The constant influx of commuters, visitors, and residents in these areas creates a conducive environment for businesses to thrive (Ribalaygua & Perez-Del-Caño, 2019) (Du et al., 2021) (Wang et al., 2022). Proximity to transportation hubs provides businesses with a strategic advantage, increasing their visibility and customer base. The study by (Pokharel et al., 2023). reinforces the positive relationship between transportation hubs and the economic success of businesses in their vicinity. Another study conducted by (Nikiforiadis et al.,2020) in the city of Thessaloniki found that businesses near metro stations saw significant revenue increases, and business owners and experts are optimistic about metro system operations due to greater accessibility. Previous studies have highlighted that proximity to transportation hubs enhances accessibility, reduces travel time, and increases convenience for users (Zhao et al., 2013) (Zeng & Lin, 2016). Study (Alexander & Hamilton, 2015) in Scotland and (Ferbrache & Knowles, 2017) in the U.K. highlight the role of transportation hubs in promoting social interaction and placemaking. These hubs attract various venues such as restaurants, cafes, retail stores, entertainment venues, and service providers. The interdependence of transportation infrastructure, venue variety, and busy areas is evident (Karthiheyan & Chander,2020) (Zhao et al., 2013) (Zeng & Lin, 2016). While a transportation hub alone may attract businesses, its success and impact are enhanced by the presence of a busy area and a significant population. The presence of metro stations in a region contributes to higher venue densities, which turn enhances user satisfaction by providing a wider range of options. A study on shopping

satisfaction (Lehew & Wesley, 2007) reinforces this notion, highlighting the positive impact of venue density and variety on overall satisfaction. Applying this understanding to the context of purchasing around metro lines, increasing the density of shops, restaurants, entertainment venues, and service facilities would create a vibrant and diverse shopping environment, benefiting both tourists and locals and enhancing overall user satisfaction.

In order to understand the presence of venues around metro stations, selecting the appropriate influence zone is a crucial step. The spatial extent of influence around a station cannot be confined to a fixed radius alone. Previous studies have often defined the influence zone using predetermined distances, such as 500m, 800m, or 1000m (Ye et al.,2017) (Lang et al.,2020) (Zhou et al.,2017), which may not fully capture the actual area affected by these stations. While it is true that the influence zone of stations can impact the immediate area surrounding the stations, (Li, 1999) study provides valuable insights suggesting that this influence extends beyond, reaching larger regions within reachable distances. This implies that the impact of a station is not limited to a small radius but can encompass neighboring areas as well.

The availability of user-generated data from Location-Based Social Networking (LBSN) platforms has facilitated the analysis of user behavior and the identification of hotspot areas around metro stations. (Jiang et al., 2015) LBSN data comprises user check-ins, tips, and comments about venues and points of interest (POI) within an area. Several studies have demonstrated that LBSN data can reflect social interactions occurring in urban spaces. (Agryzkov et al.,2016) One study compared the authenticity of LBSN data with fieldwork data in Murcia, finding that LBSN data was adequate, particularly in a quantitative sense, for food services and the entertainment sector. Another study employed the Facebook Places Search API to perform a spatial-temporal analysis of retail and services in Brno, revealing variations in the opening and closing hours of different Facebook Places based on demand. Historical locations were identified as vital and socially active areas within the city. (Üsküplü et al., 2020) In Istanbul, researchers utilized Foursquare check-in data from venues in central zones to

identify urban hotspots. (Hong, 2015) In Seoul, a study conducted spatial analysis of venue categories at the regional level, comparing Foursquare API data within a 400-meter buffer region to census data to authenticate the results. Similarly, (Hong & Jung, 2017) a study in Seattle employed Foursquare data to conduct cluster analysis and extract statistical attributes about venues. Studies by (Sun & Li, 2015) and (Ullah Khan et al.,2020) have demonstrated the usefulness of LBSN data in identifying popular venues, activity patterns, and user preferences. Hotspot areas around metro stations exhibit high levels of economic activity, social interactions, and urban vitality.

Our research focuses on conducting a comprehensive analysis of venue distribution in the vicinity of Delhi Metro stations and characterizing different metro lines. While previous studies have explored various aspects of the Delhi Metro, such as commercial land value (Gupta & Srinivas, 2015) and travel behavior, there is a noticeable gap in the literature regarding the specific investigation of venue distribution around metro stations. Our study aims to fill this gap by providing valuable insights into the concentration, diversity, and characteristics of venues near metro stations. To address this research gap, we have formulated the following research questions: density estimation of main groups for a better understanding of concentrations based on each venue category, land use characteristics and degree of agglomeration based on Foursquare venue data, cluster patterns among metro Delhi metro stations using LBSN data, difference urban activities around Delhi metro stations. By addressing these research problems, our study contributes to a better understanding of the venue density mix, spatial dynamics, ultimately informing urban planning and decision-making processes.

2. Dataset & Methodology

2.1 Study Area and Data source

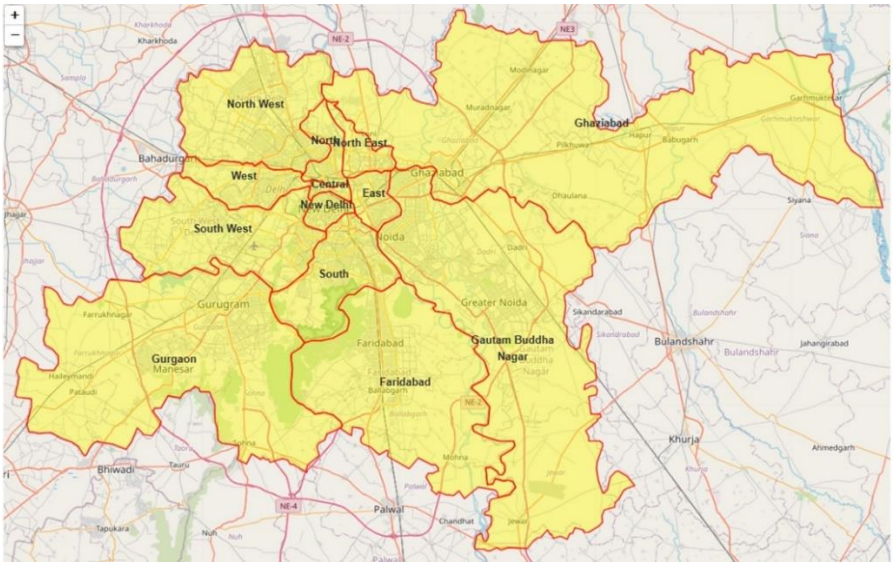

Fig. 1. Study area

Delhi is a significant metropolis located in the Ganges plain and serves as the national capital territory of India (NCTD). The city, along with its satellite cities in the National Capital Region (NCR), is efficiently connected by the Delhi Metro (as shown in Fig.1.), a rapid transit system. This study focuses on the 13 districts within Delhi and the NCR due to their coverage by the Delhi Metro. Delhi is known for its high population density and impressive economic growth, with a projected GSDP of ₹10.83 lakh crore (US$140 billion) (Das, 2023) for 2022-23. The metro system in Delhi comprises multiple lines developed in different phases. The initial phase introduced the red, yellow, and blue lines, with the red line spanning 35 kilometers and featuring 29 stations. The yellow line covers 49 kilometers and intersects with the red line at Kashmir Gate, while the blue line extends over 65 kilometers, making it the longest line with 57 stations. Subsequent phases added the green, orange, violet, magenta, and pink lines. The green line connects Central Delhi, featuring reverse branches at the red and blue lines. The violet line runs north-south, linking the yellow and red lines. The orange line serves as a high-

speed Airport Express connecting New Delhi station to the airport and beyond. The magenta line is India's first automated line, connecting the blue, violet, and yellow lines. Finally, the pink line forms a complete loop around the city, covering 59 kilometers and connecting to all other lines (Reece, 2022).

2.2 DMRC Network and Geocoding

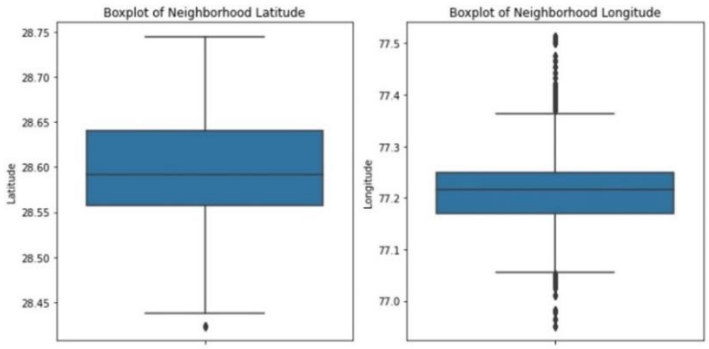

Fig. 2. Most stations are concentrated around coordinate 28.591872 & 77.216631

Using the Geopy Python Library, we performed geocoding to obtain the coordinates (latitude and longitude) for each station. Geocoding was done through the Nominatim geocoding service, which provides accurate location information. Despite broken links, we obtained valid coordinates for 239 stations. The geocoded data was saved in a CSV file for future use. We further categorized the stations by metro lines, creating the Station Line dataframe with station names, longitude, latitude, and metro line information. The resulting data was saved as Station_Line.csv. To ensure data accuracy and relevance, we analyzed latitude and longitude values. Using the interquartile range (IQR), we identified a representative range for latitude (28.556897 to 28.640459) and longitude (77.951199 to 77.249551) within Delhi. Fig. 2. shows that the latitude values for the stations have minimal variation, as indicated by the close proximity of the 25th percentile, median (50th percentile), and 75th percentile values.

2.3 Venue data collection and Preprocessing

We used the Foursquare API and a Python script to collect venue data around Delhi Metro Rail Corporation (DMRC) stations. The script retrieved venue details based on station names, metro line, latitude, and longitude coordinates. With a 2000-meter radius, we obtained a comprehensive list of venues near each station. The extracted information included venue names, locations, categories, opening hours, price ranges, user ratings, tips count, and review texts. In total, we obtained 10,710 records within a 2 km radius. Food and beverages venues accounted for the majority (59%), followed by retail and shopping venues. We identified 238 venue categories but focused on seven main groups (Fig. 3.): Culture and Entertainment, Food and Beverages, Nightlife Spot, Professional & Other Places, Recreational Facilities, Shop & Services, and Travel and Transport. Categories such as 'Moving Target' were excluded as they did not align with specific main groups.

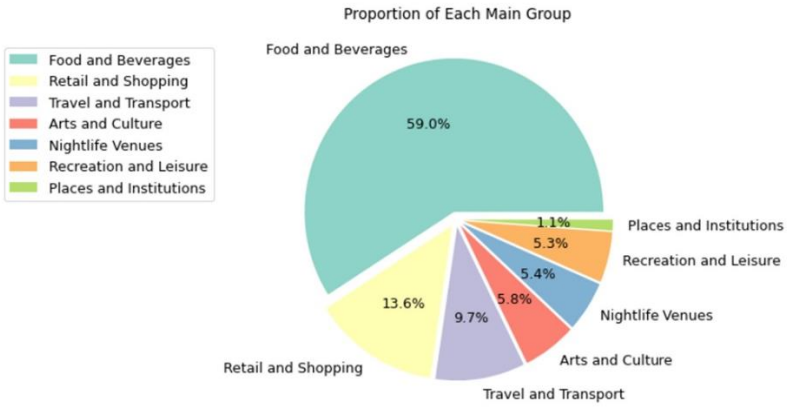

Fig. 3. Types and proportion of main groups

2.4 Land use characteristics around DMRC stations

The DMRC network consists of 10 metro lines. To examine venue distribution around these stations, we adopted methods from a study conducted in Shanghai by [4]. They established 500-meter interval buffer zones within a 2 km study area and assessed the presence of main groups. The number of venues in each buffer zone reflects the density and concentration of

establishments in that area, providing insights into commercial activity, amenities, and services close to the metro line. The proportions of each main group within a buffer zone reveal the diversity and composition of venue categories in that specific area, highlighting the specialization of venues near the metro line. Variations in main group proportions across buffer zones can signify differences in the types of amenities and services available at varying distances from the metro line.

During our study, using the Places API, we collected a total of 10,710 venues within a 2,000-meter radius of 213 metro stations.

2.5 Analysis of compositions of main groups along the metro lines

The city of Delhi has been at the forefront of urban metro transit system development in India. As of 2021, the city boasts an impressive metro network, encompassing 10 lines stretching a total of 390.14 km with 286 stations. To conduct our analysis, we relied on data obtained from the Foursquare Places API, which allowed us to gain valuable insights into the characteristics of venues along the metro transit network. Our examination involved scrutinizing the individual metro lines.

To ensure accuracy, a clear analysis range for the station area was essential. For metro lines, individual stations under each line were considered. Previous studies commonly used immediate buffer zones around the stations, such as 300m, 500m, and 800m. However, this study extended the area to 2KM around the stations. Research by [17] suggests a station's influence extends beyond its immediate vicinity, encompassing larger reachable regions via various means of transportation like cars, bikes, or bicycles. A 2km buffer zone was recommended as the maximum range, reachable by vehicles like cars or bikes, indicating the station's impact on neighboring areas.

Our analysis explored main groups across different metro lines, categorized into seven distinct categories: Arts and Culture, Food and Beverages, Nightlife Venues, Places and

Institutions, Recreation and Leisure, Retail and Shopping, and Travel and Transport. Observing venue distribution within each metro line led to better observations. To understand station spacing, we calculated average distances between metro stations on each line, using the precise Haversine formula to account for the Earth's curvature and gain insight into the overall metro network.

2.6 Diversity Indices

The venue data allowed us to calculate diversity indices for each main group within the line: Shannon Index, Simpson Index, and Pielou's Evenness Index. Each index offers a unique perspective. The Shannon Index measures the variety and diversity of venue categories, indicating the richness and diversity of venues within a metro line. The Simpson Index shows the dominance of specific main groups, highlighting the concentration of certain venue types. Pielou's Evenness Index assesses the evenness or imbalance in the distribution of main groups within the metro line.

2.7 Evaluation of Gathering Effects for DRMC metro lines

We utilized methods proposed in a study conducted in Shanghai [4] to evaluate gathering effects using three indicators: development density, degree of concentration, and entropy based on POI data. The analysis focused on the DMRC metro line, using venue data obtained from the Foursquare API. Below, we outline the formulas we employed:

1. Density of Land Use (d):

$$d = N / S \quad (1)$$

where N represents the number of venues in the study region and S is the area of the study region.

We calculated both density and standardized density. Density indicates the number of venues per unit area (km^2), showing the concentration of venues in specific areas. On the other hand,

standardized density is the density value divided by the number of stations in the metro line, offering an average density per station. This helps account for variations in station numbers across different metro lines.

1. Degree of Concentration (c):

$$c = N_{500} / N_{2000} \quad (2)$$

N_{500} represents the number of venues within a 500m radius, and N_{2000} is the number of venues within a 2000m radius from metro stations. This indicator measures the concentration of land development within walking distance.

2. Entropy of Land Use Structure (H):

$$H = -\Sigma (p_i \times \log(p_i)) \quad (3)$$

Where pi represents the percentage of different types of main groups within a 500m radius from the metro line. This value represents the complexity and diversity of land use within the 500m area. By applying these indicators, we gained insights into the gathering effects and land use characteristics around the DMRC metro line based on the Foursquare venue data.

2.8 KDE Analysis and Cluster Analysis

We employed KDE (Kernel Density Estimation) analysis to assess the spatial distribution and density of venues along the Delhi metro track. This allowed us to identify areas with concentrated venue presence and areas lacking specific amenities. The analysis utilized GeoJSON data obtained from OpenStreetMap, processed with geopandas, and a custom function for KDE analysis. The results were visualized as heatmap layers using the folium. plugins. Heatmap module.

For cluster analysis, we followed several data processing steps, including one-hot encoding to convert categorical data into numerical values. The top five nearby venues for each neighborhood were selected, and the K-means algorithm was applied to cluster neighborhoods

based on venue category similarity. We evaluated the clusters using the silhouette score and the elbow method, with the silhouette scores indicating well-defined and separated clusters ranging from approximately 0.63 to 0.74. We proceeded with 6 clusters to capture meaningful patterns while avoiding complexity.

3. Result

3.1 Land use for DMRC stations

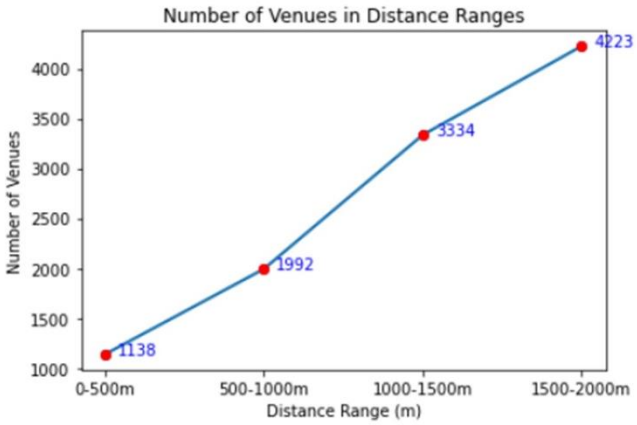

Fig. 4. Exploring the Spatial Distribution of Venues: Increasing Venue Presence with Distance

The DMRC network comprises 10 metro lines. To understand the spatial distribution of venues around these lines, we created buffer zones at distances of 500m, 1000m, 1500m, and 2000m from each line as shown in (Fig.4.). We then calculated the quantities and proportions of main groups within these buffer zones. (Fig.4.) shows that the number of venues generally increases as we move away from the neighborhoods, indicating a higher concentration of venues in buffer zones further from the metro stations. This trend can be attributed to several factors. Firstly, areas farther from the center may offer more available land or lower rental costs, making them appealing for businesses (particularly SMEs) to establish venues. Secondly, certain venues may require more space and favor locations with easy access to transportation

infrastructure like highways, leading them to be positioned slightly away from the stations. These factors collectively contribute to the observed increase in venue density with distance.

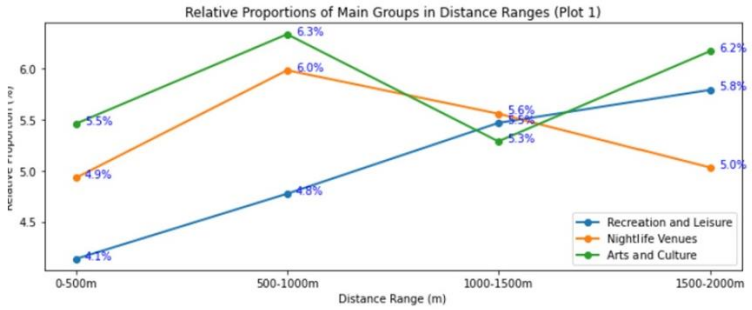

Fig. 5. Percentage of main group I

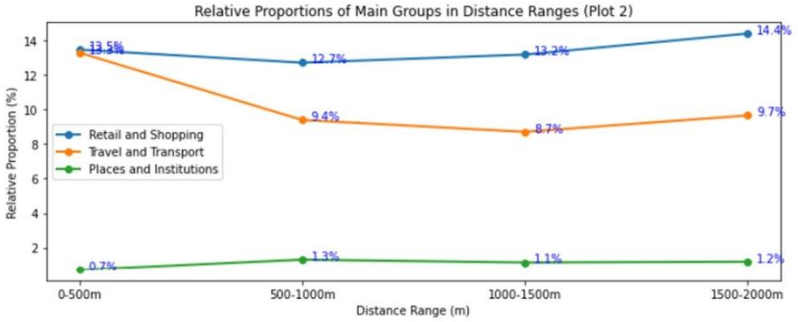

Fig. 6. Percentage of main group II

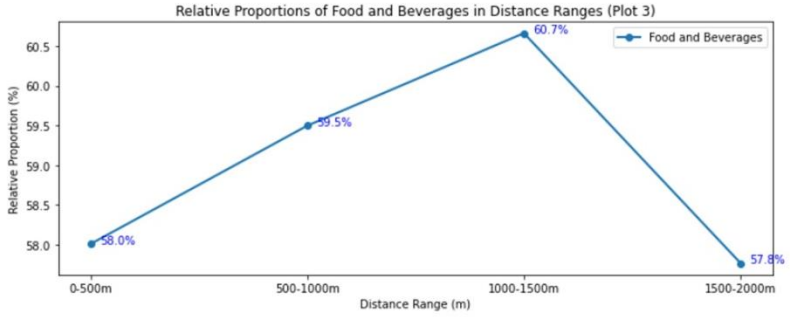

Fig. 7. Percentage of main group III

(Fig.5.), (Fig.6.), (Fig.7.) show the presence all the main groups. Presence of food and beverage establishments remains consistently high near metro stations, even as the distance increases (58.0%, 59.5%, 60.7%, 57.8%). Retail and shopping activities also show a relatively high proportion with some fluctuations across distance intervals (13.5%, 12.7%, 13.2%,

14.4%). Travel and transport-related establishments initially have a higher proportion near the metro station but decrease as the distance increases (13.3%, 9.4%, 8.7%, 9.7%). The presence of nightlife venues, arts and culture establishments, and recreational facilities varies with distance, suggesting their distribution is influenced by factors beyond proximity to the station. Places and institutions include residential property like apartments and condos, govt. buildings like city halls, religious places etc. have a consistently low proportion (0.7%, 1.3%, 1.1%, 1.2%). We can conclude that DMRC stations attract commercial facilities, but other venue types may not be equally attracted to these locations.

3.2 Main Groups distribution along Metro Lines

DMRC 10 metro lines considered for the analysis (Fig.8.). The most dominant venue categories across all stations were identified. The top ten categories included Indian Restaurant, Café, Coffee Shop, Hotel, Fast Food Restaurant, Pizza Place, Bar, Chinese Restaurant, Restaurant, and Market. Hauz Khas in the South district and Rajiv Chowk in New Delhi stood out as the top neighborhoods, each with 200 venues. Lajpat Nagar and Rajiv Chowk followed closely with 198 venues as can be seen in (Fig.9).

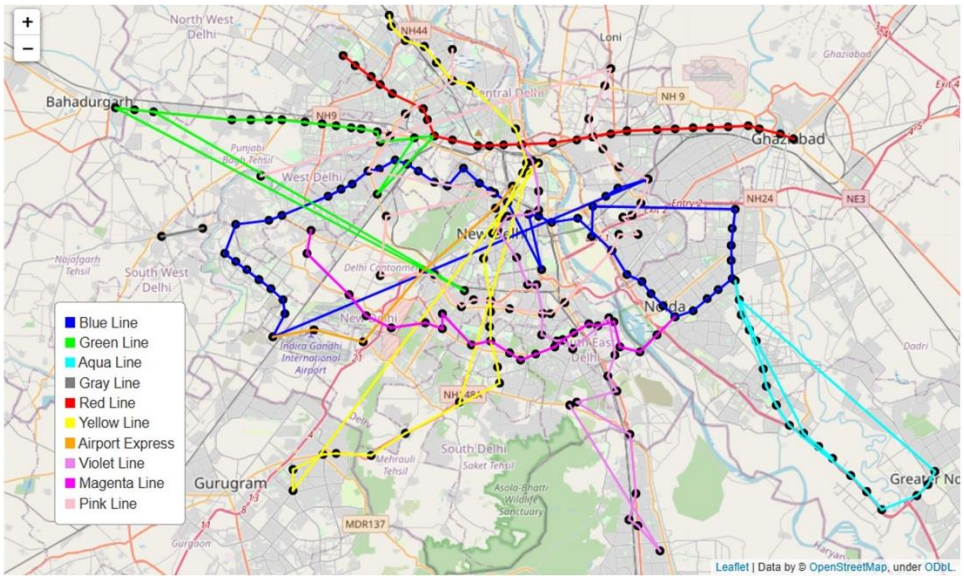

Fig. 8. DMRC 10 metro lines considered for the analysis

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Most popular venue categories:
Indian Restaurant       746
Café                    458
Coffee Shop             366
Hotel                   344
Fast Food Restaurant    322
Pizza Place             286
Bar                     181
Chinese Restaurant      172
Restaurant              171
Market                  148
Name: Venue_Category, dtype: int64

Neighborhoods with the highest number o
Hauz Khas              198
Rajiv Chowk            198
Lajpat Nagar           196
Mandi House            184
Central Secretariat    178
Dilli Haat INA         128
Kalkaji Mandir         126
Janpath                100
R K Ashram Marg         99
Kashmere Gate           99
Name: Neighborhood, dtype: int64
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Fig. 9. Most popular venues and stations with highest number of venues

Further analysis was conducted to examine the distribution of venues categories under each main group across different metro lines. The distribution of venue categories within each main group across different metro lines was analyzed (Fig.10.). The main groups include Arts and Culture, Food and Beverages, Nightlife Venues, Places and Institutions, Recreation and Leisure, Retail and Shopping, and Travel and Transport. Several interesting observations can be made. The Aqua Line has a high percentage of venues in the Food and Beverages category (57.5%), while the Gray Line is dominated by Retail and Shopping venues (78.6%). The Blue Line shows a balanced distribution across categories, with Food and Beverages being the most prevalent (57.6%). The Violet Line also has a relatively high proportion of venues in the Food and Beverages category (60.1%).

Metro Line	Arts	Food	Nightlife	Institutions	Recreation	Retail	Transport
Airport Express	11 (2.7%)	215 (53.2%)	34 (8.4%)	6 (1.5%)	14 (3.5%)	35 (8.7%)	89 (22.0%)
Aqua Line	9 (4.5%)	115 (57.5%)	3 (1.5%)	1 (0.5%)	22 (11.0%)	32 (16.0%)	18 (9.0%)
Blue Line	148 (6.2%)	1366 (57.6%)	107 (4.5%)	18 (0.8%)	141 (5.9%)	357 (15.1%)	227 (9.6%)
Gray Line	1 (7.1%)	1 (7.1%)	-	-	-	11 (78.6%)	1 (7.1%)
Green Line	15 (3.1%)	253 (52.4%)	12 (2.5%)	2 (0.4%)	18 (3.7%)	93 (19.3%)	88 (18.2%)
Magenta Line	58 (3.8%)	978 (63.4%)	98 (6.4%)	16 (1.0%)	86 (5.6%)	192 (12.4%)	115 (7.5%)
Pink Line	63 (4.5%)	870 (62.6%)	67 (4.8%)	17 (1.2%)	69 (5.0%)	200 (14.4%)	102 (7.3%)
Red Line	37 (5.2%)	383 (54.3%)	-	1 (0.1%)	55 (7.8%)	136 (19.3%)	89 (12.6%)
Violet Line	135 (8.8%)	919 (60.1%)	98 (6.4%)	32 (2.1%)	73 (4.8%)	157 (10.3%)	115 (7.5%)
Yellow Line	147 (7.1%)	1214 (58.6%)	154 (7.4%)	29 (1.4%)	91 (4.4%)	243 (11.7%)	192 (9.3%)

Fig. 10. Main groups along different metro lines of DMRC network

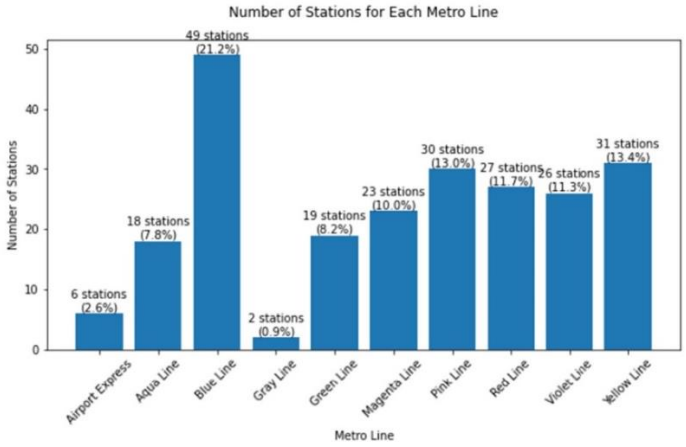

Fig. 11. Stations under different DMRC metro lines

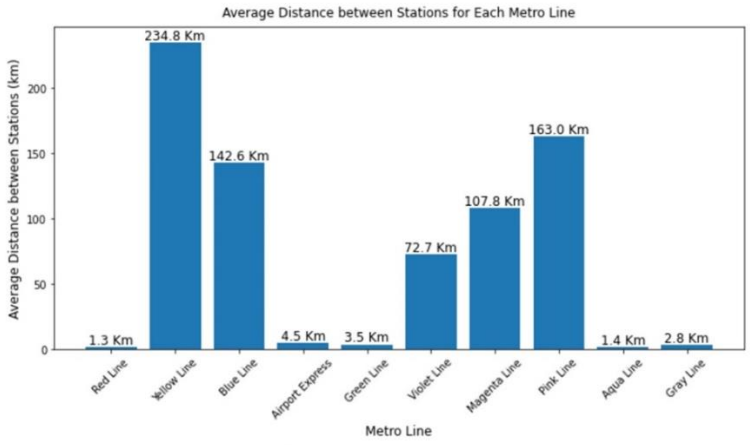

Fig. 12. Notable difference in stations spacing across 10 metro lines

(Fig.11.) depicts number of stations varies among the metro lines, with the Airport Express line having the fewest (6) and the Blue Line having the most (49). The Gray Line has only 2 stations, indicating its relatively shorter length. The Aqua Line, Pink Line, and Yellow Line have a higher number of stations (18, 30, and 31 respectively). The Yellow Line has the highest number of unique venue categories (175), while the Gray Line has the lowest (12).

The results shown in (Fig. 12) indicate significant variations in the average distance between stations across the metro lines for the data. The Yellow Line has the longest average distance of 234.84 km, while the Aqua Line and Gray Line have relatively shorter average distances of 1.36 km and 2.80 km, respectively. This suggests differences in station spacing and network design among the metro lines. The dataset highlights the Yellow Line as an outlier with a significantly higher average distance between stations, potentially due to the need to cover longer distances between major destinations.

(Fig.10.) presents actual percentage of various main groups which can’t be used to compare main groups presence across different metro lines. So, Z-scores or standardized values were calculated to compare the values of main groups across metro lines. Z-scores provide a standardized measure of how each metro line's main group performs relative to the average and variation of that group. (Fig.13.) suggests high venue variety do not always result in high z-scores. We can observe this for Airport line, which has lower z scores for all main groups but has a high venue variety. The z-scores are calculated based on the standard deviation from the mean, and they take into account the overall distribution of venues for each main group across all metro lines. Therefore, even if a metro line has a high venue variety, its z-scores may not be high if the distribution of venue types is more balanced across all metro lines. On the other hand, a metro line with a lower venue variety may have higher z-scores if it is more specialized in certain main groups, leading to a higher concentration of those venues compared to other metro lines. Blue Line and Yellow Line both have positive z scores suggesting they have a

diverse range of venue categories. Gray and Aqua Line have lower presence in multiple main groups.

Metro Line	Venues variety	Arts and Culture	Food and Beverages	Nightlife Venues	Places and Institutions	Recreation and Leisure	Retail and Shopping	Travel and Transport
Airport Express	101	-0.909622	-0.891588	-0.769423	-0.676625	-1.261438	-1.076619	-0.225745
Aqua Line	46	-0.945016	-1.105706	-1.403367	-1.124392	-1.056419	-1.105823	-1.323543
Blue Line	165	1.514857	1.572912	0.723411	0.398015	1.993243	2.057842	1.908005
Gray Line	12	-1.086591	-1.349801	-	-	-	-1.310244	-1.586396
Green Line	91	-0.838834	-0.810223	-1.219319	-1.034839	-1.158928	-0.512027	-0.241206
Magenta Line	154	-0.077866	0.742134	0.539363	0.218908	0.583735	0.451674	0.176266
Pink Line	160	0.010618	0.510886	-0.094580	0.308462	0.148069	0.529549	-0.024739
Red Line	90	-0.449502	-0.531870	-	-1.124392	-0.210714	-0.093450	-0.225745
Violet Line	151	1.284797	0.615804	0.539363	1.651762	0.250579	0.110972	0.176266
Yellow Line	175	1.497160	1.247453	1.684552	1.383102	0.711872	0.948126	1.366837

Fig. 13. Z scores of main groups for different metro lines

3.3 Diversity Indices

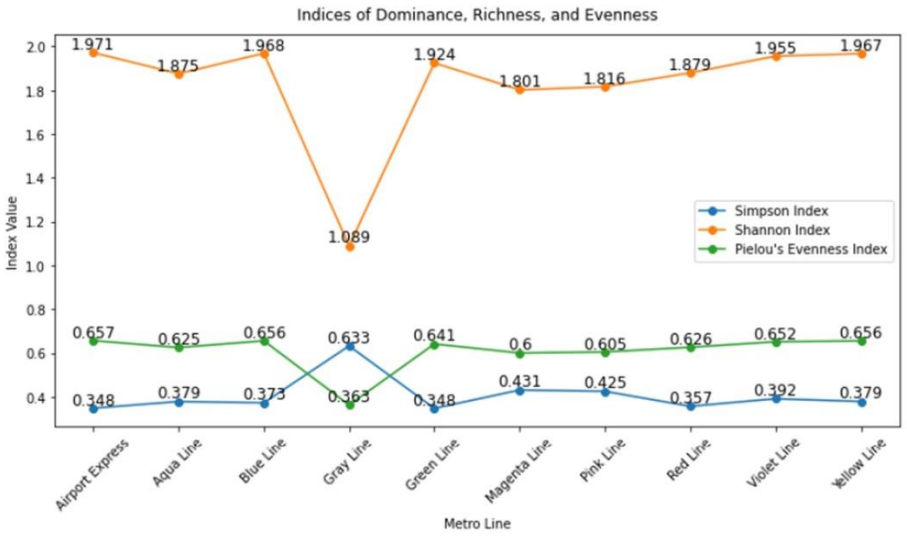

Fig. 14. Diversity Indices

Diversity indices (Fig.14.) were calculated for each metro line based on the main groups. The Gray Line has the lowest Shannon Index value, suggesting a lower variety and diversity

of venue categories. In contrast, the Airport Express and Blue Line have higher Shannon Index values, indicating a greater richness and diversity of venue categories. The Aqua Line and Gray Line have lower diversity and variety, possibly due to their smaller number of stations. The Gray Line stands out with a high Simpson Index value, indicating a strong dominance of the Retail and Shopping main group. Conversely, the Airport Express and Green Line have relatively lower Simpson Index values, suggesting a more balanced distribution of main groups. Pielou's Evenness Index highlights the Gray Line's uneven distribution of main groups, with Retail and Shopping being dominant. In contrast, the Blue Line exhibits a relatively higher evenness in the distribution of main groups.

3.4 Density, Entropy & Concentration Estimation for 10 metro lines

In (Fig.15.) we show the results of density and standardized density. The results of density of land use tell us that the Airport Express metro line has the highest density of 5.36 venues/km², indicating a relatively high concentration of venues in the studied area. The Gray Line has the lowest density of 0.56 venues/km², suggesting a sparser distribution of venues. In terms of standardized density, the Gray Line stands out with a value of 0.28 venues/station, indicating a higher average density per station compared to other lines. The Aqua Line has the lowest standardized density of 0.05 venues/station, suggesting a relatively lower average density per station. The standardized density suggests high density around Airport express metro lines station while gray line has a lower overall density but a higher standardized density, indicating a higher concentration of venues around each station. The Aqua Line has a relatively lower density and standardized density, suggesting a less dense distribution of venues in the studied area.

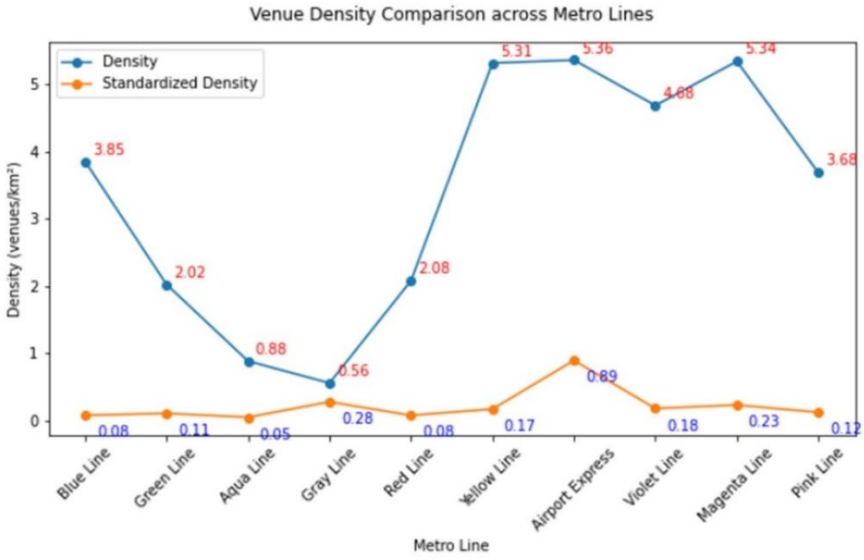

Fig. 15. Venue density and standardized density

(Fig.16.) tells us about density in 2 Km area, venue concentration and entropy within 500m area which is the area in the immediate vicinity of the stations and is reachable on foot. We can observe that Aqa line has a higher concentration within the 500m buffer zone. Many other metro lines have low concentration, this means more venues are required in immediate vicinity of the stations. Yellow line and blue line have the highest entropy suggesting the lines are highly disordered and developed. We may infer that Gray and Aqua line need further development and diverse venue variety. Overall, this analysis provides valuable insights into the characteristics of main groups across different metro lines. It helps us understand the variety, dominance, and evenness of venues within each line, highlighting the unique nature and offerings of different metro lines.

Metro Line	Density	Concentration in (0-500 m) interval	Entropy in (0-500 m) interval	Interpretation
Airport Express	Moderate-High (5.36)	Moderate (0.170792079)	1.8261746048970937	Relatively well-developed with a mix of different facilities.
Aqua Line	Low (0.88)	High (0.227272727)	1.917721707245619	Potential for further development and mixed land use patterns.
Blue Line	Moderate (3.85)	Moderate (0.131022823)	1.9457667669362124	Moderately developed with a diverse range of facilities.
Gray Line	Low (0.56)	Low (0.071428571)	-0.0	Requires further development and more diverse land use patterns.
Green Line	Moderate (2.02)	Moderate (0.14699793)	1.7579337180913426	Moderately developed with a diverse range of facilities.
Magenta Line	Moderate-High (5.34)	Low (0.068831168)	1.5062214148006667	Well-developed with a mix of different facilities.
Pink Line	Moderate (3.68)	Low (0.088808664)	1.6003128115649112	Moderately developed with a mix of different facilities.
Red Line	Moderate (2.08)	Low (0.053977273)	1.9448757156180314	Moderately developed with a diverse range of facilities.
Violet Line	Moderate-High (4.68)	Low (0.103921569)	1.936177421658068	Well-developed with a mix of different facilities.
Yellow Line	Moderate-High (5.31)	Low (0.104600484)	1.9552618673162119	Well-developed with a mix of different facilities.

Fig. 16. Evaluation result

3.5 Visualizing Venue Density

The (Fig. 17.) illustrates the density distribution of venues within a 2km radius of DMRC metro stations in Delhi.

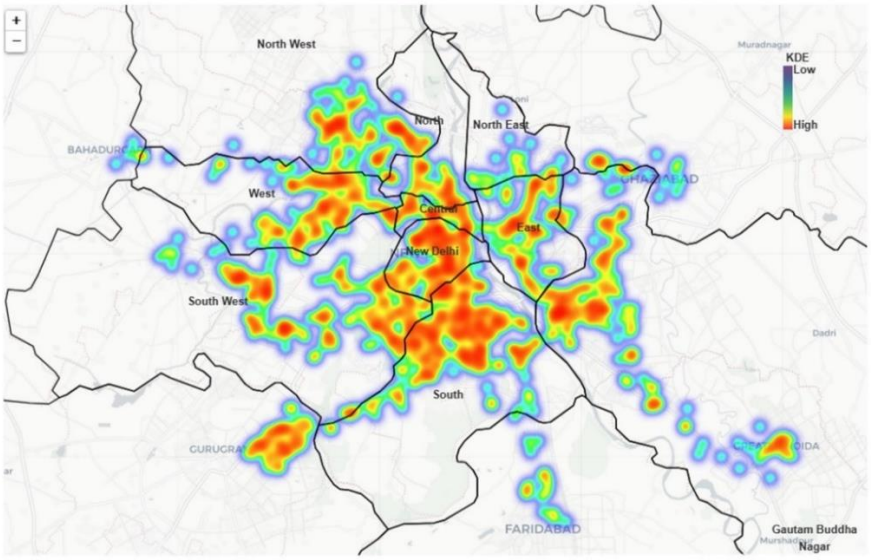

Fig. 17. Overall venue density

The varying levels of density, with high-density areas are depicted in red and lower-density areas in purple or blue. Prominent regions with high venue density include Connaught Place, Hauz Khas, Saket, and Nehru Place. Other areas like Khan Market, Rajendra Nagar, and Karol Bagh have a lower concentration of venues. New Delhi and the Central district of Delhi exhibit the highest density, indicating well-developed facilities and amenities. Some regions show venue density beyond the immediate vicinity of metro stations, suggesting a wider reach of venue concentration. Outside of Delhi, Noida and Gurugram demonstrate moderate venue density. This analysis highlights the variation in venue density across different regions, emphasizing the importance of city centers, mixed-use neighborhoods, and transport hubs in terms of venue concentration and development.

1. **Travel and Transport**

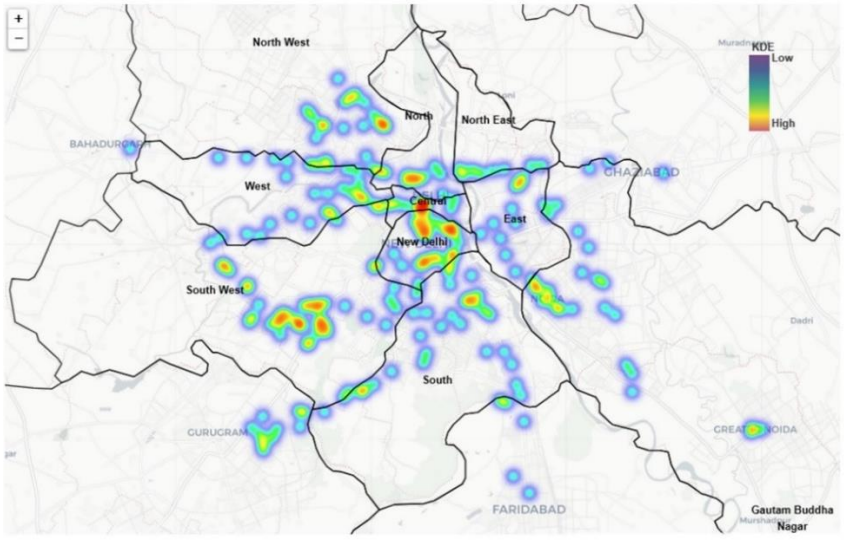

Fig. 18. KDE plot for Travel and Transport category

The KDE analysis for the "Travel and Transport" main group reveals varying patterns of venue concentration across different regions as shown in (Fig. 18). Paharganj and Delhi-Gurugram Expressway near IGI Airport Terminal 3 show the highest venue density, catering to commercial and transportation needs. Janpath, Maharani Bagh, and Nehru Place have average venue presence due to their mixed residential and commercial nature. Saket District

Centre, Sector 3, Noida Link Road, Patel Chowk, Supreme Court, Mandi House, Sector 26, and Sector 26A exhibit low venue concentration.

2. Food and Beverages

The KDE (Kernel Density Estimation) analysis for the "Food and Beverages" main group reveals several regions with a high concentration of venues, offering a diverse culinary experience as shown in (Fig. 19). In Central Delhi, Sansad Marg and Janpath emerge as prominent hubs for Middle Eastern and Bengali restaurants. Old Delhi's Indira Chowk stands out with vibrant markets and a wide selection of Indian restaurants and street food vendors. West Delhi's Karol Bagh showcases a concentration of dining options. In South Delhi, Chhatra Marg near JNU Campus caters to diverse culinary preferences with cafes, Indian restaurants, and vegetarian/vegan options. Hauz Khas Village and Nehru Place offer a fusion of Asian, Italian, and fast food, while Green Park boasts cafes, dessert shops, and sandwich places. Beyond Delhi, Noida Sector 18 in Gautam Buddha Nagar District presents a thriving food and beverage scene with diverse restaurants and food trucks. These regions exemplify Delhi's rich culinary heritage and provide residents and visitors with a wide range of dining experiences.

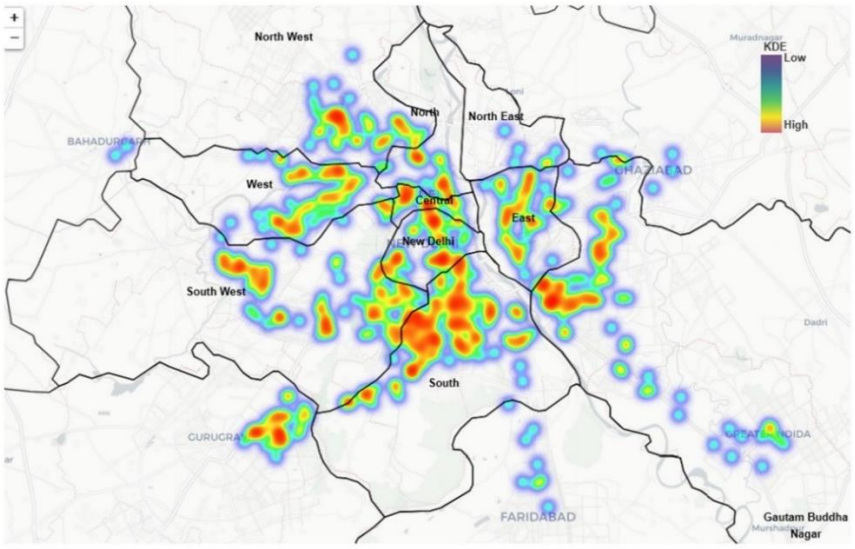

Fig. 19. KDE ploy for Food and Beverages category

3. Shopping and Retail

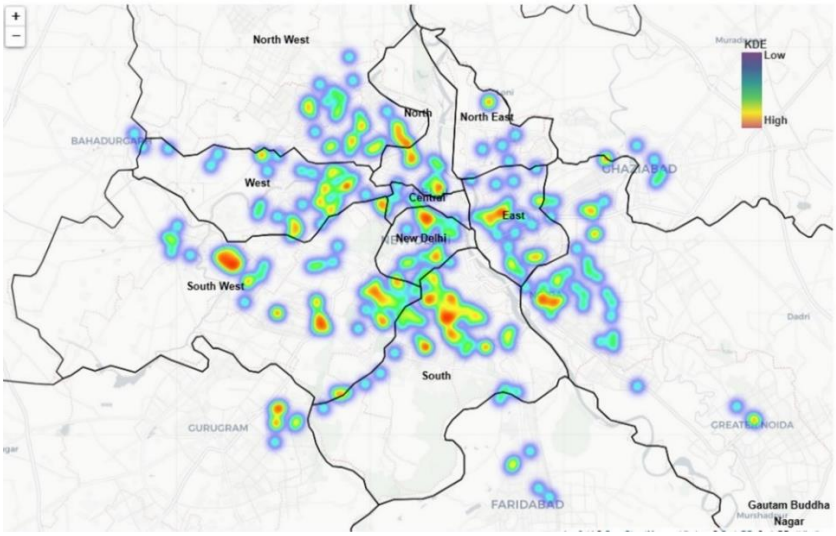

Fig. 20. KDE plot for Shopping and Retail category

The KDE analysis highlights the distribution of venues related to retail and shopping as shown in (Fig. 20) across different districts. Connaught Place in Central Delhi stands out as a major commercial hub with a high concentration of venues, offering a vibrant shopping experience. In South Delhi, Saket District Center attracts visitors with its shopping malls, entertainment venues, and dining options, while Noida's Sector 18 offers a comprehensive shopping experience adjacent to Delhi. Sector 15A in Noida provides a mix of shopping complexes, educational institutions, and residential spaces. Metro stations conveniently connect these regions, ensuring easy access for residents and visitors.

4. Recreation and Leisure

The KDE analysis of the "Recreation & Leisure" main group reveals interesting patterns across various regions as shown in (Fig. 21). South Delhi emerges as a hub for recreational activities, with areas like Green Park, Siri Fort Road, Greater Kailash, and Sarojini Nagar offering diverse leisure options. Central Delhi's Connaught Place stands out as a major recreational hub, while West Delhi showcases a medium density of venues, with Rajouri Garden being a prominent hub. East Delhi regions like Karkarduma and Badarpur display a lower density of recreational venues. The extensive Delhi Metro network provides convenient

access to these areas, making them popular destinations for leisure activities. Overall, South Delhi and New Delhi contribute significantly to the presence of recreational facilities in Delhi, catering to the diverse leisure needs of residents and visitors.

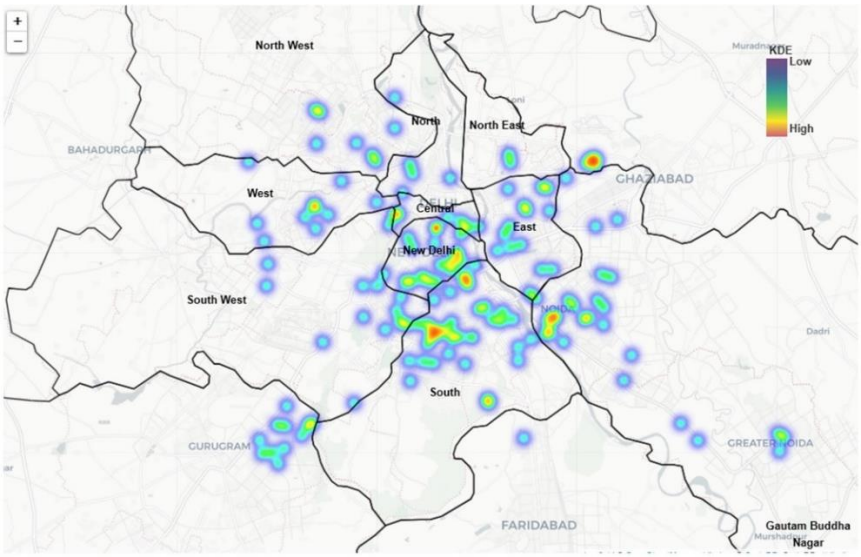

Fig. 21. KDE plot for recreation and leisure category

5. Places and Institutions

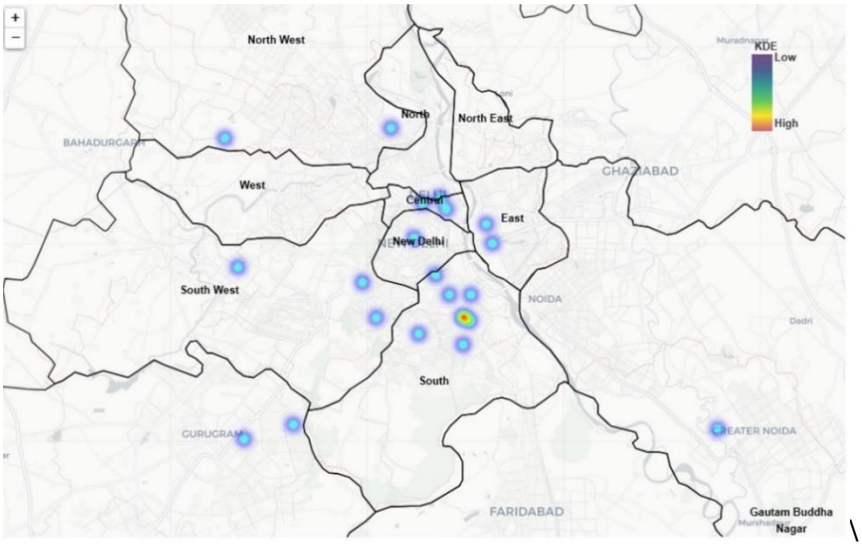

Fig. 22. KDE plot for Places and Institutions category

The (Fig. 22) for "Places & Institutions" category provides insights into the distribution of venues such as temples, mosques, offices, universities, banks, and hostels across different

regions. Limited venue concentration is observed in certain areas, including South Delhi districts like Defence Colony Tehsil, Asaf Ali Road, Meena Bazar, and Chawari Bazar, known for their commercial importance and historical significance. Regions like Lodhi Colony, University of Delhi South Campus, Munirka, Panchsheel Park contribute to the professional landscape with some level of venue density.

6. Arts and Culture

The (Fig. 23) reveals that the "Arts & Culture" main group exhibits a relatively lower number of venues compared to other groups, except for the "Places & Institutions" main group. However, specific areas showcase significant concentrations of cultural and entertainment venues. In Central Delhi, India Gate Park attracts visitors with its historical significance and a notable concentration of venues. Sector 18 in Noida, located near Maharaja Agrasen Marg and Worlds of Wonder Water Park, has low venue concentration. Hauz Khas in South Delhi offers a low concentration of cultural and entertainment venues, known for its artistic ambiance. Jantar Mantar and the vicinity of Humayun Tomb in New Delhi also exhibit notable concentrations of cultural and entertainment venues, showcasing Delhi's rich cultural heritage. These regions contribute to the vibrant cultural landscape of Delhi, catering to the diverse interests of residents and visitors.

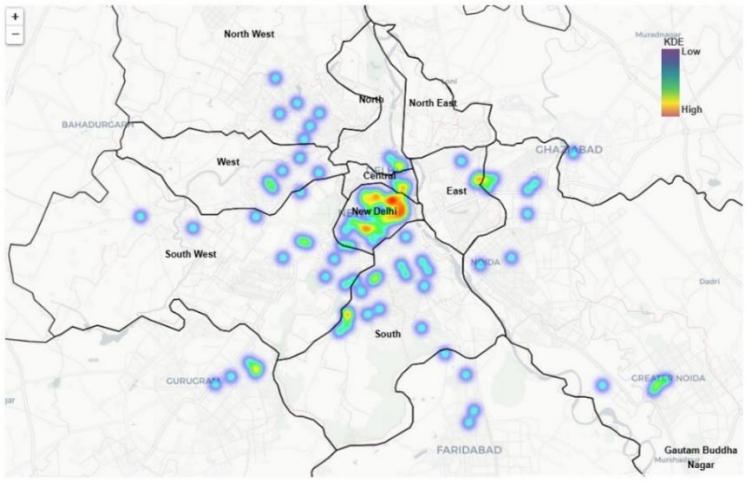

Fig. 23. KDE plot for Arts and Culture category

7. Nightlife venues

Among the analyzed main groups, "Nightlife venues" demonstrated the second lowest concentration of venues as shown in (Fig. 24). New Delhi stood out as a vibrant hub with significant concentrations of nightlife venues, particularly in areas like the Outer Circle. South Delhi displayed a moderate concentration of nightlife venues, with notable areas including Hauz Khas, Saket District Center, Greater Kailash, Nehru Place, and Hansraj Gupta Marg. On the other hand, Noida, Indira Chowk in East Delhi, Mayur Vihar, Defence Colony, Gurugram, West Delhi, East Delhi, and New Rajendra Nagar exhibited relatively lower concentrations of nightlife venues. Overall, New Delhi exhibited the highest concentration of nightlife venues, followed by South Delhi.

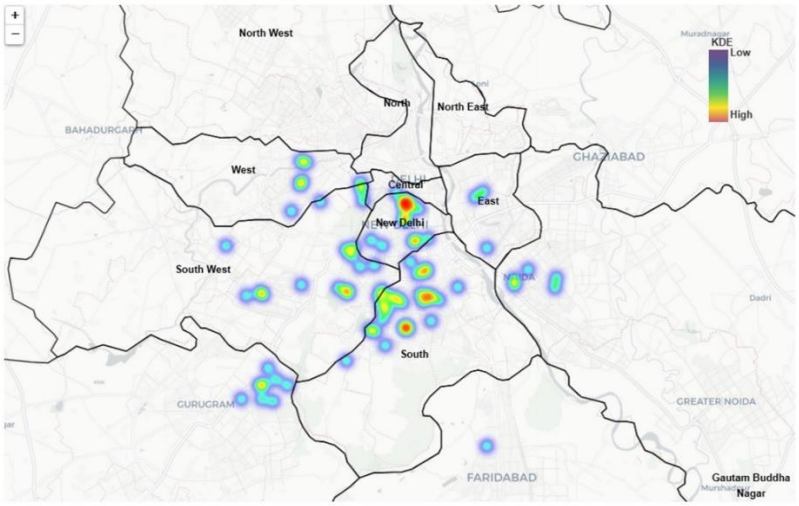

Fig. 24. KDE plot for Nightlife venues

3.6 Venue Clusters through K-means Clustering

The K-means clustering analysis was performed on the frequency of venue categories in each neighborhood as shown in (Fig. 25). Main groups distribution in all clusters is shown in (Fig.26.). The objective was to identify groups of neighborhoods that exhibited similar patterns in terms of the types of venues present.

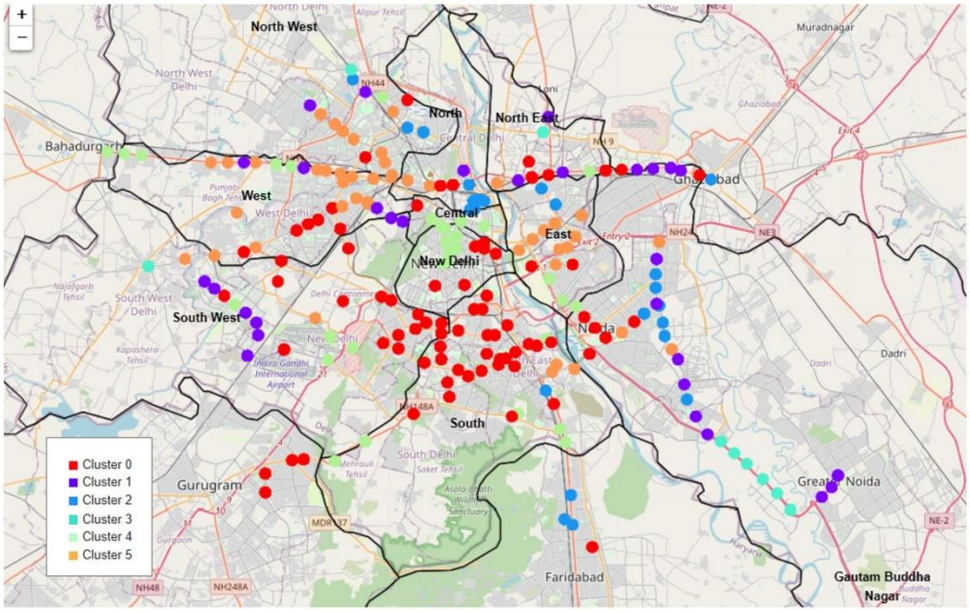

Fig. 25. Stations color coded according to station labels

Cluster	Size	%	Food	Transport	Retail	Nightlife	Recreatio	Arts	Institutions
0	78	36.6	62.1	5.9	12.3	6.4	6.0	6.2	1.1
1	30	14	57.7	15.1	16.2	2.6	4.8	2.9	0.2
2	23	10.8	59.5	10.2	17.1	1.0	3.4	5.9	2.8
3	9	4.23	42.0	6.0	30.0	-	16.0	4.0	2.0
4	30	14	53.3	17.9	9.5	8.1	3.6	6.6	1.1
5	43	20.1	55.1	11.4	20.2	1.7	5.8	4.8	0.7

Fig. 26. Main groups distribution in all clusters

Cluster	Transport	Retail	Recreation	Institutions	Arts	Nightlife	Food
0	1.35	2.07	2.18	2.08	2.12	2.06	2.16
1	-0.58	-0.60	-0.55	-0.86	-0.70	-0.59	-0.57
2	-0.70	-0.46	-0.58	0.07	-0.47	-0.66	-0.49
3	-1.32	-0.99	-0.74	-0.86	-0.84	-0.72	-0.87
4	1.27	-0.28	-0.24	-0.01	0.17	0.42	-0.04
5	-0.01	0.27	-0.07	-0.42	-0.26	-0.53	-0.19

Fig. 27. Z scores of main groups in clusters

Since comparing the actual percentages across clusters can be misleading, we calculated z-scores to determine the relative presence of each main group within the clusters. In (Fig.27.) positive z-scores indicate a higher presence, while negative z-scores indicate a lower presence compared to the overall average. Cluster 0 emerged as the standout cluster with a high presence across all main groups, indicating a diverse range of facilities and establishments. On the other hand, Cluster 4 exhibited relatively higher presence in Travel and Transport, Arts and Culture, and Nightlife Venues. Clusters 1, 2, and 3 showed lower presence in most main groups,

indicating a less diverse mix of venues. Cluster 5 had a slightly higher presence in Retail and Shopping. In summary, Cluster 0 represents a vibrant and diverse area around the metro stations, characterized by a high presence across multiple main groups. This cluster stands out as a hub of various amenities and attractions, making it an appealing destination for residents and visitors alike.

3.7 Cluster description

Cluster 0, characterized by a high density of food and beverages venues, encompasses 78 metro stations across 8 metro lines in South Delhi. Notable areas within this cluster include Lajpat Nagar, Hauz Khas, Mandi House, Botanical Garden, Kalkaji Mandir, IIT Delhi, and AIIMS. Lajpat Nagar station contributes the highest venue density (3.7%) in its vicinity, known for its bustling market and eateries. Hauz Khas, a cultural hub, offers historical landmarks, art galleries, and cafes. Theaters and other cultural institutions encircle Central Delhi's Mandi House. Residential areas with academic institutions are served by the metro stations of AIIMS and IIT Delhi. The venue categories in this cluster are dominated by Indian eateries, cafes, and coffee shops. With the most venue categories (58) and Magenta Line stations, Cluster 0 draws visitors, residents, and students with its wide range of culinary offerings. All things considered, South Delhi's Cluster 0 is a thriving neighborhood known for its variety of cuisines and dining establishments.

The 'dodger blue' color represents Cluster 1, which is distinguished by the presence of food and beverage venues (57.7%), shopping areas (16.2%), and travel and transport venues (15.1%). This cluster provides residents and tourists with convenience and accessibility across East, West, and South West Delhi. Its thirty metro stations combine to create a bustling retail district with a wide range of stores. This cluster includes 19 distinct venue categories within a 2 km radius, with hotels being the most prevalent category (8.9% of total venues). The stations in this cluster are situated in communities with a mix of commercial, residential, and office spaces, such as Rajendra Place, Patel Nagar, and Civil Lines. Rajendra Place Metro Station and

Patel Nagar Station on the Blue Line contribute the highest percentage of venues within this cluster. The Blue Line's Patel Nagar Station and Rajendra Place Metro Station account for the largest percentage of the venues in this cluster. The most notable metro line that serves this cluster is the Blue Line, which contributes 54.7% of the total venue contribution. Cluster 1 shows a relatively low presence of multiple main groups when compared to other clusters.

Cluster 2, with only 23 stations (10.8% of the total), is the second smallest cluster, but it has some distinctive features. With a notable presence of museums, landmarks, and historic sites, it is primarily focused on Indian restaurants, hotels, and markets. This cluster includes the well-known Old Delhi neighborhoods of Kashmere Gate, Chawri Bazar, and Chandni Chowk, which are known for their street food, traditional markets, and rich cultural legacy. Within this cluster, Kashmere Gate Metro Station contributes the highest percentage of venues (17.1%), acting as an interchange between the violet, yellow, and red lines. Another significant contributor (10.5%) is the Yellow Line's Chawri Bazar Metro Station, which is well-known for being a popular shopping destination. With a total venue contribution of 42.5%, the Yellow Line contributes more to this cluster than any of the other five metro lines combined. Offering food and drink, travel and transportation choices, nightlife destinations, culture and entertainment, and recreational amenities, Cluster 2 presents a well-rounded selection of venue categories. Cluster 2 draws in both tourists and residents with its historical sites, lively markets, and varied culinary scene.

Cluster 3, which is represented by the color "turquoise," is composed of 50 venues spread across 5 venue categories that are located within a 2 km radius of metro stations. This cluster encompasses food and beverages, travel and transport, arts and culture, as well as shopping and retail services, but lacks nightlife venues. It appeals to individuals interested in recreational activities and fitness. Cluster 3 stations are located in Gautam Buddha district outside Delhi and consist primarily of residential neighborhoods with some commercial establishments serving the local community. The main customer base in this cluster includes residents,

students, and daily commuters. Samaypur Badli Metro Station in North Delhi stands out, contributing 20% of the venues within this cluster and serving as a hub for various activities. Cluster 3 provides convenient access to commercial and business centers, offering an engaging experience for those seeking an active lifestyle in Delhi.

Cluster 4, depicted in the menthol color, consists of 30 metro stations and encompasses 33 venue categories within a 2 km radius. The cluster is characterized by an uneven concentration of all main venue groups, with food and beverages being the most prominent (53.3%). As important administrative and commercial hubs, Rajiv Chowk and Central Secretariat in Central Delhi are important components of this cluster. They serve tourists, shoppers, and those looking for a good time with a wide variety of amenities, such as hotels, restaurants, cafes, and bars. There are also a lot of travel and transportation-related venues in this cluster; two major transit hubs for travelers are Delhi Aerocity Metro Station and IGI Airport Terminal 1 Metro Station. With its lively and busy atmosphere, Cluster 4 is a popular hangout for Delhi residents and tourists alike.

The pastel orange-colored Cluster 5 Balanced Cluster includes 43 metro stations in East and some West Delhi, such as Anand Vihar, Kirti Nagar, and Ramesh Nagar. This cluster offers a wide range of fast-food restaurants, cafes, and dining options. It is primarily residential with a mix of commercial establishments. Cluster 5 demonstrates a varied and uniformly distributed range of venues, with food and beverages accounting for 55.3% of the venue categories. Within a 2 km radius, it features a total of 35 venue categories, comprising a remarkable count of 1505 venues. Anand Vihar Metro Station, a major interchange station between the blue and pink lines, stands out within this cluster, hosting the highest number of venue categories. Other notable metro stations include IP Extension on the Pink Line and Preet Vihar on the Blue Line. Vinod Nagar East Metro Station, situated near a residential area, also contributes significantly to the venue categories. Cluster 5 offers a wide range of dining options and recreational facilities, making it an appealing destination for food enthusiasts and shoppers seeking diverse

retail experiences. Additionally, it boasts excellent connectivity, as it is covered by a total of 9 metro lines (excluding the airport express).

3.6 Districts with Vibrant Venue Density

When it comes to high venue category density within a 2km radius of various Delhi metro stations, New Delhi, South East Delhi, and South Delhi districts stand out as can be seen in the (Fig. 28.). New Delhi district serves as the administrative center, boasting government offices, embassies, and iconic landmarks like India Gate. South East Delhi has experienced urban development, giving rise to residential colonies, commercial centers, and educational institutions. South Delhi, on the other hand, is renowned for its affluent neighborhoods, bustling markets such as Hauz Khas and Green Park, and esteemed educational institutions. These districts are steeped in historical and cultural significance, with architectural marvels like Humayun's Tomb and the Lotus Temple adorning their landscapes. Moreover, they serve as prominent educational hubs, housing renowned institutions.

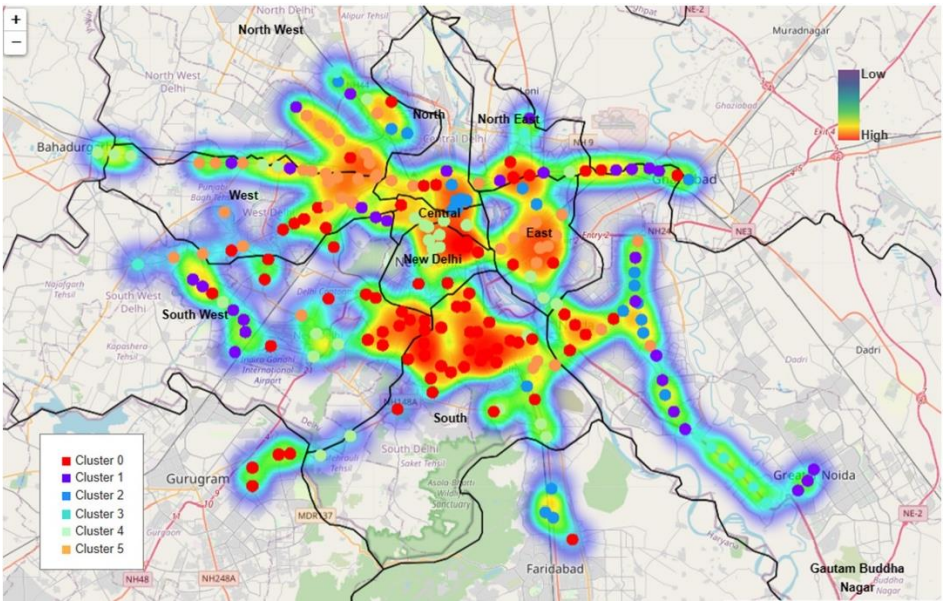

Fig. 28. Venue Density of clusters - New Delhi, Central and South Delhi with high density

4. Conclusion & Future Scope

In conclusion, this study examines the spatial distribution and density of venues surrounding Delhi Metro stations, shedding light on urban dynamics and accessibility. Through the use of KDE analysis, clustering techniques, and data from Foursquare's 'Places API', we identified venue density, distinct clusters, and examined the characteristics of different metro lines. The findings enhance our understanding of the spatial dynamics and suitability of venue clusters within the vicinity of Delhi Metro stations. The analysis considered seven main groups of venues, with varying densities and diversity across different metro lines. The Gray Line stood out with a dominant presence of retail and shopping establishments and lower overall venue density. In contrast, the Blue Line exhibited the highest variety of venues, while the Airport Express Line demonstrated a balanced nature with a well-developed status. The Aqua Line and Gray Line appeared to be less developed, with limited venue diversity.

We observed a higher concentration of venues in buffer zones further away from the metro stations, indicating the influence of distance on venue distribution. Commercial facilities and travel-related establishments were more prominent near the stations, while places and institutions were relatively distant. The presence of nightlife venues, arts and culture establishments, and recreational facilities varied with distance, suggesting other factors influencing their distribution. KDE analysis highlighted the concentration of venues related to places, institutions, and nightlife in city centers, while shopping and food venues extended into suburban areas. Certain metro lines, such as the Violet Line, Yellow Line, and Blue Line, played a significant role in attracting visitors to vibrant districts. The cluster analysis identified six distinct clusters with unique characteristics around the metro stations. Cluster 0 exhibited the highest venue diversity and a balanced nature, mainly located in South Delhi. Cluster 1 displayed an even distribution, covering various districts including parts of Noida. Cluster 3

showed low diversity but a well-distributed pattern in Noida. Cluster 4 presented diverse characteristics with a slightly uneven spread in New Delhi and South Delhi. Cluster 5 encompassed West Delhi, Central Delhi, and East Delhi, offering a diverse and well-balanced cluster.

Overall, this study provides valuable insights into the land use characteristics, venue distribution, and patterns of diversity and concentration along the Delhi Metro lines. These findings contribute to our understanding of urban dynamics, accessibility, and inform future planning and development strategies. Limitation of this study is the availability of data on Foursquare, which resulted in a lack of comprehensive data for professional and other places. Additionally, venue data was obtained for only 213 out of the originally considered 264 stations in the DMRC network in Delhi. Future research can overcome this limitation by exploring alternative location-based social networking platforms or utilizing other APIs such as the Twitter API to gather more diverse and comprehensive data for analysis.

To sum up, this study offers insightful information about the density and distribution of venues in Delhi Metro station areas. The results pinpoint particular groups and areas with high concentrations of venues, which can help guide urban planning initiatives and improve the general experience for locals and tourists. The study emphasizes the importance of considering spatial dynamics and potential development opportunities in these areas for a well-rounded analysis.

Declarations

Ethical Approval

Not applicable

Competing interests

The authors declare that they have no conflicts of interest.

Authors' contributions

Kanishka Thakur conceived, designed, collected data, analysed and wrote the paper. Rakesh Arya contributed to the manuscript design and provided critical review. Ritika Mehra gave valuable feedback, reviewed and edited the manuscript, and contributed to the intellectual content. All authors reviewed the manuscript.

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Availability of data and materials

The data for the station (DMRC network) comes from the DMRC website, and the information about the venues is obtained through the Foursquare Places API version 2.

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