EXAMINATION OF METRO STATIONS PEDESTRIAN ACCESSIBILITY FOR ALL USING OPEN DATA KIT: A CASE STUDY OF NOIDA CITY IN INDIA

S. S. Kapoor [1] *, T. S. Brar[1]

[1] School of Art & Architecture, Sushant University, Gurugram, India – kapoorsahilsingh@gmail.com, brartejwant@yahoo.com

Commission IV, WG IV/4

KEY WORDS: Public transit, Open Data Kit (ODK) applications, Isochrones, Accessibility, GIS, Noida.

ABSTRACT:

To make transit rail services more attractive, the preferred public travel mode and serve as the backbone of any metropolitan area, there arises a need to create a sustainable and inclusive urban environment with access to all. This study aims to map the pedestrian permeability and impermeability by categorizing roads and streets around identified transit nodes in Noida as public, private and non-accessible by all. By doing so, the study identifies very distinct and spatial divisions like gated communities and urban villages that have emerged as social ghettos in the planned city Noida and thereby, devoid it of being an inclusive city. Initial metro station smart android-based mobile surveys were done across 12 elevated metro stations falling on the blue transit corridor line connecting Delhi with its satellite town Noida using smart apps namely ODK and Kobo Toolbox with the analysis done in QGIS. It was found that trip distance and time had a strong association with walking while age, gender and purpose of the trip had no association with walking to the metro station. Most transit users living within one-kilometer walking distance prefer to walk to the nearest metro station in Noida. Finally, the study shows the area difference between the perceived and actual Isochrones prepared in QGIS as Ped-sheds after deducing areas such as gated communities, superblocks and unplanned settlements like urban villages where the existing road/street network is not accessible by all or safe to use.

1. INTRODUCTION

The Delhi metro, which is a world-class metro has been offering its services in its satellite town Noida since 2009 and has further extended its blue transit line services until Noida Electronic city metro station. Indeed, urban rail transit systems serve as the backbone of any metropolitan city as it offers large-scale complex transit networks which have high reliability and large carrying capacity to minimize pollution levels (Yang et al., 2019). But, to make metro service more attractive and preferred public travel mode, the metro station accessibility must be in a good condition for origin and destination purposes (Bhatt and Minal, 2022). Sun and Lin (2015) explain public transit station accessibility based on the level of transit service and urban road accessibility. Nowadays, the need is felt to create a sustainable and inclusive urban environment accessible to all, which requires a people-centered urban planning approach (Rossetti et al., 2020). Along with alleviating environmental problems and minimizing traffic congestion, the public transit system serves as a means of providing equal access (Lei and Church, 2010).

Many Indian metropolitan cities with planned and unplanned neighborhoods have been experiencing rapid urbanization particularly due to a swift influx of migrants from towns and adjacent urban areas. However, the recent migration of skilled workers and professionals has led to the sporadic establishment of gated communities and private townships close to major arterial roads and transit lines (Maarseveen et al., 2019). Across many Indian metropolitan cities, an array of urban fragments exists, which influence distinctive spatial urban forms across its different parts. These urban fragments can be categorized as planned, unplanned, and most recently gated communities.

* Corresponding author

The quality of life of many earlier residing residents and poor people has deteriorated as common street connectivity accessible by all is absent, which emanates social exclusion and leads to various types of urban fragmentation. This study aims to map the pedestrian permeability and impermeability by categorizing roads and streets around identified transit nodes as public, private and non-accessible by all. By doing so, the study also identifies very distinct and spatial divisions like gated communities and urban villages that have emerged as social ghettos in the planned city Noida as the study area and devoid it of being an inclusive city. The study also attempts to re-evaluate the isochrones as pedestrian catchment areas (PCAs) prepared using a GIS-based approach as the walkable area of 800 meters that can be comfortably covered in any direction from public transport nodes.

For decades, local community streets have been used for frequent social interaction and binding spaces to uplift social integration. Although, many studies have been done in the past to look into the street design and measure street qualities to restore pedestrian mobility and nearby public spaces. However, there are only limited empirical studies done within Indian cities context to realize the social dimension associated with streets in the context of housing, infrastructure services and informal settlements to promote interaction among different social groups. The isochrones predict the time to reach any area from a transport node like a transit station based on the shortest path model, however, not all roads and streets offer equal access to all (Lei and Church, 2010). In this study, macro-built-environment attributes responsible to increase pedestrian distance length and time to reach metro stations are identified using a GIS-based approach by integrating land-use and transportation data. However, the micro-built environment attributes like pedestrian behavior, preference of travel modes and purpose and frequency of transit trips made by the transit users were gathered using the ODK app linked with its ODK aggregate server.

1.1 The motivation for the study

Delhi Metro Rail Corporation (DMRC) offers its DMRC mobile app to provide static information such as metro routes and train timings but lacks to provide real-time information to urban planners and allied researchers about how its citizens behave and the travel mode, the choice to reach the desired metro station. Also, issues like last-mile connectivity and the safety of the transit users are beyond the scope of the mobile app (Bajaj and Singh, 2019). As Bhatt and Minal (2022) state, local accessibility is an assessment of several factors such as travel time and cost, and the underlying road layout and land use pattern to make an urban area more accessible with potential opportunities for social and work interaction. The definition of transit station accessibility is difficult to apprehend by city planners and researchers as transit network is not only complex but has entirely different characteristics than road network (Sun and Lin, 2015).

Across many countries offering public transit services, the 'Smart-card automated fare collection (AFC) equipment' installed at the entry and exit points of the metro stations allow urban researchers to collect entire passenger data with their entry and exit time (Yang et al., 2019). However, this data collection is quite difficult to obtain in developing countries as metro authorities are not comfortable sharing the latest ridership data of individual stations (Maarseveen et al., 2019). Moreover, the statistic smart-card data can never tell the travel mode often chosen by the transit rider and the problem they face to access their daily use transit station. The ongoing transport and urban planning methods hardly give any importance to understanding origin and destination to reach important places with more ease and mobility (Bhatt and Minal, 2022). Instead of taking 'accessibility, especially pedestrian accessibility into consideration, the transport planners solely focus to expand the road network or road width to accommodate more cars and traffic on the roads. It is the accessibility-based planning approach that takes into consideration the different public-travel modes and provisions to have safe non-motorized travel modes for short trips.

It becomes important to conduct metro station field surveys, which is not only, time-consuming and expensive but can go wrong if not done according to the study requirements of what data collection has to be done and how it has to be done. For a manual data collection survey project, the error rate can vary typically between 20% to 30% depending on the nature of the project survey (Yang et al., 2019). In such cases, the Open Data Kit (ODK) Android-based devices in a smartphone can be used to compromise with positional accuracy of about 5 meters free of cost. As Sun and Lin (2015) state, only recently researchers have realized the need for the presentation of accessibility using GIS-based Figures and tables to visually compare station accessibility identified problems at different stations offering the same level of service. Finally, there is a need to prepare specific plans based on the response of actual pedestrian behavior and the routes they take to reach the public transport nodes and other places of interest in real situations (Ha, et al., 2011).

2. LITERATURE REVIEW

Accessibility is a major function to study public transportation systems as it provides access to jobs and different parts of city areas (Lei and Church, 2010). Urban transit systems play a crucial role to reshape the form and scale of any metropolitan city. Transport accessibility is measured by encompassing a wide variety of factors including trip purpose, weekly frequency, trip length and time taken to reach transport node, availability of own vehicle, travel cost, parking availability and socio-economic factor (Bhatt and Minal, 2022). Bhatt and Minal (2022) suggest that metro station accessibility requires a multidimensional assessment to provide balance access to different community groups, especially poor people, link affordable feeder buses with metro stations and ensure safe access for individuals to comfortably reach metro stations. (Kumar et al., 2013) studied the performance of multimodal transport systems by considering time-related parameters such as travel time ratio, passenger waiting time, interconnectivity with other travel modes and interchange stations and level of service offered. They concluded that it is the access and egress distance that largely contributes to making metro services more lucrative. Travel distance and time to reach the metro station can be reduced by providing adequate parking facilities, dedicated pedestrian and cycle tracks for a pedestrian walking environment, and short-route feeder buses. Thereby, it becomes vital to identify pedestrian barriers on typical walking routes to reach the transit station. These barriers can either increase walking distance and time to reach the nearby metro station or impede walkability in and around metro station areas.

2.1 Pedestrian Accessibility Evaluation

In the past, several studies have been done to measure accessibility from various perspectives including access to employment opportunities, those with disabilities, access to core city areas, access to leisure places, and gender preferences and differences in to access various public travel modes (Lei and Church, 2010). Public and cultural amenities are believed to allure pedestrians to walk in a visually interesting environment but fail to evaluate the pedestrian accessibility around transport stations (Ha et al., 2011). Urban researchers have not investigated any studies to evaluate equal accessibility to effectively and smoothly use public transit services by easily accessing transit stations. In the past studies done to promote walkability across public spaces linked with urban design, planners and urban designers have only considered physical characteristics such as the presence of urban furniture, availability of green infrastructure and access to major arterial roads (Maarseveen, et al., 2019). However, all these aspects are related to the neighborhood's attractiveness and its connectivity with surrounding areas. The gap we have identified is to link equality and urban mobility, still being overlooked by transport planners and urban designers.

2.2 ODK and OSM

Open Data Kit (ODK) is a free-of-cost open-source software that could be easily installed in the android-based smartphone, most commonly available nowadays across both, developed and developing countries. As the ODK tool is android based app, it offers smooth and cost-effective data collection in developing countries to ground-up spatial and nonspatial data collection (Bokonda et al., 2019). Moreover, it allows collecting data available in different modes such as pictures, videos, barcodes, audio, integer and simple text with a clear logic flow (Esraz-Ul-Zannat and Haque, 2014). ODK facilitates simple and efficient digital data collection initially on smartphones and thereafter to the cloud servers. It offers out-of-the-box innovative solutions for the user to 1. Design a data collection questionnaire survey using QGIS 3.22.3 or Kobo Toolbox; thereafter 2. Easily collect survey data on the mobile device and send it to the server instantly and 3. Visualize in graphs and analyses the collected data on the ODK aggregate server and later, transfer it into desired formats. In India, very few studies have used ODK-based smart android apps to conduct metro station surveys to gather real-time information about pedestrian behavior, preferred travel modes and challenges faced to reach the nearest metro station. A study using ODK suite and its android based mobile app to conduct administered surveys at 12 metro stations across Bengaluru city (CSTEP, 2018). Recently, there has been a tremendous development in to use of GIS databases and allied applications, particularly OpenStreetMap (OSM) free of cost. These databases contain a lot of segregated information related to land use and transportation in the vector form of points, line strings, and multi-polygons (Ha, et al., 2011). Different information can be collected and marked in a separate layer for analysis purposes such as roads and intersection densities, building footprint, open versus built-up areas, road hierarchy, and population characteristics.

2.3 Isochrones

The urban planners usually generate isochrones-based GIS maps as a solution to understand specific trips made in a particular direction from a central transport node (Lei and Church, 2010). The isochrone map prepared in GIS allow urban planners and researchers to report public transport station like transit station accessibility w.r.t travel time, travel mode, and travel range (Sun and Lin, 2015). However, there are many disadvantages of relying on the isochrone map as they only consider the underlying road network to calculate travel time and distance. However, not all roads and streets are accessible by all, which arises the need to re-evaluate isochrone-based maps on-site using GPS devices like Garmin handheld GPS and ODK-based smart apps. Apart from travel cost, time and socio-economic characteristics, the ability to reach transit stations is directly linked to the direct routes connecting with them (Lei and Church, 2010). The location of the transit user and time of day also significantly contributes to improving transit ridership at any metro station.

3. METHODOLOGY

To measure actual on-ground pedestrian connectivity along the road networks used by most transit riders across the study area, we have used the Space Syntax model, which has been used in the past in many studies (Ha, et al., 2011). There was felt a need to have Intelligibility to apprehend the actual route connectivity of the transit riders along with the pedestrian networks instead of simply relying on the shortest routes shown by Google maps. With this regard, the Space Syntax model is capable to evaluate the pedestrian path network by quantifying the levels of recognition based on assigning its topology to the existing road categories. The prime function of accessibility is to link people with activities through linkages (Lei and Church, 2010). In this study, the travel modes particularly considered are on foot, non-motorized (cycle and rickshaw), shared e-rickshaw, bus service, and dropped off by two-wheeler and four-wheeler. Figure 1 illustrates the design process devised to carry out this study.

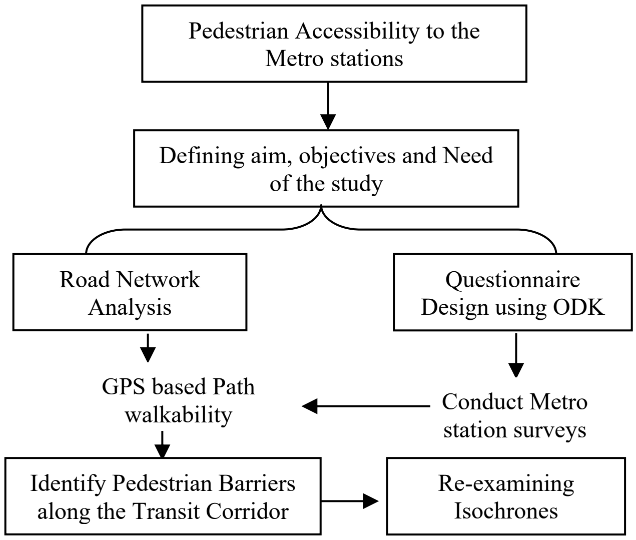

Figure 1. Research Design.

4. DATA COLLECTION AND ANALYSIS

4.1 Primary Data and Questionnaire Design

A stratified random sampling technique was adopted to calculate the sample size of 12 existing elevated metro stations in Noida. A total of 515 samples were collected across the entry/exit gates of 12 existing elevated metro stations in Noida on the Blue transit line of DMRC. Some stations like the Golf course and stations following Noida city center operational since the year 2019 have low ridership about 4000 persons per day. For these stations, the sample size was kept less than other stations with comparatively much higher daily transit ridership. While conducting metro station surveys, it was realized that females are not much open to participating in the survey, and thereby, the survey ratio of male to female was felt very challenging to be kept equal. Noida city area has earlier remained backward before its inception and is an amalgamation of earlier settled villages brought together into one urban area. Another issue identified while conducting surveys was that only low-resolution photos could be uploaded instantly to the ODK aggregate server. So, a separate android application called 'Lower' was installed on our smartphone to capture extremely low-resolution photos of the respondents. The QRealTime plugin by Shiva Reddy was used to upload the questionnaire prepared in QGIS to the identified ODK aggregate server. Most respondents were comfortable getting their photos clicked after knowing the purpose of our study. However, few people both, men and women were not comfortable, especially those living in urban villages. Out of 515 samples collected, only one respondent was found to be physically challenged and opted to use metro services. The transgender hesitates to use metro services at all although they could be easily seen using e-rickshaws for short to medium trip distances. This is probably because there are only male and female security check entry points inside metro stations in our study area. Figure 2 below shows the ODK aggregate server screen with survey results and clicked low-resolution photos of the respondents.

Figure 2. ODK Aggregate Server project screen showing data collected from the respondents.

Table 1 describes the frequency distribution of age and gender sample size interviewed at each selected metro station in Noida city.

Metro Station	Age			Gender	
	<18	18-59	>59	Female	Male
Noida Sector 15	0	55	0	07	48
Noida Sector 16	0	55	0	07	48
Noida Sector 18	2	45	3	14	36
Botanical Garden	3	53	0	17	39
Golf Course	1	58	1	13	47
Noida City Centre	1	46	1	17	31
Noida Sector 34	2	27	0	08	21
Noida Sector 52	0	30	0	07	23
Noida Sector 61	0	33	0	08	25
Noida Sector 59	0	30	0	05	25
Noida Sector 62	0	35	0	11	24
Noida Electronic City	0	29	0	02	27

Table 1. Frequency Distribution of identified Metro station samples.

Following this step, the existing land use encircling individual metro stations within a radius of 800 meters was demarcated from Noida Master Plan (NMP) 2031. Based on static master plan land-use distribution, the stations were categorized as residential, mixed-use, and transport hubs. For the study purpose, the presence of either commercial, institutional or industrial land use makes the station mixed-use while the presence of interchange options to other metro lines or multiple travel modes like city bus service, feeder buses with parking facilities were categorized as transport hubs (shown in Table 2). The ample parking facility near the metro station area is available at Noida Sector 15 metro station, Botanical Garden and Noida City center. It was taken care to have an almost equal temporal distribution of transit rider samples entering the metro station and leaving. The primary surveys were done for two weeks starting from 13th November until 25th November 2021 with prior permission from DMRC. On Sunday, considered a non-working day, few surveys were done as people travel on this weekend day with their families for leisure and social interaction purposes.

Metro Station	Land-use Typology
Noida Sector 15	Mixed-use
Noida Sector 16	Mixed-use
Noida Sector 18	Mixed-use
Botanical Garden	Transport hub
Golf Course	Residential
Noida City Centre	Mixed-use
Noida Sector 34	Residential
Noida Sector 52	Transport hub
Noida Sector 61	Residential
Noida Sector 59	Mixed-use
Noida Sector 62	Mixed-use
Noida Electronic City	Mixed-use

Table 2. Metro Stations Land-use Typology

A self-administered questionnaire was used to conduct metro station surveys using ODK mobile app at identified 12 metro stations in Noida starting from Noida Sector 15 until the last Noida Electronic city (NEC) station. The questionnaire contained 31 items which included various aspects including the usual purpose of metro trips made, employment status, availability of a driving license, household size, current city living in, number of cars available in the household, car availability during the transit trip made, building topology of the transit user, and number of floors. Most importantly, the preferred travel mode to reach the nearest metro station, frequency of trips made in a week, metro travel pattern changed in the past six months, particularly due to COVID-19 restrictions, and the reason to opt for transit services. Other allied questions were distance and time to reach the metro station using different travel modes. Finally, taking advantage of the ODK and Kobo Toolbox smart apps, a low-resolution photo of the interviewee was taken and voice recording was done in some cases of frequent transit riders facing issues due to increased walkable route length and other pedestrian challenges faced like poor pavement condition, lack of intersections and crossings, etc. The ODK aggregate server link is http://119.82.76.229:8080/ODKAggregate/.

As shown in Table 3, about half of the total samples surveyed prefer to walk to the nearest metro station. Nearly 87% of the transit users who live or work within a 1-kilometer distance walk to the nearest available metro station. So, it becomes visible from the metro station surveys done that Noida city has a good inclination of people who prefer to walk to assess nearby metro station. Further, most of its underlying existing road and street layout pattern embraces walkability. However, there is a strong need to identify pedestrian barriers related to urban planning that increase actual pedestrian distance than the perceived pedestrian desire line.

	Distance of your home/workplace to the nearest Metro station (in Km)				Total
	<1	1-1.5	1.5-2	>2	
Walk	167	40	21	18	246
Other Motorized travel mode	25	14	32	198	269
Total	192	54	53	216	515

Table 3. Frequency distribution of Trip Distances for different travel modes to access the metro station.

Table 4 describes the frequency distribution of time taken by transit respondents who walk to the metro station and those who use motorized travel modes like e-rickshaw, dropped off by private vehicle, or use bus service. It takes less than 10 minutes to cover a maximum of one-kilometer walking distance to reach the nearest metro station.

	Time of trip by different travel modes to reach nearest Metro station (in minutes)				Total
	<10	10-15	15-20	>20	
Walk	164	47	20	15	246
Other Motorized travel modes	50	61	67	91	269
Total	214	108	87	106	515

Table 4. Frequency distribution of Trip time for different travel modes to access the metro station.

From the Pearson Chi-squared test shown in Table 5, it was found that the distance to the metro station (D_m) and time consumed by different travel modes including walking (T_m) as two independent variables have a strong association with walking as a dependent variable as their P-value is less than 0.05.

Chi-square test			
	χ2	df	P
D_m	269.332	3	0.001
T_m	141.681	3	0.001

Where χ2 is Chi-Square, df – Degree of freedom, P – significance value

Table 5. Chi-square test of Trip Distance and Time.

From the Pearson's chi-squared test shown in Table 6, it was found that age, gender, and purpose of the trip had no association with walking to the metro stations across the study area.

Chi-square test			
	χ2	df	P
Gender	1.305	1	0.253
Age	2.136	2	0.344
Purpose of Trip	0.372	1	0.542

Where χ2 is Chi-Square, df – Degree of freedom, P – significance value

Table 6. Chi-square test of Age, Gender, and Trip purpose.

4.2 Data Analysis

The survey results were downloaded for the ODK aggregate server and converted to an excel sheet from CSV file format for its data analysis. In QGIS 3.22.3, a buffer distance of 800 meters in both directions was marked along the blue line transit corridor with its 12 metro stations in Noida. Initially, typically common walkable pedestrian routes terminating at individual metro stations were identified with their trip origin location in the nearby sector. Based on the farthest location found in all the directions encircling the metro station, walkable sheds were developed for all the 12 metro stations in Noida. However, as the stations are quite close between 1 to 2 kilometers, the walkable sheds overlap for some consecutive metro stations. The buffer as an analysis tool was used to create a buffer of 800 meters as a walkable distance on both sides of the study transit corridor. Within the buffer, the physical barriers that impede walkability or increase the walking distance to reach metro stations than the actual walking route were marked. The barriers that came out from the study were both, planned areas like gated communities, private townships, and unplanned settlements, particularly urban villages. All such barriers were marked in QGIS for their on-ground verification at the site.

4.3 Measuring Walkability

Following the identification of barriers to walkability, a visual survey was performed using a smartphone and the routes covered while doing the reconnaissance survey were traced back through Garmin Etrex 10 GPS device shown in Figure 3. The routes traveled on foot or partially on e-rickshaw were imported as GPX files from Garmin devices and opened in Google My Maps. Thereafter, all the site clicked photos that depict the inaccessibility of pedestrians or e-rickshaws through some areas were shown as blow-out pictures on the tracked GPS routes (shown in Figure 3). Finally, the actual boundary of impermeability of these areas was demarcated again in QGIS. Following this, the underlying road and street-layout pattern which influences mobility within a sector were categorized into road typologies to meet this study's demands. The roads and streets were categorized as public roads – accessible by all, private streets – accessible by only a few residents within the area and unsuitable roads and streets as those falling within unplanned urban villages, not fit to access for public mobility.

The OSM files were downloaded for the study area, which already has classified road typology as primary, secondary, tertiary and other roads/street levels. Using this classification, a reclassification of roads and streets was done as public, private and non-suitable roads. Finally, the point places or roads in the form of multi-lines were marked within the demarcated areas identified as non-accessible urban areas along the blue line transit corridor. Finally, the new actual walkable routes identified terminating at metro stations were compared with Google map routes to apprehend the difference in walkable lengths as conceived by all. Thereafter, Isochrones in the form of 500- and 800-meters walksheds were developed around the individual metro station. The walkshed size in each direction from the metro station was determined based on the farthest distance as determined from the metro station surveys based on accessibility instead of simply relying on the underlying road pattern and static land-use proposed in the master plan. Further, this step justifies the novelty of the study as Isochrones are made considering the availability of road and street networks and the number of road intersections. However, in reality, not all roads and streets are readily free to use by everyone so there was felt a need to re-evaluate the process of formulating Isochrones.

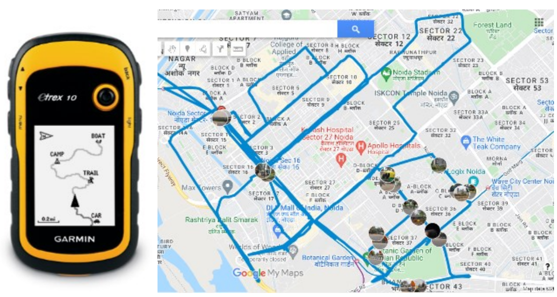

Figure 3. Garmin Etrex 10 GPS device and Tracked GPS routes and clicked photos of the Pedestrian barriers.

5. RESULT AND CONCLUSION

5.1 Result

The Impedance Pedestrian Catchment Areas (IPCAs), called ‘Ped-sheds’ can be easily covered by the pedestrian within a specified distance or time from a transport station. The term “impedance” is applied to remove all the high-speed primary and arterial roads (Schlossberg and Brown, 2004; Singh et al., 2017). So, following the removal of all high-speed roads, the IPCA denotes the recalculated PCA. The IPCA solely represents the area where a pedestrian is likely to travel along with the existing road network in both directions. The value of the IPCA indicator range from 0 to 1 and is based on the ratio of individual IPCA area in sq. km to the whole 800 meters walkable area of analysis encircling the metro station i.e. 2.9 sq. km. The theoretical walkable zones were mapped in QGIS to show the actual road network and area falling within 800 meters (about 13 minutes walk) from a transit station.

Table 7 shows the area difference between the perceived IPCA and the actual IPCA value after deducing areas both planned such as gated communities, superblocks and unplanned settlements like urban villages where the existing road/street network is not accessible by all or safe to use.

Metro Station	Isochrone Area (sq.km)	Perceived IPCA value	Actual Isochrone Area (sq.km)	Actual IPCA value
Noida Sector 15	1.34	0.46	1.34	0.46
Noida Sector 16	1.23	0.42	1.08	0.37
Noida Sector 18	1.02	0.35	0.75	0.26
Botanical Garden	0.65	0.22	0.53	0.18
Golf Course	1.10	0.38	0.78	0.27
Noida City Centre	1.27	0.44	0.83	0.29
Noida Sector 34	1.25	0.43	0.91	0.31
Noida Sector 52	1.31	0.45	1.11	0.38
Noida Sector 61	1.19	0.41	1.19	0.41
Noida Sector 59	1.32	0.46	0.84	0.29
Noida Sector 62	1.31	0.45	1.01	0.35
Noida Electronic City	1.08	0.37	1.08	0.37

Table 7. Perceived and Actual IPCA value.

As shown in Figure 4, it becomes clear that most isochrones or ped-sheds across the study area have some pedestrian-related barriers that increase the walking distance to reach the nearby metro station. Only three metro stations namely Noida Sector 15, Noida Sector 61 and NEC have their ped-sheds with road networks accessible by all irrespective of their social status, age and gender.

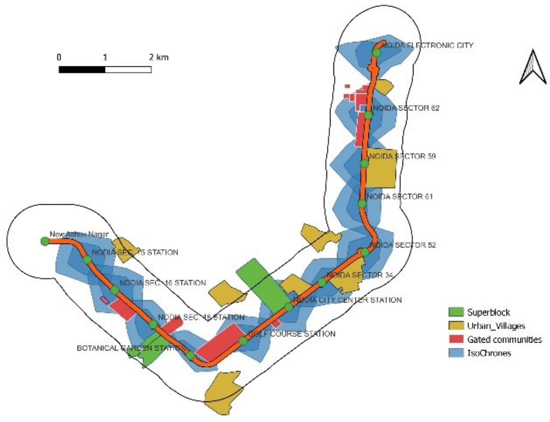

Figure 4. Garmin Etrex 10 GPS device and Tracked GPS routes and clicked photos of the Pedestrian barriers.

5.2 Conclusion

In our study area of Noida city, the pedestrian barriers such as gated communities, superblocks and unplanned settlements like urban villages act as urban fragments. They have different road-layout patterns and peculiar urban morphological characteristics that increase short trip lengths than the actual shortest route to reach the nearest metro station. However, a maximum number of the respondents who lived within a walkable distance of 1-kilometer walked to the nearest metro stations in Noida. So, the city has a high inclination toward Transit-Oriented based Development (TOD) which emphasizes walkability and compact mixed-use development with comparatively high population and job densities close to the metro stations.

REFERENCES

Bajaj, G., Singh, P., 2019: Understanding Preferences of Delhi Metro Users Using Choice-Based Conjoint Analysis. *IEEE Transactions on Intelligent Transportation Systems*, 1-10. doi.org/10.1109/TITS.2019.2958259.

Bhatt, D., Minal, 2022: GIS and Gravity Model Based Accessibility Measure for Delhi Metro. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, doi.org/10.1007/s40996-021-00795-5.

Bokonda, P. L., Ouazzani-Touhami, K., Souissi, N., 2019: Open Data Kit: Mobile Data Collection Framework For Developing Countries. *International Journal of Innovative Technology and Exploring Engineering,* 8(12), 4749-4754. doi.org/10.35940/ijitee.L3583.1081219.

CSTEP, 2018: *Integration of BMRCL and BMTC.* Center for Study of Science, Technology and Policy, Bengaluru.

Esraz-Ul-Zannat, M., Haque, M. M., 2014: Geospatial Data Collection Using Smartphone: ODK As An Open Source Solution. *Bangladesh Journal of Geoinformatics*, 67-72.

Ha, E., Joo, Y., Jun, C., 2011: An empirical study on sustainable walkability indices for transit-oriented development by using the analytic network process approach. *International Journal of Urban Sciences*, 15(2), 137-146. doi.org/10.1080/12265934.2011.615977.

Kumar, P. P., Parida, M., Swami, M., 2013: Performance Evaluation of Multimodal Transportation Systems. *Procedia - Social and Behavioral Sciences*, 104, 795 – 804. doi.org/10.1016/j.sbspro.2013.11.174.

Lei, T. L., Church, R. L., 2010: Mapping transit-based access: integrating GIS, routes and schedules. *International Journal of Geographical Information Science*, 24(2), 283-304. doi.org/10.1080/13658810902835404.

Maarseveen, M. V., Martinez, J., Flacke, J., 2019: *GIS in Sustainable Urban Planning and Management: A Global Perspective*. Taylor & Francis Group, LLC, Florida.

Rossetti, S., Tiboni, M., Vetturi, D., Zazzi, M., & Caselli, B., 2020: Measuring Pedestrian Accessibility to Public Transport in Urban Areas: a GIS-based Discretisation Approach. *European Transport*, 76(2), 1-12.

Schlossberg, M. & Brown, N., 2004: Comparing Transit-Oriented Development Sites by Walkability Indicators. *Transportation Research Record: Journal of the Transportation Research Board*, 1887, 34–42.

Singh, Y. J., Lukman, A., Flacke, J., Zuidgeest, M., Maarseveen, M. V., 2017: Measuring TOD around transit nodes - Towards TOD policy. *Transport Policy*, 56, 96–111. doi.org/10.1016/j.tranpol.2017.03.013

Sun, Y., Lin, H. F., 2015: GIS-Based Analysis of Public Transit Accessibility: Definition and Display. Beijing, China, *CICTP 2015*. doi.org/10.1061/9780784479292.112.

Yang, X. et al., 2019: Recognizing the Critical Stations in Urban Rail Networks: An Analysis Method Based on the Smart-Card Data. *IEEE Intelligent Transportation Systems Magazine*. 2-8. doi.org/10.1109/MITS.2018.2884492.