EVALUATION OF TODNESS OF STATION AREA FOR MRTS

A DISSERTATION

submitted in the partial fulfillment of the

requirements for the award of degree

of

MASTER OF TECHNOLOGY

in

CIVIL ENGINEERING

(With specialization in Transportation Engineering)

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JUNE, 2019

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation report entitled, **"EVALUATION OF TODNESS OF STATION AREA FOR MRTS",** is being submitted in partial fulfillment of the requirements for the award of the degree of "**Master of Technology**" in Civil Engineering with specialization in Transportation Engineering submitted to the Department of Civil Engineering, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out for a period of one year from June 2018 to June 2019 under the supervision of **Dr. Manoranjan parida,** Professor, Department of Civil Engineering, IIT Roorkee.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

In spite of Delhi's recent investments in Public Transport Systems which include a world class Metro System and a planned BRT Network, Delhi has been unable to deliver efficient, comfortable and affordable mobility options to its citizens. Public transport have lost its priority in options for travel due to lack of connectivity as well as a lack of safety for pedestrians. Thereby resulting in the shift of people from public transport to private vehicle in the city. Due to this inclination of people towards public transport, environmental problem (like air pollution) has been increased to an alarming situation In this situation of concern, it is important to take a step forward to motivate people to go for public transportation by providing them affordable, congenial, non- motorized transport, pleasant walking experiences and very easily approachable and reliable public transportation, convenient and comfortable access and egress.

Our city needs to redesign and reorganize in order to deal with all the problems. This can be achieve through Transit Oriented Development (TOD)

Transit Oriented Development is basically any development around a transit station, which is planned and designed in such a way that encourages people to use public transport rather than using their own personal. Also by motivating people to walk, TOD creates a walker – friendly environment around a transit station. A TOD index is calculated that quantifies and estimates TODness is useful as it enables to make accurate classification of distinct regions so as to define those areas that needs to be taken care first.

Since TOD comprises of transit, development and orientation characteristics, therefore three more indices i.e. transit index, development index and orientation index are also calculated which would help to target specific area which needs an improvement in specific dimension of TOD.

14 Metro station are selected based on metro ridership data, land use data and population data.

Various indicators were selected from international and local literature, weights to the indicators were given by using Analytical hierarchy process, Transit index, development index and orientation index were calculated using weighted sum method. Finally TOD index value is calculated by weighted sum of all three indices.

Results shows that Seelampur has Maximum value of transit index and is equal to (0.62), Rohini west has maximum Value of development index (0.694), Lajpat Nagar has maximum value of Orientation index (0.745) while Janpura has minimum Transit index (0.077) and orientation index(0.252) and kashmere gate has minimum value of development index(0.31).

The results help in drawing TOD policy for the area by identifying which station areas need more attention than other and identifying particular TOD features that need to be improved for each station at the same time.

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1.1 General

Delhi recently invested in Metro System and a BRT Network, but after all this effort efficient, comfortable and affordable travel option are not up to the mark. Public transport have lost its priority in options for travel due to lack of connectivity as well as a lack of safety for pedestrians. Thereby resulting in the shift of people from public transport to private vehicle in the city. Due to this inclination of people towards public transport, environmental problem (like air pollution) has been increased to an alarming situation. Due to large no. of private vehicle on road, there is more congestion on road resulting in the decrease in the average speed in peak hours, although to avoid this problems various measures were taken like construction of grade separated intersection but still there is no change in the congestion, in spite of reducing the problem they have caused the opposite effect by making it difficult for pedestrians to use the public transport.

In this situation of concern, it is important to take a step forward to motivate people to go for public transportation by providing them affordable, congenial, non- motorized transport, pleasant walking experiences and very easily approachable and reliable public transportation, convenient and comfortable access and egress.

Our city needs to redesign and reorganize in order to deal with all the problems. This can be achieve through Transit Oriented Development (TOD).

1.2 TOD policy in Delhi

Transit Oriented Development is essentially any development, macro or micro that is focused around a transit station, and provides easy accessibility to the transit facility thereby encouraging people to walk and use public transportation over private modes of transport. (UTTIPEC, 2012)

The Primary Goals of TOD are to:

- Reduce/ discourage private vehicle dependency and induce public transport use – through design, policy measures & enforcement.
- Provide easy public transport access to the maximum number of people within walking distance – through densification and enhanced connectivity.

TOD policy and development control norms:

Each TOD must have the following components:

1. User Friendly Environment – Creating a pedestrian friendly environment by developing a secure, easily accessible and enjoyable street networks by providing different amenities on the street.

2. Connectivity: Create compact networks of streets in such a way that it provides a multi directional options for all the modes thereby reducing the concentration of vehicle on a particular intersection or path.

3. Multi-modal Interchange: Mass transportation modes should be well integrated in such a way that maximum number of people can transfer from one mode to another in a minimum time, also the transfer should comfortable and convenient at the multi modal hub. Design and management of the multi modal hub should be done by giving priority to the pedestrians and public transport mode over the private vehicle

4. Modal Shift Measures: Shift to Sustainable Modes by Using Design, Technology, Road Use Regulation, Mixed-Use, Parking Policy and Fiscal Measures

5. Parking: To facilitate park and ride facilities

6. High Density, Mixed-Income Development: By developing a compact and diversified land use activities which attracts people towards it thereby increasing the transit ridership.

1.3 Definition of TOD

Numerous studies have given various definition of transit oriented development, some of the definition from international and local literature are listed below in table no. 1.1

Table 1.1: Definitions of Transit-Oriented Development (TOD) according to authors

Authors	Definition
Calthorpe (1993)	"Mixed use network inside a normal 600 m walking distance of a travel stop and a center business zone that blends private, retail, office, open

	space, and open uses in a walkable domain, making it helpful for occupants and travelers to go by bicycle, foot or vehicle."
Bernick and Cervero (1997)	"A compact, mix use network, oriented on a travel station that, by design, encourage people to drive their vehicles less and ride mass travel more."
Still (2002)	"A mixed-use development that motivates people to live around transit node and to decrease their relying on personal mode of travel"
Cervero et al. (2004)	"TOD is a tool for promoting smart growth, leveraging economic development, and catering for shifting housing market demands and lifestyle preferences."
Schlossberg and Brown, 2004	"It is a planning approach that means to incorporate land use and transport planning"
UTTIPEC, 2012	"Transit Oriented Development is essentially any development, macro or micro that is focused around a transit station, and provides easy accessibility to the transit facility thereby encouraging people to walk and use public transportation over private modes of transport."
Ministry of urban development (MOUD , 2016)	"TOD is one of the key planning tools to have recently gained momentum in urban development practice around the world. TOD involves creating concentrated nodes of moderate-to-high density developments supporting a balanced mix of land uses around transit stations."
World resource institute (WRI,2018)	"Transit-oriented development (TOD) is a sustainable urban development solution that has been successful in creating mixed-use, dense, walkable communities with access to high-quality transport."

It can be inferred from the above definition that Transit Oriented Development is basically any development around a transit station, which is planned and designed in such a way that encourages people to use public transport rather than using their own personal. Also by motivating people to walk, TOD creates a walker – friendly environment around a transit station.

1.4 Synergy between Transit and Development

Generally, TOD Comprises of the two basic components i.e. Transit and Development and their interrelation have already been discussed in Node-place model (Bertolini, 1999)

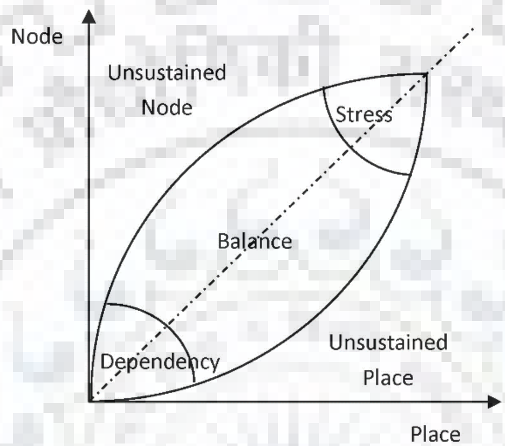


Fig.1.1 Node-place model

But this model does not explains the interrelationship between the transit and urban conditions (G.lyu et al ,2016). For instance, despite of having a very good transport facilities and dense urban development, the serviceable interdependence is not strong enough due to lack of inclination users towards the station. Likewise, the structural interdependence could be weak due to in appropriate design of the street network. This kind of development is called as a 'Transit Adjacent Development' (TAD), where transit and development characteristics are consistent, but they are not serviceably and structurally interrelated (Renne, 2009), Therefore, third component which shows the degree of orientation of developed area toward the transit station is established and termed as orientation index(Lyu et al , 2017). so to determine the quantitave value of TOD , it is bee segregated into three different indices naming transit index , development index and Orientation index and all these indices are defined as follow

Transit index – transit index is a quantitative value which explains the transit service characteristics present at an area.

Development index – this quantitative value explains the development characteristics of an area around a transit station

Orientation index – to understand and measure the synergy between the transit station and the development around it, orientation index value is used.

1.5 Need of the study

A well planned and well-designed TOD area can help in achieving an optimum solution to all problems related to environment and traffic congestions. In order to avail those benefits from TOD planning, it is important to mark the problem area and also the reason behind the problem. Therefore, a TOD index that quantifies and estimates TODness is useful as it enables to make accurate classification of distinct regions so as to define those areas that needs to be taken care first.

Since TOD comprises of transit, development and orientation characteristics, therefore three more indices i.e. transit index, development index and orientation index are also calculated which would help to target specific area which needs an improvement in specific dimension of TOD.

1.6 Objectives of the Dissertation

The objectives are:

- To calculate a quantitative value of transit component of TOD (Transit index)
- To calculate a quantitative value of development component of TOD (development index)
- To quantify the interrelation between Transit and urban development by using orientation index.
- To determine the weights of different TOD indicators by using Analytical hierarchy process (AHP)
- To calculate the TOD Index at station level

1.7 Organization of Report

This report is organized in to 5 chapters. The first chapter giver general introduction and includes problem definition and objective of the study. The second chapter covers the literature review which gives the idea of previously done studies and their various approaches. The third chapter includes the methodology and the data collection procedure. Chapter four shows the results and discussion. Chapter five includes the conclusion and recommendations.

2.1 General

This chapter reviews the various studies regarding the topics Transit-oriented Development, measurement of Transit-oriented development, Analytic hierarchy process. This provide a background for the research problem.

2.2 Transit-oriented Development

There are various definition of TOD which explains the concept of new urban development. New urbanist theory suggests that dense, mixed-use communities are the solution to the suburban problem. Several authors gave their own explanation regarding TOD. One of the original and most popular definitions of the transit-oriented concept came from Peter Calthorpe, According to Calthorpe (Calthorpe 1993) TODs are hybrid use network inside a 600 m walking distance of a travel stop and a center business zone that contain private, retail, office, open space, and open uses in a walkable domain, making it helpful for occupants and travelers to go by bicycle, foot or vehicle. TOD contains a diverse business, private, and institutional improvements worked to help a transportation center point and to energize non-motorized vehicle travel choices, for example, cycling and walking, inside the Transit-Oriented Development

Despite the fact that the essential reasoning of TOD is same in all specific situations, studies show enormous contrasts in the uses of TOD standards as shown in table below

Table 2.1: Application of TOD principles in different region

Region	TOD principles	Literature source
North America and Australia	The attention appears to be generally on re-basing rural spread on travel stops and systems	"Cervero(1998), Cervero(2004), Dittmar and Ohland(2004), Hemsley(2009)"
Europe	It seems rather on the improvement by restoring and renewing existing station areas	"Bertolini and Spit(1998)"

Asia	TOD is by all accounts seen most importantly as a procedure of directing large city development in mass fast travel corridors	“Zhang and Liu (2007)”
South America	It appears to be all the more frequently considered as a method for re-interfacing and re-centering around transit already dense urban development	“Lindau et al(2010)”

2.3 Measurement of TOD-ness

Numerous examinations have executed the TOD idea for nearby spaces around open transportation Station However, there are just a couple of studies that emphasis on the assessment of TOD dimensions by means of the TOD index. Renne and Wells (2005) and Evans and Pratt (2007) examined the significance of utilizing a index in TOD examinations. For sure, for them, this quantitative value TOD has the ability to measure TOD dimensions in an area, and they think that these TOD dimensions can help researchers to design well organized development.

The vast majority of researchers have stressed on different side of TOD, Bernick and Cervero (1996) for the most part centered on the evaluation of the built up condition and featured the concept of three D's (Density, Diversity and Design) in the achievement of TOD. Later Ewing and Cervero (2010) included Destination availability, Distance to travel, Managing Demand and Demographics.

Loo et al. (2010) analyzed the connection between certain factors about transportation, built up condition, and designing towards travel ridership for TOD zone in Hongkong and New York Cities. The examination plans to inspect the components that impact travel ridership and to evaluate their relationship. The point of utilizing the two urban communities as contextual analyses is to analyze the normal elements affecting transit ridership in the expectation of creating helpful strategy to advance TOD. The factors are gathered under four measurements which are land use, station attributes, financial and statistical qualities, and multi-modal rivalry. The factors utilized by Loo et al. (2010) are comparative with the parameters found before for example all out business/private floor area, absolute business floor area, hybrid land use, population size and work, and number of transport stops inside the station buffer (walkability)

Schlossberg et al. (2003) thought about the TOD dimension of transit station in Portland dependent on the walkability parameters utilizing GIS based walkability measures. The outcome is the position of eleven TOD zones around travel hubs in Portland. Schlossberg et al. (2003) contended that a mix of a visual spatially-based examination with the evaluation of walkable urban structure can give researchers and planners valuable data about the presentation of existing or potential TOD regions.

Institute for Transportation and Development Policy (2014) evaluated TOD utilizing TOD standard scoring framework. The focal point of their work was to score a new development in terms of its orientation towards the transit station just in the case that it is inside walking distance to the closest transit station. They evaluate the areas dedicated to walking and cycling , land use diversity, denseness, minimization of areas and land involved by motorized vehicles and these criteria were secured under seven standards of Walk, Cycle, Connect, Mix, Densify, Compact and Shift. Their methodology for estimating TOD was intuitive and contained just urban development attributes.

Aston et al. (2016) expected to evaluate and think about the degree of transit orientation of area for four distinctive open transport (tram ,train , neighborhood transport, smart transport modes and 'no travel' catchments , TOD scores were given to area of specific mode.

The TOD score was calculated from three variables, population density (density), land use entropy (diversity); and walkability (design),

$$\text{TOD score} = (P/50) + (Q_{lue}) + (W/100) \quad (2.1)$$

Where,

(P – no. of person in buffer area (p/ha) , Q_{lue} – Land use mixness , W- Walkibilty)

Every indicator was adjusted to contribute roughly 33% of the last score. Eq. (2.1) delineates the division factor related with every factor. Of course, mixed-ness of land use was scored out of 1 and required no alteration. Walk score required division by 100 to have a score out of 1. The division factor for density, the main un-topped variable, was resolved to be 50. 90% of buffer area recorded densities lower than 50 p/ha and all things considered this implied most of density scores would be less than one, without altogether decreasing the weighting contrasted with the other two part scores.

Results: Trams, trains and neighborhood transports demonstrate a positive relationship to the TOD score of their development catchments contrasted with 'no travel' catchments. Smart Busses demonstrate a negative connection. Tram catchments accomplish the most astounding TOD scores over a huge number of factors, including the general TOD score and the part scores of density and walkability.

Table 2.2 (TOD score for tram, train, local bus, smart bus modes and 'no transit' catchments Aston et al. (2016))

	TOD score
Tram	2.13
Train	1.74
Local bus	1.49
Smart bus	1.34
No transit	1.32

Singh et al. (2017) proposed a structure system to evaluate the TOD dimension utilizing spatial multi criteria investigation and GIS. A Multiple Criteria Analysis (MCA) is embraced to ascertain the TOD Index for each station zone of city locale Arnhem Nijmegen. MCA is an exceptional strategy that takes into consideration an extensive appraisal of numerous criteria with various units of estimation. When managing spatial indicators GIS-based MCA (Malczewski, 1999) (otherwise called 'Spatial MCA' or 'SMCA') can be utilized to evaluate various spatial parameters (Beukes et al., 2011).Weights of various parameters were determined by using rank sum strategy.

Table 2.3 criteria and Indicators (*Singh et al. (2017)*)

Criteria	Indicators
Density	• Population density • Commercial density

Land use diversity	• Land use Diversity
Walkability and Cyclability	• Complete length of walkable/cyclable ways • Intersection density • Impedance Pedestrian catchment area (IPCA)
Financial development	• Density of business foundations
Limit Utilization of travel	• Rider traffic at peak hours and off-peak hours
Transit Characteristics	• Frequency of travel mode • Interchange to various routes of same travel mode • Transfer to other travel modes
Parking capacity	• Parking capacity for motorized and non motorized vehicle

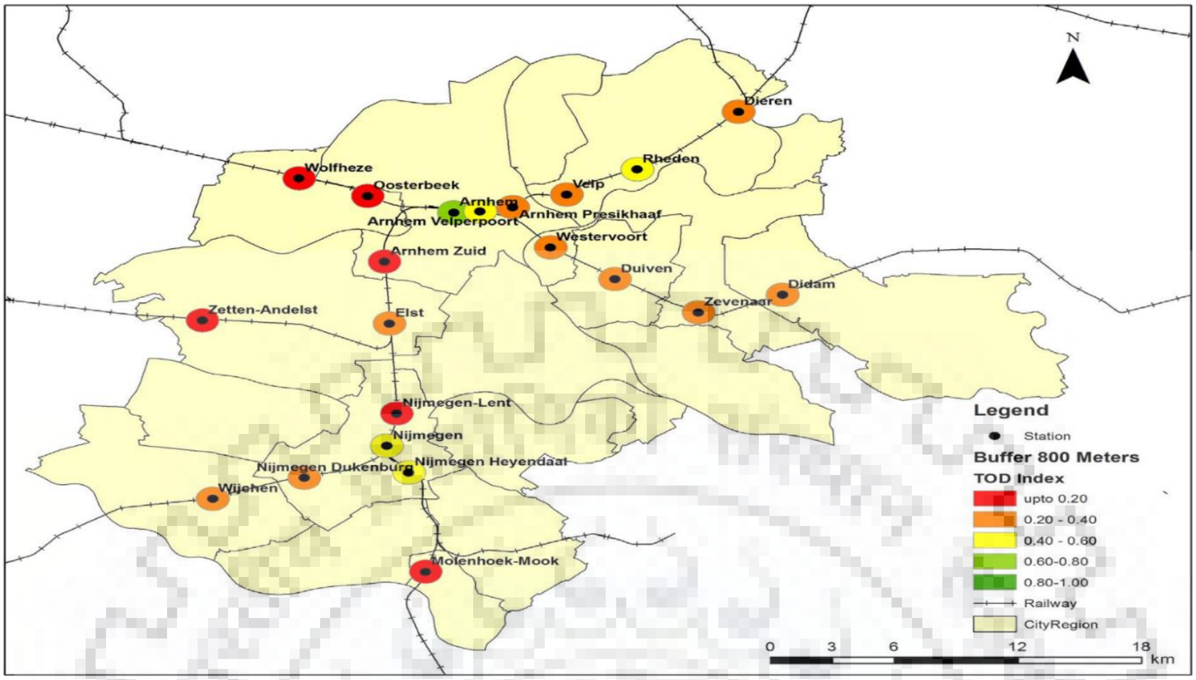


Fig. 2.1. : TOD Index for all 21 stations in the City Region of Arnhem and Nijmegen. (Singh et al. (2017))

Results: The TOD Index results for all 21 stations in the City Region with highest value of 0.77 for Arnhem and lowest TOD index value of 0.16 for Wolfheze are shown in Fig. 1.

Motieyan and Mesgari (2017) propose a multi-criteria decision making (MCDM) technique in four phases as a method for building up a spatial index. Criteria and index of the Transit-Oriented Development index.

Table 2.4 Criteria and Indicators (Motieyan and Mesgari (2017))

Criteria	**Indicators**
Density	Residential density Job density Administrative density
Diversity	Land use mixedness Index

Design	Street network Accessibility Level of streets' design
Socio-economic development	Total no. of people Number of employed person Percentage of young people No. of member in family Educational level Level of facilities

Results: So as to get the TOD index, the standardized indicators are collected dependent on their three sorts of weights. Because of this conglomeration procedure, three maps are created dependent on the idealistic, skeptical, and moderate perspectives so as to render the example of TOD dimensions in the study area, these dimensions are arranged into five classes: very low, low, moderate, high, and very high.

2.4 Analytical hierarchy process

The Analytic Hierarchy Process (AHP), presented by Saaty (1980), is a successful instrument for managing complex choice making, and may help the researchers and planners to set needs and settle on the best choice. By lessening complex choices to a progression of pairwise correlations, and afterward arranging the outcomes, the AHP catches both abstract and target parts of a choice. What's more, the AHP joins a helpful system for checking the consistency of the decision maker's assessments, along these lines decreasing the inclination in the basic choice making process.

If there are two criteria's, then based on their relative importance scores are given as below.

Table 2.5: Table of relative scores (Saaty and Vargas 2014)

Value	Intensity of a related to b
1	Equal importance

3	Moderate Prevalence of one over another
5	Strong prevalence
7	Very strong Prevalence
9	Extreme high prevalence
2,4,6,8	Intermediate values

There are three fundamental standards in critical thinking of AHP as per Saaty (1990), to be specific: Decomposition, Comparative Judgment, and Logical Consistency.

Understanding the AHP methodology incorporates the accompanying stages:

- Selection of indicators
- Development of Relative preferences
- Consistency test (Reject (If Cr>10%))
- Calculation of weights

Formula used to determine consistency in AHP is given below

$$Cr = Ci/Ri$$

Where Cr is consistency proportion, Ci is consistency index, r_i is random index. While the consistency index (Ci) is determined utilizing the formula.

$$Ci = (\lambda \max - n)/(n - 1)$$

Where n is the criteria number and λ max is the most extreme estimation of eigenvector.

Following literature have used AHP for determining criteria's weight-

Wey et al.(2015) proposed a consolidated methodology containing the fuzzy AHP and the information envelopment investigation with probabilistic confirmation area. The proposed methodology is connected to a contextual investigation concerning the best site determination for new metro travel station in Taipei (Taiwan).

Six Experts (allot the cardinal scores to the nine smart development standards utilizing their very own abstract decisions are appeared table beneath

Nine smart growth principles: Mix Land Uses (C1) Infill Development of Existing Communities (C2) , Environmental Areas (C3),Compact Building (C4) , Variety of Housing Choices (C5) , Walkable Neighborhoods (C6) ,Variety of Transportation Choices (C7) ,Community-stakeholder partnership (C8) , Cost Effective Development (C9).

Table 2.6 AHP Results (Wey et al.(2015))

Principle	C1	C2	C3	C4	C5	C6	C7	C8	C9
Average weight	0.206	0.142	0.091	0.159	0.03	0.121	0.10	0.04	0.107

Sahu et al. (2017) purposed a strategy to alter land utilizes in a TOD situation through delicate processing. TOD attributes were considered and executed in target capacities. Worldwide TOD parameters (density, diversity, and distance to station) were chosen. Traits for TOD parameters were removed through expert opinion. The approach was connected to two areas of Naya Raipur. Issues in the current land utilizes were found through site visits.

Seven specialists gave their decisions. The gathering comprised of a specialist from the planning branch of Naya Raipur, a TOD master from Japan, two scholastics, two designers and a transportation engineer. The gathering had specialists from the scholastics just as expert fields. Result of AHP Shown in table below:

Table 2.7 AHP results (Sahu et al. ,2017)

Parameter	Average weight (%)	Indicators
Density	35.21	Person per kilometer square F.A.R/F.S.I
Diversity	20.22	Percentage of diversification
Distance to transit	44.44	Distance to station(m) Time taken by walk/cycle

Taki et al (2018) expected to prescript potential territories for spatial planning of green TOD utilizing a joined technique for Geographic Information System (GIS) and Analytical Hierarchy

Process (AHP) ways to deal with be actualized in Jakarta Metropolitan Region (JMR). Multi-criteria and weighting strategies were connected dependent on the apparent conclusion of the individual specialists and experts.

AHP essential information were finished by meeting 12 specialists for getting their feelings. While the auxiliary information on spatial were gathered from the foundations and organizations subsequently perception review in the field.

3.1 General

The theoretical background and past research studies on transit-oriented development have been discussed in previous chapters. Various methods and tools for determining TODness of a station area have also been discussed. This chapter begins with the explanation methodology. It also discusses the study area selected and data collection procedure adopted. The study area selected is Delhi and its physical characteristics are discussed. Data collection procedure with sub section like design of questionnaire survey, data collection technique and sample size collection are also discussed in this chapter.

3.2 Methodology

In order to find the TODness (TOD Index) of a station area, we initially collected 'Travel', 'orientation', and 'development 'indicators from the global TOD literature. Second, from local learning, literature reference, uniqueness, and open accessibility of information, we chose a lot of indicators .Third, we geographically delineated TOD areas and measured the selected indicators after selection of sites in study area. Fourth, measured indicators are normalized and using Analytical hierarchy process indicators are given weight. After this transit index, development index and oriented index are calculated using weighted sum method. Using these indices as a output, data envelopment analysis will be done to find out the most efficient metro station out of the selected stations.

3.3 Study area characteristics

Delhi, officially the National Capital Territory of Delhi or NCT, has been selected as a study area. The National Capital Territory (NCT) is situated at the center of the National Capital Region (NCR). It has a population of 16.75 million inside the NCR which has a population of 45.2 million (Registrar General of India 2011). NCT Delhi is exceptionally urbanized with 97.50 percent of its populace living in urban zones as against the national mean of 27.81 percent. the Delhi Development Authority (DDA) is responsible for the arrangement of the strategic plan 2021 ,TOD plans, a TOD manual that will consider Delhi TOD approach and aides in the elucidation of guidelines was created by Unified Traffic and Transport Infrastructure (Planning and Engineering) Center (UTTIPEC).

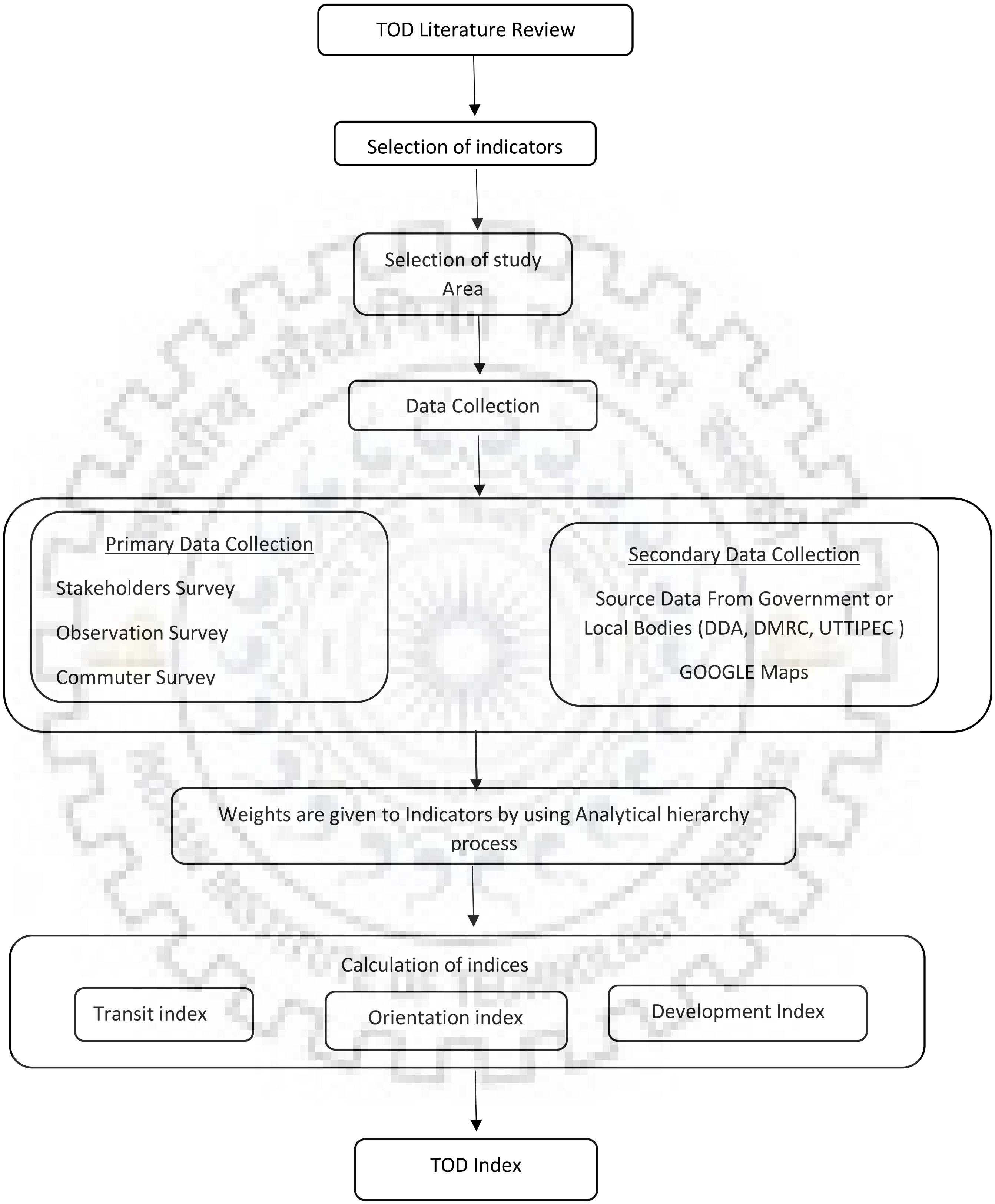


Fig 3.1 TOD METHODOLOGY

3.1.1 Delhi Metro

In Delhi, public transport modes form a strong network to serve the need of the public. The different mass transit system are bus and metro. Inter para-transit modes such as auto rickshaw, e-rickshaw, and manual rickshaw also plays significant role in commuting public. The current major public transit in the city is metro, operated by Delhi Metro Rail Corporation (DMRC) that provides good commuting facilities with an average daily ridership of 2.76 million in 2017 (DMRC,2017) and its network consists of eight colour-coded regular lines shown in fig 3.2 , with a total length of 313.7 kilometers (194.9 mi) serving 229 stations including 6 on Airport Express line and interchange stations.

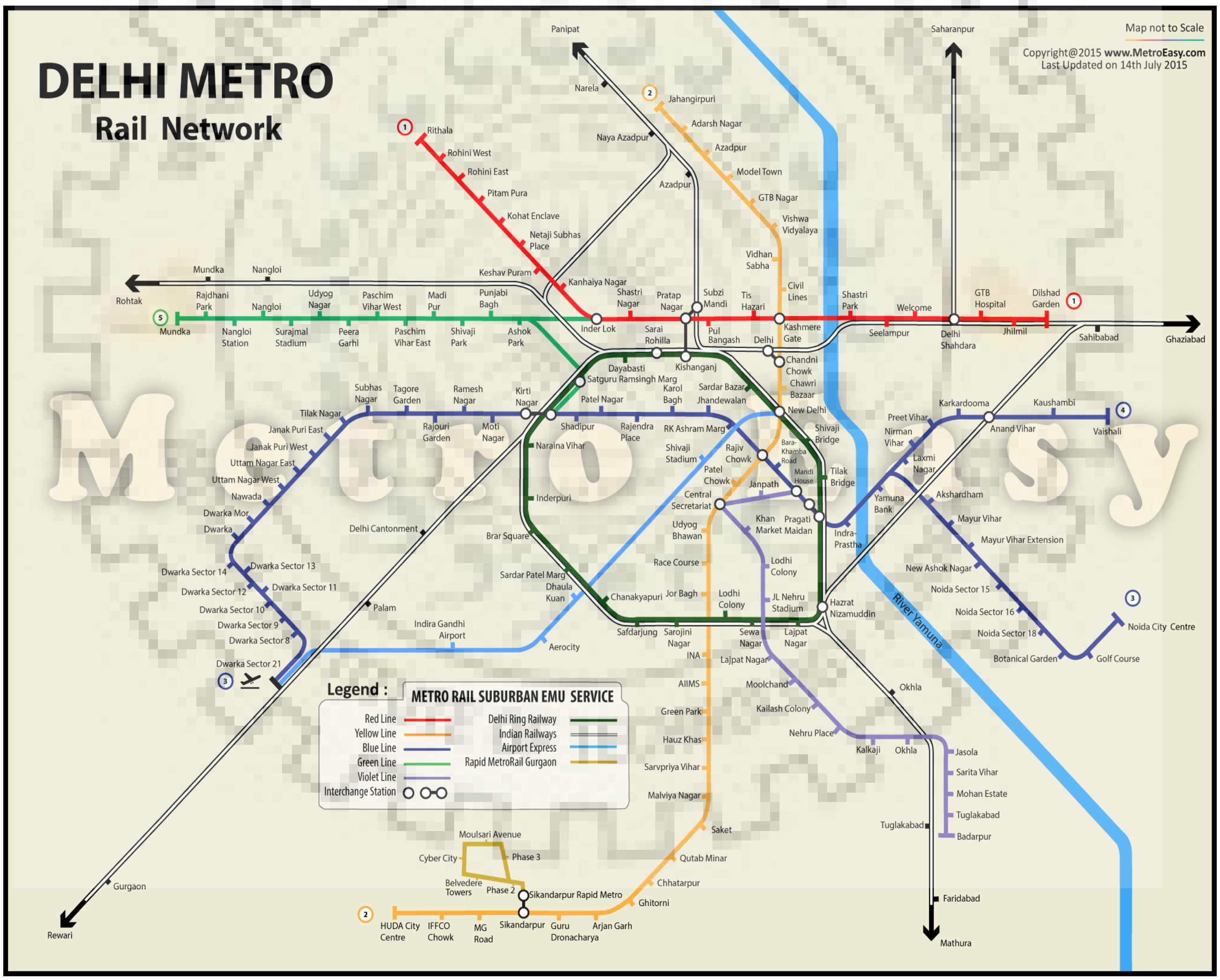


Fig. 3.2 Delhi Metro Rail Network (DMRC)

3.4 Identification of sites

Metro station are selected based on metro ridership data, land use data and population data.

Red Line – Dilshad Garden, Shahdara, Seelampur, Shastri Nagar, kaishav Puram, Pitampura, Rohini west.

Voilet line – Badarpur, Govindpuri, Kailash Colony, Lajpat Nagar, nehru place, Jangpura, kashmere gate.

Fig 3.3 Selected Metro Stations

Buffer area of 500 m is selected based on the study of literature and document available on TOD policy in India and especially in Delhi created by UTTIPEC and Delhi development authority.

According to UTTIPEC documents TOD influence area are divided into three Zone

- Intense TOD area :it is a 300 m influencing area of all metro station
- Standard TOD area: it is a 800 m or 10 minute walking distance influence area of all metro station

- TOD transition area : it is a 2000m or 10-minute cycling distance influence zone of all MRTS Stations

Here speed of pedestrians is assumed to be 1.4 m/s and that of cycle is 3 m/s.

Demarcation of TOD Influence Zones at Station level is show in figure below

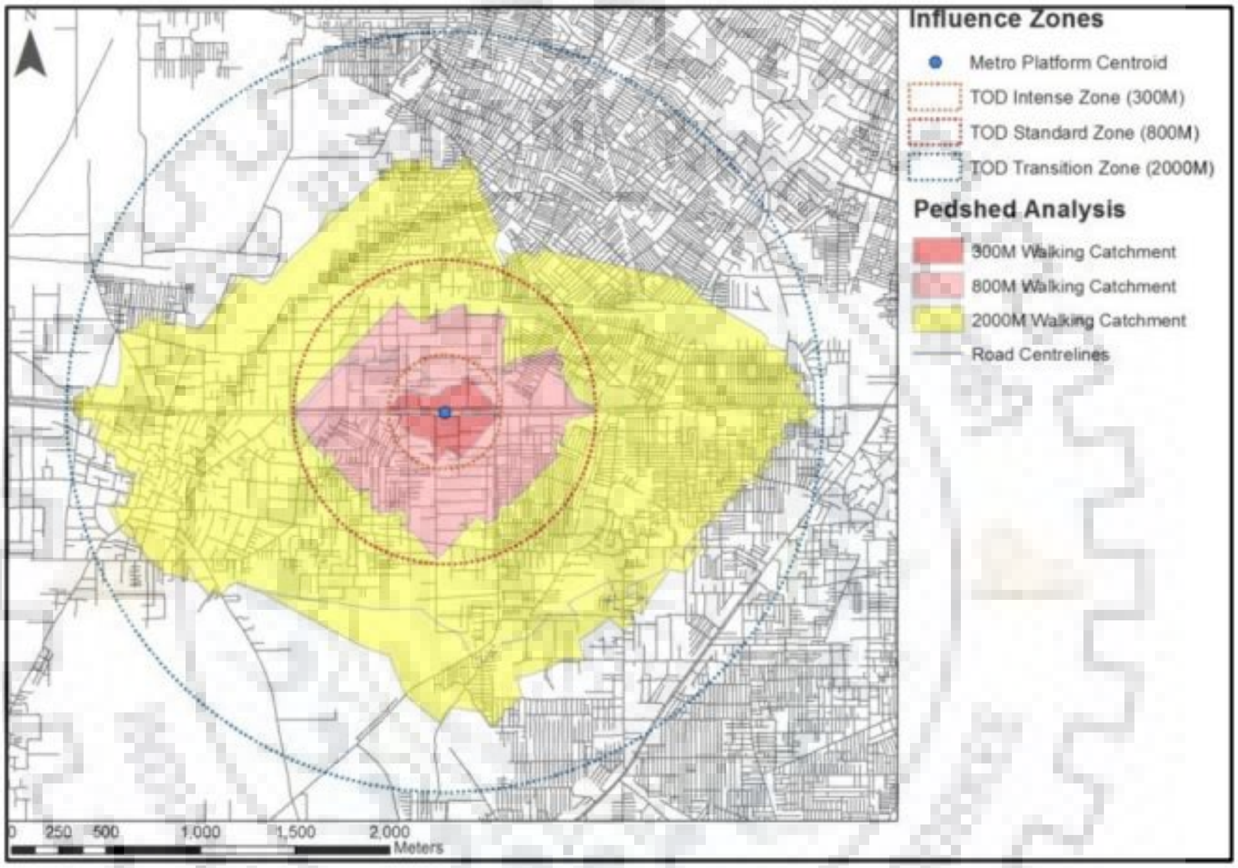


Figure 3.4 Example showing plotting of the 300m, 800m, 2000m catchments and actual ped shed of an MRTS Station(UTTIPEC ,2012)

According to the observation study on violet and red line of Delhi metro, it was found that the average distance between two consecutive metro station was approx. 1.5 km so the buffer area selected in such a way that buffer zone of two metro stations should not overlap.

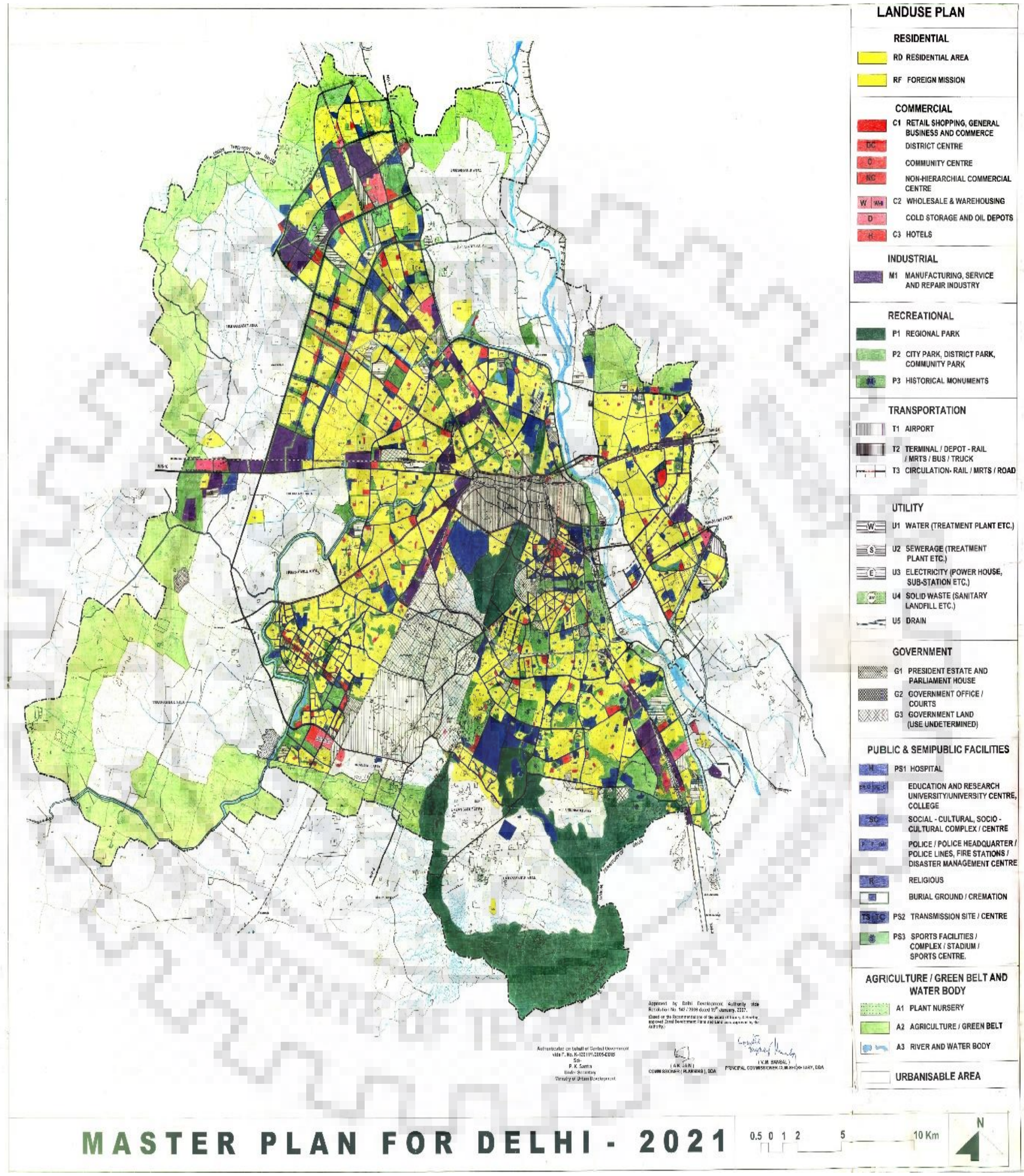


Fig 3.5 Land Use Map of Delhi (Delhi development authority)

3.5 Selection of Indicators

No. of researchers have purposed various methods and indicators to evaluate TOD attributes in different geographical aspects .Based on a systematic review of these studies, we have identified following indicators which focus on the Transit aspect, Development aspect and Orientation aspect

Table 3.1 Selected indicators

(Transit characteristics) Indicators	**Literature source**	**Data source**
Transit ridership (T1)	"Reusser et al. (2008), "	DMRC
Parking capacity (T2)	"Vale(2015)"	DMRC
Feeder Buses (T3)	"Song and Deguchi (2013)"	DMRC
Public Transport walk Accessibility Level(T4)	"Kamruzzaman et al. (2014)"	Commuter survey data

(Development characteristics) Indicators	**Literature source**	**Data source**
Population density (D1)	"Singh et al.(2014)"	Census of India 2011
Land use mix (D2)	"Singh et al.(2014)"	Land use map from DDA
Education level (D3)	"CTOD(2013), Pollack et al. (2014)"	Commuter Survey Data
Vehicle ownership(D4)		
Average Monthly per capita income (D5)		
Workers in household (D6)		

(orientation characteristics) Indicators	**Literature source**	**Data source**
Intersection density (O1)	"Singh et al.(2014)"	Open street map
No. Of entry Gates to the station(O2)	"Shastry (2010)"	Observation survey data

Betweenness index(O3)	"Monajem and Nosratian (2015)"	Metro Network map (DMRC)
Walk Scores(O4)	"Pollack et al. (2014)"	www.walkscore.com

3.6 Data collection

3.6.1 Primary data collection

Data obtained from the respondent from survey is called primary data. It cannot be measured directly by some observation. Three type of survey have been done to collect the primary data.

1) *Observation survey* – In this visual inspection of the study area is done and based on the preset parameter (Density, Diversity etc.) sites are selected . It is basically preliminary survey done for site selection.

2) *Commuter survey* – It is done to collect the data related to socio-economic characteristics, travel behavior and the trip characteristics of the selected area.
For commuter survey sample size is determined by following eq. (Krejcie and Morgan, 1970):

Sample Size = $[\chi^2 \text{ NP } (1\text{-P})] / [d^2 (\text{N-1}) + \chi^2 \text{ P } (1\text{-P})]$

Where,

χ^2 = 3.84 (table value if chi-square at degree of freedom = 1 for desired confidence level of 95 %).
N = population size
P = population proportion (assumed to be = 0.50)
D = degree of accuracy expressed as a proportion (0.05)

Total of 490 samples were collected from 14 stations i.e. 35 samples from each station, data collected through google survey form-
The survey includes-

- Commuter's basic information on socio-demographic characteristics includes gender, age, monthly income, education level, vehicle ownership and no. of workers in the household.
- Travel characteristics include origin and destination point, nearest metro station, access and egress time, journey time, journey cost, trip purpose
- Acceptable walking distance and time and travel choice in absence of metro service.
- Average walking time and average waiting for different pubic transport mode (feeder buses, e- rickshaw and auto- rickshaw)

3) *Expert opinion survey (stakeholder's survey)*: this is done by the various stakeholders (Researchers, planners, Builders and users) to get the relative importance of the various indicators that are used to fulfill the desired objectives. Results From this survey are used in Analytical hierarchy process. Total of 16 experts which includes one Director and two Assistant director from UTTIPEC , three Assistant director from planning department of Delhi development authority , Two Assistant engineer and one Assistant manager from planning department of Godrej property limited and seven daily users filled the form.

3.6.2 **Secondary data collection**

Data collected from various sources are called as secondary data. For calculation of TODness of station area, data are collected from government organizations i.e. Delhi metro rail corporation (DMRC), Unified Traffic and Transport Infrastructure (Planning & Engineering) Centre (UTTIPEC), Delhi Development Authority (DDA).

3.7 Calculation of Indicators

Transit ridership – It is the measure of average number of passengers travelling by a particular transit mode for a particular period of time. Transit ridership is an important parameter to measure the success of a particular transit mode. The priority of a particular transit mode is decided by the number of people using that mode i.e. more the no of people using a transit mode, higher will be its priority. Data for transit ridership is taken from DMRC.

Parking Capacity – It is a measure of the area dedicated by the transit service provider for the parking of personal vehicles , By having a parking area near the station it would be easier for commuters to come and park their vehicles and continue their journey through a public transit mode i.e. park and ride option is available for the users. Data for parking capacity is taken from DMRC.

Feeder Bus -Along with the seamless and efficient transit service it is also important to provide last mile connectivity from the station to the origin or destination point, it is achieved by providing a supplementary mode of transport such as Feeder buses, E-rickshaw etc. Data for the frequency of feeder bus and other IPT present near the station area were taken from commuter survey and also by noting the time between two consecutive modes manually by using stop watch for 30-45 minutes time interval.

Public transport walk accessibility index (PTWAI)

It is developed in 1992, by London Borought of Hammersmith and Fulham and the method is adopted by London Transport, and considered to be a comprehensive and precise evaluation of the access or egress to the public transport system, going for into record walk access and service accessibility.

It consider:

- Access and egress time from trip start or to trip end point.
- The availability of the dependable public transport modes.
- The number of accessible transport mode inside the study area
- Frequency of available public transport

It is calculated as,

$PTWAI = EDF_{max} + (0.5 * \text{All other EDFs})$

$EDF = 30/(\text{Total Access Time})$

Total Access Time = Walk Time + Average Waiting Time

EDF – Equivalent Doorstep Frequency

Population density – It is the measure of no. of people living in the buffer area (No. of person /sq.km), More the population density of area means more no. of people are available to use a transit service. Data for population was taken from census of India 2011.

Land Use Mix

Areas with diversified land use such as Residential, Commercial, Industrial, Recreational, Government buildings etc. attract more people and thus improve transit utilization in off-peak Hours and on weekends.

To determine the land use mix of a selected area, land use diversity is calculated by using entropy (Cervero and Kockelman,(1997), Ritsema Van Eck and Koomen (2008)).

Land use Entropy is given by formula:

$L_{ud}(i) = - [\sum (Q_{lui} * \ln (Q_{lui}))] / \ln(n)$

Where,

$Q_{lui} = (S_{lui}) / (S_i)$

Lui = Land use type in buffer area i

Q_{lui} = The proportion of particular land use within study area i

S_{lui} = Total area of particular land use within the study area

S_i = Total area of study area i

Table 3.2 Different Type of Land Use

Legends	Commercial land use	Legends	Residential Land use
	District Centre		Residential
	Community Centre		Redevelopment area
	Non Hierarchy Commercial Centre		Urban renewal area
	Wholesale and Warehousing		Industrial land use
	Warehouse and Depots		Government offices\courts
	CNG Station\ Petrol Pump		
	Hotels		Government land

Legends	Transportation Land use	Legends	Recreational land use
RS	Railway station		Regional park
	Bus terminals		City park, District park
BT D	Road circulation	MPG	Multi-purpose ground
	Rail circulation	M	Historical Monuments
	MRTS		
	BRTS		
P	Parking		

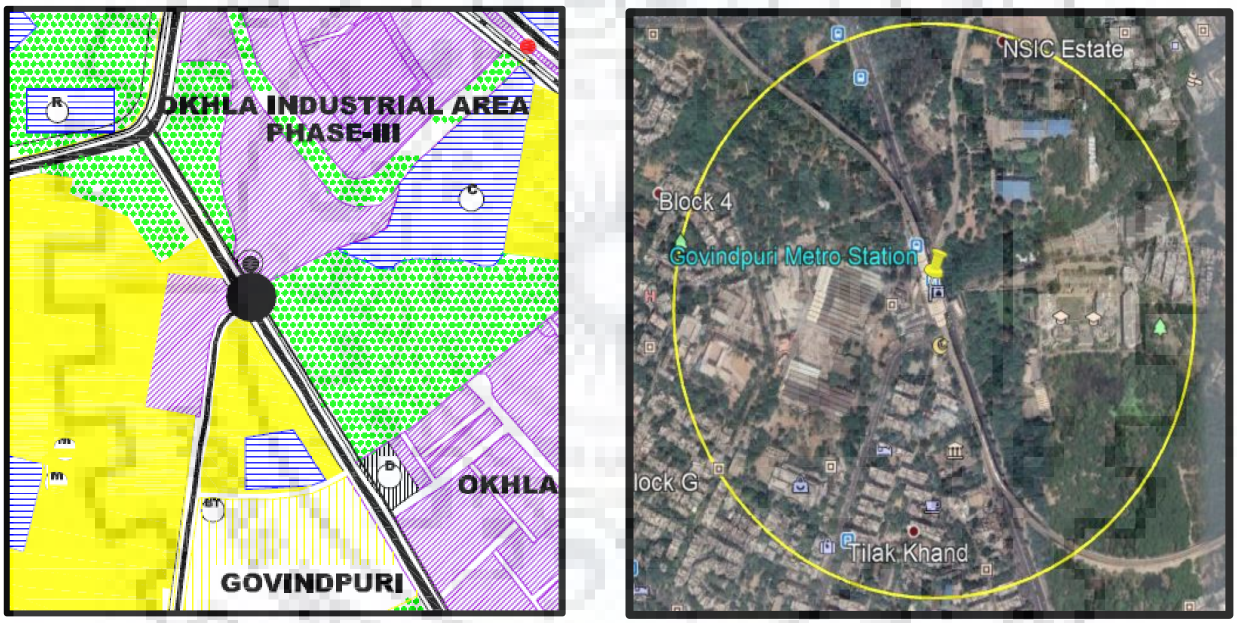
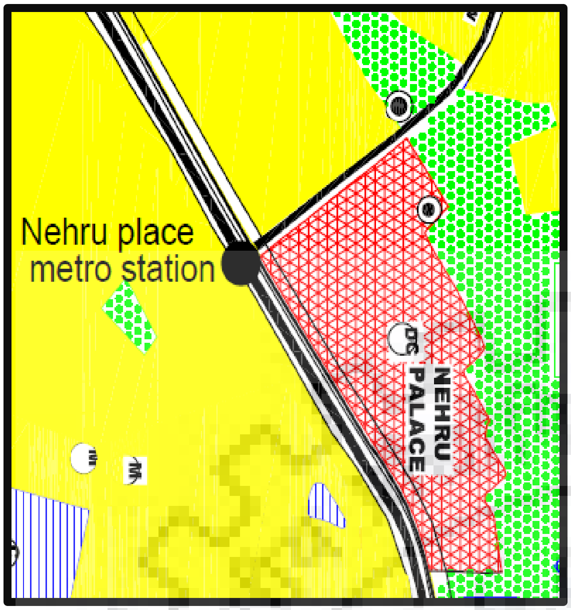


Fig 3.6. Govindpuri metro station area land use pattern and 500 meter buffer area



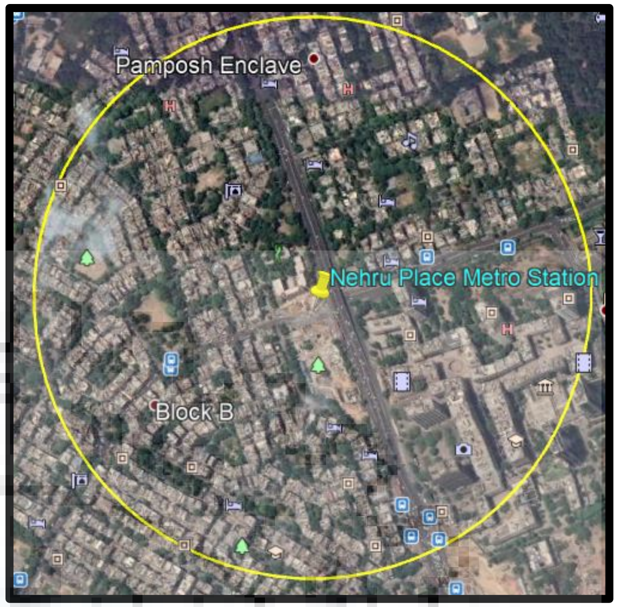


Fig 3.7. Nehru place metro station area land use pattern and 500 meter buffer area

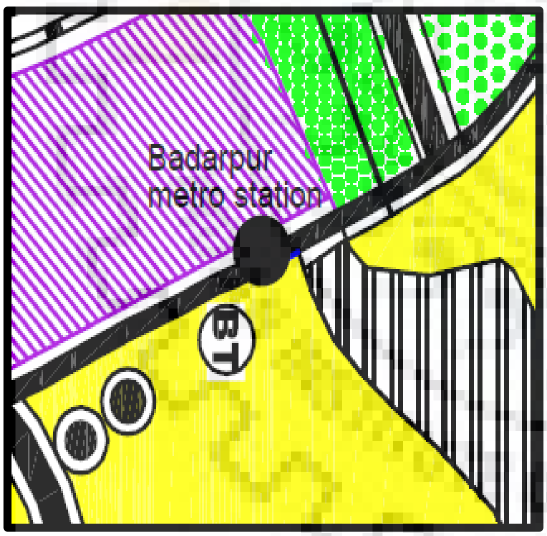
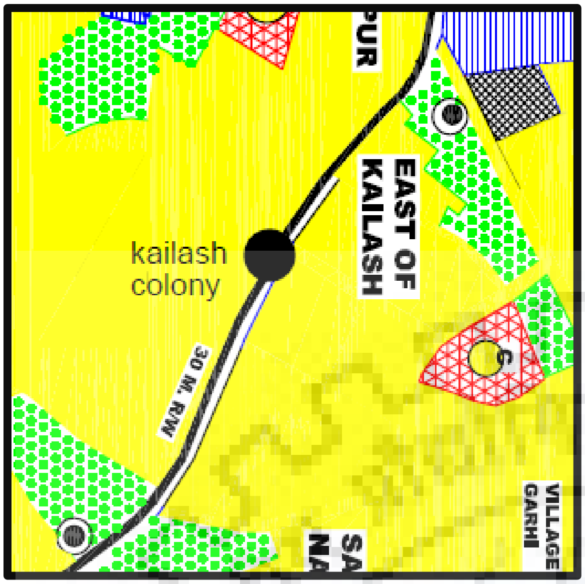


Fig 3.8. Badarpur metro station area land use pattern and 500 meter buffer area



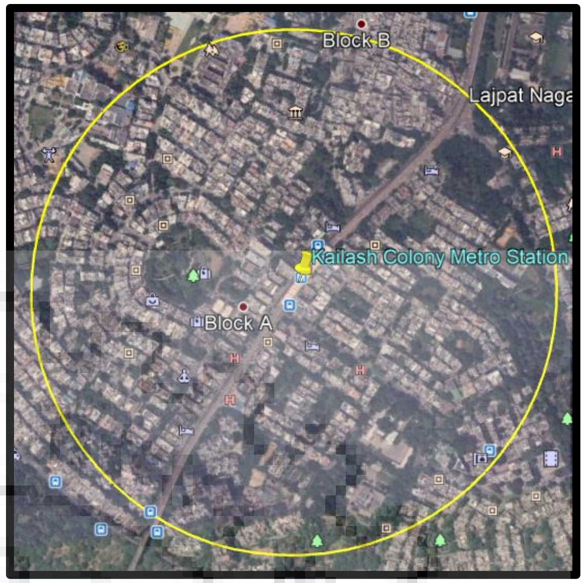
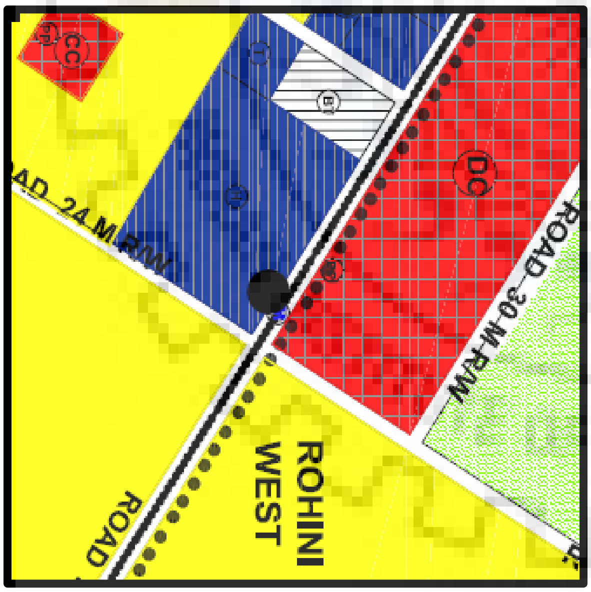


Fig 3.9. Kailash Colony metro station area land use pattern and 500 meter buffer area



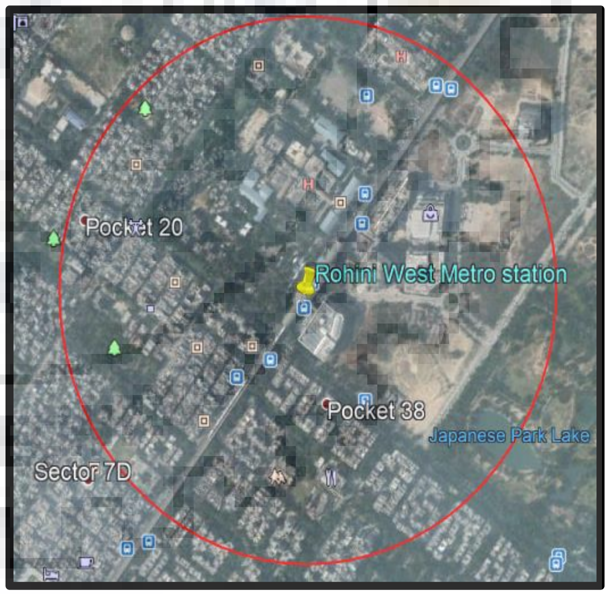


Fig 3.10.Rohini west metro station area land use pattern and 500 meter buffer area

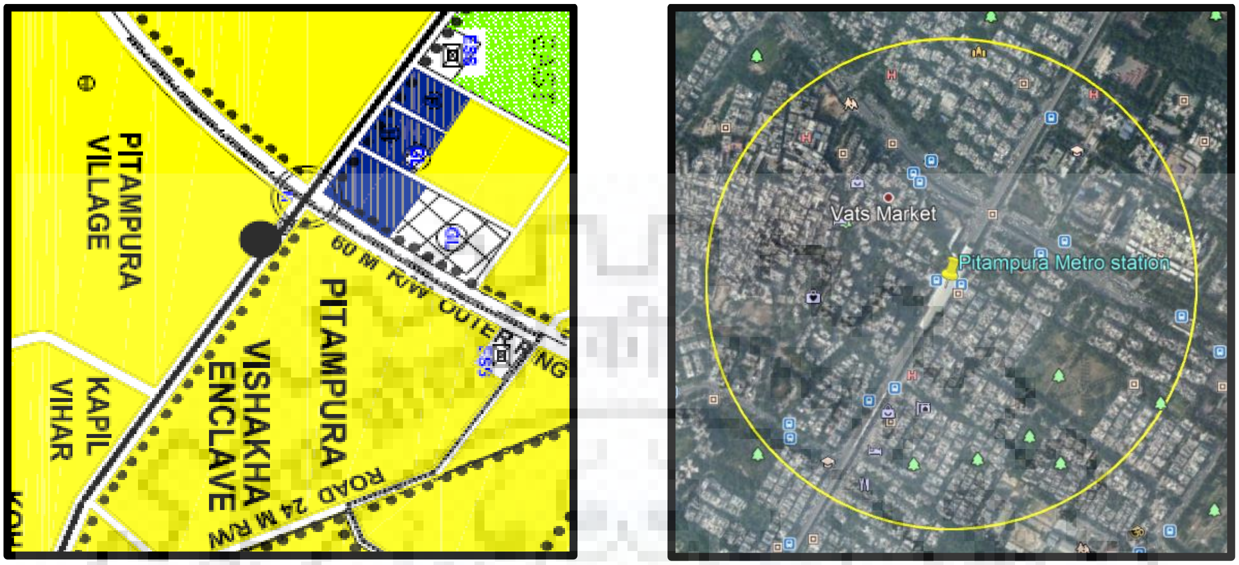


Fig 3.11. Pitampura metro station area land use pattern and 500 meter buffer area

Above pictures shows the land use pattern in the buffer area of 500 m radius of some stations,

Betweenness Index-

This indicator measures the proportion of journey between any two network nodes that pass through the node in concern, assuming that users determine their choice of route by shortest metric distance (No. of station) (Jan Scheurer and Carey Curtis, (2007).

It is calculated by the formula:

$CB_k = \sum P_{ij}(k) / (N(N-1))$

$P_{ij}(k)$ = paths between nodes i and j that passes through node k, for all , j € N, i ≠ j, i ≠k, j≠k

N = no. of nodes in the network

Betweenness index (BI) is calculated through network analysis, a network of selected metro station was prepared and the total no of path between any two station is calculated, then the no. of path that are passing through the concern node are noted and the BI of that station is measured by dividing the no. of path passing through that station to the total no. of path. It is to be noted that

BI of terminal station would be zero as on that station, train would either start the trip on terminate the trip.

Walk score

It is a measure of walkability on a scale of 0 to 100 depending on walking course to the various attraction points such as grocery stores, schools, parks, restaurants, and retail shops. According to Manaugh et al. (2011) a walk friendly environment with access to various amenities plays an important role to understand and measure walkability.

Walk Score also measures pedestrian friendliness by analyzing population density and road metrics such as block length and intersection density.

Basic methodology of walk score is that , it measures the walkable distance to different amenities present in the area and then by taking the average of distances keeping the weightage of closest amenities (5 min walking distance) more than those which are distant (15-20 minute walking distance) . Data sources are google map and open street map.

Calculation of weights of different indicators

The weights of different indicator are calculated using the analytical hierarchy process, which uses the data obtained from experts opinion survey. In expert opinion survey pairwise comparison was established to understand the relative importance of each indicator against other indicator also the relative importance of each fundamental component (Transit, Development and Orientation) against each other. The pair wise comparison uses the scale that ranges from equally strong to absolutely strong. The scale is shown below-

Weights are calculated by providing Size of Pairwise Comparison Matrix and Pairwise Comparison Matrix as input into the AHP online system. The output was the relative weights of indicators which are shown and discussed in next chapter.

Normalising the indicators

Since the indicators were measured in different units therefore to analysis and compare all of them at once, they needed to be converted into a single unit, thus all the indicators were normalised by using the formula given below so that they will have a value between 0 to 1.

$$Xnew = \frac{X - Xmin}{Xmax - xmin}$$

Where,

X_{new} = Normalized value of indicator

X= value of particular indicator in the sample

X_{max} = Maximum value of indicator in the sample set

X_{min} = Minimum Value of indicator in the sample set

4.1. Socio-Demographic characteristics

Commuter survey was done in Delhi at 14 selected metro stations to understand the characteristics of population using Delhi metro, 35 sample were taken at each metro station i.e. total of 490 sample were taken . Stratification based on working age population, age, gender, education level, average monthly income, average vehicle ownership are shown below. Out of 490 respondent 62% were male and 38 % were female.

Stratification based on working age population shows that maximum percentage is between 31 to 40 years (31%) and minimum is for age greater than 50 (19%), if it is seen as station wise then maximum percentage of working age population between 31 to 40 years (37.14%) is for Dilshad Garden and minimum percentage of working age for age greater than 50 is for Pitampura (8.57%)

Stratification based on education level shows that 50% of respondents are undergraduate and only 24 percent are 12^{th} pass or less than that, if we see station wise then maximum 68.57 percent of respondent were undergraduate at Nehru place and only 8.57 % were 12^{th} pass or less at Dilshad garden.

Based on income maximum people have income between Rs 15000 and Rs 30000 (27%) and for station Jangpura has maximum 45.71% people who have income in between 15000-30000 Rs

Stratification based on average no. of vehicle ownership shows that 28 percent of people do not have vehicle, and 24 percent of people have more than 2 vehicle at home , hence it can be inferred from above data that 28 percent of people are bound to use public transport as they do not have their own private vehicle that means they are transit captive riders on the other hand 24 percent of people do have choice between metro and their own vehicle still they using the metro that means they transit choice riders .

Stratification in the form of pie chart are shown in fig4.1.

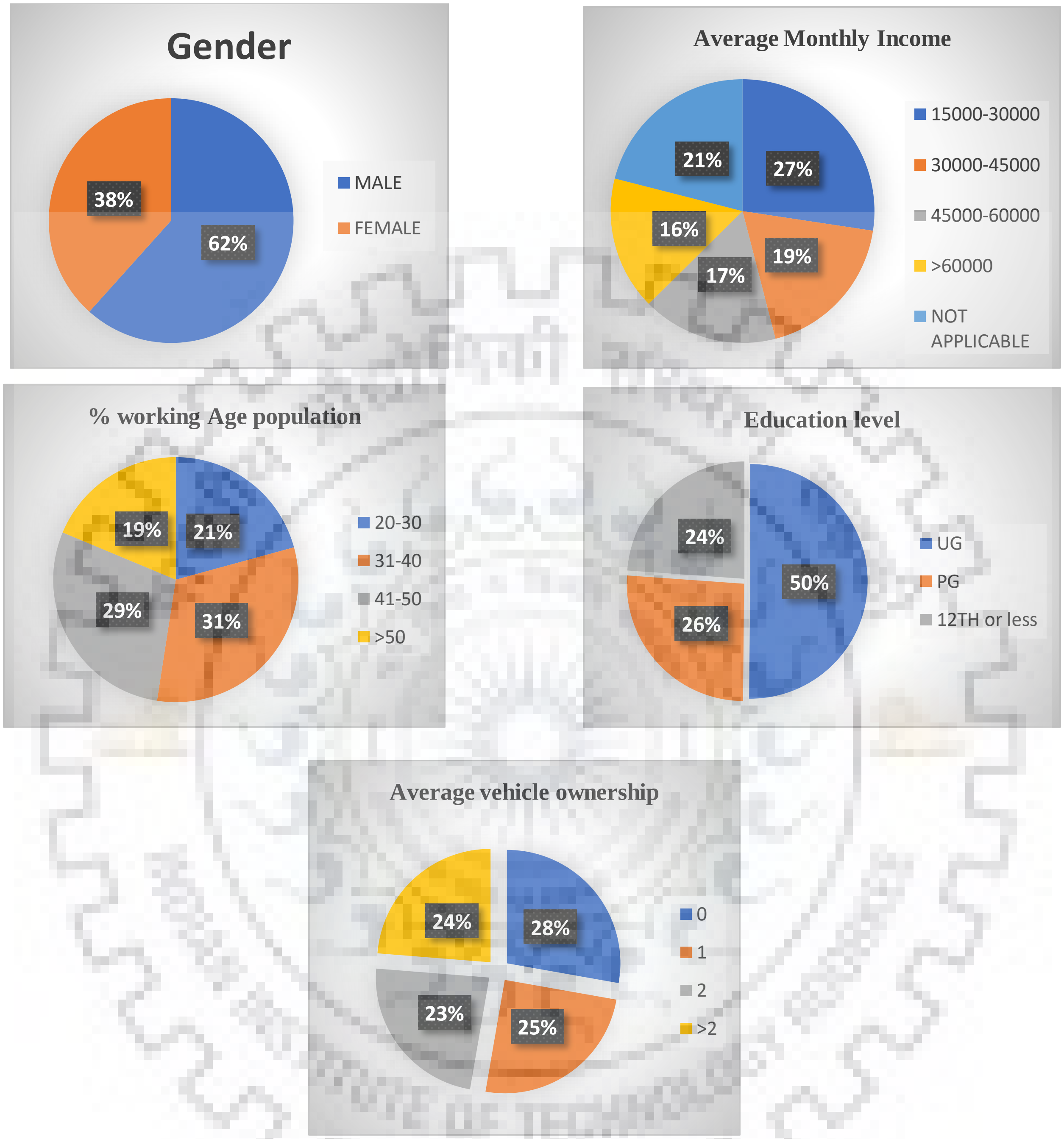


Fig 4.1 Stratification of Sample

4.2 Results of Analytical hierarchy process

AHP is done by using expert opinion survey data collected from 16 experts are shown in table below

Table 4.1 Results of AHP

Component	Weights	Indicators	Weights	Consistency ratio (%)
Transit	0.26	Transit ridership	0.322	5.3
		Parking capacity	0.083	
		Feeder buses	0.397	
		Public transport accessibility	0.198	
Development	0.327	Population density	0.261	9.5
		Land use mix	0.246	
		Workers in household	0.203	
		Household income	0.062	
		Vehicle ownership	0.049	
		Education	0.179	
Orientation	0.413	Intersection density	0.312	6.4
		Walk score	0.385	
		No. of entry gates	0.193	
		Betweeness of the station	0.110	

CR- 5.6%

It is clear from the above results that orientation of an area toward the transit facility also plays an important role.

In the transit component, weight of feeder buses is highest among all, which indicates that with more no. of feeder buses will make more people to use transit services.

4.3 Calculation of Indices

4.3.1 Transit index

Transit index represents the transit characteristics of a selected area, it is the measure of the quality of existing transit service and the services provided by it to the users. To calculate the transit index, values of selected indicators that are Transit ridership (T1) (Average daily riders), Parking Area (T2) (sq.m), feeder Bus frequency (T3) (bus per hour) and Public transport accessibility index (T4) were calculated, normalized value of indicators for each station is given below

Table 4.2 Normalized value of Indicators of Transit Index

	T1	**T2**	**T3**	**T4**	**Transit Index**
BADARPUR	0.517	1	0.5	0.68	0.583
KAILASH COLONY	0.095	0	0.16	0.33	0.159
LAJPAT NAGAR	0.175	0	0.33	0.182	0.223
NEHRU PLACE	0.25	0.333	0.83	0	0.437
JANGPURA	0	0	0.167	0.056	0.077
KASHMERE GATE	1	0.89	0	0.215	0.434
GOVIND PURI	0.36	0.68	0.167	0.236	0.285
DILSHAD GARDEN	0.526	0.958	0.34	0.232	0.429
SHAHDARA	0.552	0.84	0.67	0.501	0.61
SHASHTRI NAGAR	0.207	0.335	0.167	0.03	0.167
SEELAMPUR	0.288	0.729	0.83	0.697	0.62
PITAMPURA	0.202	0.324	1	0.116	0.512
KAISHAV PURAM	0.164	0.543	0	0.612	0.219
ROHINI WEST	0.4	0	0.5	1	0.5253

Seelampur has Maximum value of transit index and is equal to 0.62 due to presence of employment density of the area more no. of people use this station , easy accessibility to the station due to presence of feeder services and minimum values is 0.077 for jangpura due to poor accessibility , lack of feeder services .

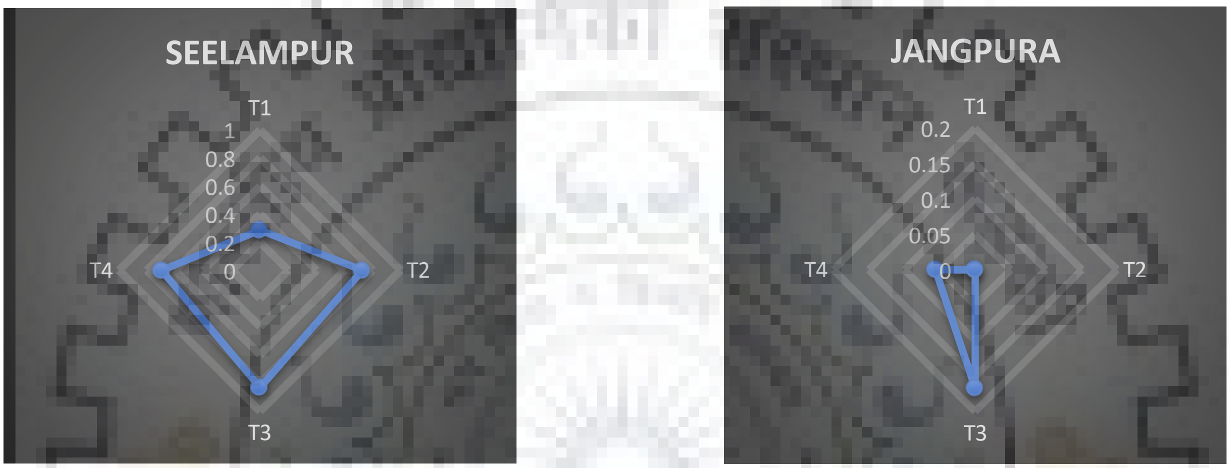
Transit index is calculated as a weighted sum of all the indicator's value, weights are taken for AHP results.

$$\text{Transit Index value} = \sum_{i=1}^{n} w_i T_i$$

Where,

T_i = Normalized value of Transit indicators

w_i = Weights Given to indicators respectively ($\sum_{i=1}^{n} w_i = 1$)



Maximum (0.62) **Minimum (0.077)**

Fig 4.2 Web diagram showing Stations with maximum and minimum transit index value

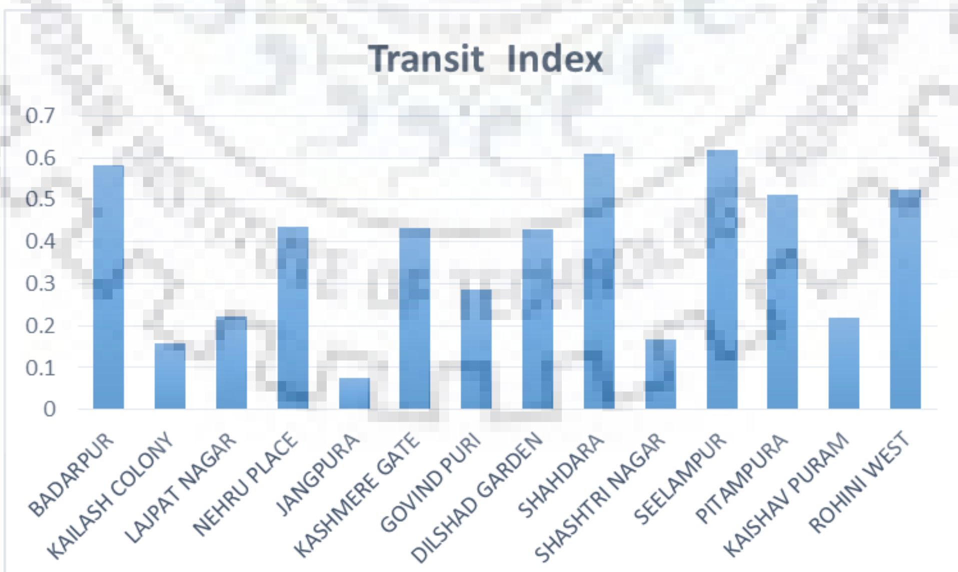


Fig 4.3 Transit Index For all Stations

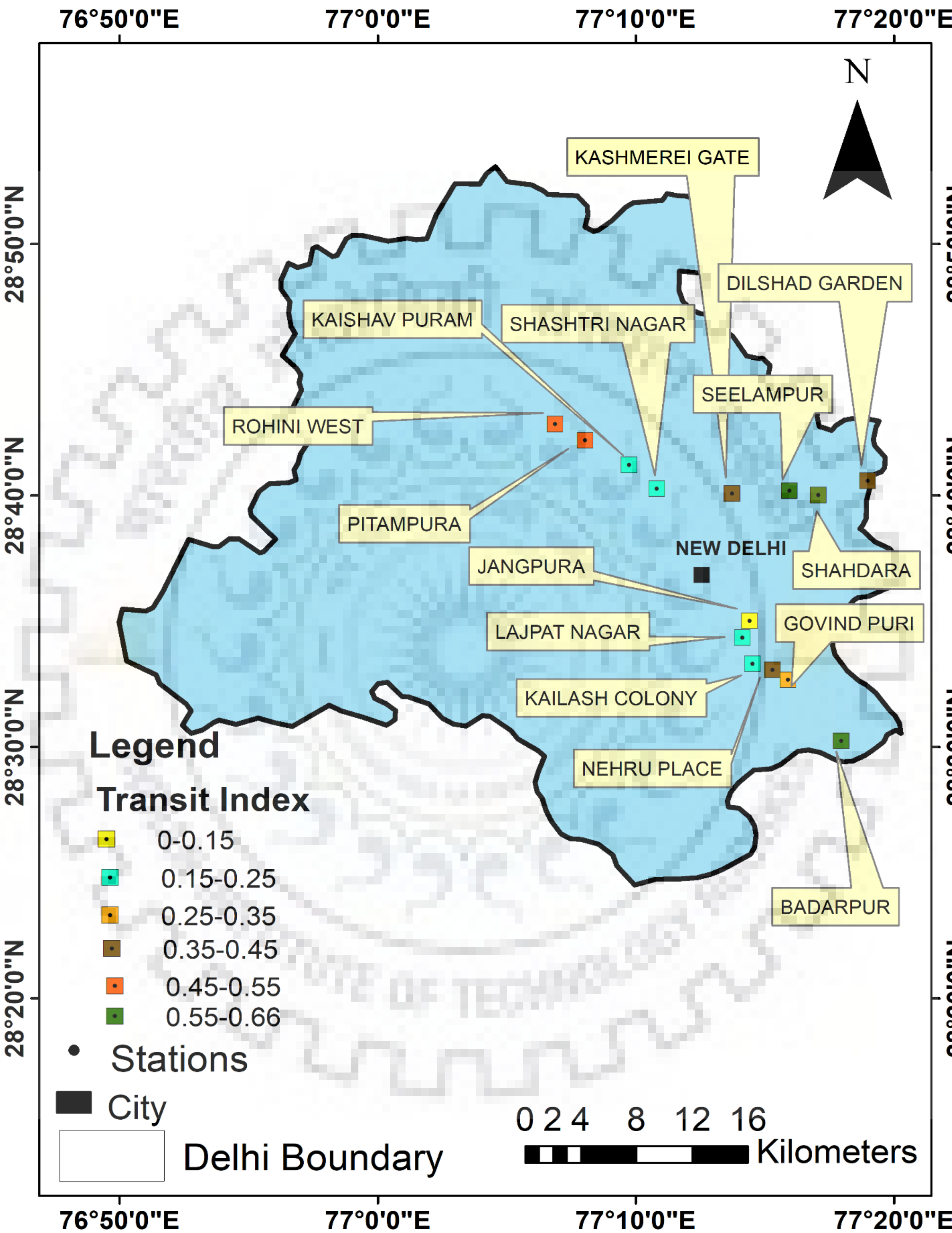


Fig 4.4 Transit index of all 14 metro stations (buffer area 500m)

4.3.2 Development index

Development index represents the development characteristics of the selected area, it is the measure of type and extent of development around a transit node including the socio-economic demographics of the area.

To calculate the development index, values of selected indicators that are population density (person/sq.km) (D1). Land use diversity factor (D2)and Education level(D3), Vehicle Ownership (D4), Average Monthly income(Rs) (D5), No. of workers in household(D6). Normalized value of indicators are given below-

Table 4.3 Normalized value of Indicators of Development Index

	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**Development index**
BADARPUR	0.167	0.924	0.89	0.287	0.93	0.285	0.56
KAILASH COLONY	0.077	0.21	0.823	0.727	0.917	0.082	0.328
LAJPAT NAGAR	0.159	0	0.706	1	0.273	0.412	0.317
NEHRU PLACE	0.38	0.607	1	0.545	0.416	0.526	0.586
JANGPURA	0.062	0.717	0.706	0.091	1	0.0515	0.395
KASHMERE GATE	0.009	0.267	0.799	0.331	0.583	0.226	0.31
GOVIND PURI	0	0.683	0.882	0.454	0.5	0.31	0.44
DILSHAD GARDEN	0.215	0.948	0.71	0.45	0.33	0.381	0.536
SHAHDARA	0.37	1	0.353	0.818	0.083	0.587	0.57
SHASHTRI NAGAR	0.72	0.294	0.588	0.545	0.25	0	0.41
SEELAMPUR	0.738	0.654	0.313	0.091	0.333	0.33	0.501
PITAMPURA	0.44	0.17	0.313	0	0	1	0.415
KAISHAV PURAM	0.874	0.677	0	0.181	0.415	0.556	0.542
ROHINI WEST	1	0.861	0.647	0.46	0.5	0.257	0.694

Results shows that Rohini west has maximum Value of development index (0.694) this is due to the presence of various land use mix such as Shopping Mall, High rise residential buildings etc. and kashmere gate has minimum value (0.31) because more vacant area is near the station area .

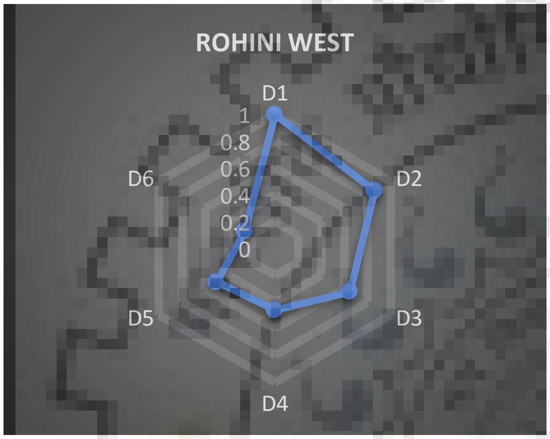
Development index, is calculated as a weighted sum of all the indicator's value, weights are taken for AHP results

Development Index value = $\sum_{i=1}^{n} w_i D_i$

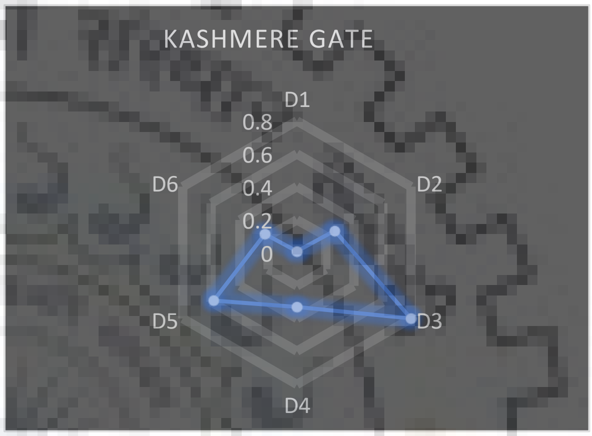
Where,

D_i = Normalized value of develpment indicators

w_i = Weights Given to indicators respectively ($\sum_{i=1}^{n} w_i = 1$)



Maximum (0.694)



Minimum (0.31)

Fig 4.5 Web diagram showing Stations with maximum and minimum Development index value

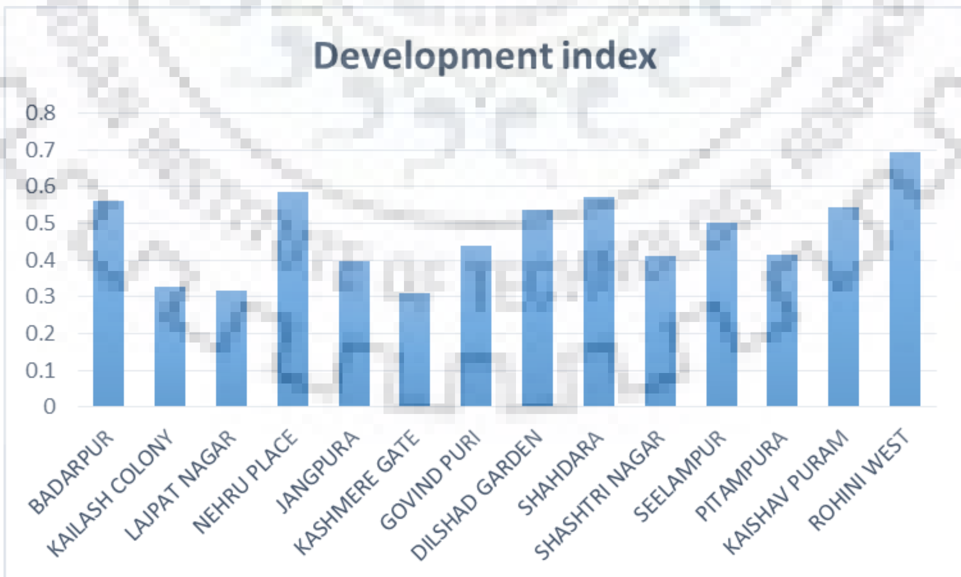


Fig 4.6 Development Index For all Station

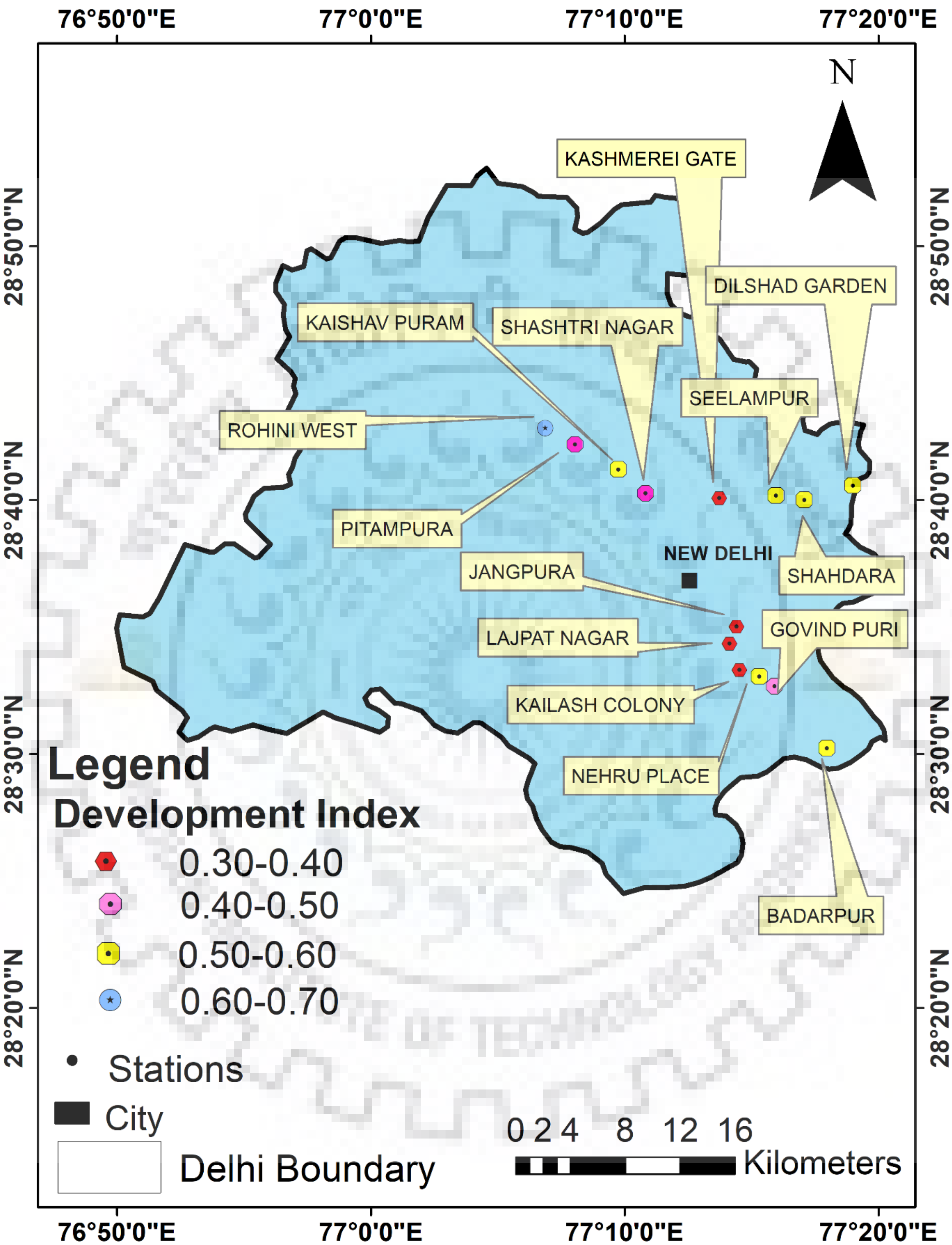


Fig 4.7 Development index of all 14 metro stations (buffer area 500m)

4.3.3 Orientation index

Orientation represent the degree of inclination of development toward the transit service, it basically shows the interdependency of the transit service and the development around it.
To calculate the Orientation index, values of selected indicators that are intersection density (O1), No. of entry gate to the station (O2), Betweenness Index (O3), Walk score (O4).
Normalized value of indicators are given below-

Table 4.4 Normalized value of Indicators of Orientation Index

	O1	O2	O3	O4	Orientation index
BADARPUR	0.416	0.167	0	0.475	0.345
KAILASH COLONY	0.507	0.167	0.713	0.934	0.628
LAJPAT NAGAR	0.648	0.33	0.856	1	0.745
NEHRU PLACE	0.681	0	0.526	1	0.655
JANGPURA	0.367	0.167	0.956	0	0.252
KASHMERE GATE	0	1	1	0.82	0.618
GOVIND PURI	0.11	0.167	0.286	0.754	0.388
DILSHAD GARDEN	0.361	0.167	0	0.951	0.511
SHAHDARA	0.89	0.167	0.286	0.803	0.65
SHASHTRI NAGAR	0.65	0.167	0.72	0.262	0.415
SEELAMPUR	1	0	0.53	0.737	0.654
PITAMPURA	0.678	0.167	0.287	0.852	0.603
KAISHAV PURAM	0.561	0.167	0.53	0.918	0.618
ROHINI WEST	0.465	0.167	0	0.967	0.55

Lajpat Nagar has maximum value of Orientation index (0.745) due to presence of frequent intermediate public transport modes, Central market is near the station which makes it a attraction point, Jangpura has least orientation index (0.252) due to the lack of IPT, poor accessibility to the station area .

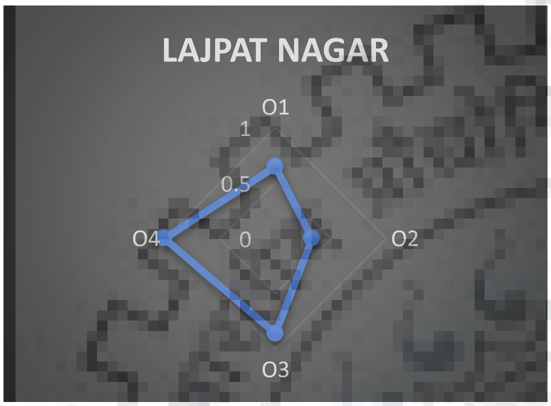
Orientation index, is calculated as a weighted sum of all the indicator’s value, weights are taken for AHP results

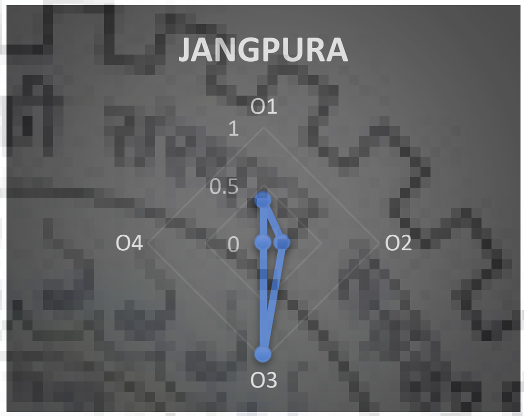
$$\text{Orientation Index value} = \sum_{i=1}^{n} w_i O_i \quad ..3.4$$

Where,

O_i = Normalized value of orientation indicators

w_i = Weights Given to indicators respectively ($\sum_{i=1}^{n} w_i = 1$)





Maximum (0.754) **Minimum (0.252)**

Fig 4.8 Web diagram showing Stations with maximum and minimum orientation index value

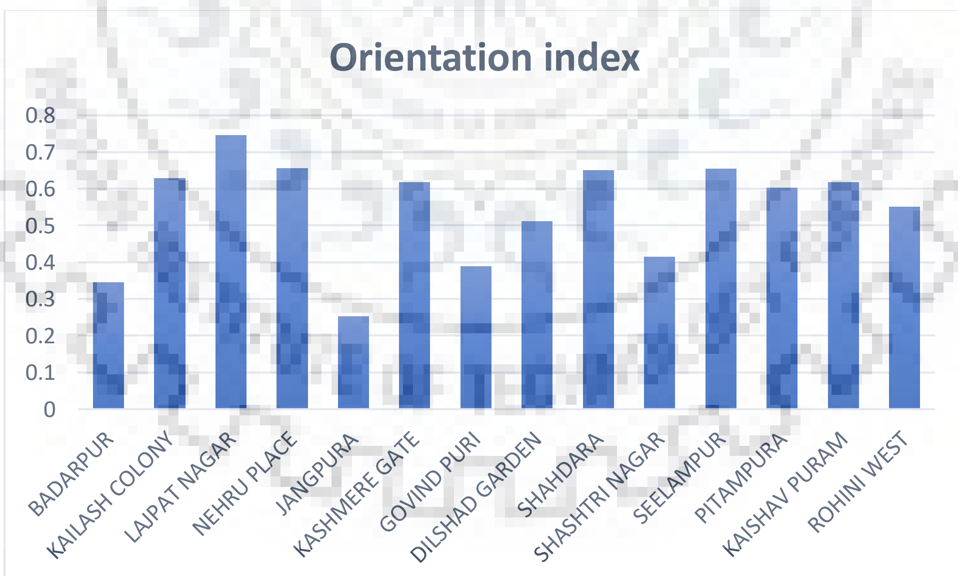


Fig 4.9 Orientation Index For all Station

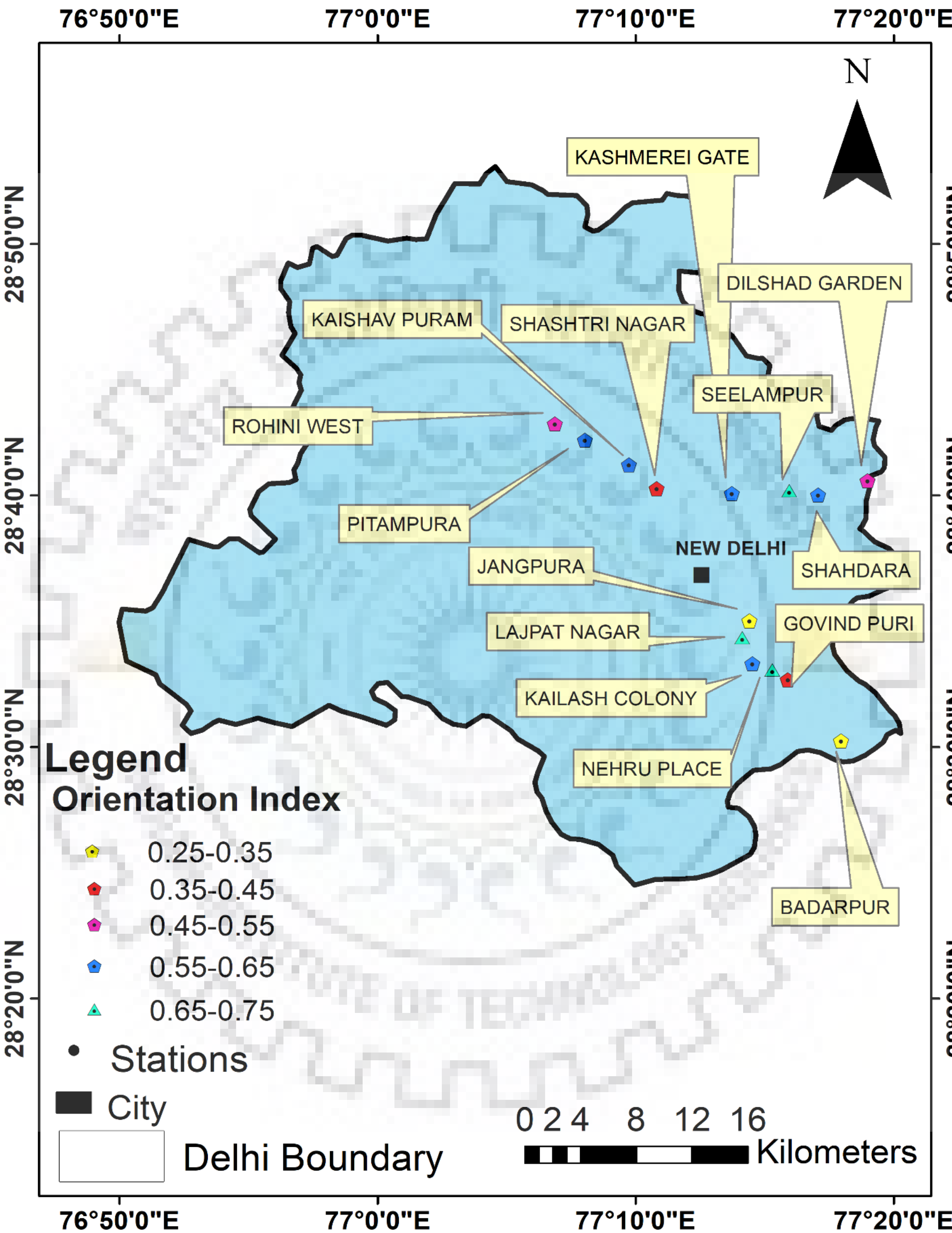


Fig 4.10 Orientation index of all 14 metro stations (buffer area 500m)

4.4 TOD index

The transit index, development index and orientation index are clubbed together to form TOD index, which represents the combined effect of transit service, development around the transit and the interdependency of both.

Table 4.5 TOD index value for all stations

S.no		Transit Index	Orientation index	Development index	TOD INDEX
1	BADARPUR	0.583	0.345	0.56	0.48
2	KAILASH COLONY	0.159	0.628	0.328	0.41
3	LAJPAT NAGAR	0.223	0.745	0.317	0.47
4	NEHRU PLACE	0.437	0.655	0.586	0.58
5	JANGPURA	0.077	0.252	0.395	0.26
6	KASHMERE GATE	0.434	0.618	0.31	0.47
7	GOVIND PURI	0.285	0.388	0.44	0.38
8	DILSHAD GARDEN	0.429	0.511	0.536	0.49
9	SHAHDARA	0.61	0.65	0.57	0.62
10	SHASHTRI NAGAR	0.167	0.415	0.41	0.35
11	SEELAMPUR	0.62	0.654	0.501	0.59
12	PITAMPURA	0.512	0.603	0.415	0.52
13	KAISHAV PURAM	0.219	0.618	0.542	0.49
14	ROHINI WEST	0.5253	0.55	0.694	0.59

Results shows that Shahdara (0.62), Seelampur (0.59) ,Nehru place (0.58) have the maximum value of TOD index this is due to the high population density (High rise building and compact colonies) , diversified land use (offices, light industries etc.) while Jangpura (0.253) have the least TOD index value among all due to lack of connectivity and poor accessibility to the metro station.

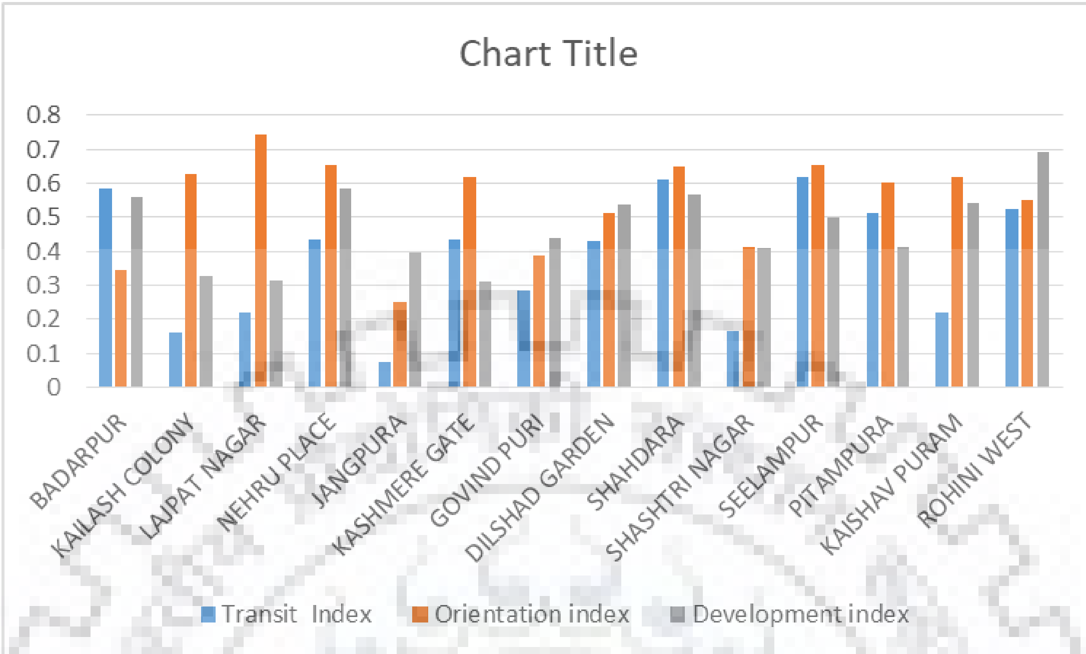


Fig 4.11 Comparison chart of all indices for all Stations

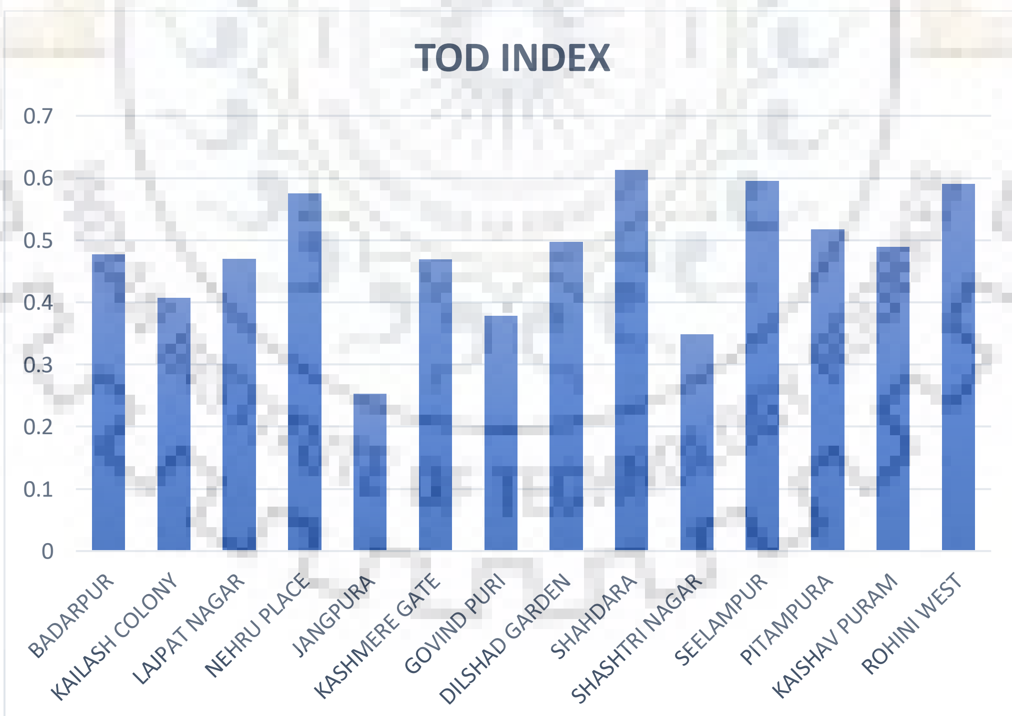


Fig 4.12 TOD index for all Stations

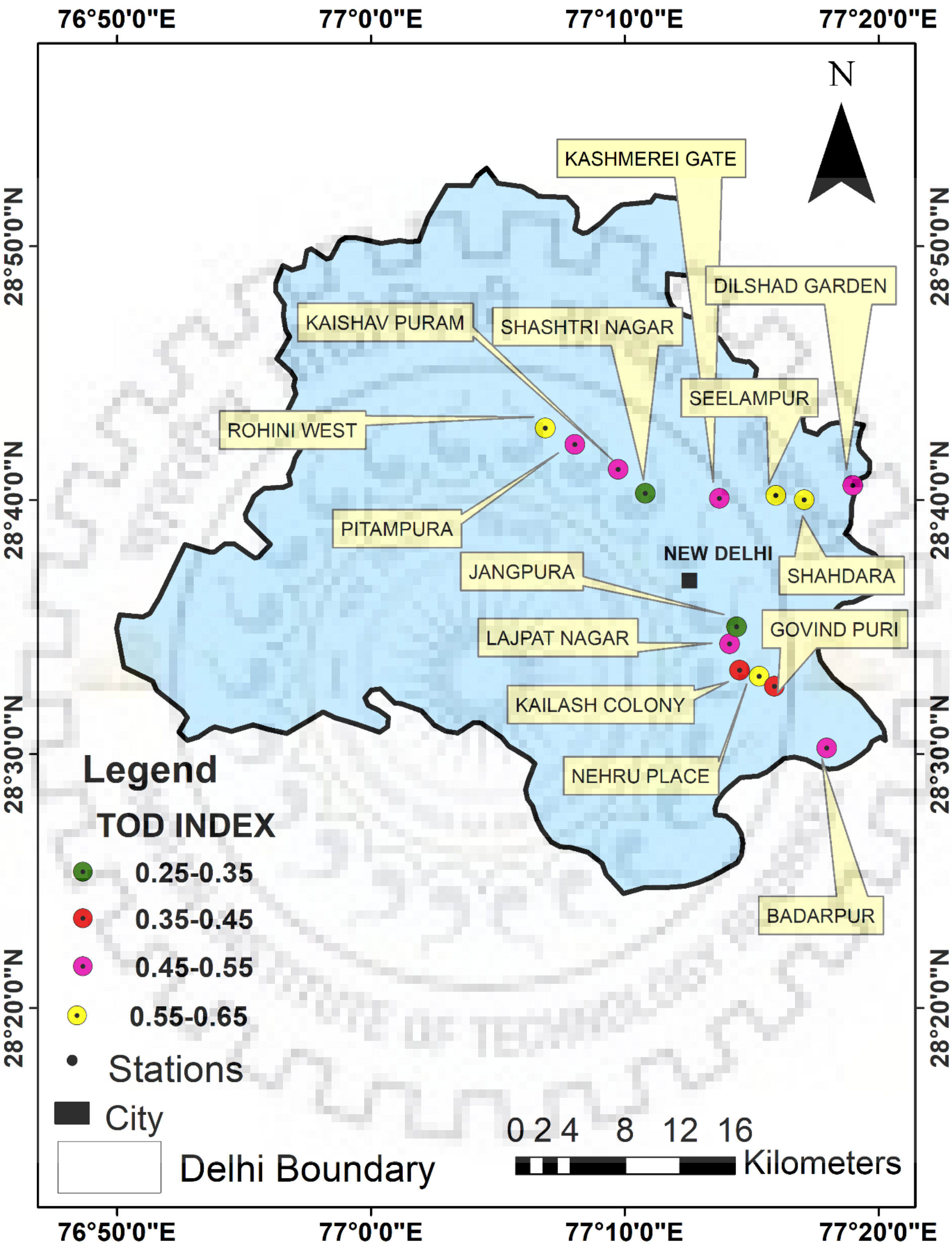


Fig 4.13 TOD index of all 14 metro stations (buffer area 500m)

Station wise comparison of transit index, development index, orientation index and TOD index are shown below from figure 14 to figure 27

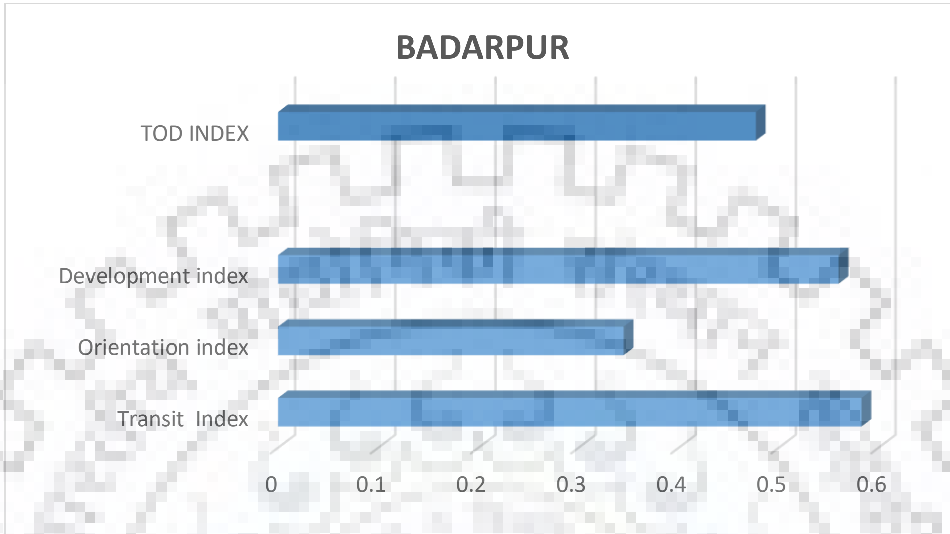


Fig 4.14 Comparison of all indices for Badarpur

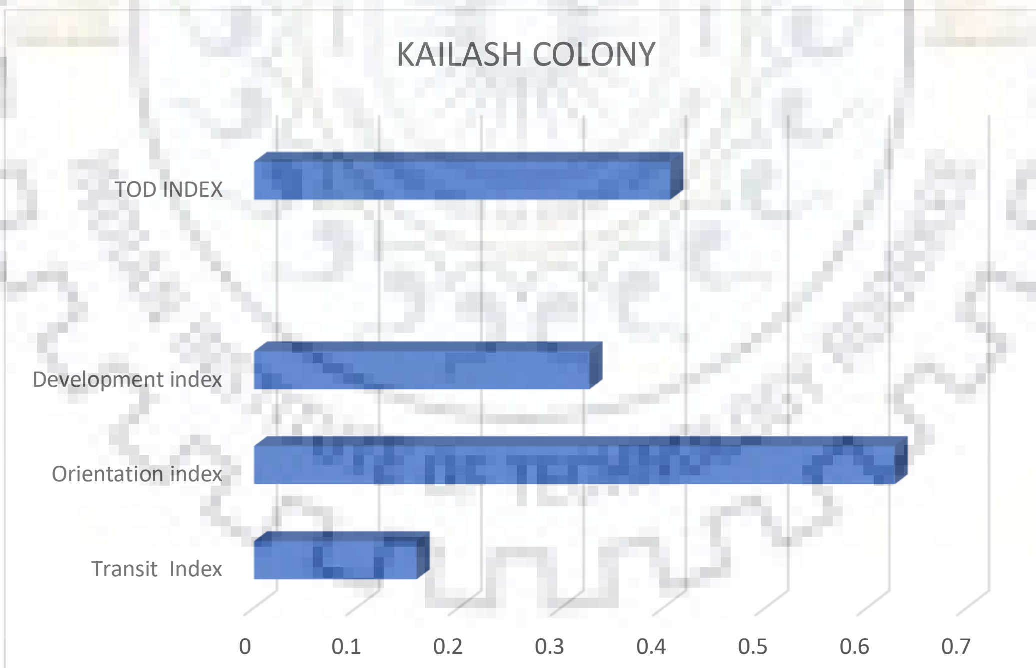


Fig 4.15 Comparison of all indices for kailash colony

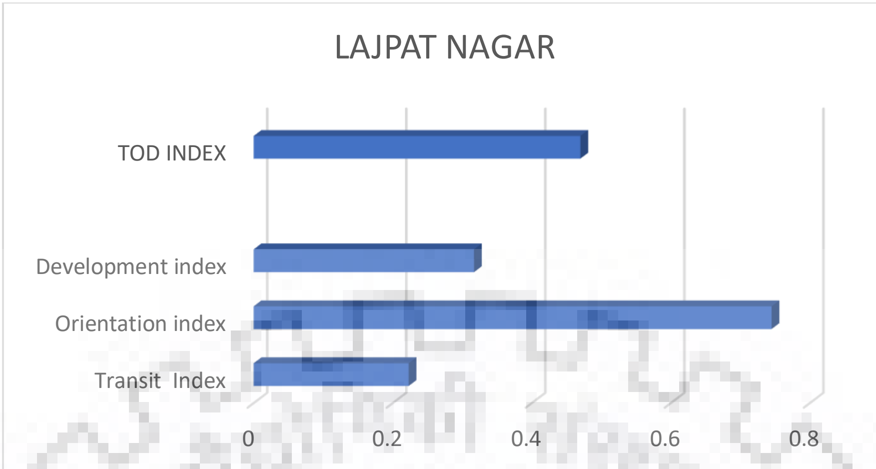


Fig 4.16 Comparison of all indices for Lajpat nagar

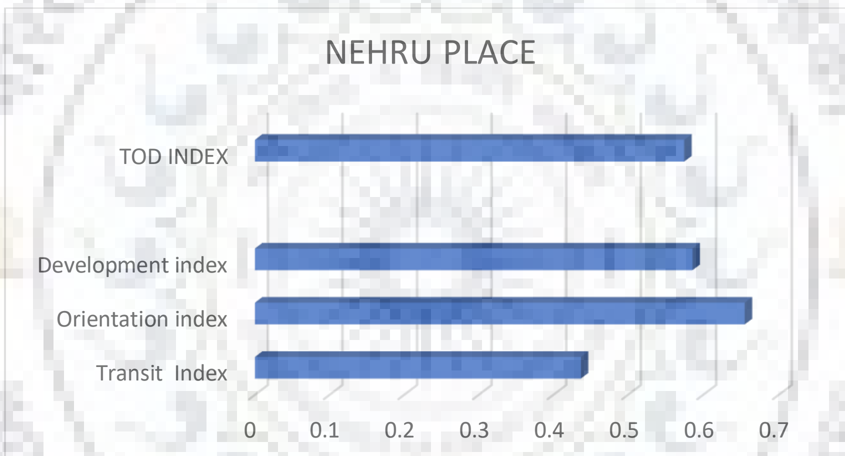


Fig 4.17 Comparison of all indices for Nehru Place

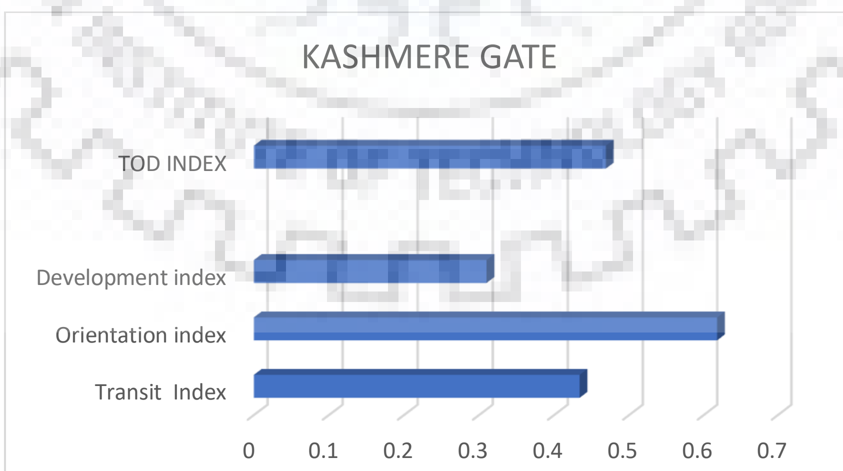


Fig 4.18 Comparison of all indices for Kashmere gate

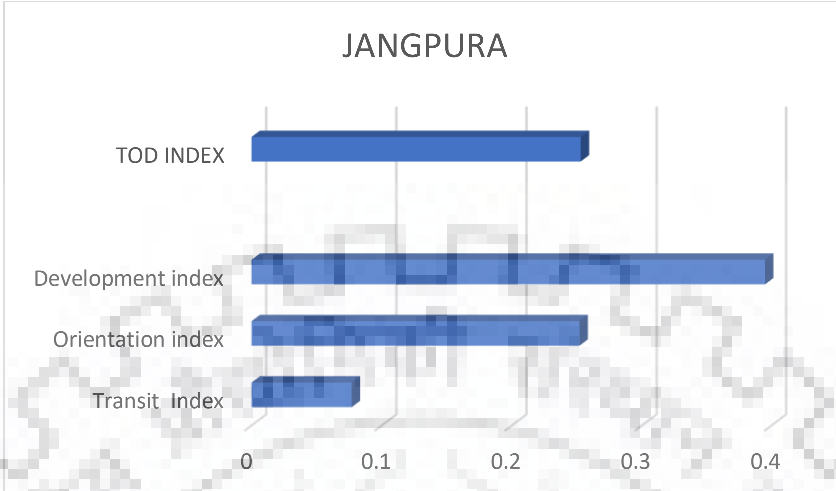


Fig 4.19 Comparison of all indices for jangpura

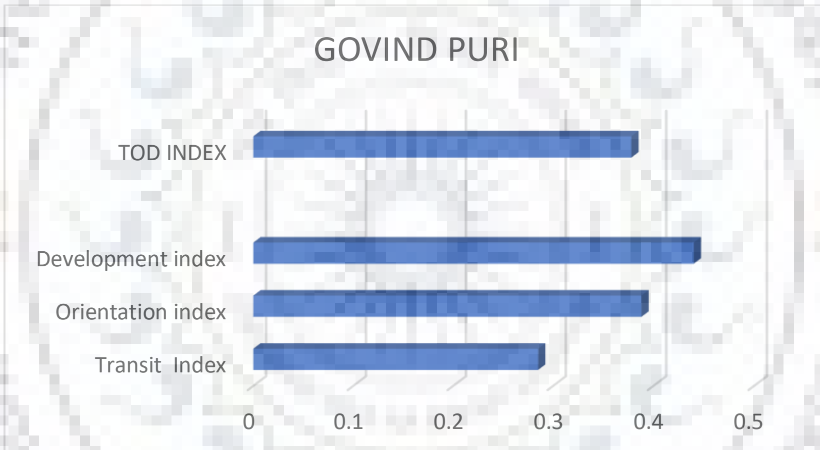


Fig 4.20 Comparison of all indices for Govindpuri

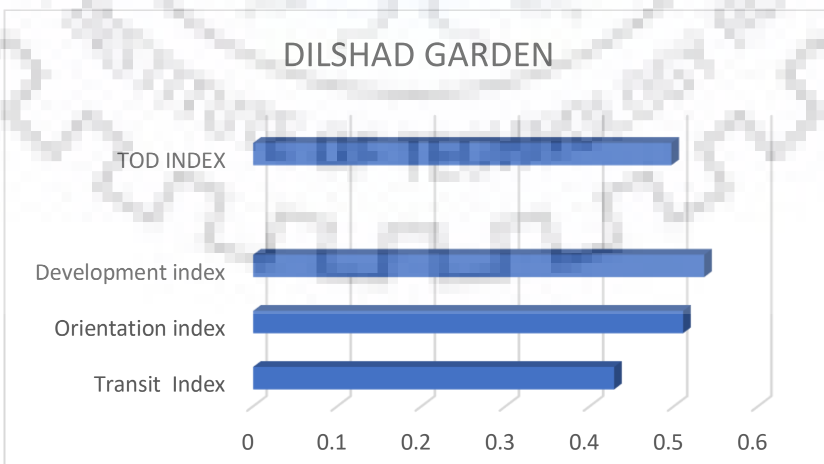


Fig 4.21 Comparison of all indices for Dilshad Garden

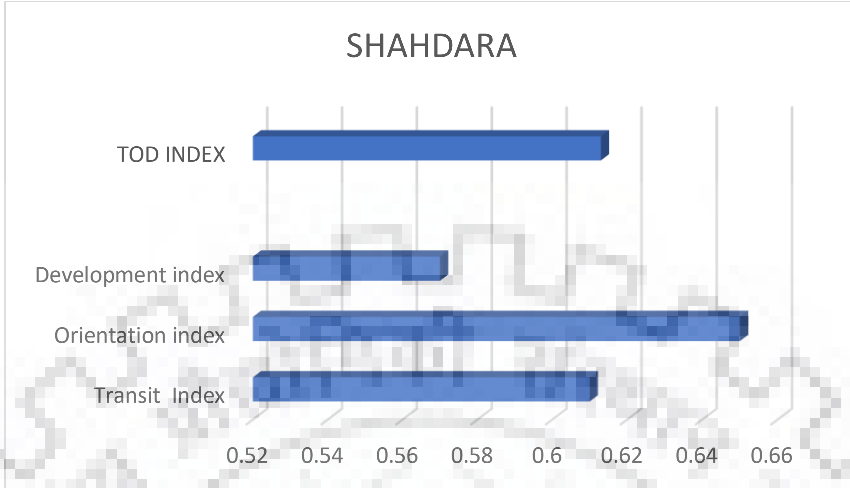


Fig 4.22 Comparison of all indices for Shahdara

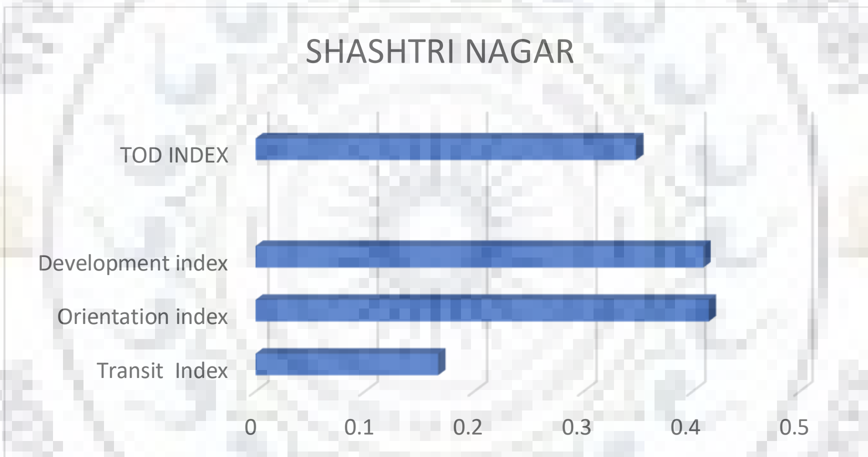


Fig 4.23 Comparison of all indices for Shastri Nagar

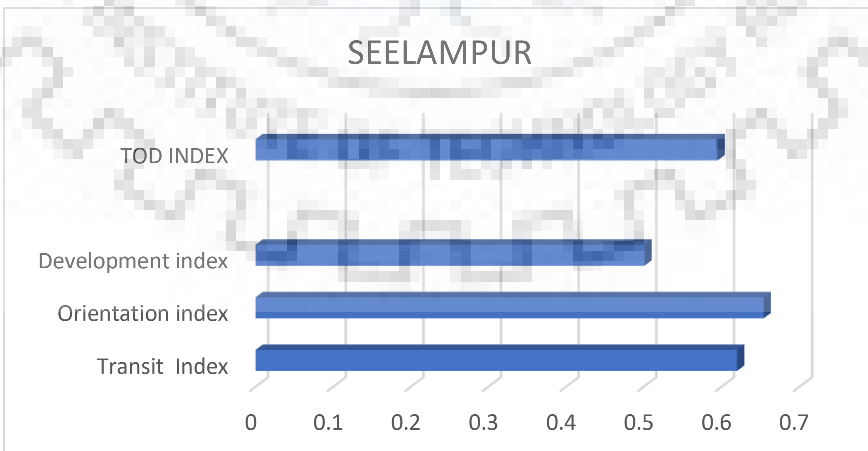


Fig 4.24 Comparison of all indices for Seelampur

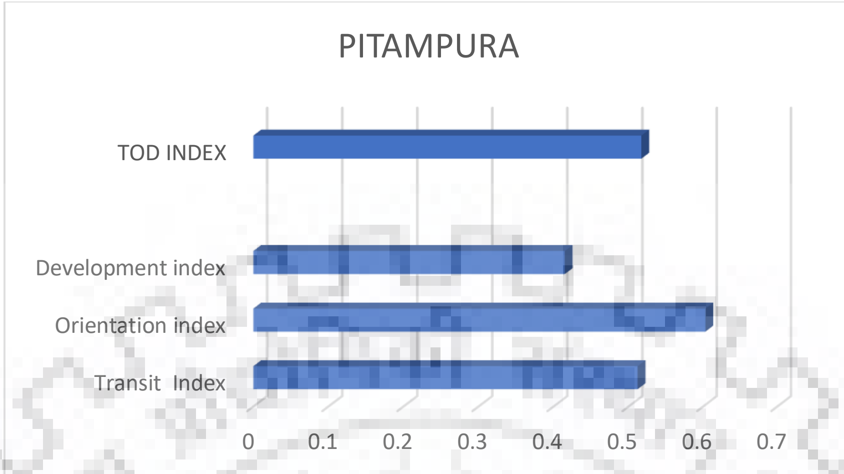


Fig 4.25 Comparison of all indices For pitampura

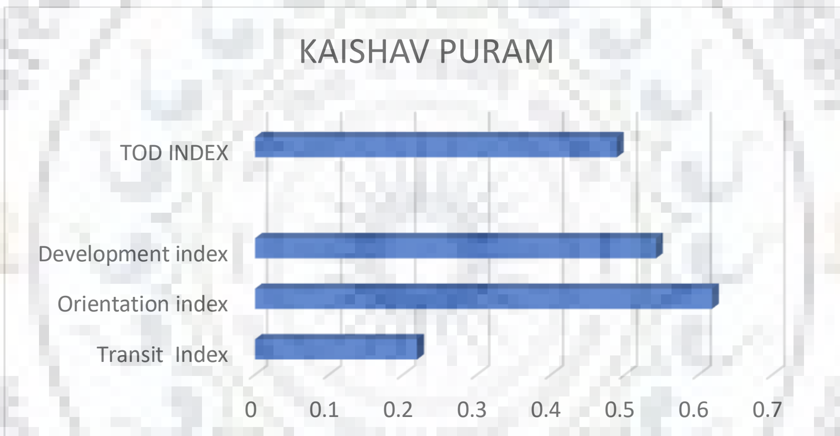


Fig 4.26 Comparison of all indices for Kaishav Puram

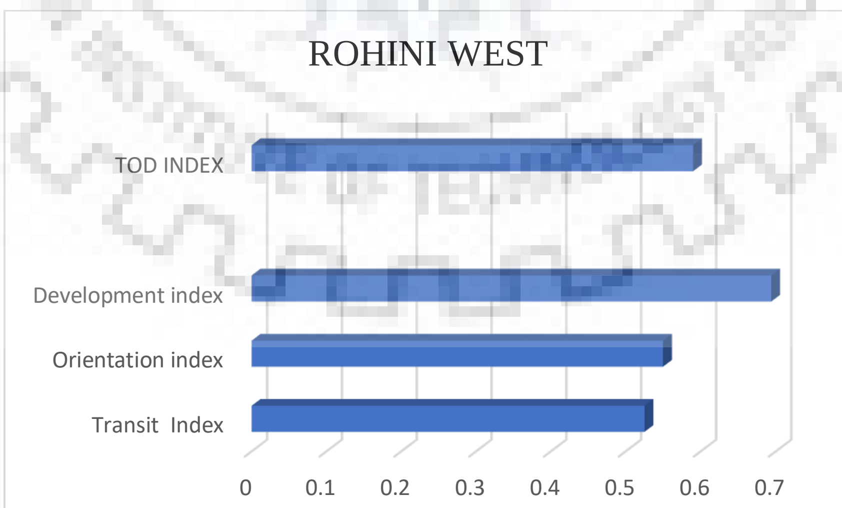


Fig 4.27 Comparison of all indices for Rohini West

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aim of this study was to calculate a quantitative value of TOD i.e. TOD index for the selected metro station areas in Delhi .The approach to understand TOD by considering only Transit and development characteristics was improved and one more dimension was considered which explains the degree of inclination of development towards transit services and that one more dimension is called as “Orientation index “. 14 metro station were selected based on observational survey and transit ridership data, Total of 14 Indicators were selected that measures the transit , development and orientation characteristics based on literature available on TOD, weights to all indicators were given by using analytical hierarchy process which include the experts opinion of various stakeholders such as Researcher , planners, builders and Users.

The idea of using three different indices is to understand that which dimension to target for improvement for a particular station in context of TOD planning, for example Transit index for Jangpura is least among all other station that means transit services needs improvement Similarly kashmere gate have least development index but have above average value of transit and orientation index, therefore investment should be made to increase the urban densities and land use mix in order to have higher TOD index value. This way higher cost to benefit ratio can be achieved.

It should also kept in mind that the values obtained for different indicators are normalized values i.e maximum development index of 0.694 for Rohini west station means that , comparatively , Rohini west have good development among all selected metro station but there may still be a scope of improvement in development of that particular area . However those station with least index values should be dealt first in order to improve the overall TOD index value of the area.

Thus it can be said that by calculating three different index i.e. Transit index, Development index and orientation index, specific problem area can be easily identified and can be dealt accordingly.

5.2 Recommendations

After the thorough study of TOD typology given in international and local literature it is clear that TOD index plays an important role in developing a TOD policy in Indian context.

As TOD comprises of the three basic component, transit, development and their interdependency i.e. orientation, so in order to have a well-planned and well-designed TOD area these component should be consider separately.

Transit utilization can be increased

- By increasing the Passenger carrying capacity of transit service.
- By providing sufficient Parking spaces for private vehicle, cycle as well as for IPT.
- By providing more no. of feeder buses
- By providing comfort and affordable travel

To encourage people to live near the transit station, development near station should made in such a way that

- It provides affordable housing
- Maximum densities should be near the transit station so that max no. of people can easily use public transport , this can be achieve by constructing high rise buildings
- Enables a balance mix between the job and housing along metro corridor.
- Diversified land use which includes residential, commercial, Offices/ Light Industrial Schools/ Libraries/ Civic uses Public Parks.

In order to have synergy between the development and the transit service a TOD area must have

- Well-designed, compact, secure and enjoyable street network.
- Pedestrian and cycle friendly environment.
- Frequent feeder transport services such as e- rickshaw, auto rickshaw etc.
- Presence of various amenities such as shopping complex , grocery stores at a walkable distance from transit station
- Easily accessible entry points to the metro station.

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TOD EXPERT OPINION SURVEY

MTech Thesis on "Development of TOD index For Developing cities", IIT Roorkee

A TOD (Transit oriented development) is a high or medium dense place or community with mixed uses, integrating within walkable distance to public transport. More recently, India renowned the TOD concept, after being aware of success of TOD across the world, in mitigating traffic congestion and pollution. This MTech study is taken up by Ramandeep Singh, IIT Roorkee, under the supervision of Prof. M. Parida , IIT Roorkee to develop the TOD index for Indian cities. It is hereby assured that the data collected would be kept confidential and would be utilized for academic purpose only, your valuable time and cooperation will be helpful for the research work.

Date: ....

Name of the Expert: ____________________

Designation: ____________________ Organization: ____________________

Area of Expertise: ____________________ Years of Experience: ____________________

Rate the following criteria/ indicators and mark their relative importance with respect to each other.

NOTE: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance .

1.) How important are the following component of TOD are important in comparison when you recommend for implementing TOD in India?

A	9	7	5	3	1	3	5	7	9	B
Transit										Development
Transit										Orientation
Development										Orientation

2.) Relative importance of different indicators showing the ***Transit characteristics*** of TOD area.

	9	7	5	3	1	3	5	7	9	
Transit ridership										Parking Capacity
Transit ridership										Feeder Buses
Transit ridership										Public Transport Accessibility
Parking Capacity										Feeder Buses
Parking Capacity										Public Transport Accessibility
Feeder Buses										Public Transport Accessibility

3.) Relative importance of different indicators showing the ***Development characteristics*** of TOD area.

	9	7	5	3	1	3	5	7	9	
Population Density										Land Use mix
Population Density										Workers in household
Population Density										Household Income
Population Density										Vehicle ownership
Population Density										Education
Land Use mix										Workers in household
Land Use mix										Household Income
Land Use mix										Vehicle ownership
Land Use mix										Education
Workers in household										Household Income
Workers in household										Vehicle ownership
Workers in household										Education
Household Income										Vehicle ownership
Household Income										Education
Vehicle ownership										Education

4.) Relative importance of different indicators showing the ***Orientation characteristics*** of TOD area.

	9	7	5	3	1	3	5	7	9	
Intersection Density										No. of entry Gates
Intersection Density										Betweeness of station
Intersection Density										Distance accessibility
No. of entry Gates										Betweeness of station
No. of entry Gates										Distance accessibility
Betweeness of station										Distance accessibility