Case Report

Assessing Sustainability of Mixed Use Neighbourhoods through Residents' Travel Behaviour and Perception: The Case of Nagpur, India

Sarika Bahadure [†],* and Rajashree Kotharkar [†]

Department of Architecture and Planning, Visvesvaraya National Institute of Technology (VNIT), Nagpur Pin-440010, India; E-Mail: rskotharkar@arc.vnit.ac.in

[†] These authors contributed equally to this work.

* Author to whom correspondence should be addressed; E-Mail: sarikabahadure@arc.vnit.ac.in; Tel.: +91-712-280-1290; Fax: +91-712-280-1376.

Abstract: Mixed land-use development is the integration of different land-use functions like residential, commercial, recreational, and institutional in an urban sector or a neighbourhood. Integrating transport and land-use mix is one of the goals of planning policies around the world. Prior studies mention the benefits of mixed land-use development towards creating sustainable environment, but do not specify the proportion of the mix of compatible land uses. This study attempts to assess the sustainability of the neighbourhoods with mixed land-use in the context of the Nagpur city, India. Residents' travel behaviour in twelve neighbourhoods is studied by means of indicators namely trip lengths, mode of travel, vehicle ownership, and travel expenses. To investigate the users' insight, the study further examines residents' perception with the help of parameters such as safety, satisfaction, pollution, and mix. The sustainability indices are computed for both residents' travel behaviour and perception, for each neighbourhood. The study revealed that neighbourhoods with high and moderate land-use mix are sustainable with travel behaviour. Residents' perception sustainability index indicates neighbourhoods with moderate land-use mix are more sustainable than those with high and low land-use mixed neighbourhoods. This study advocates stakeholders' insight and the proportion of mix in land-use planning decisions.

Keywords: sustainability index; mixed land-use; neighbourhood; travel behaviour; perception

1. Introduction

Mixed land-use development is about co-existence of more than one type of land-use function like residential, commercial, recreational, educational, *etc.* in a specific area. It gives emphasis on higher intensity and diversity of land uses [1]. It is a key component of many development trends, including traditional neighbourhood development, transit oriented development, new urbanism, liveable communities, and smart growth principles [2]. These development trends act as a strong proponent to create a sustainable environment [3–7]. The land-use mix is associated with certain externalities both in terms of benefits (proximity, vibrancy, and social bonding) and cost (over loaded infrastructure and pollution), creating either a sustainable or unsustainable built environment. Prior studies mention that areas with mixed land-use are more sustainable than segregate areas [6]; however, the proportion of the mix of compatible land uses for sustainable development is not understood.

Traditionally, Indian cities had mixed land-use characteristics [8] with a high mix of commercial and residential uses. Over time, the residential land-use has been replaced by commercial activities due to economic market pressures [9,10]. Other areas in the city have a moderate mix in sub-centres or along a major road. It is obvious from the current state of Indian cities that land-use mix when left uncontrolled leads to the issues of environmental externalities related to mixed land-use. Thus, there is a need to investigate the range of the land-use mix that will enhance sustainability. To investigate this, the neighbourhood scale is appropriate as it provides both residential and non-residential functions [11] and connects communities and dwellings to the wider urban context.

There are various factors like the density, transport facility, travel behaviour, and socio-economic aspects which influence mixed land-use development. Amongst the various factors that affect mixed land-use, transport and land-use mix (as part of urban form or built environment) are strongly interrelated and integrating them is one of the goals of planning policies around the world [4,11–16]. Reid states, the measures of travel demand [trip frequency, trip length, vehicle-miles of travel (VMT), and mode choice] are the functions of socioeconomic and built environment [17]. Leck also supported these variables along with vehicle-hour travel and travel frequency influencing density and mix [18]. Trip generation, trip distribution, modal split, and route assignment also influence travel demand [19].

1.1. Mixed Land-Use and Transport

In a mixed land-use area, as various activities are in close proximity, they support sustainable forms of transport (walking, cycling or transit) [20]. Professional services are permitted in residential areas in few Master plans [21]. Different studies in the past reveal the advantages of mixed land-use supporting sustainable transport, health wellbeing, and reduction of air pollution. Mixing of uses near the employment destination is found to reduce travel demand [13]. Land-use mix reduces personal vehicle travel and significantly increases walking and cycling [16]. Increased walking has a direct connection to health wellbeing. The performance of the body mass index model with mixed land-use suggests that the presence of mixed land uses improves walk-ability [12]. Neighbourhoods with mixed uses facilitate the use of non-automobile travel modes and shorten car trips, thereby reducing vehicle greenhouse gas emissions [22,23].

1.2. Mixed Land-Use and Social Aspects

Social aspects also influence mixed land-use development. A mixed land-use environment creates social benefits favouring the residents [24]. A mix of diverse housing types based on income, functions, and forms provides residents with multiple choices when selecting their abode. A fine-grained mix of attractive destinations and good aesthetic qualities like tree cover in a neighbourhood supports walking for various activities and also for pleasure [25]. Dwellers in neighbourhoods with mixed land-use are more likely to use public spaces [26]. A neighbourhood with mixed land-use promotes a high level of activity on the street, keeping it safe. Children feel safe to play or cycle, elderly meet and talk, and strangers feel they are intruding [27]. Community cohesion, interaction, and sense of belonging are strong in a mixed land-use community. People perform diverse activities (live, shop, play, and work) in the same environs. The frequencies of their meeting, greeting, smiling, and talking increase. Neighbourhoods with mixed land-use provide convenient access to people and places and so residents and workers prefer such neighbourhoods for a balanced life [4].

An insight of the social aspects can be gained with the help of the stakeholders' perception. In a neighbourhood residents are the prime stakeholders. Residents' perception presents the inhabitants' views about the socio-physical services and other aspects of life in their local areas. An insight can be sought on various aspects of the neighbourhood such as diversity, vitality, attractiveness, health, safety, satisfaction, community cohesion, interaction, a sense of belonging, and quality of life. Residents' perception includes community participation, provides an insight on the current status, and reveals the focus area where improvement is needed. This tool is used to assess sustainability aspects. The residents' self-report tool is used to create, a neighbourhood sustainability framework for New Zealand. Behaviours, perceptions and experiences associated with their neighbourhoods are used to get information on the built environment (land-use mix and density) [11]. Residents' perception has been supported in prior studies to provide a robust understanding of various aspects of sustainability like mixed land-use, travel behaviour, environment, density, connectivity, social benefits, *etc.* [12,28–30].

1.3. Need Identification: Mixed Land-Use—Residents' Travel Behaviour and Perception

The interaction of mixed land-use with transport supports sustainability, but the proportion of mix has not been specified in prior studies. Hence, this study attempts to investigate the same with the help of residents' travel behaviour in the mixed land-use neighbourhoods. Travel behaviour is the study of how people use transport. It probes into the number, pattern, and purpose of trips, destinations, modes, route choices, *etc.* [31,32]. Besides these parameters age, gender, status, values, self-selection, attitude, and lifestyles also influence travel behaviour [28,33]. As residents' perception provides an insight of the neighbourhood, this study is further extended to investigate the residents' perception in the mixed land-use neighbourhoods.

The neighbourhoods are selected based on the high to low mix of commercial and residential land-use in the urban context of Nagpur, India. Residents' travel behaviour and perception in the neighbourhoods with mixed land-use is presented in terms of the sustainability indices.

Travel behaviour studies the residents' travel habits like commuting distance, mode of travel, vehicle ownership, and expenses on travel, while perception examines residents' opinion, feelings, safety,

satisfaction, and mix indicators. Though the residents' travel behaviour and perception are less related, the study tries to compare the sustainability indices of these two domains. The purpose of this study is to explore the sustainability of varying land-use mixed neighbourhoods. It addresses the following research questions:

(1) Whether the inhabitants of mixed land-use neighbourhoods support mixing, and if they do, then how much mix is supported to achieve sustainability?

(2) Are the sustainability indices of residents' travel behaviour and perception similar or different?

The organization of the paper is as follows. The introduction presents the mixed land-use and its influencing factors. It further states the need to conduct the study in the neighbourhoods with mixed land-use (through residents' travel behaviour and perception indicators) to achieve sustainability. The second section describes the methodology (data, indicators, results, and observation) in three stages; (a) study area; (b) residents' travel behaviour; and (c) perception. The third section presents the sustainability index model (normalization, weights and aggregation) and discusses the findings. The last section concludes the study.

2. Methodology and Data Presentation

The methodology is divided into three stages (refer Figure 1). The first stage elucidates the study area selection criteria. Twelve neighbourhoods spread across the city, with varying residential and commercial mix were selected for the study. Entropy index is used to measure the land-use mix for these neighbourhoods.
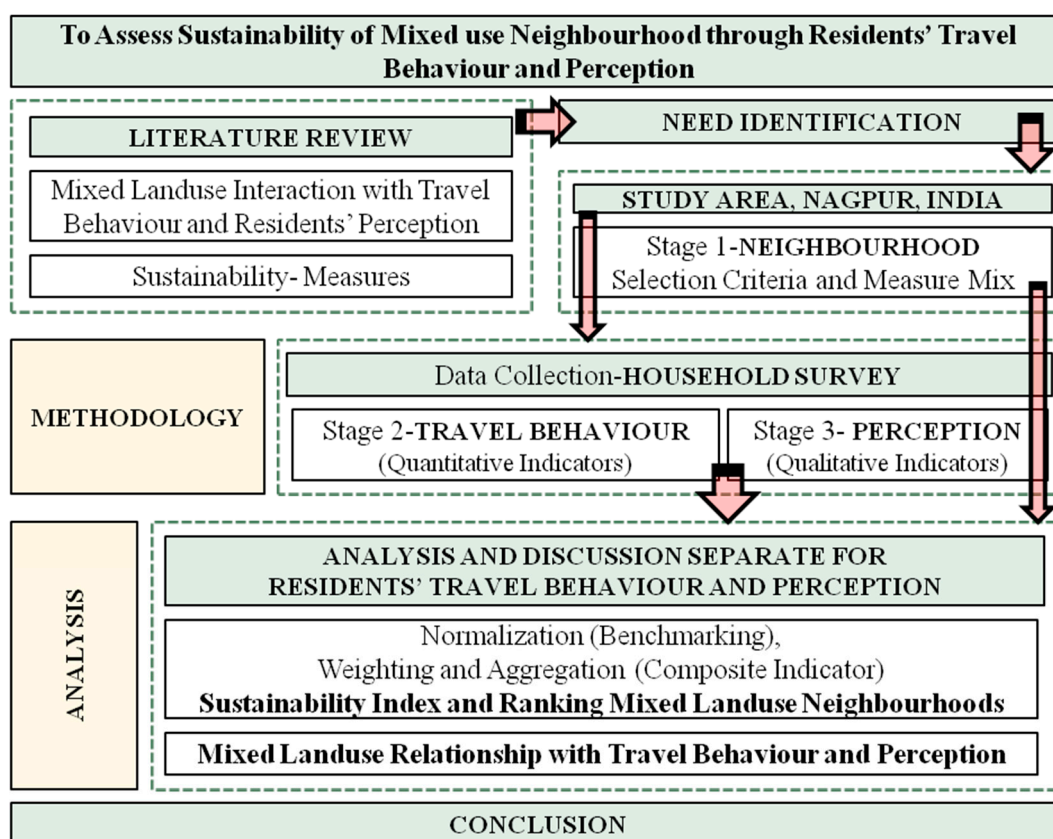

Figure 1. Methodology adopted for the study.

In the second and third stages, residents' travel behaviour and perception is studied. Household survey is conducted to understand various aspects like trip length to various destinations, travel mode, vehicle ownership, safety, satisfaction, pollution, social interaction, *etc.* of residents' travel behaviour and perception. Travel behaviour is studied with the help of quantitative indicators while perception is studied using qualitative indicators. Although a variety of indicators could have been used to operationalize sustainability index, the study is restricted to eleven travel behaviour indicators and twelve perception indicators.

Indicator scores are used to compute the sustainability index for each neighbourhood under travel behaviour and perception domains. At the end, the sustainability index score is correlated with the land-use mix measure (entropy index) to identify the relationship.

2.1. First Stage—Study Area: Neighbourhoods in Nagpur City, India

Nagpur is centrally located in the country and well connected to major cities in India by air, rail, and road. It acts as the key administrative, business and institutional centre for central India. The total area of Nagpur Municipal Corporation is 21,756 hectares. The Nagpur city has a population of 2,405,665 as per 2011 census with a gross density of 110 persons per hectare. Nagpur is ranked the thirteenth largest urban agglomeration in India [34].

There is an observed pattern of a varying land-use mix within the city. The core has a dense mixed land-use environment that has evolved over time. These areas have high land and rental value making it less feasible for pure residential use so mixed land-use exists. There are planned and semi-planned areas with a balance of residential and non-residential activities. Sprawled areas near the fringe are partly planned and partly unplanned plotted development with residential and no commercial use [27].

2.1.1. Selection Criteria for Neighbourhoods

There are different typologies of neighbourhoods within the Nagpur Municipal Corporation limit, each with a different land-use mix. The city-core has a dense mixed land-use environment evolved over time. In these areas more commercial land-use prevails due to the high land and rental value making it less feasible for pure residential use. The other areas of the city are planned and semi-planned with a moderate mix of residential and non-residential activities. The sprawled areas near the fringe are partly planned and partly un-planned plotted development with residential and no or little commercial use [27]. The development potential is bringing changes to the existing land-use pattern of the city. Whether this change is creating sustainable or unsustainable environ for the city needs to be explored. An attempt is made to study the sustainability status of neighbourhoods with varying mixed land-use.

Twelve neighbourhoods (NH1 to NH12) under four categories (L1 to L4) of varying residential and commercial mix were selected for the study (refer to Table 1 and Figure 2). Within a category the age of the included neighbourhoods and their socio-economic characteristics are similar.

Table 1. Twelve neighbourhoods under four categories of varying land-mix.

Category		Neighbourhoods	Population Density	Population Density Including Floating Population	Age of Neighbourhood (Years)	Spatial Distribution	Mix Characteristics
Level-1 (L1)	NH1	Buldi—CBD and centrally located	230.29	394.62	150	core area, compact, organic, medium rise high density	high mix of commercial and residential land-use
	NH2	Itwari—known for wholesale market	466.46	596.56	150		
	NH3	Mahal—known for heritage and retail market	323.62	442.48	150		
Level-2 (L2)	NH4	Sadar—in North West Nagpur	75.65	102.77	100	partly old core compact, organic, dense and partly new planned	moderate mix of commercial with residential land-use
	NH5	Dharampeth—in West Nagpur	158.04	193.76	75	moderately dense, low to medium rise and planned	
	NH6	Buddha Nagar—in North Nagpur	234.49	250.20	75		
Level-3 (L3)	NH7	Nagsen Nagar, Jaripatka—along Nara Road and Ring Road in North Nagpur	257.70	259.13	40	moderately dense, low to medium rise and planned	mix of commercial only along the major road with no influx of commercial in the residential areas
	NH8	Trimurti Nagar—along Ring Road in South West Nagpur	176.16	177.05	30		
	NH9	Friends Colony—along Katol Road in North West Nagpur	142.04	142.79	25	partly moderately dense and planned and partly sprawled low rise	

Table 1. *Cont.*

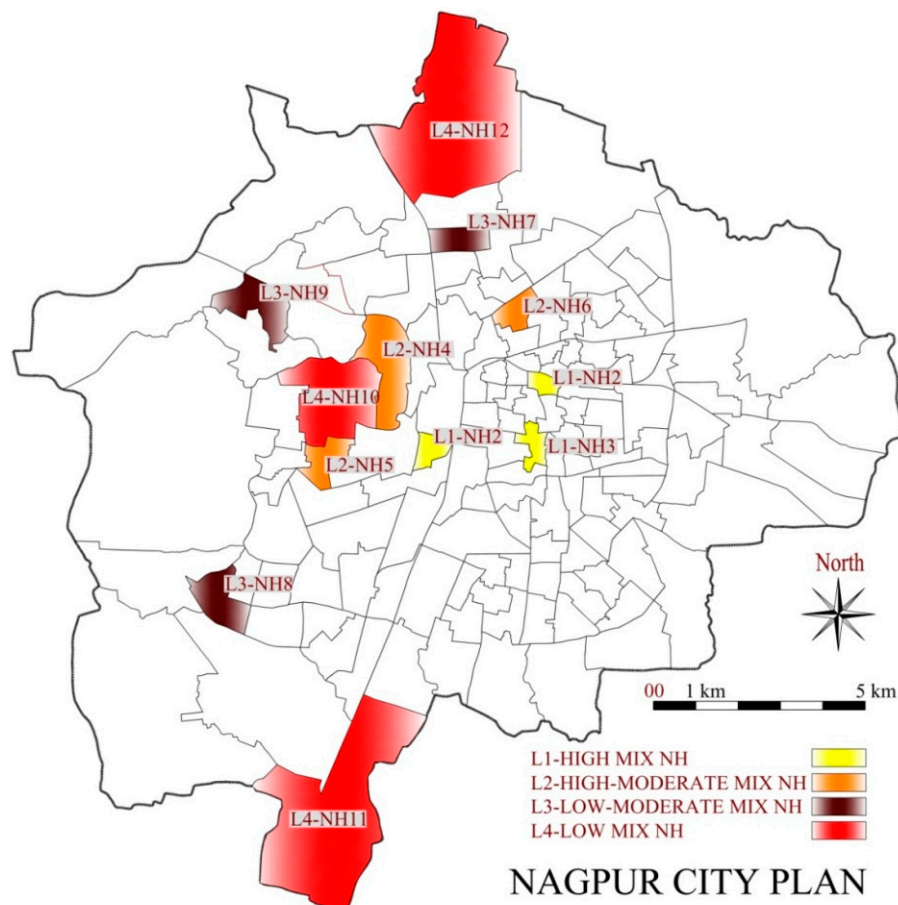| Category	Neighbourhoods		Population Density	Population Density Including Floating Population	Age of Neighbourhood (Years)	Spatial Distribution	Mix Characteristics
Level-4 (L4)	NH10	Civil Lines—Residential and administrative area planned and designed during British period in West Nagpur	39.32	41.95	90	planned and sprawled low rise	no or very less ingress of commercial activity and has only residential land use
	NH11	Nara—Sprawl growth in North suburb Nagpur	32.64	32.73	5–10	partly planned and partly unplanned sprawled low rise	
	NH12	Manish Nagar—Sprawl growth in South suburb Nagpur	32.64	32.69	5–10		

Figure 2. Spatial location of the selected neighbourhoods in Nagpur City.

2.1.2. Sample Selection

The procedure for selecting the sample size is important since the study depends on data surveyed. Simple random sampling across the twelve neighbourhoods with uniform stratification was carried out. The initial sample size n_1 is calculated by Equation (1a). The size of population is adjusted using Equation (1b), but this has an effect on the small and moderate size populations. In this study n_1/N is negligible, so assumed $n_2 = n_1$. The design effect is the ratio of the sampling variance of an estimator under a given design to the sampling variance of an estimator under the simple random sampling of the same sample. The design effect is accommodated by Equation (1c). Finally, the response rate is adjusted to determine the final sample size by Equation (1d) [35].

$$n_1 = \frac{z^2 P(1-P)}{e^2} \tag{1a}$$

$$n_2 = n_1 \frac{N}{N + n_1} \tag{1b}$$

$$n_3 = d_{eff} \times n_2 \tag{1c}$$

$$n = \frac{n_3}{r} \tag{1d}$$

The assumptions and constants used for the above equations are: the total population of twelve neighbourhoods (N) which is 216,829; margin of error (e) is taken to be 6%; confidence level is 95% so

(z) is 1.96; population variance (P) is 50%; design effect (d_{eff}) for simple random sampling is 1 and response rate (r) is 75%.

Using the above technique n_1, n_2, and n_3 is 268 and the final sample n is 357. Thus, total samples considered for the study is 360. Carrying out uniform stratification, each study area is allotted 30 samples.

2.1.3. Measuring Land-Use Mix

Measuring land-use mix is critical to mix land-use studies and there have been numerous methods of measuring like entropy index, dissimilarity index, distance to walkable destination (amenities and transit stops), and the number of amenities available within a certain distance [12]. Entropy index quantifies randomness, segregation, diversity or compressibility in the data. Land-use mix exhibits a pattern of combination and segregation of different land uses. So, entropy index is the most widely accepted and commonly used index by researchers for representing the land-use mix within geographic area [12,13,15,36,37]. Crevero [13] derived the entropy Equation (2a) as:

$$Entropy\ Index = (-1) \times \sum_{j} \frac{P_j \times \ln(P_j)}{\ln(J)} \tag{2a}$$

where, P_j is the proportion of developed land in the Jth land-use type. Frank described the evenness of the distribution of built square footage among seven land-use categories as single family, multi-family, retail and service, office, entertainment, institutional and industrial and later for a three-category mix of residential, commercial, and office [36,37].

Entropy index varies between 0 and 1, wherein 0 indicates single use (homogenous) and 1 maximum land-use mix (heterogeneous).

The existing land-use distribution for each neighbourhood is plotted on the base map through a field survey. High resolution is used for the base map which is at plot or property level. The entropy index is computed for commercial and residential land-use by Equation (2b).

$$Landuse\ Mix\ Entropy\ Index\ (EI) = (-1) \times \frac{\left[\left(\frac{b1}{a}\right) \times \ln\left(\frac{b1}{a}\right) + \left(\frac{b2}{a}\right) \times \ln\left(\frac{b2}{a}\right)\right]}{\ln(n)} \tag{2b}$$

where, a is the total area in square meter of two land uses, b1 is the commercial land-use area in square meters, b2 is the residential land-use area in square meters, and n is 2 (total number of land uses in the mix). Table 2 shows the entropy index of the neighbourhoods. The neighbourhoods are placed in the descending order of entropy index values in each category.

Table 2. Entropy index of the selected twelve neighbourhoods.

Category Levels	L1			L2			L3			L4		
Neighbourhoods	NH1	NH2	NH3	NH4	NH5	NH6	NH7	NH8	NH9	NH10	NH11	NH12
Entropy Index	1.00	0.95	0.78	0.78	0.77	0.71	0.35	0.30	0.17	0.21	0.08	0.12

2.2. Second Stage—Residents' Travel Behaviour: Indicators, Results, and Observations

Travel behaviour explores the accessibility, mode, vehicle ownership, and expenses related to travel. The study on residents' travel behaviour is based on measurable indicators (refer Table 3). Each indicator score is computed from the household survey and the average score is taken for analysis.

Table 3. Travel behaviour (quantitative indicators).

Indicator Set	Indicator Description
Accessibility to land-use destination (Trip length of travel in kilometres)	1. Trip length for Work 2. Trip length for Shop 3. Trip length for Vegetable market 4. Trip length for School 5. Trip length for College 6. Trip length to Health facility 7. Trip length for Restaurant/Theatre 8. Trip length for Garden
Travel Mode to work	9. Percentage of Sustainable Mode (Walk + Cycle + Transit)
Vehicle Ownership	10. Two-wheelers and Four-wheelers {Converted to Passenger Car Unit (PCU) for uniformity}
Travel Expenses	11. Percentage of Income spend on travelling

2.2.1. Accessibility to Land-Use Destinations

The trip length is the actual network distance travelled by the residents from their own residence to various destinations. The trip length to various destinations is computed from the survey report. The selected destinations are workplaces, shops, educational institutions, health amenities, and recreational areas.

The trip lengths to different destinations vary across the neighbourhood categories (refer Figure 3). The proximity to the amenities is directly proportional to the number of trips. In NH1, due to commercial dominance, only those people having their workplaces in the same neighbourhood reside there, while others have migrated to different parts of the city leaving their residential space for commercial use. It is observed that the high land-use mix in neighbourhoods results in more residents having their workplaces within 25 meters (assumed as work from home). This indicates the proximity to the workplace in high land-use mix areas. In the higher income group (HIG), children travel more than 5 km in all neighbourhoods to reach school. Residents from low land-use mix areas (NH11 and NH12) move outside the neighbourhood to access almost all amenities and travel around 9.5, 5.5 and 4.5 km on an average for work, school, and health facilities respectively.

2.2.2. Mode of Travel

Mode of travel to the destination includes two-wheeler, four-wheeler, walking or traveling by cycle, para-transit (motorized cycle rickshaw), and bus. High walkability is noted in areas with high land-use mix (refer Figure 4). The mode share of public transport does not show a relationship with the land-use mix which indicates that the land-use mix does not promote or discourage the use of public mode.

Instead, residents prefer to use a personal vehicle rather than public transport. In L4 category, due to greater commuting distance to work, residents do not prefer to walk or cycle.
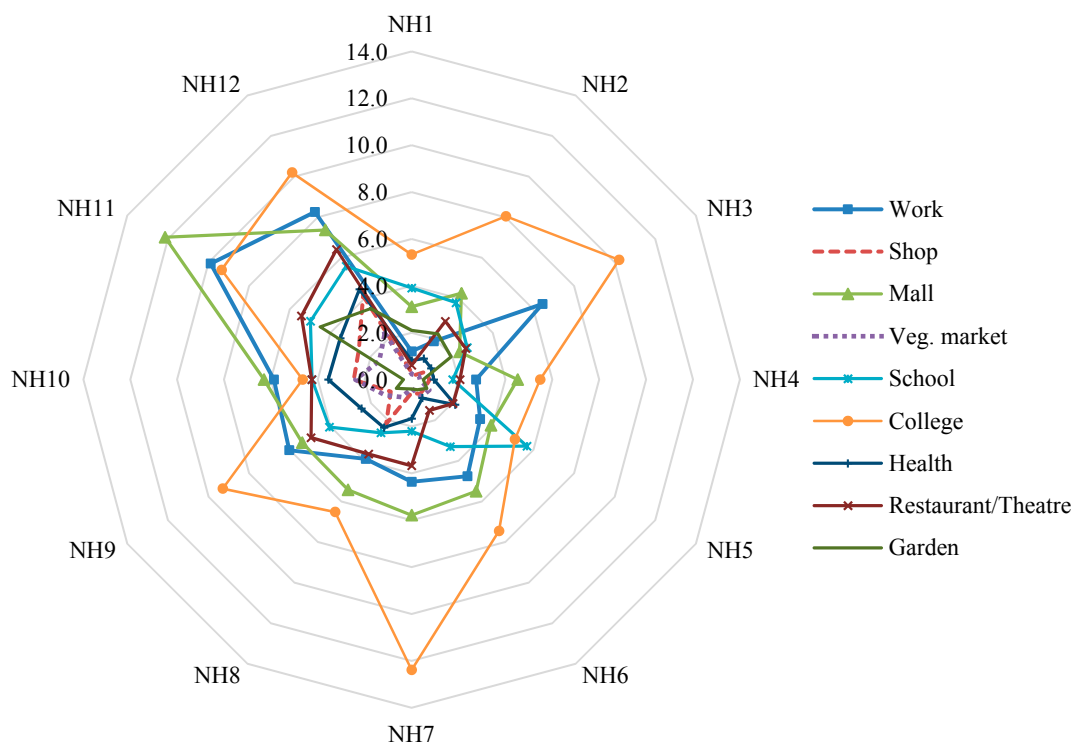

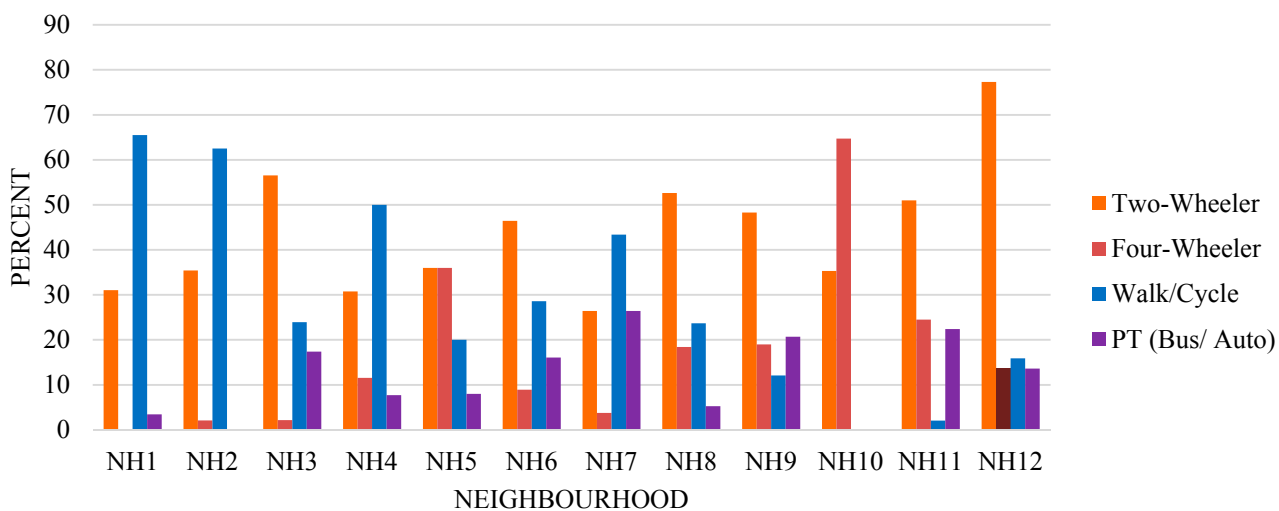**Figure 3.** Access to various land-use destinations.

Figure 4. Travel mode percentage for work trip.

2.2.3. Vehicle Ownership

Vehicle ownership is recorded in terms of the number of cycles, two-wheelers, and four-wheelers. Vehicle ownership per household is calculated in terms of percentage (refer Figure 5). Nagpur is a two-wheeler city, where two-wheelers contribute to 55 percent of all mode of transport share and 65 percent of non-motorized mode share [38]. It is observed that irrespective of the income group and

neighbourhood type, two-wheeler ownership is high and constant. Vehicle ownership is observed to be linked with the income levels as cycle ownership is high in neighbourhoods with low income residents (NH7) whereas, car ownership is higher in neighbourhoods with high income residents (NH5 and NH10). However, many residents in high mix (L1) neighbourhoods reported that, they can afford a car but are discouraged to own one due to the unavailability of parking space and congestion.
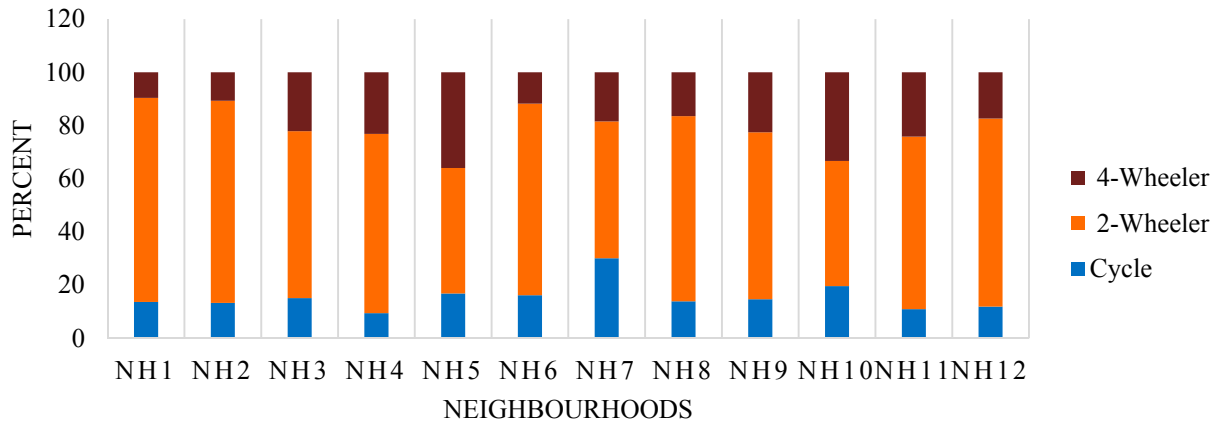

Figure 5. Vehicle ownership in percentage.

2.2.4. Travel Expenses

The average household income of residents from NH4, NH5, and NH10 is high, and that of residents from NH7 is low; the income of inhabitants from other neighbourhoods is in a similar range. Total travel expenses per month are calculated as a sum of spending for different destination trips and the maintenance of the vehicles (refer to Figure 6). It is observed that residents in neighbourhoods with high land-use mix spend less and those living in neighbourhoods with low land-use mix spend more on travel.
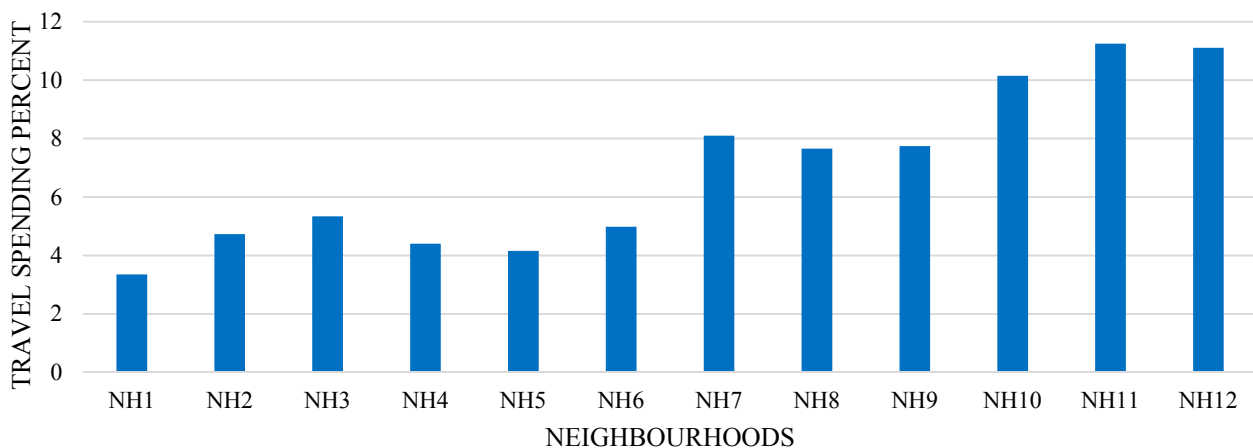

Figure 6. Percentage of household income on travel expenses per month.

2.3. Third Stage—Residents' Perception: Indicators, Results and Observations

The study of perception tries to understand residents' perception about the neighbourhood in the context of safety, satisfaction, pollution, interaction, and mix. This insight is obtained through a household survey. The questionnaire is formulated on the five-point Likert scale (LS) (scored as 1-strongly satisfied; 2-satisfied; 3-neither; 4-dissatisfied; and 5-strongly dissatisfied) and "yes/no" (Y/N) answers nominal scale as mentioned in Table 4.

Table 4. Residents' perception (qualitative indicators).

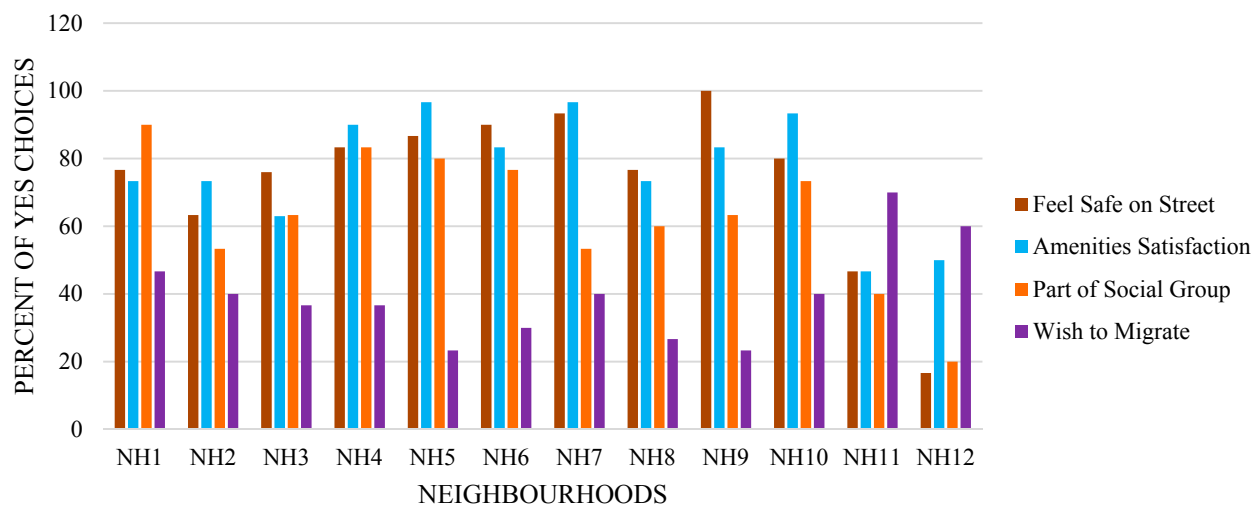| Indicator Set	Indicator Description
Safety and Satisfaction	1. On street Safety (Y/N)
	2. Satisfied with amenities in NH (Y/N)
	3. Wish to shift from current NH (Y/N)
	4. Part of Social Group (Y/N)
	5. Neighbourhood Safety (LS)
	6. Neighbourhood Quality (LS)
	7. Sense of Belonging (LS)
Pollution	8. Feel Traffic Problem (Y/N)
	9. Feel Noise Pollution(Y/N)
	10. Feel Air Pollution(Y/N)
Favour Mix	11. Favour mix of residential and commercial land-use (LS)
	12. Favour mix LIG, MIG and HIG (LS)

2.3.1. Safety and Satisfaction

The road and neighbourhood safety is studied. Road safety is studied through accidents and neighbourhood safety in terms of natural surveillance, citizen's safety, and safety from theft. Satisfaction is studied in terms of neighbourhood quality, availability of amenities, a sense of belonging, residents' wish to migrate to another neighbourhood, and their participation in a social group. Figure 7a indicates the residents' aspiration towards safety and satisfaction measured as the percentage of "yes choices". The high score on "yes choices" for street safety, satisfaction about amenities, and participation indicates that residents feel safe and are satisfied, however a high score on migration indicates dissatisfaction. Figure 7b indicates the cumulative count of the Likert scale for thirty households in each neighbourhood. The higher score on the Likert scale indicates higher neighbourhood safety, quality and sense of belonging.
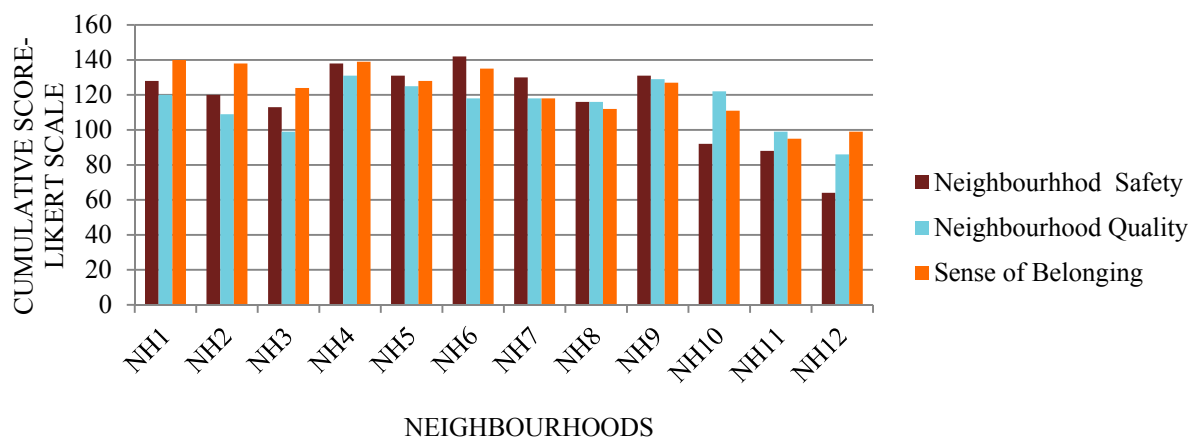
The amount of satisfaction felt by the residents towards their neighbourhood is studied. Quality amenities within the neighbourhood satisfy the residents. In many neighbourhoods some amenities are highly accessible, while others are less accessible. Dissatisfaction with the quality of the neighbourhood leads to an urge to migrate to a better neighbourhood. The sense of belonging is highly related to the social factor rather than the physical factor.

The overall satisfaction level is above average even when there is inadequate infrastructure. Areas with high land-use mix (L1) are safer in terms of natural surveillance and theft, but not in road safety. They suffer from poor quality of life due to high congestion and, lack of infrastructure and open spaces. Due to the environmental externalities and the pressure to accommodate space for commercial use, L1 residents prefer migration. L1 and L2 residents have a strong sense of belonging and social bonding.

They also interact and take active part in social activities and know more people in their neighbourhood. Residents in moderate mix (L2, L3, and NH10) areas perceive their neighbourhoods as safe and have a higher level of satisfaction. Low land-use mix (NH11 and NH12) residents feel unsafe and dissatisfied due to sprawl, poor road infrastructure, lack of street lights, and little natural surveillance. They show the lowest sense of belonging.

(**a**)

(**b**)

Figure 7. (**a**) Safety and satisfaction—percentage; (**b**) safety and satisfaction—cumulative scores.

2.3.2. Pollution and Traffic Problem

Figure 8 shows the percentage of "yes choices" for pollution and traffic problems. High pollution and the problem of traffic congestion are observed in L1 neighbourhoods. However, some residents from the highly noisy L1 area mentioned that they are used to the high noise level and feel uncomfortable in complete silence. L3 neighbourhoods are perceived as less polluted neighbourhoods. NH10 does not have pollution issues due to high greenery and low density. Some pollution in NH11 and NH12 is seen due to continuous construction work. Neighbourhoods with a high land-use mix see pollution and traffic congestion as externalities.
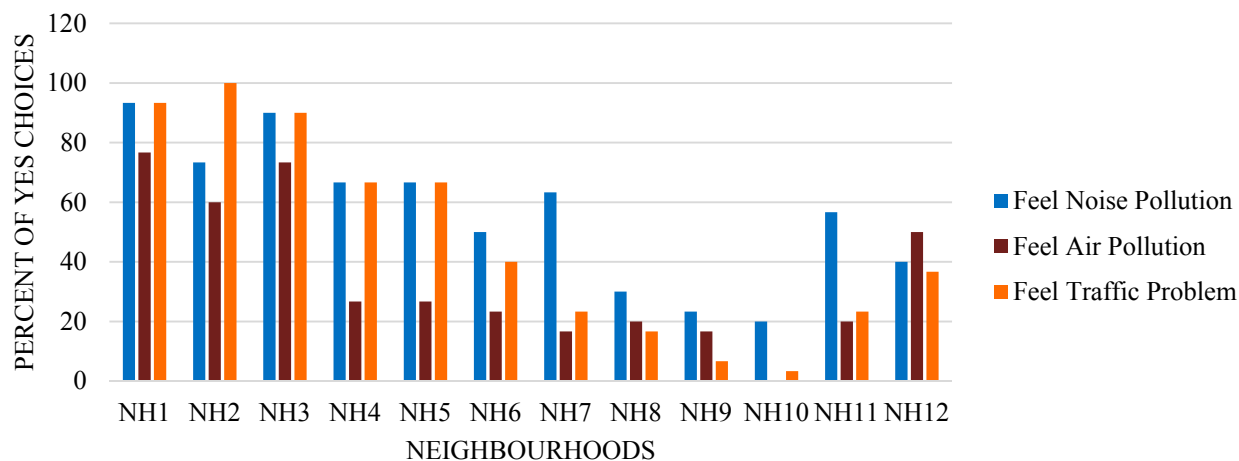
Figure 8. Pollution and traffic related problems.

2.3.3. Favour Mix

This section studies residents' opinion on the mixing of land uses and income. Dwellers favoured a mix of land uses. They mentioned that the commercial area should be on the main road and the residential area should be in the inner part of the neighbourhood by which they would benefit from the proximity to daily needs without having to suffer the externalities associated with commercial use. Most residents expressed their inclination towards a mix of Middle Income Group (MIG) or HIG but not Lower Income Group (LIG) (refer Figure 9). They also stated they are more comfortable with a similar income group.
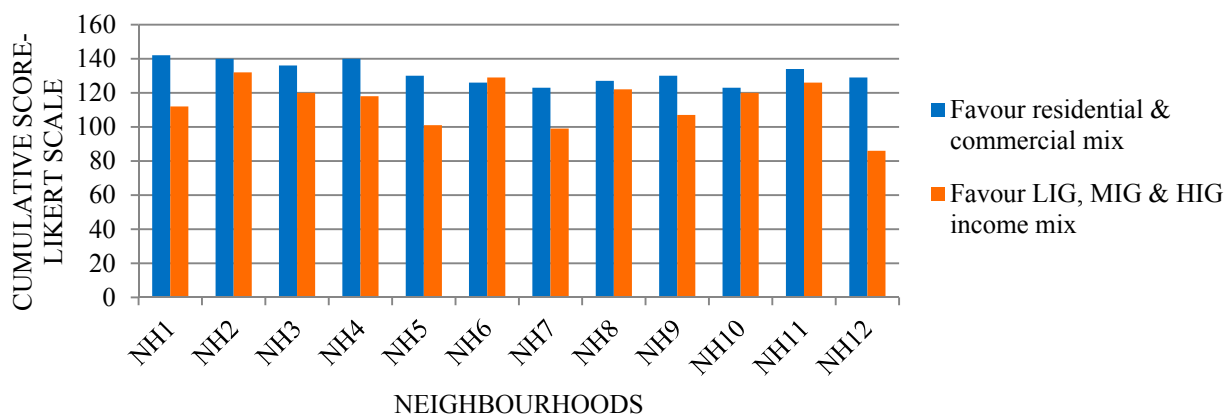

Figure 9. Residents favouring mix—cumulative scores.

3. Sustainability Index Based on Composite Indicators

Sustainability index is calculated using composite indicators which are assigned performance based benchmarking and weights for each neighbourhood.

3.1. Normalization and Benchmarking

Normalization is used to convert different indicator units into a common and comparable scale. The various normalization methods are: (a) ranking based on the indicators' performance over time; (b) standardization or z score; (c) rescaling or min-max method; (d) categorical scale [39].

This study uses normalization on a five-point scale as shown in the Table 5. The colours in the table act as a visual aid for representing the levels of sustainability. To achieve sustainability, the goal for the neighbourhood is to attain a five score.

Table 5. Sustainability benchmarks scores based on normalization.

Five-Point Scale	Sustainability Benchmark (Colours represents levels)
1	Low (extremely unsustainable situation)
2	Medium-Low (not suitable but not as bad as in previous case)
3	Medium (discrete level of sustainability)
4	Medium-High (satisfactory level of sustainability)
5	High (target level of sustainability)

Benchmarking establishes a baseline measure for the performance of individual indicators and acts as a yardstick to measure and compare effectiveness. It helps in the appraisal of performance and comparative analysis of neighbourhoods and allows for improvement on current performance.

3.1.1. Benchmarking for Travel Behaviour

The benchmarking for travel behaviour is based on the literature review, expert opinions, and the comparative scale. A lower distance to the destination results in high sustainability. Studies mention that the walking distance to the destination should be less than a quarter of a mile (~0.4 km) [40,41]. Preferred trip length for various purpose of travel varies. The benchmark for a shopping trip length starts from a range of 0.0–0.4 km with an increment of 0.4 km as shops must be accessible by foot. For school, health, and recreational facilities, benchmarking range starts at 0.0–0.8 km as these can be accessible by foot or cycle. Work places are scattered all over the city and residents move out of the neighbourhood for work, thus the benchmarking range starts at 0.0–1.5 km. Institutes for higher education are usually not within or near the neighbourhoods but are spread at different locations in the city and suburbs, thus college going students commute long distances. So, the benchmarking range for higher education starts at 0.0–1.5 km.

Walk, cycle, and transit are the sustainable modes of travel whereas two-wheelers and four-wheelers are non-sustainable modes. The percentage mode share is used for benchmarking.

To compute vehicle ownership two-wheeler and four-wheeler ownership is converted to Passenger Carriage Unit (PCU) for uniformity. The final PCU (vehicle ownership) is computed by the following Equation (3).

$$Passanger\ Carriage\ Unit\ (PCU) = 0.5 \times \left(\frac{Avg\ 2W \times 4.8}{Avg\ HH}\right) + 1 \times \left(\frac{Avg\ 4W \times 4.8}{Avg\ HH}\right) \quad (3)$$

where, 0.5 and 1.0 is the conversion factor for two-wheeler and four-wheeler respectively [42], *Avg 2W* and *Avg 4W* is the two-wheeler and four-wheeler ownership per neighbourhood respectively, *Avg HH* is the average household size in each neighbourhood which varies from 5.27 in NH1 to 3.37 in

NH9 and 4.8 is the average national household size [43]. For benchmarking of vehicle ownership, a lower PCU score specifies higher sustainability.

Household spending on travel is calculated in the percentage of household income. Expenses more than 3% are considered for the benchmark value. The higher the percentage of travel expenses, the lower is the sustainability (refer to Table 6).

3.1.2. Benchmarking for Perception

The benchmarking for perception is based on the expert opinions and comparative scale. The "yes/no" nominal scale questions are converted into the percentage of the households who answered yes. For street safety, satisfaction, and social participation, higher sustainability means a higher percentage of "yes" and *vice-versa*. The residents' "urge to migrate" is recorded in the reverse scale, thus its higher percentage means lower sustainability. Similarly, if perception for pollution and traffic problems is high then the neighbourhood has low sustainability. Neighbourhood safety, quality, sense of belonging, and favouring mix are recorded on a five-point Likert scale. Scores are converted to a 1 to 5 sustainability scale (refer Table 7).

3.2. Weights and Aggregation

Assigning weights to indicators is critical because weighting reflects the relative importance given to each indicator. For travel behaviour indicators, weights are assigned based on researcher's insight, peers opinion, and residents' view. The share of trip length in indicators is 70%, as it has eight sub-indicators under it. Other indicators (travel mode, vehicle ownership and travel expenses) have a share of 10% each.

The equal weighting technique is adopted for perception data. This is adopted because diversified indicators are present, and it is difficult to judge which is better than the other. There are twelve indicators and each has one twelfth of the weight as shown in Table 5.

Aggregation groups all the indicator scores into a composite index score. To determine the composite indicator score, linear aggregation of the weighted normalized indicator is derived by the Equation no (4).

$$Composite\ Indicator\ Score = \sum_{i=1}^{n} w_i\, I_i \tag{4}$$

where, i = 1,2,3,….n, and n is 11 for travel behaviour and 12 for perception indicator; w is the weight of each indicator as mentioned in Tables 5 and 6; and I correspond to the normalized indicator score between 1 to 5.

Table 6. Benchmarking and weights for travel behaviour indicators.

Indicator Description	Sustainability Benchmarking Range						Weights	
	Low	Medium-Low	Medium	Medium-High	High	A	Fraction of A	Weights
	1	2	3	4	5	%		
1. Trip length for Work	6.01–more	4.51–6.00	3.01–4.50	1.51–3.00	0–1.50		(2/8) × A	0.175
2. Trip length for Shop	1.61–more	1.21–1.60	0.81–1.20	0.41–0.80	0.00–0.40		(1/8) × A	0.088
3. Trip length for Vegetable market	1.61–more	1.21–1.60	0.81–1.20	0.41–0.80	0.00–0.40		(0.75/8) × A	0.066
4. Trip length for School	3.21–more	2.41–3.20	1.61–2.40	0.81–1.61	0.00–0.80	70	(1/8) × A	0.088
5. Trip length for College	6.01–more	4.51–6.00	3.01–4.50	1.51–3.00	0–1.50		(0.75/8) × A	0.066
6. Trip length to Health facility	3.21–more	2.41–3.20	1.61–2.40	0.81–1.61	0.00–0.80		(1/8) × A	0.088
7. Trip length for Restaurant/Theatre	3.21–more	2.41–3.20	1.61–2.40	0.81–1.61	0.00–0.80		(0.75/8) × A	0.066
8. Trip length for Garden	1.61–more	1.21–1.60	0.81–1.20	0.41–0.80	0.00–0.40		(0.75/8) × A	0.066
9. Percentage of Sustainable mode (Walk + Cycle + Transit)	0.00–20.00	20.01–40.00	41.01–60.00	60.01–80.00	80.01–100		(1/3) × A	0.1
10. Two-Wheelers and Four-Wheelers Converted in Passenger Car Unit (PCU)	4.01–more	3.01–4.00	2.01–3.00	1.01–2.00	0.00–1.00	30	(1/3) × A	0.1
11. Percentage of Income spent on Travelling	12.01–more	9.01–12.00	6.01–9.00	3.01–6.00	0.00–3.00		(1/3) × A	0.1

Table 7. Benchmarking and weights for perception indicators.

Indicator Description	Units	Sustainability Normalization Range					Equal Weights
		Low	Medium-Low	Medium	Medium-High	High	
		1	2	3	4	5	
1. On Street Safety	Percentage of household answered Yes	59–less	60–69	70–79	80–99	90–100	
2. Satisfied with Amenities in NH		59–less	60–69	70–79	80–99	90–100	
3. Part of Social Group		59–less	60–69	70–79	80–99	90–100	
4. Wish to Shift from Current NH		61–more	46–60	31–45	16–30	0–15	
5. Neighbourhood Safety	5 point Likert scale	1	2	3	4	5	
6. Neighbourhood Quality		1	2	3	4	5	
7. Sense of Belonging		1	2	3	4	5	1/12 = 0.083 each
8. Feel Traffic Problem	Percentage of household answered Yes	86–100	71–85	56–70	41–55	40–less	
9. Feel Noise Pollution		86–100	71–85	56–70	41–55	40–less	
10. Feel Air Pollution		86–100	71–85	56–70	41–55	40–less	
11. Favour Mix of Residential and Commercial use	5 point Likert scale	1	2	3	4	5	
12. Favour Mix of LIG, MIG and HIG		1	2	3	4	5	

3.3. Discussion

The composite indicator, sustainability index, sustainability level, and ranking of the neighbourhoods for both residents' travel behaviour and perception is presented in Table 8. The composite indicators' score is in the range of 0 to 5. It is converted to 0 to 1 scale to compute the sustainability index. The sustainability index of travel behaviour is in the range of 0.27 (for NH11) to 0.78 (for NH1) and perception is in the range of 0.47 (for NH12) to 0.83 (for NH6 and NH9).

Table 8. Sustainability index for travel behaviour and perception.

Category Levels	Selected Neighbourhoods		Travel Behaviour				Residents Perception			
			Composite Indicator Score	Sustainability Index	Comparative Sustainability level	Ranking	Composite Indicators Score	Sustainability Index	Comparative Sustainability level	Ranking
L1	Buldi	NH1	3.90	0.78	4	1	3.25	0.65	3	8
	Itvari	NH2	3.27	0.65	3	3	3.11	0.62	3	9
	Mahal	NH3	2.65	0.53	3	7	3.02	0.60	3	10
L2	Sadar	NH4	3.50	0.70	4	2	3.97	0.79	4	4
	Dharampeth	NH5	2.89	0.58	3	6	3.92	0.78	4	6
	Buddha Nagar	NH6	3.10	0.62	3	5	4.17	0.83	4	1
L3	Nagsen Nagar	NH7	3.20	0.64	3	4	3.84	0.77	4	7
	Trimurti Nagar	NH8	2.41	0.48	2	8	3.97	0.79	4	4
	Friends Colony	NH9	1.84	0.37	2	9	4.17	0.83	4	1
L4	Civil Lines	NH10	1.61	0.32	2	10	4.11	0.82	4	3
	Manish Nagar	NH11	1.37	0.27	1	12	2.51	0.50	3	11
	Nara	NH12	1.40	0.28	1	11	2.34	0.47	2	12

Note: Refer Table 5 for color coding.

The resultant sustainability scores of the neighbourhoods are grouped in five comparative sustainability levels. The final ranking is decided based on the sustainability index score. The neighbourhood with a high index is sustainable and ranked first in the list. Neighbourhoods with a high land-use mix are ranked at the top in travel behaviour, but ranked eighth to tenth in a perception survey. Neighbourhoods with moderate land-use mix are ranked between the third and ninth position for travel behaviour and first to seventh for perception. L4 neighbourhoods having a low land-use mix are ranked last in both cases except NH10 which is placed at third position in perception due to green ambiance and superior infrastructure.

3.3.1. Residents' Travel Behaviour

The travel behaviour study revealed that areas with a high mix of land-use (with entropy index between 0.71 and 1.00) have less trip length, less vehicle ownership, and less travel expenses. Thus, they are more sustainable with a score of 3 and 4 out of 5. However, the neighbourhoods with less land-use

mix are scaled as extremely unsustainable (score 1) to unsustainable (score 2) as they need to travel long distances for all amenities and thus, have high vehicle ownership and more travel expenses (refer to Figure 10). Neighbourhoods with moderate land-use mixed are placed at the satisfactory level of sustainability. The findings in this study confirm the results of prior studies on land-use and travel relationship.
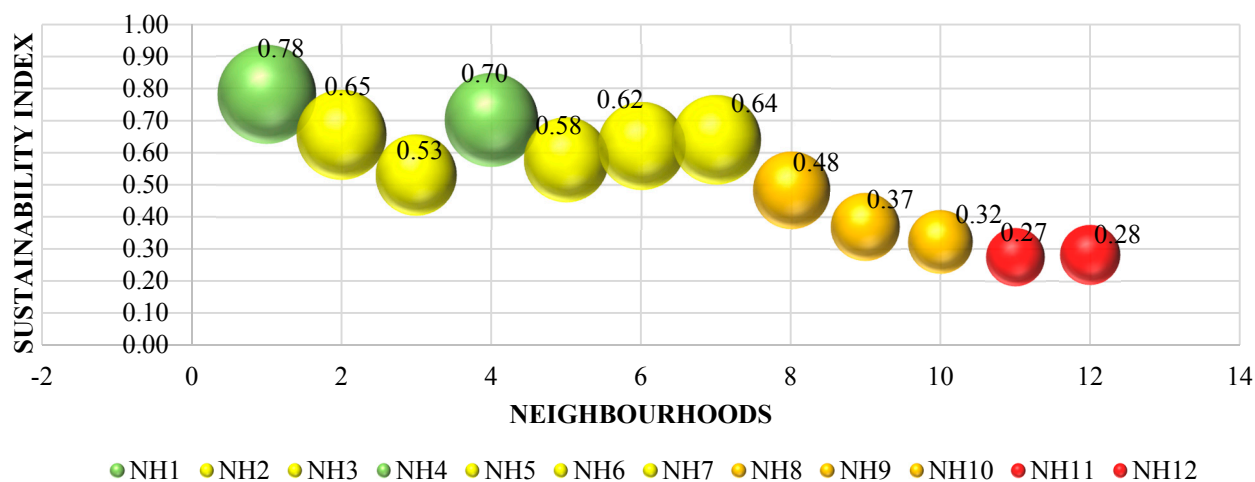

Figure 10. Sustainability index for travel behaviour.

3.3.2. Residents' Perception

Prior studies mention the social benefits of the mix land-use [6], but the study presented here reveals that neighbourhoods with moderate land-use mix are better liveable spaces than neighbourhoods with high land-use mix. This may be due to the fact that most prior studies have been in the context of developed countries where the land-use mix characteristics are very different from developing countries. Moreover, peoples' adaptability to various impacts of land-use mix also varies. It is observed that overall residents express a level of satisfaction even with inadequate facilities and infrastructure. Thus, none of the neighbourhood is extremely-sustainable (score 5) or extremely-unsustainable (score 1) and only one is unsustainable (score 2). Neighbourhoods with moderate land-use mix are sustainable, areas with high and low land-use mix have average sustainability (score 3) (refer to Figure 11).

The sustainability index of residents' travel behaviour with perception shows low correlation (0.30). The findings suggest that, even though neighbourhoods with high land-use mixed are sustainable in travel domain, the residents do not prefer to be part of these neighbourhoods; nor do they want to be part of neighbourhoods with low land-use mix (NH11 and NH12). They prefer neighbourhoods with moderate land-use mix. This advocates that residents wish to stay in neighbourhoods with moderate land-use mix and not in high or low land-use mix.
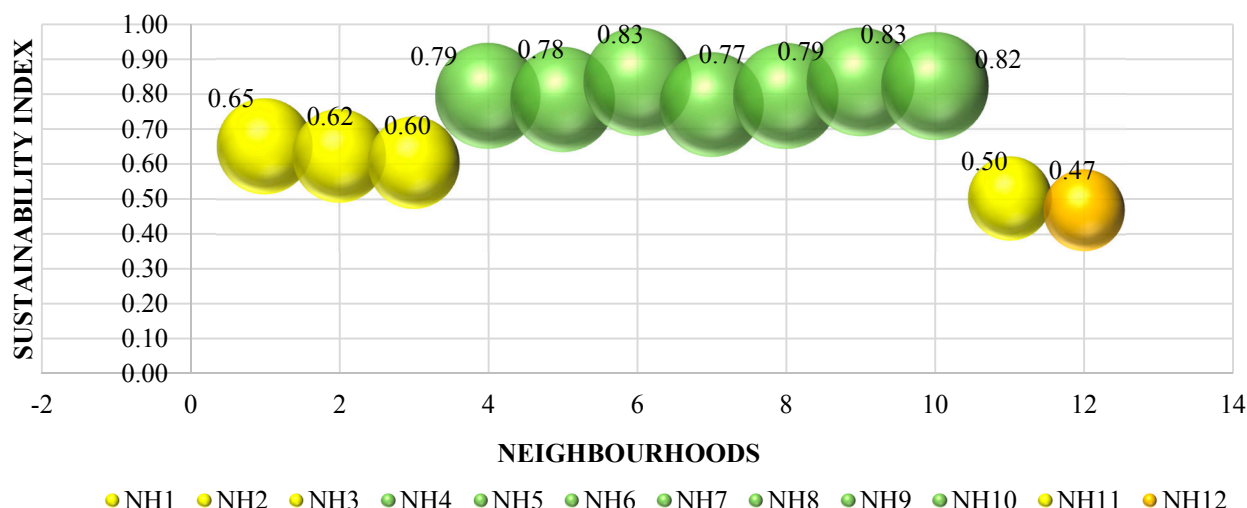
Figure 11. Sustainability index for residents' perception.

3.3.3. Relationship of Mixed Land-Use Measure with Residents' Travel Behaviour and Perception

Figure 12 shows the relationship of land-use mix measure (entropy index) with resident's travel behaviour and perception. The sustainability index score of resident's perception is higher than that of travel behaviour. Low entropy index score (*i.e.*, low mix land-use) is related to low sustainability. Moderate to high entropy index score (*i.e.*, moderate to high mix land-use) is related to moderate to high sustainability.
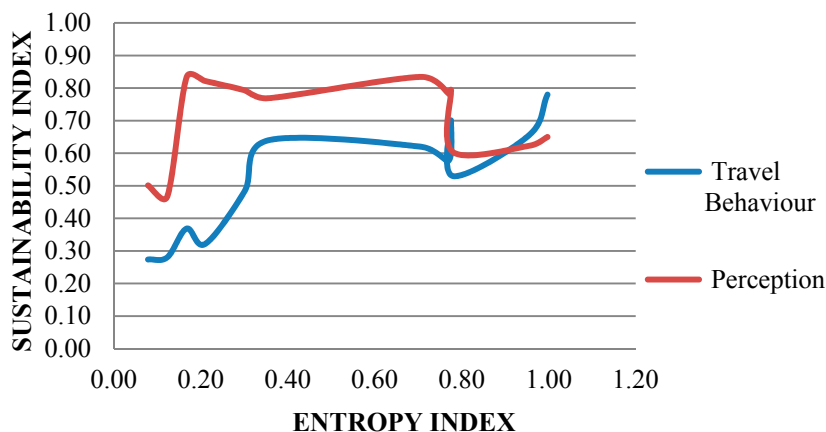

Figure 12. Scatter plot showing relationship of entropy index and sustainability index.

The correlation of the land-use mix (entropy index) with travel behaviour is 0.88 indicating both are highly correlated. Travel behaviour is sustainable when the land-use mix is high and *vice versa*.

The correlation of the land-use mix entropy index with perception is 0.10 indicating poor correlation. It signifies that land-use mix does not directly encourage perception, however, adequate amenities, good infrastructure, and less pollution contribute to an affirmative opinion. In study areas, neighbourhoods with high and low land-use mix lacked infrastructure, leading to dissatisfaction. Thus the poor correlation is perceived.

4. Conclusions

There is a strong advocacy to bring different land uses together for achieving sustainability. Indian cities have a legacy of mixed land-use character. There is an evident mix of land uses in the present context which hints towards a similar trend in the future as well. Here the concern is the proportion of the mix of different land uses for creating sustainable built environment.

Residential and commercial land-use mix is the most compatible mix type. However, the proportion of the mix of these two compatible land uses (commercial and residential) which leads to sustainability has not been explored in prior studies. The change in the land-use mix affects the inhabitants' travel behaviour, their safety and their satisfaction. The current study tries to identify sustainability indices for neighbourhoods with different land-use mix. By surveying twelve neighbourhoods (NH1 to NH12) categorized under four levels (L1 to L4) with different land-use mix, the study has attempted to comprehend how the neighbourhood performs with the change in land-use mix proportion. Mixed land-use is measured as entropy index of commercial and residential land-use.

Perception is carried out to encompass participatory approach, behaviour and experiences with the neighbourhood. The relationship between mixed land-use and travel behaviour has been well established in prior studies and is confirmed in the current study. Mixed land-use measure is highly correlated with the travel behaviour sustainability index, but is weakly correlated to the residents' perception sustainability index.

It can be concluded that the neighbourhoods with high land-use mix (L1 category with entropy nearing 1) are sustainable when it comes to travel behaviour but residents are not satisfied here due to the externalities associated with pollution, congestion, and lack of infrastructure.

The neighbourhoods with low land-use mix (L4 category with entropy nearing 0) are extremely unsustainable due to greater travel distance, poor accessibility of amenities, inadequate infrastructure, as well as safety and satisfaction issues. NH10 even though being a low and segregated land-use mixed neighbourhood, is more sustainable as it is planned and maintained with a good physical infrastructure and is the greenest part of the city.

Moderate land-use mix neighbourhoods (L2 and L3 category with entropy in the range of 0.77 to 0.33) are sustainable both in terms of residents' travel behaviour and perception, and are preferred by the residents. The citizens prefer to be a part of a green, aesthetically appealing, with adequate infrastructure, mixed land-use neighbourhood.

The outcome of the study suggests that high land-use mixed areas though sustainable in the travel domain are not likewise sustainable in the perception domain, due to dissatisfaction amongst the residents here. Low land-use mix and sprawled areas are unsustainable both for the travel and the perception domain. Moderate mix neighbourhoods lead to sustainable development.

Author Contributions

Sarika Bahadure, first author, took the initiative and conceived the study, shortlisted the indicators, collected data through household surveys, and carried out the statistical analysis. Rajashree Kotharkar, the second author, provided a methodology, framework and revisions for study, and structure of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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