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Case Report

Measuring Compact Urban Form: A Case of Nagpur City, India

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Abstract: The compact city concept is adopted in city planning policies of many developed countries for the following benefits: efficient use of land while curtailing sprawl, reduction in transport network and reliance on mass transport, a socially interactive environment with vibrancy of activities, economic viability, *etc.* However, it is still debated whether the cities in developing countries like India, which are already dense, will really benefit from the compact city form. Measuring urban form and compactness of these cities becomes more important for understanding the spatial urban structure to intervene accordingly for sustainable urban development. This paper explores various parameters and dimensions of measurement of compactness. Urban form characteristics and their indicators are derived for the study of Nagpur city, India. This study is an attempt to measure the urban form to derive the benefits of compactness. The study indicates that Nagpur city, inherently has a compact form, but may disperse in near future; and there is a need to implement policies to retain its compact character to achieve sustainable urban development.

Keywords: compact cities; urban form; planning Indian cities; measuring urban compactness; sustainable urban development

1. Introduction

Various urban forms evolved through modern urban planning practices, but often the concern for their negative impacts is observed as missing. This disregard is apparent in the developed world in "Sprawl" as a prime urban form. As significance of "sustainability" is internationally acclaimed, lately but consciously the sprawl is being incitingly condemned for its negative environmental, social and economic impacts [1]. The central premise of this study is that the form of a city can affect its sustainability. Several studies have tried to prove that sustainability of a city might depend on its shape, size, density and land use distribution. Urban form has positive or negative impact on accessibility to facilities, travel attributes (distance and time), energy used, social equity, efficient use of land, economic benefits, reduction in CO_2 emissions, liveliness, *etc.* [2]. But the debate on the most suitable urban form to achieve sustainability is still unresolved. To evolve urban sustainability, the relationships between urban form and the various elements of a city need to be understood [3].

This study is an attempt to measure the existing urban form of a city and to assess its potential to develop it towards more sustainable existence. Possibilities to restructure the city to develop itself into a compact city model are explored.

1.1. Sustainable Urban Development

The major problems in many cities are related to long travel distances, congestion and fuel emissions, degrading environment, social inequity, environmental degradation, health, loss of surrounding land (with agricultural and natural resources). Many of these problems are perceived as an impact of physical urban form [4]. It is widely accepted that cities must be at focus in the sustainable development agenda as cities through their forms affect overall environmental performance and management. Therefore, sustainable urban form can be defined as the form "*which enables the city to function within its natural and manmade carrying capacities—is user friendly for its occupants and promotes social equity*" through inclusive decision making processes [3].

1.2. Models of Sustainable Urban Form

Urban form is a spatial composition of elements that repeat, and if based on certain sustainable concepts, can lead to the sustainability of cities. Various approaches are explored for achieving sustainable urban development through a city's form. Jabareen [5] identifies four urban forms based on seven design principles to attain the goals of sustainable urban development. The seven concepts or principles of sustainable cities are (a) Compactness (b) Sustainable Transport (c) Density (d) Mixed Land uses (e) Diversity (f) Passive Solar Design and (g) Greening. All of these aim at reducing travel distances, saving energy, increase quality of life, efficient use of land, save infrastructure costs, *etc.* contributing to sustainable urban development. The four identified sustainable urban forms by Jabareen are Neo-traditional Development, Urban Containment, Compact City and Eco-City; comprised of combination of the seven design principles or concepts. Each of these urban forms contribute differently in making cities sustainable, however conceptually compact city seems to be more convincing than other urban forms. Similarly Haughton and Hunter identified alternative forms for sustainable cities *i.e.*, (a) *large concentrated centers*; (b) *decentralized but concentrated and* *compact settlements linked by public transport*; (c) *dispersal in self-sufficient communities* [6]. The variations described mostly deal with the form of a compact city. Compact urban form development becomes one of the approaches that seem to have the potential to play an important role in designing sustainable cities.

1.3. Urbanization in India

The last few decades have experienced unprecedented urban growth in the developing world, particularly in Asia and Africa, where a three times increase in the built up urban area (up to 0.6 million square km of cities with million plus populations) from year 2000 to 2030 is projected [7]. Developing countries see it as an opportunity for development and accept it as preferable. Urbanization is perceived as the result of up gradation of human civilizations with proven benefits of economic growth and development. Developing countries need cities to attract human capital for basic economic sustenance [8].

Indian cities occupy 10% of the world's total urban area and house more than one tenth of the world urban population [9]. The present pace and scale of urbanization in India will shortly result in the majority of its population residing in urban areas, which may threaten its sustainability. The quality of life in already strained cities is likely to degrade further, and the tremendous rate of urbanization will have a significant environmental impact. The development of self-capability is a challenge, while the opportunity is in creating growth which is socially inclusive and environmentally friendly [10]. The urbanization in India will definitely have an impact on global sustainability as India's share in global ecological footprint will increase in near future (refer Table 1). Hence, building sustainable cities will be a key to hold India's growth in future.

Table 1. Status of Urban India with relation to the World.

Continent/Country	Average (Persons per Hectare)	% of World's Urban Area	% of World's Urban Population
World	43	100	100
Africa	70	11.2	10.3
North America	16	13.4	13.5
South America	57	7.7	8.5
Australia	14	0.7	0.7
Europe (EU)	28	9.3	7.4
Russia	32	4.2	2.6
Asia	70	51.3	56.0
India	120	10.1	10.6

1.4. Concept of Compact City

The genesis of Compact City lies in the sustainability imperatives of resource conservation and waste-minimization as embodied in the Brundtland Commission report and the UNCED Agenda 21 proposals published in the late eighties and the early nineties [11].

Ewing's argued idea is "*high densities impels less space observed per capita with more land for agriculture and open spaces*; *bus and rail serves better in dense settlements with lesser reliance on* *automobiles; and higher densities reduce society's environmental footprint and slow the consumption of nonrenewable resources*" [12]. A compact city form can facilitate for mass transport and reduction in travel distances, emphasis on pedestrian traffic, efficient use of land through high population densities, social cohesion and cultural development, and the economy in per capita cost of infrastructure provision and minor businesses by making a supportive threshold population available, implanting more vibrancy in cities. The benefits of compact cities are perceived more through high density and public transit [13].

Thus, a possible solution offered for achieving sustainable urban form is that of "Compact City Model Development". Essentially the compact city model defined as "…a high density, mixed use development, within a restrictive geographical area with enhanced public transport and infrastructure facilities". However, there are debates about the merits of a compact urban form. The excess increase in building and population density may result in overcrowding in residential areas as is seen from the examples of Hong Kong. Provision of ample amount of per capita open space is important to maintain quality of life, which becomes difficult in compact cities. Irrespective of the type of urban form, management of the city is more important to achieve sustainability, and it is more complex in compact urban forms [5]. The contained urban land in compact settlements which is shared by more people with high density may have higher land prices not affordable to disadvantageous groups. Noise pollution is the major concern in mix land use areas and conflict may occur with diversified uses. Adaptability to compact living, high density and mass transit is highly culturally and regionally dependent. Compact forms may be more prone to devastation in case of disasters. Thus, the constraints lie in provision of open spaces, overcrowding, complex urban management, increased land prices, pollution, regional adaptability, disaster resiliency, *etc.*

2. Measuring the Urban Form

2.1. Need for Measuring Urban Form

Cities are constantly evolving and at any point of time exhibit their unique character through their urban structure, which can be mapped and measured. Cities have a hidden structure which is to be understood only through analyzing the data, more particularly the land use and population distribution. It becomes evident in today's context to monitor and manage the spatial expansion of cities which is more complex now [14,15].

The scales at which urban form can be measured include the individual building, street, urban block, neighborhood and city [16]. These levels of spatial disaggregation influence how urban form is measured, analyzed and ultimately understood. Understanding the spatial organization of a city allows planners to (i) decide the course of action for future development; (ii) frame strategies that are integral to the existing spatial structure; and (iii) influence the evolution of the existing structure in a manner consistent with planning objectives [15,17]. Spatial structure of a city is a result of impact of events, technologies, policies and preferences throughout the history of a city, and hence investigating it is much more complex and challenging [2].

Though compact urban form is seen as a sustainable urban form, it is important to measure the compactness of urban form through various urban characteristics, for its intended benefits.

2.2. Approaches for Measuring Urban Form

Various measures of urban form are developed by researchers, which also include the methods of diagnosing sprawl in a city. The research work majorly relates to understanding the impact of urban form on transport behavior and environmental, social, and economic variables. The indicators (refer to Table 2) broadly represent key urban form characteristics and mainly attempt to study the four aspects: (i) resident population distribution over the urban area measured by density distribution; (ii) distribution of areas of commercial and recreational activities, services, employment, *etc.* within the city in relation to the place of residence; measured by diversity, mixed use; accessibility, composition, size, shape; (iii) nature of transportation network and modes people use for travel; (iv) design quality of the built form encouraging or discouraging certain behaviors. Thus, urban form can be studied and evaluated on the basis of analysis of the data related to the above aspects [2].

Table 2. Various Approaches to Measure Urban Form; Source: [2], Literature Review.

S. No.	Researcher	Trends Measured	Indicators/Study Variables
1	Jabareen, Y.R. [5]	Urban Form Types and their Sustainability	Assessment of urban forms for their sustainability through ranking of various urban elements or concepts in each urban form type viz. Density, Diversity, Mixed land use, Compactness, Sustainable Transportation, Passive Solar Design and Ecological Design (Greening)
2	Galster, G., *et al.* [18]	Urban Sprawl Index	Measurable aspects of land use patterns: density, continuity, concentration, clustering, centrality, nuclearity, mixed use and proximity
3	Ewing R., Pendall, R. and Chen, D. [19]	Sprawl Indices for four components	Indicators of urban form: (a) residential density; (b) neighborhood mix of homes, jobs and services; (c) strength of activity centers and downtowns; (d) accessibility of the street network
4	Bertaud, A. [14]	Spatial Structure of City	Two principal components (a) the spatial distribution of the population as recorded by census data and (b) the pattern of trips made by people when they go from their residence to other locations for work, school, shopping, social activity, *etc.*
5	Song, Y. and Knaap, G. [20]	Development patterns	Five key characteristics of neighborhood form: street design and circulation system; density; land use mix; accessibility; and pedestrian access.
6	Krizek, K.J. [21]	Relationship between neighborhood accessibility and transportation behavior	Composite indicator of neighborhood accessibility based on housing density, landuse mix (number of employees in neighborhood retail) and street design.
7	Hess, P.M., *et al.* [22]	Relationship between site design and pedestrian travel.	Using block size and length and completeness of sidewalks as indicators
8	Burton, E. [23]	Relationship between density social equity	Key urban form characteristics looked at were: density, mix of uses, and intensification.
9	Fulton, W., *et al.* [24]	Trends in urban form and land consumption	Actual measurement of urbanized land and density in metropolitan areas
10	Knaap *et al.* [16]	Multidisciplinary measures of urban sprawl	Measurement of density- its distribution and variation; measures of shape, accessibility, transport networks, neighborhood design, landscape ecology, *etc.*
11	Tsai, Y. [25]	Measures to distinguish compactness from sprawl; at the metropolitan level	Measuring form through dimensions of—size (population), density, degree of equal distribution (Gini coefficient) and degree of clustering (Moran coefficient)

3. Methodology

3.1. Aim, Objective and Case Study Selection

The aim of this study is to measure the urban form for discovering the potential of its compactness if present. The objectives are: (i) to explore various measures of urban form through literature review; (ii) to derive appropriate indicators and to find out whether present urban form of the selected city contains compact urban characteristics which are favorable for achieving sustainable urban development. The premise of this study is that compact urban form is sustainable.

Initially a set of urban form characteristics and the respective indicators are derived from the literature review. As a case study, Nagpur city—the largest city in central India within a radius of 500 km with considerable urban growth and influence on the region is selected (refer to Table 3 for statistics). The urban context of Nagpur city is studied by interpreting data collected (through secondary sources) for measuring and understanding the urban form. At the end, the level of compact development of Nagpur is assessed through data analysis and findings. The conclusions drawn are used to propose policies and strategies to intervene and restructure the urban form to achieve sustainable (compact) urban form.

Table 3. Landuse Distribution as per Development Plan 2000–2011 of Nagpur and Comparison with UDPFI Guidelines (Source: [26,27]).

Sr. No.	Major Landuse Purpose	Area (ha)	% to Total Area	% to Developed Land	
				Actual Existing in City (%)	UDPFI Recommendations (%)
1	Residential	3500	16.08	41.966	40–45
2	Commercial	185	0.85	2.218	3–4
3	Industrial	225	1.08	2.697	8–12
4	Public Purpose	2000	9.19	23.980	10–12
5	Public Utility	100	0.47	1.199	
6	Roads	555	2.55	6.654	12–14
7	Railway	440	2.08	5.275	
8	Airport	525	2.42	6.294	-
9	Garden and Playground	150	0.69	1.798	18–20
10	Developable Vacant Land	660	3.03	7.919	-
	Total Developed Area	**8340**	**38.40**	-	-
11	Agriculture	8000	36.78	-	-
12	Forest	225	1.03	-	-
13	Water Tank	456	2.09	-	-
14	Nallas (Rivulets)	380	1.74	-	-
15	Non-Developable Land	4355	20.02	-	-
Total Area under Municipal Corporation		**21756**	**100**	-	-

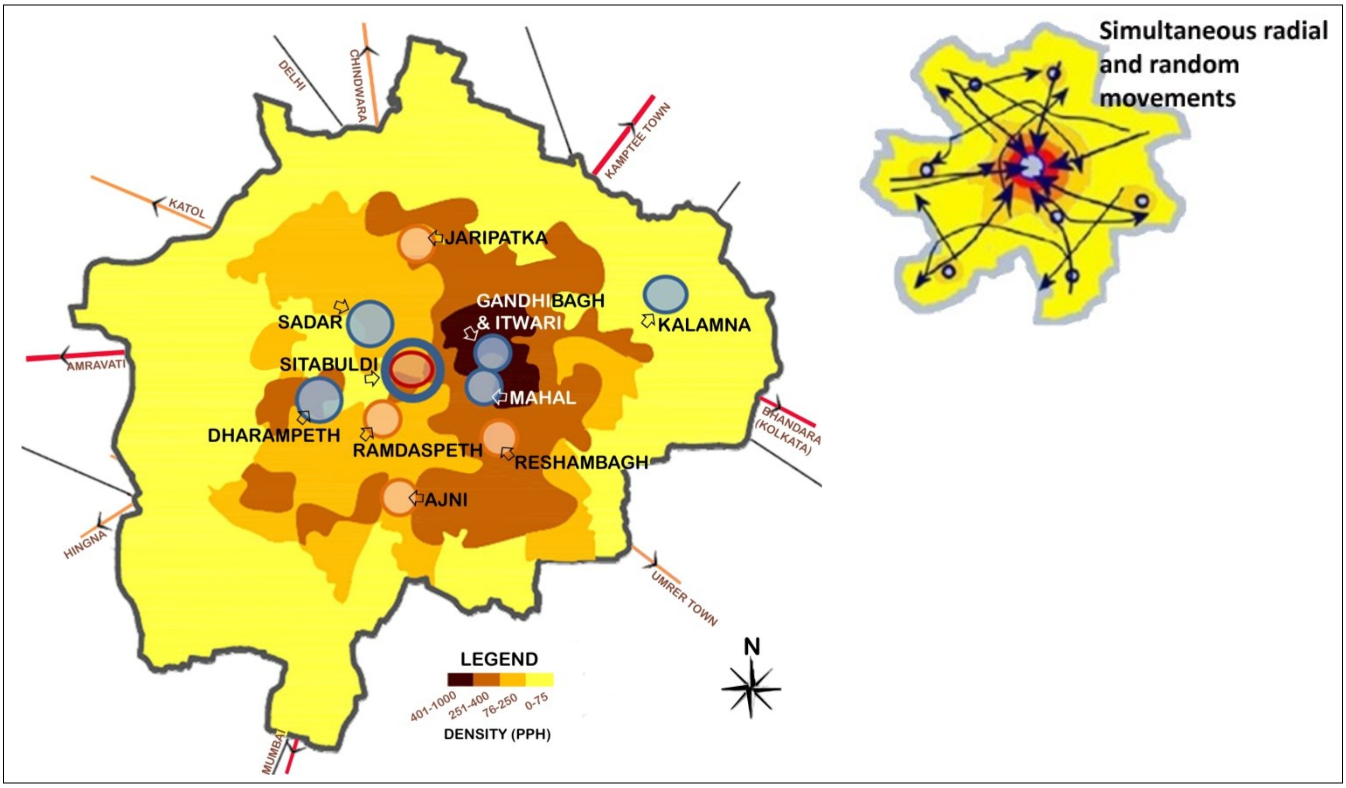
3.2. Analysis: Measuring the Urban Form of Nagpur City

3.2.1. Analyzing Form of the City

Nagpur has a history of 300 years and its urban growth expanded from the central historic core. Alain Bertaud's [14] method of analyzing the spatial organization of a city is used to assess whether

Nagpur city demonstrates a monocentric, polycentric or a composite model. Here, the spatial organization of a city means the two superimposed patterns—(i) the spatial pattern of population distribution within the city's built up area when people are at home and (ii) the pattern of movement people make around the city during the day. Thus, after superimposing the two patterns *i.e.*, population distribution and population movement pattern, the model derived for Nagpur city is found to be a composite model *i.e.*, *mono—polycentric model* with a dominant center and some sub-centers (Sub centers identified within the city on the basis of Origin and Destination survey for intra city trips. These are the special zones where trip-ends are very high [28]); and with simultaneous radial and random movements of people across the urban area [28]. The "Center of Gravity" (CG) (Center of Gravity is the point to which the sum of distance from all other points of the shape (*i.e.*, urban builtup area) is the shortest) identified is Sitabuldi (Sitabuldi area has been identified as the CBD as well as CG which is located in the center of the city, along the major interchange node *i.e*. railway station, inter-city and intra-city bus stations. It is a major interface between East and West city parts) area (refer Figure 1).

Figure 1. Nagpur's composite model of spatial organization: Density Distribution; Traffic movements; Sub-Centers and Sitabuldi area as CG.



3.2.2. Derived Set of Indicators

A set of urban form characteristics are identified and their indicators are derived with reference to the literature (refer to Table 4).

For the purpose of measuring the spatial structure/urban form of the city, the set of indicators for mixed use and land composition characteristics (item F in Table 4) are mapped and analyzed at the ward (tract) level as they could not be mapped at the city level. This is out of the scope of this paper and hence omitted in the discussion.

Table 4. Derived Set of Urban form Characteristics and Indicators.

Key Urban Form Characteristics	Indicators	Key Urban Form Characteristics	Indicators
A. Density	• Gross population density • Average (built up area) density • Landuse spilt up • Average land consumption per person	**D.** Accessibility	• Service Accessibility • Public transport Accessibility
B. Density Distribution/Dispersion	• Density profile • Density gradient • Population by distance to the center of gravity or CBD	**E.** Shape	• Dispersion Index
C. Transportation Network	• Mode share • Average trip length • Road network density • Congestion index • Walkability index	**F.** Mixed Use Land Composition	• Land use split up • Ratio of residential to non-residential use • Ratio of built to open area

4. Data Interpretation

The urban context of Nagpur is studied; the findings are then used to assess the existing level of city's compactness and to evaluate the appropriateness of compact development as a growth option for Nagpur. The detailed interpretations of the derived urban form characteristics in this study are described below.

4.1. Density

Density and its spatial distribution is a basic component of urban form and is used widely for sprawl assessments. Reduction in density over time is considered an indication of urban sprawl and density distribution defines the compactness of urban form [2]. More logically, the density calculations should be based on the built-up area (developed area (Developed area/Built up area: Measures land area consumed by urban activities within a metropolitan area across administrative boundaries. It does not include large parks (>4Ha), airport, agricultural land, undeveloped vacant land and water bodies. In this study, such areas are deducted to calculate built-up area (developed area), e.g., the areas under campuses of government restricted areas, educational and research institutes (e.g., VNIT, NEERI and Central Jail) *etc.*)) rather than the administrative area of the city. This is because a city may not be occupying the whole administrative area or may spill over the administrative area limits or has large undeveloped patches within administrative area; and hence may not represent the true average population density. Three indicators are derived to understand the "Density" pattern in the city: (i) Gross population density (ii) Average (built up area) density; (iii) Average land consumption per person.

The total area under Development Plan 2000–2011 of Nagpur is 235.21 square km, consists of the area under Nagpur Municipal Corporation (NMC) and area outside of NMC limits admeasuring 217.56 square km and 17.65 square km respectively. For administrative purposes, the NMC area is divided into 10 zones which are presently subdivided into 136 wards [26]. To understand Nagpur city's context internationally, a comparison with similar world cities is done with respect to population size, density and urban area (refer to Table 5).

4.1.1. Gross Population Density & Average (Built up Area) Density

It is observed that in Nagpur, almost 50% zones and about 25% of total 136 wards have gross population density below 100 pph (Figure 2 and Figure 3a,b). In some peripheral wards density is as low as 20–32 pph whereas inner and core area density is as high as 750–1000 pph. As per UDPFI (Urban Development Plans Formulation and Implementation (UDPFI) Guidelines are prepared and published by Ministry of Urban Development, Government of India, New Delhi in 1996 to facilitate preparation of spatial development plans of urban centers in India) guidelines, urban density of developed area should be 100–150 pph [27]. Two dominant density range in Nagpur are of 75–150 and 250–400 pph and population is mainly concentrated within 5 km radius from CG. The gross density increased almost three times since 1971 whereas the average (builtup area) density increased one and a half times (refer to Table 6).

Figure 2. Density Distribution Map of Nagpur City (Ward wise), 2001.

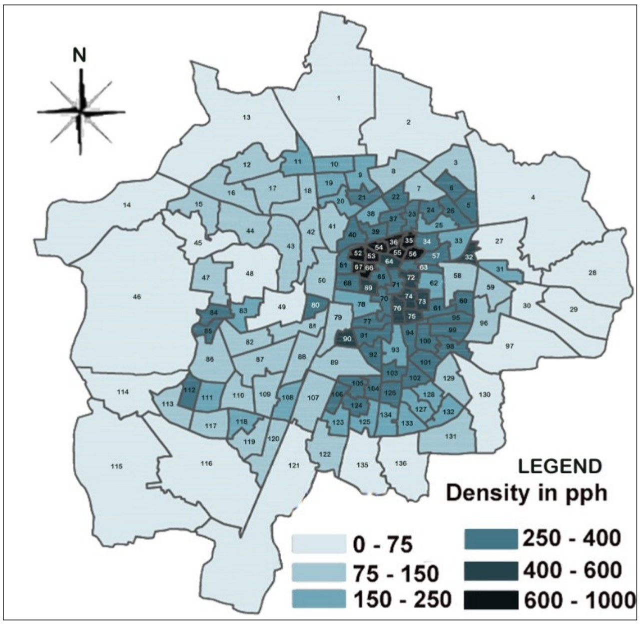


Figure 3. (**a**) Zone Wise Population Distribution, 2001 & 2011; (**b**) % of City's Area Covered by Population Densities.

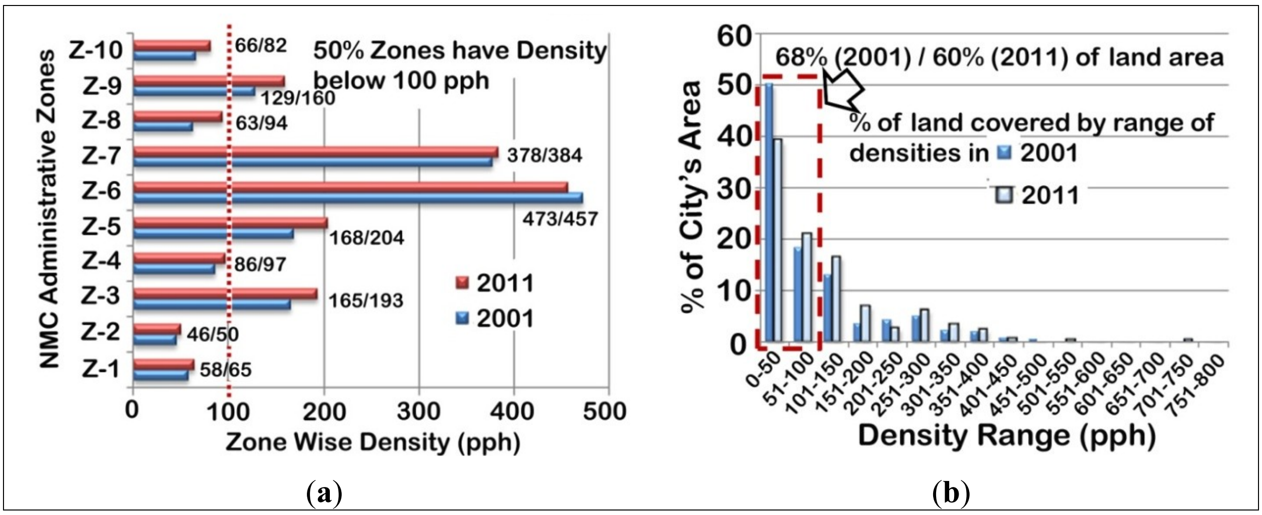


Table 5. Comparison of Nagpur City with World Cities (Source: [9]).

A: Similar Population Wise							
Countries	**Guiyang (China)**	**Lisbon**	**Tampa USA)**	**Manchester (UK)**	**Pretoria**	**Brasilia**	**Nagpur**
Population	2,600,000	2,669,000	2,683,000	2,560,000	2,550,000	2,426,000	2,405,665
Urban Area of city (Hectares)	32400	65800	264700	630	123000	67300	21756
Gross Population Density (pph)	86	28	10	41	21	36	111
B: Similar Urban Area Wise							
Countries	**Leipzig (Germany)**	**Zurich**	**Daegu (S.Korea)**	**Catania (Italy)**	**Shiraj (Iran)**	**Mendoza (Argentina)**	**Nagpur**
Urban Area of city (Hectares)	24600	24600	24600	24600	24600	24600	21756
Population	575,000	747,000	2,400,000	720,000	1,729,000	970,000	2,405,665
Gross Population Density (pph)	23	30	98	29	70	39	111
C: Similar Density Wise							
Countries	**Lima**	**Lahore**	**Jos (Nigeria)**	**San Salvador**	**Singapore**	**Xinxiang**	**Nagpur**
Gross Population Density (pph)	113	113	110	108	105	103	111
Urban Area of city (Hectares)	85500	73800	7000	15500	51800	10400	21756
Population	9,668,000	8,376,000	772,000	1,672,000	5,428,000	1,068,000	2,405,665

Table 6. General Statistics about Nagpur City (Source: [26,29], Census of India Data).

Year	**1971**	**1981**	**1991**	**2001**	**2011**
Adm. Area of city (Hectares)	-	21756	21756	21756	21756
Population	864,488	1,219,461	1,650,751	2,051,946	2,405,665
Gross Population Density (pph)	40	56	76	94	111
Developed (built up) Area (Hectares)	7057	8425	9794	12481	13609
Developed Area (built up) Density (pph)	123	145	169	164	178

4.1.2. Land Use Split up

As per the Development Plan of Nagpur 2000–2011, out of the total area of 21,756 hectares available within the Municipal Corporation limits, only 8340 hectares (38%) was notified for development (refer Table 3). Another about 38% of the land was kept under agriculture and forest cover and 4% was under nallahs (rivulets) and water bodies. As per Urban Development Plans Formulation and Implementation (UDPFI) guidelines, the land use distribution of developed land (as proposed in Development Plan) conforms to the guidelines in the case of residential usage. Presently, much of the agricultural green belt is encroached upon and developed as built-up residential sprawl. The city has large agriculture land, forest cover and institutional open spaces which is compensating the deficit of land under parks and gardens (recreational spaces) which is only 2%. There is need to avail more land for recreational purposes from the proportion of land earmarked for public and semi-public use. This will increase the proportion and accessibility of commercial and recreational uses to support high density and compact development. Almost 660 Ha (*i.e.*, approximately 8%) of developable vacant land is still available within the NMC administrative limits [26,29] that may be put to use.

4.1.3. Average Land Consumption Per Capita

The land consumption per capita is directly derived from the density. Figure 4 and Table 7 show the per capita land consumption for Nagpur. In absence of ideal figures for land consumption, benchmarks may be decided by comparing space consumption by other uses, in this case the transport mode is compared [14]. The dotted line in Figure 4 shows the amount of land space required by a car to park and to maneuver which is 40 sqm. In 2011, the developed land area per person in Nagpur was 56.57 sqm, so it may be inferred that in Nagpur a car consumes almost 70% space of a person. Individual use of car as transport means will be more disruptive in cities with lesser consumption of land per capita. In cities with very low land consumption per capita, such as Nagpur or even in other metropolitans around the world like Shanghai, Moscow and Paris the car is encroaching on people's share of space, which is spatially more disastrous in very dense cities. To carve for more space for vehicles, the policies for promoting dispersal of population will be adopted resulting in low population densities and sprawl. Alternately, the option of restricting car use will retain and promote compact developments [14].

Figure 4. Average land consumption per capita for Nagpur.

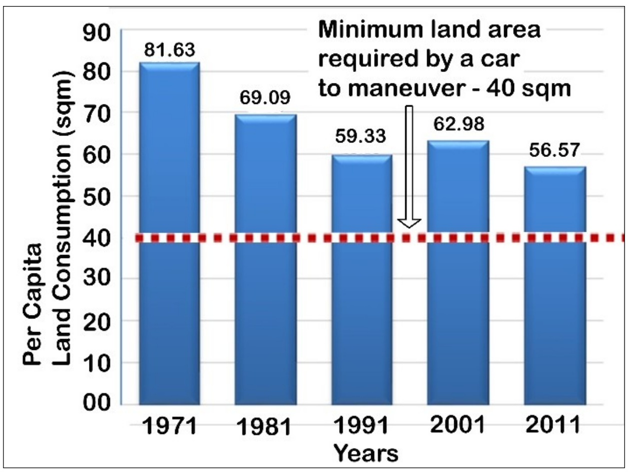


Table 7. Land Consumption Change Over Decades.

Year	1971	1981	1991	2001	2011	land space required by a Car
Per Capita Land Consumption (sqm)	81.63	69.09	59.33	62.98	56.57	40.00

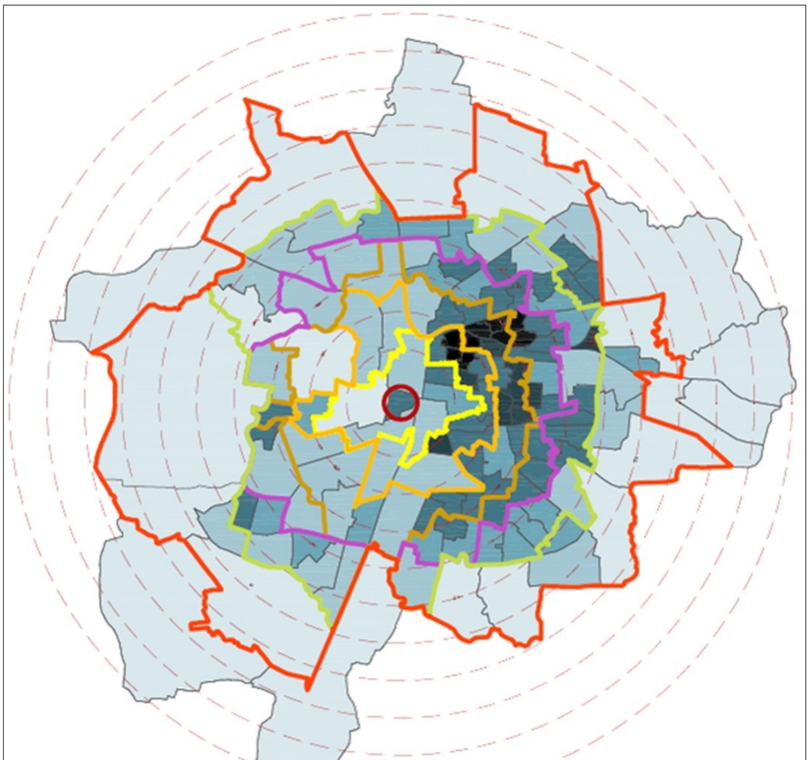
4.2. Density Distribution/Dispersion

Population is distributed or dispersed within a metropolitan area (developed urban area or urbanized area) with varying densities. "Density distribution" pattern in a city can be understood through three indicators: (i) density profile; (ii) population by distance to the CBD or Center of Gravity (CG) and (iii) density gradient.

4.2.1. Density Profile

The density profile is derived by plotting population on x-y axis where vertical axis denotes the urban builtup area densities or developed area densities and the horizontal axis represents the distance from the CBD or CG in regular intervals of 1 km. Figure 5 shows the rings (at approximately 1 km interval) around CG delineated as per the ward boundaries of Nagpur. The rings are not perfectly circular due to the constraint of ward wise population data availability. Thus, the density profile represents the dispersion across metropolitan area and agglomeration of people around CBD or CG.

Figure 5. Consecutive rings at a horizontal spacing of 1 km centered on the CG are rearranged as per the ward delineation.



A negatively sloped exponential curve is formed if the densities are high at the center of city and decrease away towards periphery [14]. Thus, the average trip length *i.e.*, the median distance per person to the CBD will be less in such case where more people reside near CBD [30]. On the contrary, longer average trip lengths will occur in positively sloped density profile.

The spatial distribution of density in a metropolitan area determines the shape performance in terms of average travel distance from CBD or CG. The density profile is a measure of the average consumption of land and distribution of this consumption across the city. It also determines the origin of majority of trips within a city [15].

By observing the density distribution map of Nagpur city (Figure 2), it can be inferred that the density profile in Figure 6a is not a very true representation of the actual spatial density distribution pattern within the city. The north-south railway line divides the city into east and west parts. These parts hold distinct urban characteristics. There seems to a high pressure on East, as all the high range densities are concentrated in the East part only. Therefore, to analyze the actual density distribution pattern within the city, the density profile of East and West Nagpur is also mapped separately and compared (Figure 7).

Figure 6. (**a**) Density Profile and Distribution from CG; (**b**) Cumulative Population by Distance from CG or CBD, for Nagpur city (year 2001).

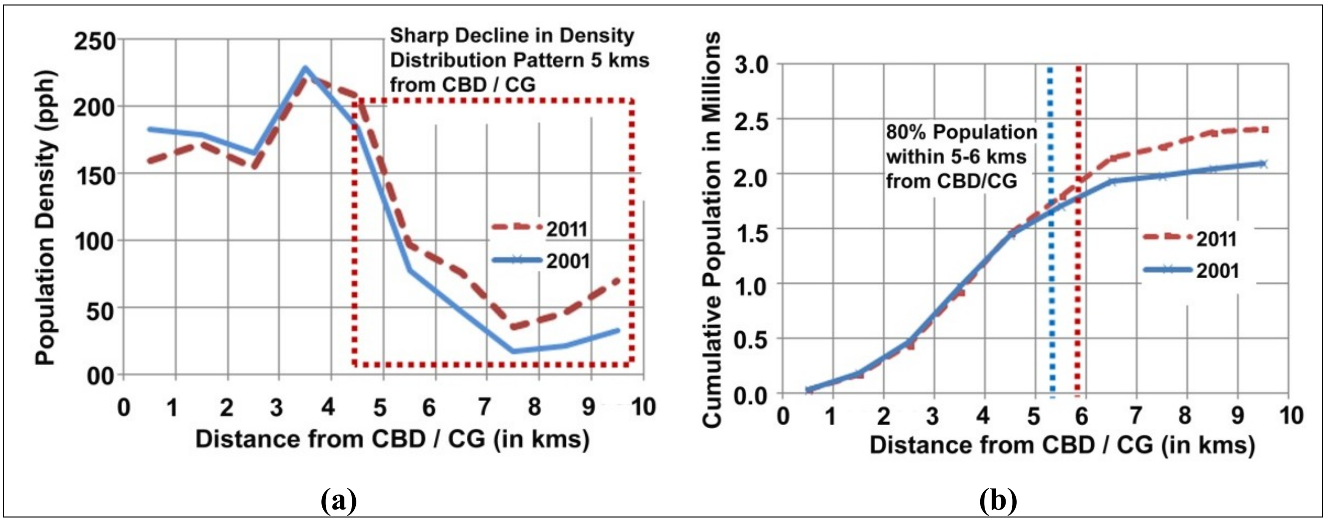
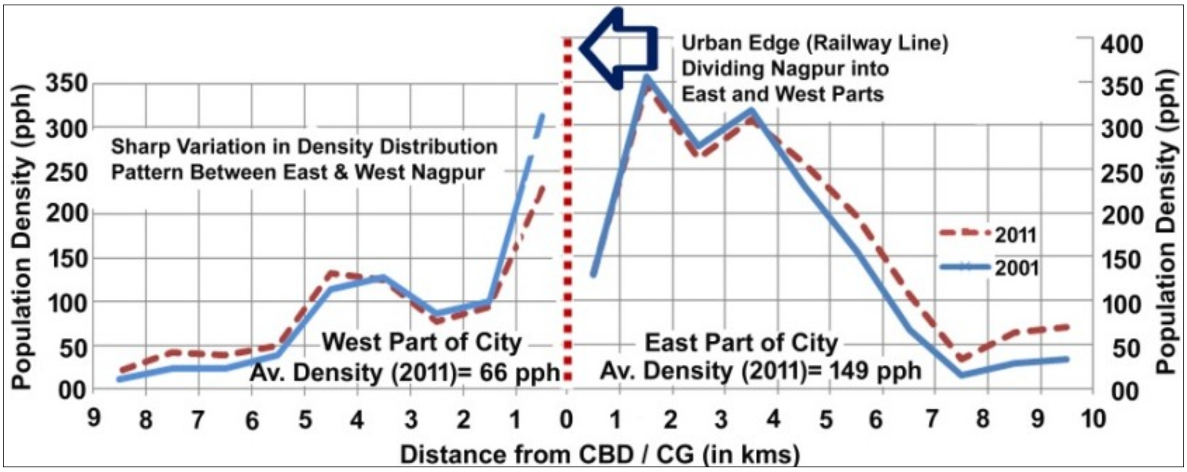


Figure 7. East-West Distribution of Density Profile.



Thus, a sharp variation in density distribution pattern between East and West Nagpur is observed. It indicates that there is inequity in population distribution. There is lot of scope for increasing density in almost 40% wards which have density below 150 pph (as per UDPFI guidelines) especially in West part of the city.

A steeper gradient of the density profile indicates higher accessibility to the center [14]. The density profile of Nagpur shows that more number of people have easy access to the center of city (refer Figure 6a). The spatial structure of Nagpur gives it a decisive advantage in terms of accessibility to city center.

4.2.2. Population by distance to CBD/CG

Figure 6a illustrates the cumulative population of Nagpur residing within a particular distance from the CBD/CG. For instance, Nagpur has more than 75% of its population residing within 5 km radius from identified CG which is quite convincing (In urban areas, a distance of 5 km may be considered as short and can be covered by bicycle in about 15–20 min; and by bus or two-wheeler in about 10–15 min), as average travel distance in the city is approximately 4.6 km [28]. The significance of this parameter is that it indicates shorter trip lengths for the majority of people and less per capita land consumption in case of Nagpur. However, this indicator is more relevant for cities with dominantly mono-centric spatial organization [14].

4.2.3. Density Gradient

Clark [31] while introducing the concept of density gradient in his study of "Urban population densities" observes that: (*1) In every large city, excluding central business zone, which has few resident inhabitants, we have districts of dense population in the interior with density falling off progressively as we proceed to the outer suburbs. (2) In most (but not all) cities, as time goes on, density tends to fall in the most populous inner suburbs, and the whole city tends to "spread itself out"*. Clark proved the validity of the above relationship by studying twenty cities. The mathematical relation between residential density and distance from the city center is expressed as:

$$“D_x = D_0 \exp(-gx)”$$

where, D_x is the density of resident population in a ward (persons per unit area);

x is the distance of that ward from the city center;

D_0 is a coefficient that indicates the density at the center of the city (CG);

g is a coefficient that measures the rate of decline of density.

Coefficients D_0 and g are determined using linear regression by transforming above equation into a linear form as "$\text{Ln}\, D_x = \ln D_0 - gx$" [32].

High value of "g" indicates that the urban form represents a compact city *i.e.*, densities decline sharply with increase in distance from the city center; and a low value represents a spread out city. Travel costs influences the value of "g" where higher travel costs result in high value of "g" and vice versa. Thus, by using the values of "g" and "D_0"growth trends of cities can be studied to classify cities as compact or spread [17,32].

In a similar study in India, Adhvaryu [31] calculated density gradient values for Ahmedabad city over a span of three decades and observed that density gradients in Ahmedabad are becoming flatter over the years, and represent a similarity with the exponential model derived by Clark.

The density gradient values calculated in this study of Nagpur for the years 1971 to 2011 show a declining trend (refer to Figure 8 and Table 8). It is inferred that the city is exhibiting a tendency towards "spreading out" or dispersion. The city center densities declined during the last few decades hinting that people are moving out from central areas to peripheral ones, as predicted by Clark. The density gradient value (for year 1991) of Nagpur is compared with other world cities to know the similitude (refer to Table 9). Density gradient directly represents the urban sprawl, wherein a flattening density gradient indicates the sprawl with increasing densities in the periphery. In the case of polycentric cities it may be an exception as the densities are higher around multiple centers or nodes, resulting in flatter density gradient.

Figure 8. Density Gradients for Nagpur City from 1971–2011.

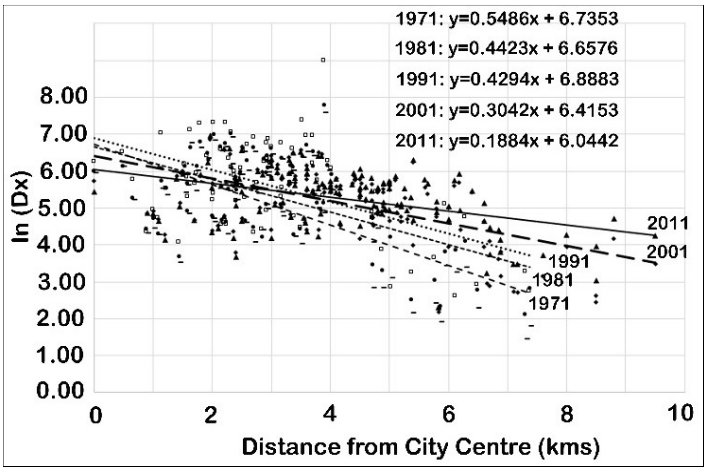


Table 8. Density gradient values for Nagpur City.

Year	1971	1981	1991	2001	2011
"g" value for Nagpur	−0.549	−0.442	−0.429	−0.304	−0.188
"D_0" value for Nagpur	6.735	6.658	6.888	6.415	6.044
"R^2" value for Nagpur	0.398	0.320	0.273	0.320	0.172

Table 9. Comparison of Density gradient values (1990 data) of World Cities with Nagpur City Source [17].

Countries	Brasilia	Hong Kong	Mexico City	Singapore	Cape Town	Barcelona	Atlanta	Guangzhou	Moscow	Nagpur
"g" value	+0.037	−0.113	−0.034	−0.195	+0.010	−0.98	−0.036	−0.489	+0.047	−0.429
"R^2" value	0.34	0.69	0.79	0.97	0.32	0.89	0.97	0.95	0.44	0.32

4.3. Transportation Network

There is a strong relationship between transport networks and urban forms. Better intra urban connectivity and accessibility is a prerequisite for sustaining compact urban form. Hence, the transportation network is an important urban form characteristic at all spatial scales (metropolitan level, sub-metropolitan or neighborhood level). Better connectivity with transport facilities and shorter trip distances encourage the use of non-motorized modes, which results in better air quality and imbibing a greater sense of belonging among residents: these are the desired ingredients of the compact urban form [2].

In this part of the study, five indicators (all the indicators under transportation network have been derived on the basis of secondary source data *i.e.*, transportation and household surveys conducted by a government appointed agency (L&T Ramboll) in the year August 2007) are selected directly from the secondary sources to understand the transportation network in the city: (i) Mode share; (ii) Average trip length; (iii) Road network density; (iv) Congestion index; (v) Walkability index. The secondary data and indicator values in this set are based on a study by Wilber Smith Associates [33].

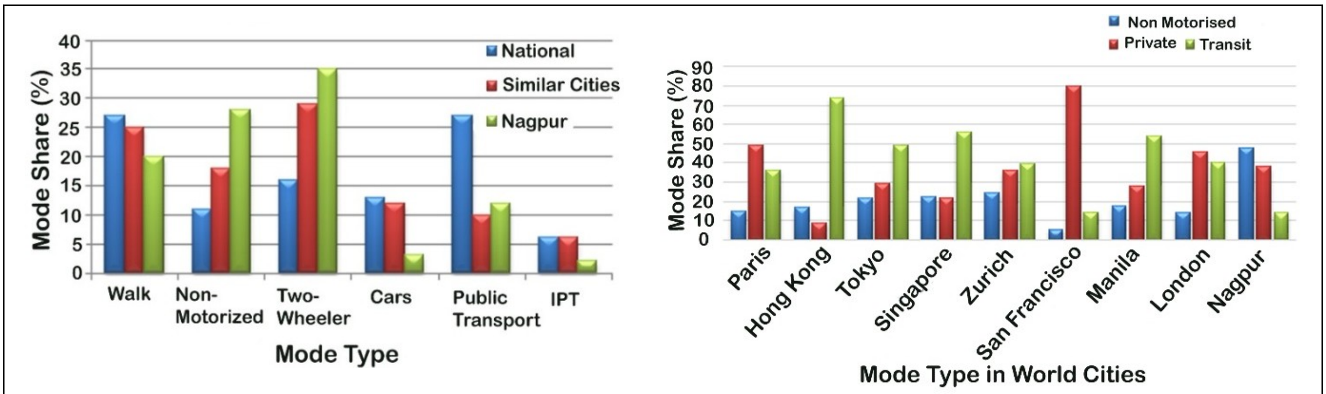
4.3.1. Mode share

"Significant number of trips in Indian cities is made by foot, i.e. around 16%–58%" [33]. Another study specific for Nagpur by L&T Ramboll in 2008 put the figure of non-motorized traffic as 58%, while other modes as: Cars—1%, IPT—9%, Bus—5% [28] (refer to Table 10). In case of Nagpur, non-motorized mode of transportation has a high share in modal split and a very less share of cars (refer to Figure 9a for national comparison), therefore the approach and strategies should be either to increase or at least maintain the high share of non-motorized traffic. If compared with large cities around the world (Figure 9b), Nagpur has less share of transit or public transport modes, this may be due to less investment in public transport infrastructure and probably due its medium city size.

Table 10. Mode Share of Trips in Nagpur (Source: [28,33]).

Transit Mode	% of Trips (Source [28])	% of Trips (Source [33])	Ideal Values (%) for this Category of City (2–4 million) (Source [33])
Non-Motorized mode (Walk)	25.6	20	-
Non-Motorized mode (Cycle Rickshaw and Bicycle)	32.4	28	15–20
Two-wheelers	26.6	35	10–15
Cars	0.9	3	
Bus	4.9	12	60–70
Intermediate Public Transport (IPT)	9.2	2	

Figure 9. (**a**) Mode Share Comparison (National), Source [33]; (**b**) Mode Share Comparison (Global), Source [34].



(a) **(b)**

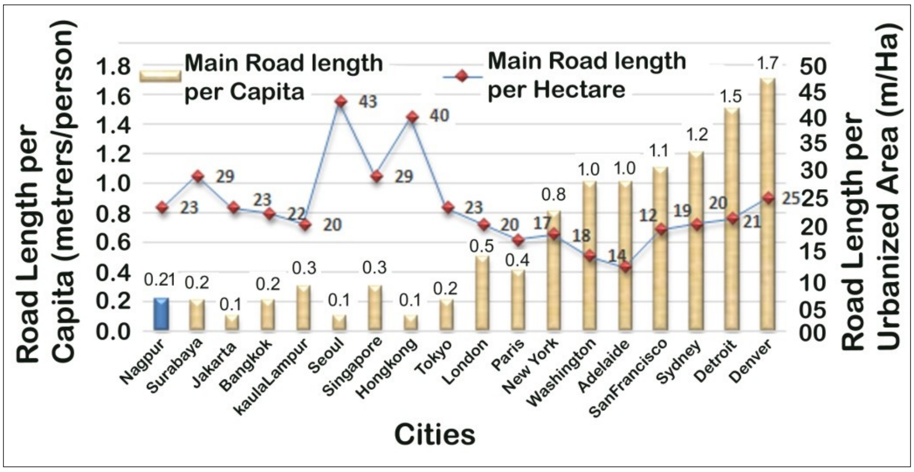
4.3.2. Average Trip Length

Average trip length is calculated as the ratio of total passenger- kilometers travelled to the total number of trips. Trip length is directly related to the city size or area of a city; trip length increases as city size increases. It is also dependent on the population density distribution over the urbanized area. In Nagpur city, 64.85% of work trips and about 74.16% of business trips are confined to a distance of 5 km while 69.37% of education trips and 65.67% of shopping trips are confined to distance of 3 km. The key observations are: (i) average travel distance in the city is 4.6 km and average travel time is 18.64 min; (ii) average travel distance for purpose of work and business is 5.3 km; (iii) trip length by mode (under private mode of transportation), the average travel distance is 6.46 km by 2 wheelers and 9.92 km by cars [28]. Thus, it may be concluded that the average trip length for Nagpur is shorter (as per the study conducted by Wilber Smith Associates (2008) the average trip length for Nagpur is shorter when compared to few cities having similar population range and much shorter when compared to large cities in India) and the majority of trips are within 5 km.

4.3.3. Road Network Density

The main road network consists of the primary and secondary road network (arterial) and it essentially services major intra urban connections. Road Network Density assesses penetration of transport arteries into the urban builtup areas and their accessibility. This indicator also evaluates the road capacity and permeability of urban land. Higher value of road network density and lower value of road length per person indicates sustainable urban form with respect to transportation parameters (refer to Figure 10 showing Seoul, Singapore, Hong Kong, etc. with more reliance on transit or public mode). Higher road network density may curb congestion on roads by providing more transport corridors and route alternatives. Less road length per person may indicate higher congestion levels if more reliance is on private modes *i.e.*, cars [35]. As the city spreads out with decline in population density, the road network density may decline and road length per person may increase. In Nagpur, the total length of major roads is 500 km (plus 1500 km internal roads) [36]. The gross road network density calculated is 22.98 m/ha (total road length/total builtup of city) and builtup area road network density is 36.74 m/ha; road length per person is 0.2078 m/person.

Figure 10. Road Network Density for Nagpur and World Cities [35,36].

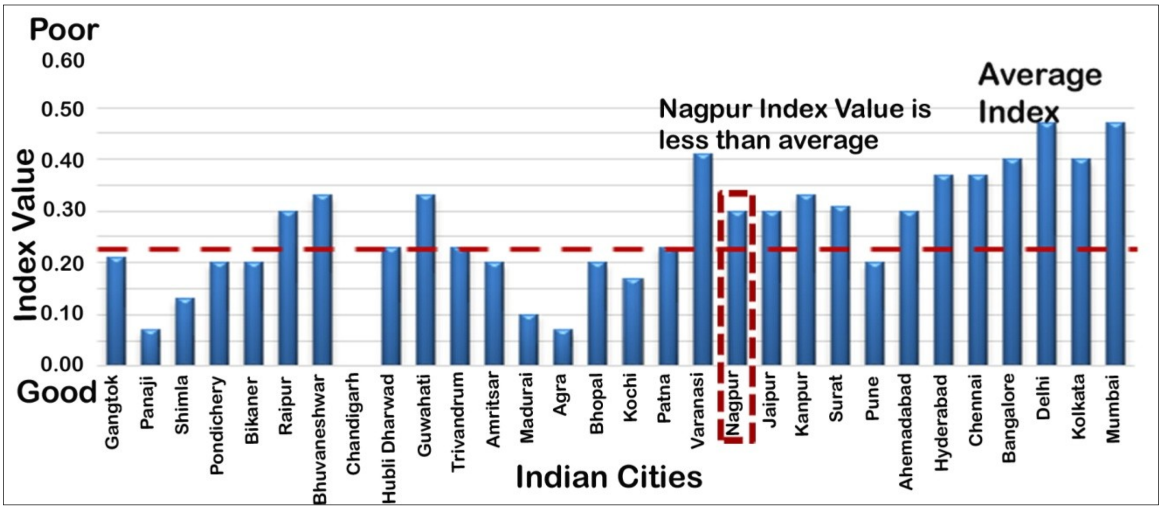


4.3.4. Congestion Index

Congestion may lead to increase in travel time due to less travel speed which in turn reduces road efficiency. In other terms, higher congestion reduces the mobility *i.e.*, how effectively users can perform trips. Increase in congestion leads to lesser safety, degrading environment and limiting economic developments [33]. Congestion and mobility are like antonyms, most often the same measures of effectiveness can be used to monitor both of them.

The congestion index is formulated as follows: ***Congestion index*** *= 1 − (A/M); where,* ***M*** *is Desirable Average journey speed on major road networks of a city during peak hour, which is assumed as 30 kmph*, *and* ***A*** *is Average journey speed observed on major corridors of the city during peak hours.* In a study by Wilber Smith and Associates, the index for the 30 Indian cities is presented in Figure 11. A lower index value indicates better mobility and lower congestion levels. For Nagpur, the evaluated value of congestion index is 0.24, which is close to the average index value reflecting an average road network system in the city. Chandigarh has the lowest congestion index (value-0), reflecting the very good quality of road network [33].

Figure 11. Congestion Index for Indian Cities, Source: [33].

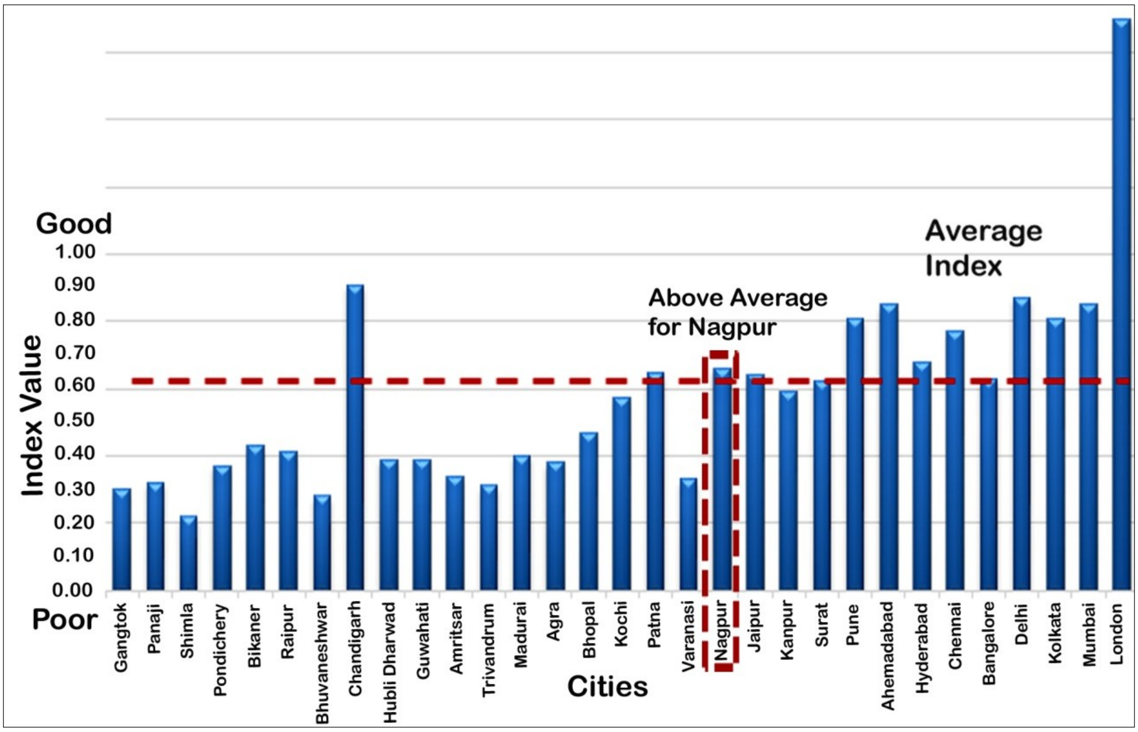


4.3.5. Walkability Index

Though a significant number of trips in Indian cities are made by foot (16%–58%), pedestrian infrastructure and facilities in Indian cities are inadequate and neglected. A walkability index—considering availability of foot path on major corridors and overall facility rating by pedestrians, is developed in a study by Wilber Smith Associates [33] and performance of pedestrian infrastructure is evaluated. It is expressed as: *Walkability Index = [(W1 x Availability) + (W2 x Facility rating)]; where, W1 and W2 are Parametric weights (assumed 50% for both), Availability is Footpath length/Length of major roads in the city, and Facility Rating is a "Score" estimated based on opinion on available pedestrian facility.*

Figure 12 shows the walkability index calculated for the 30 Indian cities where in higher index value indicates better pedestrian facilities. For Nagpur, the evaluated value of walkability index is 0.67, which is above the average index value reflecting that the city has above average or moderate pedestrian facilities. Though, it is far below the walkability index value for London which is estimated at 1.5 to 1.7 [33].

Figure 12. Walkability Index for Indian Cities, Source: [33].



4.4. Accessibility (Proximity)

Accessibility or proximity of a service, place, or intended activity may be described as how efficiently with less time and travel distance a person can reach there. It can be measured as the distance to the nearest place or activity, number of places or activities within a given distance, *etc.* Often, it is dependent on the accessibility of travel facilities and the landuse planning [2]. This is a different approach to study the efficiency of transport network from the conventional one where transportation is perceived only as motor vehicle traffic, per capita vehicle ownership, vehicle-kilometers, average traffic speed, roadway, level of service, *etc.* [33].

Two types of Accessibility indices are developed as part of the study by Wilber Smith Associates [33], they are (i) Public Transport Accessibility Index and (ii) Service Accessibility Index.

4.4.1. Public Transport Accessibility Index

It is formulated as the inverse of the average distance (in km) required to be travelled to reach the nearest bus-stop/railway station (suburban/metro) by residents. Higher the index means better public transport accessibility. For Nagpur the index value is 1.05. *i.e.*, same as the average value for various Indian cities [33] (refer to Figure 13).

4.4.2. Service Accessibility Index

This index is based on the percentage of work trips completed within 15 min time and 30 min time for each city. Higher index indicates better service accessibility. In Nagpur, almost 35% of total work trips are made within 15 min and almost 78% of work trips are accessible within 30 min time. For

Nagpur, index value is 0.78, which is above the average index value of 0.68 (refer to Figure 14) reflecting that the city has good service accessibility [33]. This could be a result of moderate trip lengths due to medium city size.

Figure 13. Public Transport Accessibility Index, Source: [33].

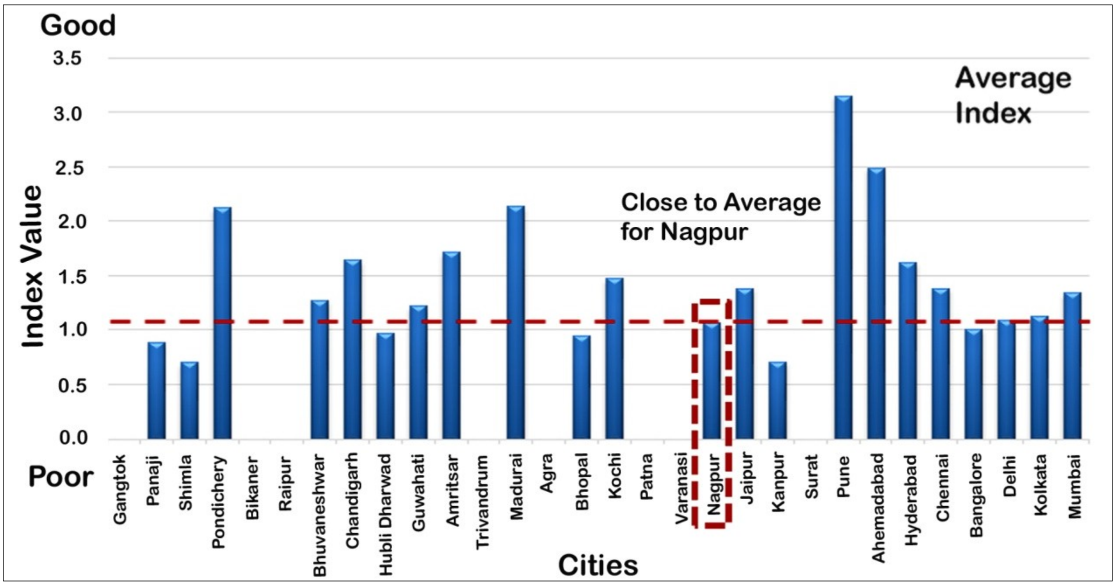
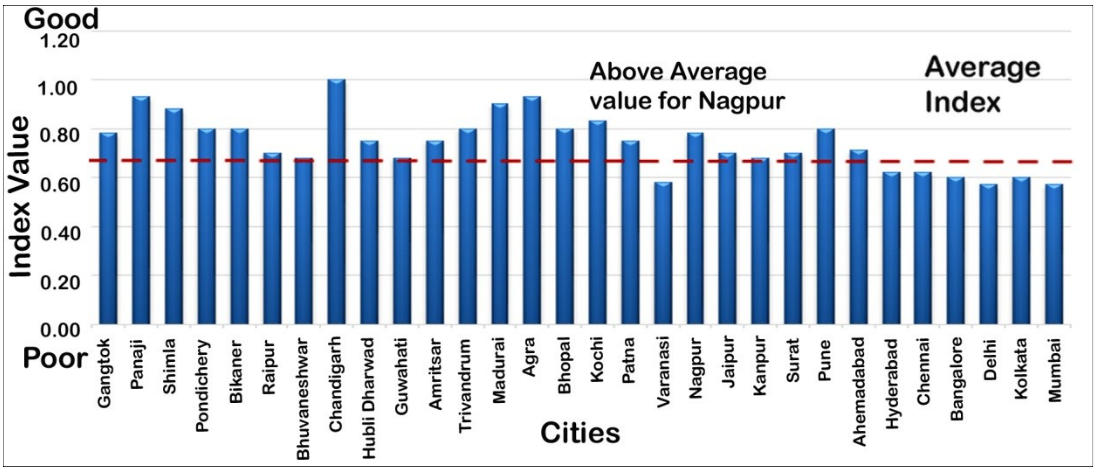


Figure 14. Service Accessibility Index, Source [33].



4.5. Shape Performance

The shape of a city can determine its compactness as "*intuition suggests that the more compact and circular cities should have shorter travel distances*" [16]. "Dispersion index" (The dispersion index (earlier known as compactness index) was first defined by Bertaud and Malpezzi in 1999 as: "*All else being equal, a city shape which decreases the distance between people's residence and the main place of work and consumption will be more favorable to the functioning of labor and consumer markets. For a given built-up area, the shorter the average distance per person to the main place of work or the main commercial areas, the better would be the performance of the city shape*" [14]) is used to evaluate the shape performance of the city.

Dispersion Index

The study of spatial structure of a city involves two components: (a) the distribution of population over entire city's built-up areas and (b) the pattern of trips people make from their residence to reach the place of desired activity. Bertaud argues that the pattern of trips can be expressed as the average distance per person to the center. In case of a monocentric city, the center is the CBD and in a polycentric city, the center is assumed to be the geometric center of the city called the center of gravity (CG). Average distance per person to the center is calculated as: "[the] product of distance from the centroid of a ward to the city center and the respective ward's population" and the sum of such products for all wards divided by city's total population. Thus, it depends on the weighted score given to each ward as per its population or density [14]. The average distance per person to the geometric center (CG) or CBD, which will be shorter in a city with less built up area than in a city with more built up area. Hence, the measure to compare shapes (or spatial structure) of different cities shall be independent of the built up area. "Dispersion index" is calculated as the ratio of "the average distance per person to the center and the average distance per person to the center of a circle whose area would be equal to the built up area" with uniform density. This measure called as dispersion index "p" which can be mathematically expressed as:

$$p = (\sum d_i w_i)/[2/3(A/\pi)^{1/2}] \text{ or } p = (\sum d_i w_i)/(2/3)r$$

where, d_i is the distance of the centroid of the i^{th} tract (or ward or zone) from the CBD or CG, weighted by the tract's share of population w_i; A is the built-up area of the city; r is the radius of a circle with area A [14].

The spatial distribution of population can be mapped in 3D graphical form where each tract or ward is given a height proportioned to its population (refer to Figure 15 for Nagpur city). The spatial distribution of population can be simply mapped using census data for the wards in a city. This graphical representation is a three-dimensional map wherein the height of each of the wards is scaled to its population. The dispersion index reflects the "shape performance" of a city indicating whether a city is compact or dispersed. As this index is independent of the area and the density of a city; comparison of various cities with different shapes, sizes, and densities or study of the same city over time, can be made using this index [14]. Table 11 shows dispersion index values for various cities around globe, wherein the trend of compactness or dispersion is reiterated from the values in Table 9 for density gradient values.

Figure 15. 3D Representation of Spatial Distribution of Population for Nagpur City.

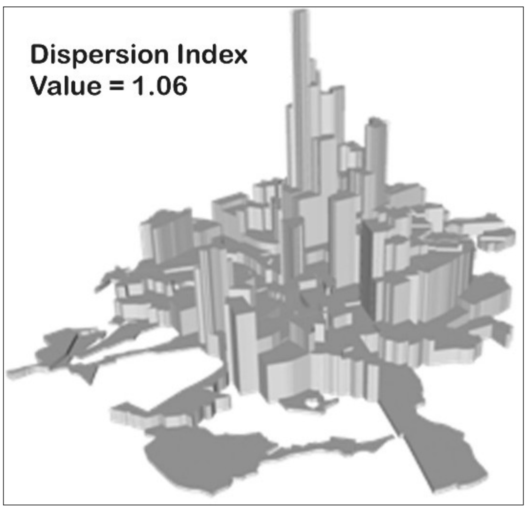


Table 11. Comparison of Dispersion Index values (1990 data) of World Cities with Nagpur City, Source [17].

Countries	Brasilia	Hong Kong	Mexico City	Singapore	CapeTown	Barcelona	Atlanta	Guangzhou	Moscow	Nagpur 1990 (2011)
Builtup area (Ha)	27200	14700	162400	18900	70100	16300	4279	5500	47000	9794 (13609)
Dispersion Index	3.26	1.94	1.06	1.12	1.98	1.32	0.95	0.93	1.39	1.02 (1.06)

Value of dispersion index as 1.0 is considered as the threshold between compactness and dispersion. Larger the index, less compact the city is (Figure 16 showing world cities crossing the threshold line). Dispersion index for Nagpur is calculated for the years 1971 to 2011 (refer to Table 12).

Figure 16. Comparison of Dispersion Index Values of Different Cities, Source [17].

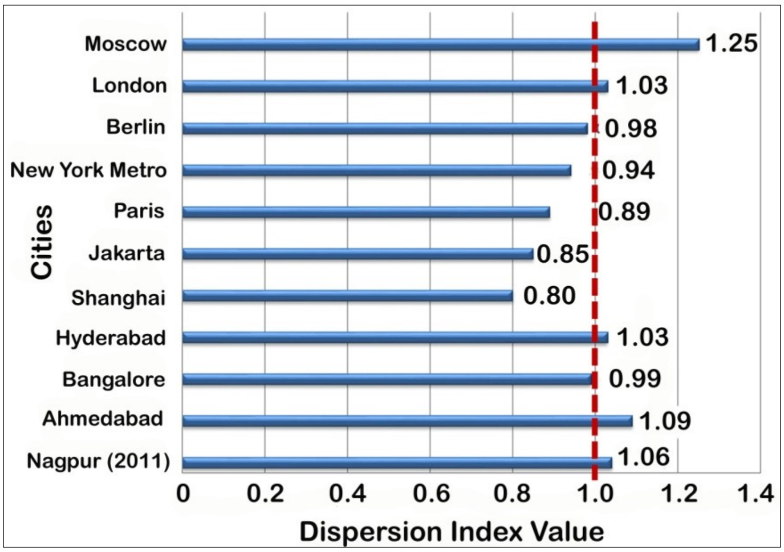


Table 12. Dispersion Index values for Nagpur City.

Year	1971	1981	1991	2001	2011
Builtup area (Hectares)	7057	8425	9794	12481	13609
Av. Distance/person to CBD	3.36	3.73	3.80	4.22	4.66
DT	3.16	3.45	3.72	4.20	4.39
Dispersion Index	1.06	1.08	1.02	1.00	1.06

In terms of the shape performance of the city, Nagpur is presently standing on the just above the threshold value between compactness and dispersion and may show a trend of gradually moving towards a dispersed form.

5. Discussion

Nagpur city is predominantly a monocentric city with major commercial areas in center; and few sub centers spread over the city. The CBD and CG of the city are almost coinciding. It is observed that the population densities in central areas are very high (750–1000 pph) while in the periphery they are very less (20–32 pph). 25% of wards and 50% of zones have density below 100 pph. 60% of land area is occupied by low density wards (below 100 pph). Large tracts of land are allocated for peripheral wards (as the division is based on population) which is increasing the scope for low density sprawl. Whereas the policy should be to keep the land reserved for future development rather than allowing development on entire available peripheral land. There seems to be a lot of scope for increasing density in almost 40% wards which have density below 150 pph (UDPFI guidelines suggest a moderate urban density of 150 pph). Comparatively East part of Nagpur has higher density than the West part of the city. Inequity in population distribution, along with disparity in landuse distribution is seen. There is an increased pressure on East Nagpur. This is undesirable as equity is one of the parameter for sustainability.

The density distribution follows the exponential curve as suggested by Clark's theory (of distribution of urban population densities) and the tendency of population moving from the center to the peripheral areas is observed. The present density profile of the city indicates that a major population portion is concentrated near the city center (within a distance of 5 kms from the city center or CBD) but presently tends to move from the center to peripheral areas. This movement of people is likely to be further accentuated in the near future with the upcoming development and extension of city's infrastructure and facilities in the city's periphery. This will promote sprawl and increase the travel distance.

The density gradient curves for Nagpur plotted for last fifty years indicate that the densities in central areas are decreasing hinting at spreading out of the city and increase in average travel length. This is a universal phenomenon as the densities in central areas can't be increased beyond a certain limit. People move out under pressures of congestion, overcrowding, pollution, *etc.* With an increase in population people need to be settled in other areas away from the center. However, this outflow can be controlled and slowed by improving the central area quality. The density gradient values for Nagpur need to be monitored and compared over timeline and with other cities to know the dispersal status of the city. The dispersion index values for Nagpur for last fifty years are in range of 1.00 to 1.08 which is very close to the watershed value (1.0) between compactness and dispersion. Though the change is not much, it is towards dispersion.

The measures for understanding the transportation network indicate an average score for Nagpur. Though the car ownership is low, but steadily increasing and is not a good trend for a medium size and compact city. A car consumes some of the space of a person here, therefore increasing dependency on private modes of transportation will be disruptive. Nagpur already has a high percentage (58%) of non-motorized mode of transportation, therefore the approach and strategies should be either to increase or at least maintain the present share. In terms of accessibility/proximity, it is observed that the accessibility to public modes of transportation and its share is poor (5% by buses); therefore the approach should be to enhance and improve this facility. Better accessibility to public modes of transportation will ultimately lead to reduced dependency on private modes; thus helping in increasing or at least maintaining the existing reliance on non-motorized modes of transportation. The road network density (length per hectare) in the city is at par with the other dense Asian cities (Figure 10). The road length per person is quite less which again indicates the potential for congestion and hence a need to discourage car use.

It is observed from the city level land use composition that open areas, recreational and public/semi-public landuses are unevenly distributed within the city and their concentration is in West Nagpur. Therefore, the approach should be to maintain equity in allocation of growth centers and other landuses—to achieve polycentric model with adequate mixed use and heterogeneous development. New development nodes should be identified and existing sub centers (nodes) may be strengthened. A total of approximately 876 Ha of land (including vacant developable land and brown fields) is available for new development within the NMC administrative limits. Utilizing this vacant land will promote infill rather than using new peripheral land. The last decade trend points towards increase in density in intermediate wards indicating infill and its demand too.

Nagpur city has a maximum Floor Space Index (FSI) (FSI is the ratio of total builtup allowed for a building to the total plot/land area. A concept similar to FAR) of 1.0 except in congested areas. There is need to increase the FSI (at least in high accessibility areas and along transport corridors) to increase density and reduce travel distance. In addition, it will deal majorly with overcrowding in built spaces, increase in city size (land area) and high price of built units [37]. However, there will be high probabilities of pollution and the risk of effect of linear development on property values. Reforms for allocation of FSI are required and the topic is being debated even at national level. Increasing density alone without infrastructure up gradation may have an adverse impact on sustainability as it will increase congestion and put strain on infrastructure and services. Therefore, for achieving the aforesaid goals of compact city form, infrastructure improvement and provision of more amenities and other facilities, along with improvement in transport network is necessary. This will hold high densities and sustain the compact urban form with less negativities. Better urban management, administration and strict regulations are the prerequisites to extract the benefits of compact living [38]. Large scale capacity building initiatives need to be undertaken by the municipal authority. Inclusive planning with more involvement and participation of people in the planning process cater the social and economic needs. The high component of informal sector has to be included in planning as neglecting it may be a deterrent to the compact city development. Compact city concept relates to environmental, social and economic benefits and they must be kept at the focus while carving urban planning policies. Poverty and social inequality must be addressed in the concept.

Though the compact city model is still under debate regarding its claims for achieving sustainability but if proper precautions are taken this model will definitely deliver its perceived benefits for Indian cities.

6. Conclusions

The study concluded that the measures of urban form characteristics (related to density distribution and shape performance) discussed in this paper show that Nagpur has all components of a compact city. The city is presently compact but gradually dispersing. On the basis of the analysis done in this study, it may be concluded that Nagpur is presently standing on the threshold between compactness and dispersion. The compact urban form characteristics of the city, which were present for decades, facilitated shorter travel distances, prevalence of mix landuse, higher densities with compact urban fabric in core and intermediate areas, high share of non-motorized travel modes, *etc.* Timely intervention to restructure the urban form may retain its comparatively compact urban form in future.

There is a high possibility that deterrents to achieve sustainable urban development will be at work. Lack of proper regulations and required institutional framework for fulfilling the high demand for compact and high density built areas can lead to overcrowding and environmental degradation. In addition, the city will suffer from pollution, noise, lack of privacy, isolation, breakdown of identity, *etc.* The component of informal development in the developing country cities is high, which is a deterrent to the success of compact city policies. High densities and more built area may accentuate heat island effect and vulnerability to disasters.

The compact city model can be recommended as the appropriate model to achieve sustainable urban development in context of Nagpur city, but with a word of caution. This paper suggests that such analysis can be very informative and useful for understanding the existing spatial structure and evolution of a city over time and accordingly intervention in the process of planning can be made.

Author Contributions

Rajashree Kotharkar, the first author, took the initiative for study on compact city concept and provided a methodology, framework for study and structure of the paper. The author is instrumental in revisions and deriving part conclusions. Pankaj Bahadure, second author, conceived the study, shortlisted the indicators, collected and analyzed data on world cities and Nagpur city from 1971 to 2011 (except for 2001) and discussed the findings. Neha Sarda, author three in sequence collected and analyzed the data for 2001, is also responsible for the first draft of the paper, initial mapping, partly graphical representation of figures and discussion.

Conflicts of Interest

The authors declare no conflict of interest.

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