# CHANGE IN TRAVEL BEHAVIOUR IN A DYNAMIC PERI-URBAN AREA: A CASE STUDY OF HYDERABAD, INDIA

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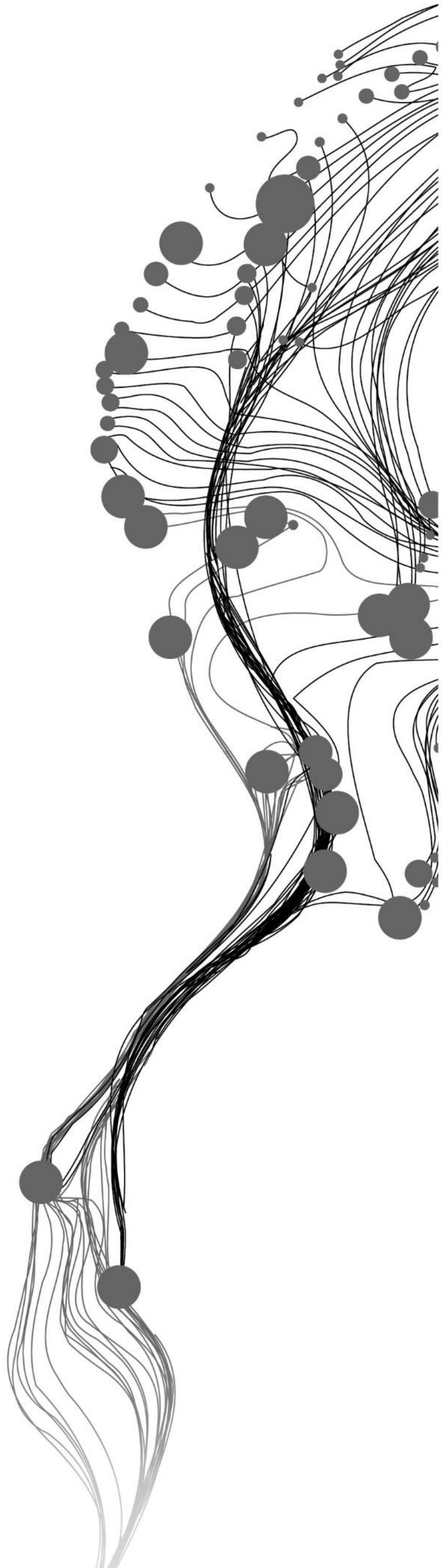

# Change in Travel Behaviour in a Dynamic Peri-Urban Area: A case study of Hyderabad, India

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# ABSTRACT

Traditional urban-rural dichotomy-based planning is being challenged by the emergence of peri-urban areas. The interaction of dynamic processes in peri-urban areas bring changes in the social and physical environment. Peri-urban dynamics and associated social and environmental transformation in the global South have raised key challenges for sustainable transport planning. Low density urban expansion, migration, economic growth and rapid motorisation in the peri-urban areas cause a shift towards a less sustainable travel behaviour. Implementation of an integrated transport and land-use planning is recommended for achieving a sustainable transport infrastructure. Successful implementation of such a plan in the peri-urban areas requires a better understanding of peri-urban dynamics and its relationship with the travel behaviour. However, urban morphology in the peri-urban areas and pertinent transformation in travel behaviour in global South is relatively less explored. This study explores the changes in travel behaviour in a peri-urban area taking the case of Hyderabad, India.

The area selected for detailed study is located near the Nanakramguda IT park and Financial district. In recent years the study area has gone through rapid peri-urban transformation. Emergence of new residential and financial areas have transformed the land-use pattern. Moreover, the demographic and socio-economic composition in the area have changed due to migration and income growth. A questionnaire survey was administered in this area to gather information about past and present travel behaviour. The results show that the respondents have significantly decreased their travel distance to employment location. Share of walk and two-wheeler trips have increased. However, majority of the respondents travel by shared auto-rickshaw. Shorter travel distances associated with increased built-up density and land-use diversity indicate a positive shift towards sustainable travel behaviour. However, rapid motorisation and increased use of two-wheelers among the long-term residents suggest a shift towards less sustainable travel behaviour.

**Keywords:** Peri-urban dynamics, Travel Behaviour dynamics, Hyderabad, India, Global South, Urban Form

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# 1. INTRODUCTION

## 1.1. Background

Traditionally, the countries around the globe classify their physical territories into two types- either 'Urban' or 'Rural' (Hugo, Champion, & Lattes, 2003). These terms (urban and rural) have been used to portray two contrasting landscapes, and most countries formulate separate planning strategies for urban and rural areas (Simon, McGregor, & Nsiah-Gyabaah, 2004). However, these urban-rural dichotomy based planning strategies are being challenged by the emergence of a new type of territory- the peri-urban areas- areas which are "not rural but not yet urban" (Lerner & Eakin, 2011).

The development of the peri-urban areas is the outcome of a process termed as peri-urbanisation, which transforms the rural areas located on the outskirts of urban cores into more urban (Webster, 2002). This transformation towards urbanity can associated with the changes in the demographic composition, economic structure, employment structure, spatial development patterns, and land use pattern of an area (Webster, 2002). Rapid population growth, increased income, emergence of secondary and tertiary employment, scattered development of built-up areas and development of mixed land-use zones introduce urbanity in a peri-urban area. Inevitably, these peri-urban areas begin to experience urban problems such as environmental degradation, social conflict, lack of infrastructure and mobility, and so on (Winarso, Hudalah, & Firman, 2015).

Scholars argue that the traditional urban-rural dichotomy based planning approach has been less equipped to address the problems of peri-urban areas (Allen, 2003). The peri-urban system consists of highly dynamic and interdependent sub-systems, which distinguishes a peri-urban area from an urban area (Allen, 2003). This dynamic system, termed as peri-urban dynamics, complicates the peri-urban planning process (Rauws & de Roo, 2011). Therefore, there is a need for a separate approach of planning and management in the peri-urban context (Allen, 2003).

Development of such specific planning and management approach for peri-urban areas should consider the distinctness of global South[1] and global North. Woltjer (2014) claims that the development of peri-urban areas in the global South shows a clear variation from that of the global North. Woltjer (2014) further claims that the peri-urbanisation in the global South is particularly strong. This strong peri-urbanisation in the global South could be associated with the "frantic urban growth", high population density and high land conversion rate, which are the distinct trends of the urban regions of the developing countries (Ravetz et al., 2013; Schneider & Woodcock, 2008; Woltjer, 2014). Such strong peri-urbanisation in the global South suggests that the peri-urban dynamics in the global South is more complex. Moreover, the transformations induced by peri-urban dynamics are more rapid in global South. Therefore, the peri-urban dynamics and pertinent sustainability issues should receive special attention from the researchers in the context of the global South.

Peri-urbanisation and associated social and environmental transformation in the global South have raised key challenges for sustainable transport planning. Cervero (2013) explores the recent trend of urban

[1] The term global South refers to the developing countries of Africa, Asia and Latin America (Harrison, 2006; Kuffer, Pfeffer, & Sliuzas, 2016). On the contrary the term global North refers to the developed countries.

development in the global south and discusses the key challenges of sustainable transportation planning in that context. The fast growth of urban population and migration, rapid motorisation, sprawled and monocentric urban expansion, poor transportation infrastructure are some of the major issues hindering the development of a sustainable transportation system in the global South (Cervero, 2013). Cervero (2013) claims that these challenges, associated with weak planning have caused a shift towards a less sustainable travel behaviour in the cities of the global South. This shift of travel behaviour could be linked to the shift in travel mode and change in travel distance. A decrease in the share of public transport and non-motorised trips (walking and cycling) is observed. On the contrary, the share of trips made by private vehicles has increased. Furthermore, distance travelled by the private vehicles are getting longer (Cervero, 2013). Such longer automobile trips cause congestion, increased fuel consumption, greenhouse gas emissions and pollution (Buchanan, Barnett, Kingham, & Johnston, 2006).

Cervero (2013) claims that the sprawling growth of urban territories and rising income in the global South are two major factors that are influencing the decline of sustainable travel behaviour (walking, cycling and public transport). For instance, in India, which has one of the fastest growing economies in the global South, the growth rate of motorisation is three times faster than the population growth. Furthermore, the development of urban towns in the peripheries of the Indian cities is likely to induce sprawl (Cervero, 2013). As a result, the Indian cities are troubled with transport related issues, which has been termed as "transport crisis" (Chidambaram, Janssen, Rommel, & Zikos, 2014). Cervero (2013) argues that an integrated transport and land-use planning, which encourages public transport and non-motorized travel could achieve a shift towards sustainable travel behaviour.

A parallel review of peri-urban dynamics and sustainable urban transport research helps to connect these two concepts. From one perspective the peri-urban areas are threats to sustainable urban transport as the rising income, growth in motorisation rate and low-density urban expansion might lead to more automobile trips. On the other hand, peri-urban areas offer greater potential for land-use and transportation integration than the urban core. Peri-urban areas are the zone of transition, where there is an ongoing change in land-use, unlike the urban core (Douglas, 2006). Therefore, it is possible to motivate sustainable travel behaviour in a peri-urban area, by carefully developing a sustainable land-use plan. However, successful implementation of such a policy in the peri-urban areas requires a better understanding of peri-urban dynamics and its relationship with the transportation demand and travel behaviour.

### 1.2. Research Gap

Review of past studies on peri-urban dynamics and travel behaviour change reveals two findings. First, the majority of the studies relating to peri-urban dynamics has taken a qualitative approach to explore the features of peri-urban areas and the impact of peri-urban dynamics. Second, analysing the peri-urban dynamics and travel behaviour dynamics using longitudinal survey are rare.

López-Goyburu and García-Montero (2018) review the past studies on peri-urban areas and found that the number of studies on peri-urban areas has increased since 2000. However, the major focuses of the past researches are on the features of peri-urban areas, changing landscape and economic activities. Furthermore, most of the studies are observational and qualitative study. Few studies conducted quantitative approach which are primarily focused on the change of peri-urban landscape using earth observation (EO) and Geographic Information system (GIS) (Huang, Zhou, & Wu, 2016; Schneider & Woodcock, 2008; R. Shaw & Das, 2017). Other quantitative studies which have quantified socio-economic or demographic variation associated with peri-urban areas have concentrated only on global North (Gonçalves, Gomes, & Ezequiel, 2017; Hilal, Legras, & Cavailhès, 2018; Hu, 2014; Wandl, Nadin, Zonneveld, & Rooij, 2014).

Contemporary transport planning is concerned about the dispersed and sprawled growth of the cities, and the repercussion of longer travel time, congestion, pollution, inactivity on society and environment (Buchanan et al., 2006). Nevertheless, the researchers and planning professionals have shown more interest in analysing the effect of urbanisation on the transport infrastructure by taking a perspective from the urban core (Buchanan et al., 2006). Several studies on the travel behaviour in peri-urban areas are available, albeit focusing on the global North (Gonçalves, Gomes, & Ezequiel, 2017; Joh et al., 2008; Pucci, 2017). Furthermore, these articles explore the peri-urban travel behaviour using cross-sectional study. Urban morphology in the peri-urban areas and pertinent transformation in travel demand or travel behaviour in global South is a topic relatively less explored (see e.g.with Aljoufie, Zuidgeest, Brussel, & van Maarseveen 2013).

Therefore, this research is motivated to observe the change in travel behaviour in the peri-urban areas of a city from the global South. The change in travel behaviour is explored by comparing the trip distance and mode share from two points in time. Hyderabad (India) is selected as the case because it is experiencing remarkable peri-urbanisation since the liberalisation of India's economy (Kennedy, 2007). To the best of the author's knowledge, none of the previous studies has explored the travel behaviour dynamics considering the peri-urban Hyderabad as an area of interest. However, the author claims no novelty on methods that are intended to be applied in the study.

This research focuses on the change in travel behaviour only considering the home based work (HBW) trips. It is reported that the largest portion of trips (53.1%) made in Hyderabad in 2011 were made for work purpose (Hyderabad Metropolitan Development Authority, 2012).

### 1.3. City of Hyderabad

Hyderabad is the capital of the state of Telangana in the southern part of India (Figure 1:1). The city serves as an important centre of administrative, industrial and commercial activities in the state (Das, 2015). Besides, the city is globally acclaimed as one of the biggest information technology (IT) hubs in India (Wakode, Baier, Jha, & Azzam, 2014). The urban agglomeration of Hyderabad is the sixth largest metropolis in the country with a population of 7.7 million according to the latest census of India. A report of the United Nations (2011) estimated that with the current rate of population growth the total population might reach 11.64 million by 2025 (Wakode et al., 2014). Scholars argue that the inflow of migrants from the different parts of India has largely contributed to the population growth (Das, 2015; Wakode et al., 2014). The rise of information technology (IT) industry in Hyderabad has triggered rapid development, economic growth and increased job opportunity, transforming Hyderabad as a major migration destination in the region (Das, 2015; Gumma, Mohammad, Nedumaran, Whitbread, & Lagerkvist, 2017).

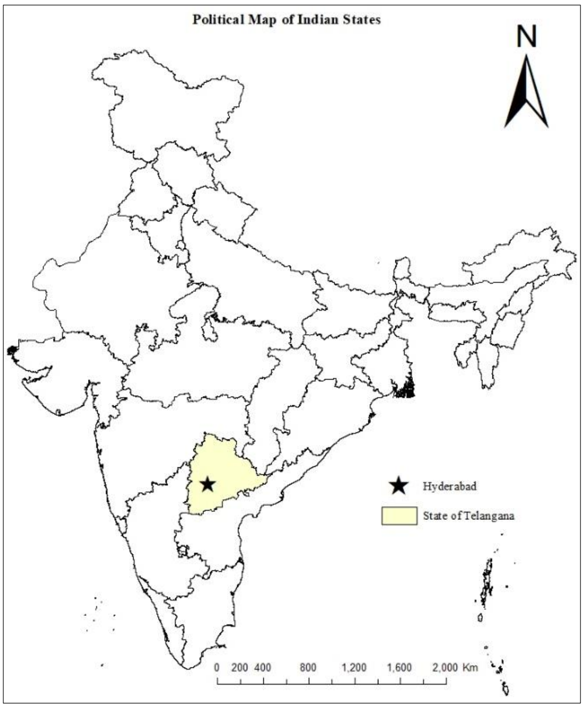


*Figure 1:1*: Location of the state of Telangana and the city of Hyderabad (data source: Open street maps)

The rapid growth of urban population inevitably increases the demand for urban land. This demand for more built-up areas affects the areas outside the urban core, resulting in urban expansion and development of peri-urban areas (Ravetz et al., 2013). Such expansion of built-up areas has been observed in Hyderabad too. From 1989 to 2011, the low-density urban land of Hyderabad has increased by more than 250 square kilometres (Wakode et al., 2014). This urban expansion resulted in the loss of water bodies, open land and agricultural land, suggesting a proliferation of peri-urban areas (Wakode et al., 2014).

However, the expansion of built-up areas due to population growth is not the sole factor influencing the peri-urban development and peri-urban dynamics in Hyderabad. Kennedy (2007) claims that the state-led policy which aims to transform the city as the growth engine for the entire region has been the driving force of peri-urban dynamics in Hyderabad. Between 1995 to 2004, the then government of Andhra Pradesh formulated policies to promote economic growth in the region, considering Hyderabad as the centre of infrastructure development. The "infrastructure-led growth model" largely targeted the periphery of Hyderabad as the location of new IT parks and support services. As a part of this strategy, the state provided energy, utilities such as water, sewage treatment plant and transportation infrastructure such as four-lane highways, metro rail service in these peri-urban areas (Kamat, 2011). These policies were successful in attracting investment from private companies and projects such as HITECH city were implemented through public-private partnership scheme. As a result of such policies large infrastructure projects, new industries, service areas, housing colonies and commercial spaces are emerging in the peri-urban Hyderabad. The development of these built-up areas is changing the urban form of peri-urban Hyderabad. Moreover, increased economic activities have created employment opportunities and wealth, which is transforming the peri-urban social structure (Kennedy, 2007).

## 1.4. Research Objective

### 1.4.1. General Objective

The research aims to investigate changes in travel behaviour in a dynamic peri-urban area in Hyderabad, India.

### 1.4.2. Specific Objectives

1. To identify areas which have gone through peri-urban transformation since 2011 in and around Hyderabad urban area,
2. To select an area of interest for detailed study,
3. To measure changes in travel behaviour (modal split, distance travelled) in the selected area from 2011 and present,
4. To identify the changes in the transportation infrastructure and urban form in the selected area within the time period of interest,
5. To describe the changes in travel behaviour with reference to the changes in infrastructure supply and urban form.

## 1.5. Research Questions

To achieve each specific objective, several research questions were developed:

1) **To identify areas which have gone through peri-urban transformation since 2011 in and around Hyderabad urban area.**
   a) Which are the suitable indicators to identify peri-urban development?
   b) What are suitable methods for data extraction and analysis of these indicators?
   c) What is the spatial extent of urban, peri-urban and rural areas of Hyderabad in 2011 and 2018?
   d) Which areas of Hyderabad have been transformed from rural or peri-urban since 2011?
2) **To select an area of interest for detailed study.**
   a) Which of the transformed areas are of interest in terms of possible infrastructure induced changes in land use and transportation?
   b) Which of the areas are suitable for carrying out a travel survey and an infrastructure survey?
3) **To measure changes in travel behaviour (modal split, distance travelled) in the selected area from 2011 and present.**
   a) What is the pattern of modal split and distance travelled for home-based work trips from the selected area in 2011 and 2018?
   b) How did this pattern change from 2011 to 2018?
4) **To identify the changes in the transportation infrastructure and urban form in the selected area within the time period of interest.**
   a) Which changes in transportation infrastructure can be observed in the selected area since 2011?
   b) What is the pattern of changes in urban form in the selected area since 2011?
   c) Do these patterns correspond with each other?
5) **To describe the changes in travel behaviour with reference to the changes in infrastructure supply and urban form.**
   a) Which patterns of change in travel behaviour and in urban form and transport infrastructure have been reported in the literature? Do the findings of this research corroborate the findings in previous literature?

## 1.6. Overall Research Approach

Figure 1:2 is a schematic representation of the overall approach of this research. The general objective of the research suggests that to explore the change in travel behaviour associated with peri-urban dynamics, this study requires a study area. Hence, the study attempts to find the areas of Hyderabad, which have been transformed into peri-urban since 2011. A combination of several indicators is used in the GIS environment to find such locations of peri-urbanisation. Later, a study area for detail study is selected based on the discussion with the local partner, Hyderabad Urban Lab (HUL) foundation. A questionnaire survey is administered in the study area to collect primary data, relating travel behaviour and socio-economic variables. Besides, land-use data is collected. Finally, the changes in travel behaviour are discussed in the context of land-use and socio-economic change.

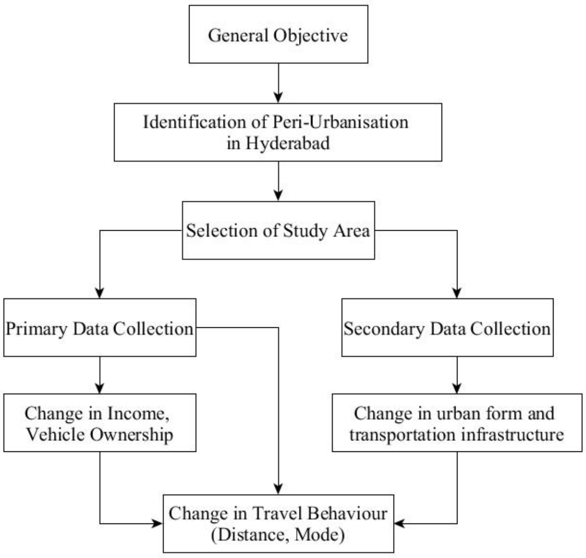



*Figure 1:2* Schematic representation of the research approach

## 1.7. Structure of the thesis

The thesis is structured into seven chapters.

**Chapter 1: Introduction**: explains the background and the justification of the study, identify the research gaps and state the objectives and research questions.

**Chapter 2: Literature Review**: discusses the key concepts and relevant literature on the field of peri-urban dynamics and travel behaviour.

**Chapter 3: Identifying Peri-urbanisation in Hyderabad:** explains the methodology applied in this study to identify the locations of peri-urbanisation in Hyderabad from 2011 to 2016, presents and discusses the results of the analysis.

**Chapter 4: Study Area: Gowlidoddy and Gopanapally:** illustrates the features of the selected study area for detailed study.

**Chapter 5: Change in Travel Behaviour and Urban Form:** discusses the methodology followed in this study to measure the changes in travel behaviour and urban form and presents the nature of these changes

**Chapter 6: Discussion,** presents a detailed discussion of the changes in travel behaviour and urban form in the study area, compares the findings with relevant literature. It also discusses the limitation of the study.

**Chapter 7: Conclusion and Recommendation**; the final chapter concludes the thesis based on the overall research and provides recommendations for future research.

# 2. LITERATURE REVIEW

This chapter discusses the theories and previous researches pertinent to two key concepts of this study, peri-urban dynamics and travel behaviour dynamics. Relevant literature regarding peri-urban areas was reviewed to understand the definition and features of peri-urban areas. Furthermore, methodologies applied to map peri-urban areas were reviewed, which facilitates the selection of an appropriate method to identify peri-urbanisation in Hyderabad since 2011. Reviewing the literature on travel behaviour dynamics reveals the critical factors behind a change in travel behaviour. Later, a link is established between the travel behaviour dynamics and peri-urban dynamics, which serves as a theoretical background for the main objectives of this study.

## 2.1. Peri-Urban Area and Peri-Urban Dynamics

### 2.1.1. Definition of Peri-Urban Areas

INSEE, the statistical agency of France, first used the term *Peri-Urban*, for identifying the territory of urban diffusion outside the urban centres (Wandl et al., 2014). Phrases such as transition zone, urban-rural ecotone, urban rural continuum, diffuse zone, peri-urban space, urban-rural interface, rural-urban fringe, suburban area, expanded periphery have been used to describe similar type of areas which fall between urban and rural system (López-Goyburu & García-Montero, 2018; Rojas-Caldelas et al., 2008).

Scholars have proposed different definitions of peri-urban areas from different perspectives. Budiyantini and Pratiwi (2016) summarise eight definitions of peri-urban areas from different literature to illustrate the variance in the definitions. It can be seen that the peri-urban areas are defined either from a spatial perspective or from the perspective of urban-rural interaction.

From the spatial perspective, Garnier and Chabot (1967) define peri-urban areas as the areas at the end of continuous built-up areas. Yunus (2001, 2008) identify them as areas in between urban and rural zone (Budiyantini & Pratiwi, 2016).

Among other definitions, Andreas (1942) define the peri-urban area as a region of mixed characteristics of agricultural and urban land use. Singh (1967), Wehrein (1942) and Dickinson (1967) while defining the peri-urban areas focus on the urban influence over a rural area. Douglas (2006) on a different work define the peri-urban areas as "transition zone" or "interaction zone" as urban and rural activities are overlapped in these areas.

Hence, it can be understood that the peri-urban areas are those areas- which are situated in between the urban core and rural zone, have a blend of urban and rural characteristics and a place of overlapping urban and rural activities.

However, Lerner and Eakin (2011) present a critical argument in the context of defining peri-urban areas. They argue that the terms urban and rural are abstract and the definition of these terms differs across the globe. Different countries use different indicators such as population, functionality, land-use and economic diversity and select an arbitrary threshold to separate urban areas from rural areas. For instance, the census of India defines those administrative units as urban which have a minimum population of 5000 and a minimum population density of 400 persons per square kilometre and where at least 75 percent of the male main working population are engaged in non-agricultural activities. Other areas which do not fall under these conditions are defined as rural (Office of the Registrar General & Census Commissioner India, 2011). Such ambiguity in the definition of urban and rural areas undermines the validity of the definitions discussed earlier. Several authors also admit that the definition of peri-urban area is an ongoing debate and a lack of clear boundary between urban, peri-urban and rural hinders the development of effective, consistent and integral planning for sustainability (Allen, 2003; Danielaini, Maheshwari, & Hagare, 2018; Dutta, 2012; Winarso et al., 2015).

Nevertheless, attempts have been made to define peri-urban areas by using quantitative attributes. The PLUREL project (Peri-urban Land Use Relationships- Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) considered those areas of discontinuous built environment which has a population size less than 20,000 and an average population density of at least 40 inhabitants per km$^2$ as peri-urban (Wandl et al., 2014). Phillips and colleagues (as cited in Simon et al., 2004) proposed a radius of forty kilometres around the city of Kumasi, Ghana as an approximate extent of the peri-urban area. However, it was realised that these quantitative definitions are context specific and only applicable to a certain point of time.

The above discussion reveals some key findings pertinent to the development of this study. First, the definitions discussed in this section are subjective. Second, the definitions could not be operationalised directly to delineate a clear boundary of peri-urban areas. Finally, peri-urban areas in India, hence in Hyderabad are not defined as a separate entity. Therefore, this research needs to adopt a robust methodology for identifying the peri-urbanisation in Hyderabad. Further review of literature reveals that methods used in previous studies have distinguished peri-urban areas from urban and rural based on certain features. Those methods are established on a basic principle- peri-urban areas have distinct features from urban and rural areas. Therefore, it is critical to study the features of peri-urban areas.

#### 2.1.2. Features of Peri-Urban Areas

A review of the features of peri-urban areas is needed to develop a clearer picture of these areas. A recent review article claims that a significant amount of works conducted in the field of urban planning have discussed the features of peri-urban areas as their primary focus (López-Goyburu & García-Montero, 2018). It is assumed that a lack of clear definition of these territories has motivated the scholars to distinguish the peri-urban areas from urban and rural areas based on their distinct features.

Allen (2003) in their pioneer work discuss the features of peri-urban areas from an environmental management perspective. They claim that the peri-urban areas either show a loss of rural aspects (loss of fertile soil, agricultural land and natural landscape) or exhibits a lack of urban attributes (low density, lack of accessibility, lack of services and infrastructure), thus creating an area of mixed urban and rural feature. They further claimed that the system in a peri-urban area is “a complex mosaic of rural, urban and natural sub-systems” in peri-urban areas (Allen, 2003).

Peri-urban areas are also distinct from urban and rural areas in socio-demographic structure. The population density in these areas is higher than the rural areas and lower than the urban core (Gonçalves et al., 2017). In addition, the peri-urban areas experience a remarkable population growth due to in-migration from both inner urban core and outer rural areas (Douglas, 2006; Simon, McGregor, & Thompson, 2006). Cheaper property values motivate urban people to move to peri-urban areas. In contrast, the marginal rural population migrates to these areas for better opportunities for work and education. This inflow of people from two different backgrounds creates a heterogeneous population structure, which displays variation in wealth and social status in peri-urban areas (Douglas, 2006).

The heterogeneity in social structure in a peri-urban area is reflected through the diversity in residential structures. A variety of houses such as formal houses, ill serviced shanties, slums and rural huts are observed in such an area (Simon et al., 2006). Douglas (2006) asserts that high value properties and low value settlements are observed in proximity in peri-urban areas. Particularly in global South coexistence of gated community and slums are observed, which implies a social and spatial segregation (Jain, Siedentop, Taubenböck, & Namperumal, 2013).

The diversity in peri-urban areas is not only limited to the residential structure. In fact, the land-use diversity in peri-urban areas is the most significant feature of a peri-urban area. Rojas-Caldelas et al. (2008) mention a list of conflicting land-use namely, residential, commercial, industrial, agricultural, recreational, infrastructure and preservation, which compete for land in such territories. Peri-urban area offers values to each type of land-uses; for lower income people it is a place for cheap residence, for middle class it is a place far from the urban chaos, for industrial sectors peri-urban areas offer large land and natural resources, for state it is a site for large infrastructure projects, freeways and airport (Douglas, 2006). As a result, peri-urban areas have a scattered and fragmented land-use pattern.

The fierce competition between the conflicting land-uses is associated with the governance issue. Urban and rural local authorities engage in conflict in a peri-urban area, often due to the absence of clearly defined boundary (Simon et al., 2004). In addition to that, the traditional chieftaincy structure adds complexity in this conflict (Simon et al., 2006). Such conflicts in governance encourage land grabbing and uncontrolled growth of built-up areas (Rojas-Caldelas et al., 2008). Hence, peri-urban areas have been characterized by poor centralised planning, leapfrog development and low density development (Hilal et al., 2018). As a consequence, peri-urban areas, particularly in Indian cities, lack the basic infrastructure network such as piped water, sanitation, solid waste management (Shaw, 2005).

However, in peri-urban Hyderabad, the state government through public private partnership have established planned commercial and financial parks, though the planning procedure of these projects have been accused of ignoring the local authority (Kennedy, 2007). These commercial and financial parks have motivated multi-national companies to set-up their regional offices in peri-urban Hyderabad (Kennedy, 2007). Aguilar and Ward (2003) observe similar trend in Latin America and claim that peri-urban areas are highly capital intensive due to the recent trend of globalisation and foreign investment. This increase and diversification of economic activities in peri-urban areas is linked to the increased GDP of the population (Gonçalves, Gomes, Ezequiel, et al., 2017).

From the perspective of mobility pattern, the peri-urban areas have been characterised by highly automobile dependent areas (Hilal et al., 2018). The peri-urban areas serve as a "dormitory space", which enables the residents to access opportunities in the urban core. Residents of these areas are forced to use private means of transportation to access the opportunities as these areas are rarely served by public transportation service (Rojas-Caldelas et al., 2008).

The features mentioned in this sub-section assist to differentiate peri-urban areas from urban and rural for a certain point of time. In other words, these features portray a static picture of peri-urban areas. Therefore, researchers have used these features to identify the spatial extent of peri-urban areas for a specific point of time. However, scholars have frequently maintained that the most critical feature of a peri-urban area is its highly dynamic nature. The dynamics in peri-urban areas are discussed in a separate section in this report.

#### 2.1.3. Identifying and Mapping Peri-Urban Areas

Studies advocate the integration of several features for identifying peri-urban areas. Gonçalves et al. (2017) argue that the "peri-urban character" is a mixture of aspects which distinguishes the peri-urban areas from urban core and rural areas. Hence, a multi-dimensional approach is required to capture the variation of the aspects. Several studies have followed this concept and mapped the peri-urban areas by integrating different features. In general, this integration is done by using corresponding indicators from several features or dimensions. Use of indicators helps to conduct a quantitative analysis of a study area to separate the peri-urban areas.

For example, Gonçalves et al. (2017) choose eighty three indicators from six dimensions (mobility, identities and lifestyle, natural elements, land cover, economic activities and spatial functions) and used a combination of principle component analysis (PCA) and cluster analysis to identify groups of peri-urban areas around the Lisbon Metropolitan Area. Danielaini et al. (2018) explored the performance of multivariate (factor analysis and K-means clustering), univariate (Jenks natural break) and multiple univariate data analysis techniques to identify the peri-urban areas using eleven social, economic and spatial indicators. Beynon, Crawley, and Munda (2016) propose a three factor model which could be used to capture the rurality of an area, which in turns could be used in delineating peri-urban areas. The three factors are population and housing dynamics, migratory dynamics and social dynamics. Hahs and McDonnell (2006) used several landscape metrics in addition to the demographic and physical indicators to quantify the urban-rural gradient. A different study used a fuzzy cognitive mapping technique to identify the peri-urban areas considering land use, population, NDVI and mobility pattern as indicators (Gopal et al., 2016).

It is essential to note that, indicators related to socio-demographic and economic dimensions are measured by census data, using census tracts as spatial unit of data organisation and aggregation. Traditionally, these tracts have irregular shapes and area, are fairly large, and therefore fail to represent internal heterogeneity. This limitation could be overcome by using high resolution census data. However, the availability of census data in high resolution is a challenge specially in Indian context (Jain, Knieling, & Taubenböck, 2015).

High resolution satellite images and land-use land cover (LULC) maps are used to address the challenge of data scarcity and precision. These data are used to calculate landscape metrics such as diversity index, land cover richness, shape index, largest patch index, density of built-up areas and used as indicators for cluster analysis. For example, Huang, Zhou, and Wu (2016) used Landsat Thematic Mapper (TM) images to calculate Shannon's Diversity Index (H) for the Guangzhou-Foshan metropolitan area of China and later identified the urban fringe based on the index value.

Table 2.1 summarises the indicators used in the previous studies to delineate the peri-urban areas. The table also mentions the typical data sources of these indicators and the smallest spatial unit of data representation.

*Table 2-1* Indicators used to identify peri-urban areas

| Sl | Indicator | Dimension | Reference | Definition | Data Source; Smallest spatial unit of data presentation |
|---|---|---|---|---|---|
| 1 | Population Density | Demographic | (Gopal et al., 2016) (Saxena & Vyas, 2016) (Danielaini, Maheshwari, & Hagare, 2018)(Hahs & McDonnell, 2006) (Budiyantini & Pratiwi, 2016) | Number of people residing in unit area. | Census; Census tract |
| 2 | Density of dwellings/Household | Demographic | (Hahs & McDonnell, 2006) (Saxena & Vyas, 2016) (Budiyantini & Pratiwi, 2016) (Khan & Munir, 2017) | Number of household per unit area. | Census; Census tract |
| 3 | % of working population (agricultural) | Demographic | (Hahs & McDonnell, 2006) (Saxena & Vyas, 2016) (Danielaini, Maheshwari, & Hagare, 2018) | Number of people working in agriculture expressed as the percentage of total population. | Census; Census tract |
| 4 | People per urban land cover/built-up area | Demographic | (Hahs & McDonnell, 2006) | Ratio of number of people living in the built-up areas by the total built-up area. | Census, Land-cover map; Census tract |
| 5 | Literacy rate | Demographic | (Saxena & Vyas, 2016) (Khan & Munir, 2017) (Danielaini, Maheshwari, & Hagare, 2018) | Percentage of people having formal education. | Census; Census tract |
| 6 | Household Size | Demographic | (Saxena & Vyas, 2016) | Average number of people living per household. | Census; Census tract |
| 7 | Population Growth | Demographic | (Khan & Munir, 2017) (Gonçalves, Gomes, Ezequiel, Moreira, & Loupa-Ramos, 2017) | Percentage of population growth per year or within a fixed time period. | Census; Census tract |
| 8 | Land Cover richness | Landscape Metric | (Hahs & McDonnell, 2006) | Number of land-cover type present in the landscape. | Land-cover Land use map; Any scale based on map resolution |

| Sl | Indicator | Dimension | Reference | Definition | Data Source; Smallest spatial unit of data presentation |
|---|---|---|---|---|---|
| 9 | Diversity Index | Landscape Metric | (Hahs & McDonnell, 2006) (Huang, Zhou, & Wu, 2016) | This index quantifies the diversity of the landscape based of land cover richness and the proportion of area distribution among the different land covers. | Land-cover Land use map; Any scale based on map resolution |
| 10 | Number of patches | Landscape Metric | (Hahs & McDonnell, 2006) | Patches are considered as a cluster of continuously built-up pixels. This indicator is quantified by counting the numbers of patches in a landscape. This is a measure of subdivision aspect of an area. | Land-cover Land use map; Any scale based on map resolution |
| 11 | Landscape shape index | Landscape Metric | (Hahs & McDonnell, 2006) | Ratio of peri-meter of patches and the total landscape area. It is a standardized measure of patch peri-meter adjusted for the size of landscape (Mcgarigal, 2015). | Land-cover Land use map; Any scale based on map resolution |
| 12 | Largest Patch Index | Landscape Metric | (Hahs & McDonnell, 2006) | Ratio of the area of largest patch over the area of landscape. It is a measure of dominance (Mcgarigal, 2015). | Land-cover Land use map; Any scale based on map resolution |
| 13 | Modal Split by car | Mobility | (Gonçalves, Gomes, Ezequiel, Moreira, & Loupa-Ramos, 2017) | Percentage of people who use a car to travel the largest distance in their trip. | Census, Transportation Survey; Census tract |
| 14 | Modal Split by bus | Mobility | (Gonçalves, Gomes, Ezequiel, Moreira, & Loupa-Ramos, 2017) | Percentage of people who use bus to travel the largest distance in their trip. | Census, Transportation Survey; Census tract |
| 15 | Road Network Density | Physical/ Mobility | (Hahs & McDonnell, 2006) (Budiyantini & Pratiwi, 2016) | Length of road per unit area. | Road Network map; Any scale based on map resolution |

| Sl | Indicator | Dimension | Reference | Definition | Data Source; Smallest spatial unit of data presentation |
|---|---|---|---|---|---|
| 16 | % of built-up areas/impervious area | Physical | (Hahs & McDonnell, 2006) (Danielaini, Maheshwari, & Hagare, 2018) | Amount of built-up area as a percentage of total area. | Land-cover Land use map; Any scale based on map resolution |
| 17 | Distance to CBD | Physical/Mobility | (Hahs & McDonnell, 2006) (Gonçalves, Gomes, Ezequiel, Moreira, & Loupa-Ramos, 2017) (Danielaini, Maheshwari, & Hagare, 2018) | Linear or network distance to the central business district. | |
| 18 | Normalised differential vegetation index (NDVI) | Physical | (Gopal et al., 2016) | Normalised difference between the reflectance values of red and near-infrared bands from a remotely sensed image. | Multi-spectral satellite images, Smallest pixel size |
| 19 | % agricultural area | Physical | (Danielaini et al., 2018) | Area of agricultural land as a percentage of total landscape. | Land-cover Land use map; Any scale based on map resolution |
| 20 | % of Forest, water bodies and semi-natural | Physical | (Danielaini et al., 2018) | Area of Forest, water bodies and semi-natural land as a percentage of total landscape. | Land-cover Land use map; Any scale based on map resolution |
| 21 | Land Value | Socio- economic | (Saxena & Vyas, 2016) | Average value of unit land or property | Census; Census tract |
| 22 | Poverty Rate/No of poor family | Socio- economic | (Saxena & Vyas, 2016) (Budiyantini & Pratiwi, 2016) (Danielaini, Maheshwari, & Hagare, 2018) | Percentage of people earning less than a certain threshold income. | Census, survey; Census tract |
| 23 | Daily Commuters | Mobility | (Khan & Munir, 2017) | Workers who commute daily for employment purpose. | Census, Transportation Survey; Census tract |

#### 2.1.4. Peri-urban Dynamics

A peri-urban area is the interface of several interlinked, dynamic processes. The interaction of these processes forms a complex web and results in a "socio-spatial dynamics" which is termed as peri-urban dynamics (Dupont, 2007). Ravetz et al. (2013) propose a five dimensional conceptual framework to understand peri-urban dynamics. The dimensions are urban expansion, regional agglomeration, political and cultural dynamics, system transition and response of policy.

Ravetz et al. (2013) further claim that all of these five dimensions can be considered as five processes or "stories." The processes themselves are dynamic, influenced by multiple temporal and spatial actors. Moreover, in peri-urban areas, these processes interact and influence each other, resulting in the peri-urban dynamics. A simplified summary of the mentioned framework is included in this report.

Several dynamic factors such as population growth, economic activities, environmental dynamics in the urban core generate demand for more urban land. As a consequence, the areas outside the urban core experience urban expansion- which is the first dimension of the framework. The second dimension- regional agglomeration refers to the regional and inter-urban processes which influence the peri-urban areas. Peri-urban areas transform and serve as linking spaces for regional and urban-rural interactions. Political and cultural dynamics, the next dimension refers to the social, economic and political forces which interact in the peri-urban areas. Ravetz et al. (2013) mention globalisation, localisation, liberalization as the major events related to this dimension. Ravetz et al. (2013) claim that the first three dimensions interact within themselves and triggers transitions in rural, peri-urban and urban systems. The transition in the whole system is identified as the fourth dimension. The final dimension is related to the policy, spatial planning and governance. Ravetz et al. (2013) argue that the actors of this dimension and the peri-urban dynamics have a bidirectional relationship of influence. Changes in policies are reflected as a response in peri-urban dynamics. On the contrary, peri-urban dynamics trigger changes in policy and spatial planning.

Peri-urban dynamics bring changes in the physical and social environment of the area. Changes of land-use, depletion of natural resources due to deforestation, water depletion and pollution are the major changes in the physical environment (Allen, 2003). Particularly, the conversion of agricultural lands to another type of land-use such as residential, industrial, commercial, transportation have received special attention from the perspective of environmental management (Allen, 2003; Simon et al., 2006; Zoomers, van Noorloos, Otsuki, Steel, & van Westen, 2017). Change of landscape is also observed in a peri-urban area which can be associated with the land-use modification (Douglas, 2006).

Change in the population composition due to migration, change in the economic base and job structure, growth of secondary and tertiary sector jobs and increase in household income are the socio-economic changes associated with peri-urban dynamics (Simon et al., 2006; Winarso et al., 2015).

In case of peri-urban India, four interrelated changes have been identified, namely socio-economic changes, land-use changes, introduction of urban way of life and migration (Schenk, 2005).

### 2.2. The impact of Peri-Urban Dynamics on Travel Behaviour

Kitamura (1990) categorised the factors of travel behaviour dynamics into two levels- macroscopic and microscopic level. Urbanisation, technological evolution, change in market and economy, change in transportation infrastructure and change in pertinent policies are the macroscopic factors. In contrast, the changes in individual and household attributes are the microscopic factors of travel behaviour dynamics. Kitamura (1990) listed some of these changes such as changes in income, household composition, employment, vehicle ownership and residential relocation and maintained that these changes are associated with a change in travel behaviour.

Zhou (2012) classified the factors influencing the choice of travel mode into six categories. The categories are built environment and urban form, mode specific factors, personal attributes of the trip maker, trip characteristics, existence of travel demand management (TDM) and psychological factors. Kamruzzaman, Baker, Washington, and Turrell (2013) proposed a similar classification scheme, classifying the factors into socio-demographics, psycho-sociological, trip characteristics and accessibility of locations. Changes in these factors should lead to a change in travel behaviour.

The above discussion reveals that peri-urban dynamics have impacts on many of the factors influencing travel behaviour dynamics. Peri-urban dynamics modifies the land-use of an area, resulting in a subsequent change in the built-environment and urban form. Introduction of secondary and tertiary jobs changes the economic base in a peri-urban area, which is one of the macroscopic factors of travel behaviour dynamics.

Peri-urban dynamics introduce change in the transportation infrastructure. These areas are suitable for regional and trans-regional infrastructure (Gonçalves, Gomes, Ezequiel, et al., 2017). Hence, these areas are connected to the urban core through large infrastructure such as highways, expressway and mass transit. For instance, Hyderabad has constructed an outer-ring road network, several radial roads connecting the ring roads and metro rail service, which connects its peri-urban areas to the urban core (Das, 2015).

Peri-urban dynamics influence the microscopic factors of travel behaviour dynamics such as income and employment structure. Increase in household income has been reported as an impact of peri-urban dynamics. Furthermore, the livelihood and way of life in a peri-urban area shifts towards an urban way.

Finally, peri-urban dynamics attracts in-flow of migrants. Residential relocation is an inevitable outcome of migration, which might lead to a change in travel behaviour (Bohte, Maat, & van Wee, 2009).

# 3. IDENTIFYING PERI-URBANISATION IN HYDERABAD

This chapter elaborates the major aspects regarding the specific objective 1-which aims to identify the areas which have gone through peri-urban transformation since 2011 in Hyderabad. At the beginning, the chapter explains the method used in this study. Later, it illustrates the result of the analysis and discuss the critical aspects of the result.

## 3.1. Methodology

The locations which transformed from rural to peri-urban were identified using a two-step method. At first, the area of interest (Hyderabad urban core and its surrounding area) was mapped into urban, peri-urban and rural for two different points in time (2011 and 2016). Next, a GIS overlay analysis of two maps was conducted to identify those areas which were identified as rural in 2011 and became peri-urban in 2016.

The method of mapping urban, peri-urban and rural areas for each scenario (2011 and 2016) was motivated by previous studies (see sub-section 2.1.3). The area of interest was divided into smaller cells, six indicators were calculated for each cell and finally, the cells were categorised into three groups using K-means clustering algorithm.

Figure 3.1 exhibits the major steps followed to identify the urban, peri-urban and rural areas of Hyderabad for each scenario. The extent of the area of interest (AoI) was determined following an examination of recent satellite images around Hyderabad. The selected AoI was modelled using a tessellation of equally sized square cells using the fishnet tool in ArcGIS. Three secondary data namely, population distribution layer, layer of built-up areas and road network were collected. Six indicators namely population density, density of built-up area, landscape shape index, largest patch index, number of patches, density of road network were calculated for each cell. Thus a vector layer was generated where each cell of the tessellation has the indicators as attributes. The grouping analysis operation of ArcGIS was performed using this layer. Grouping analysis applies K-means clustering analysis, classify the cells into three groups. Later the cells were labelled as either urban or rural or peri-urban and a map of the AoI was produced.

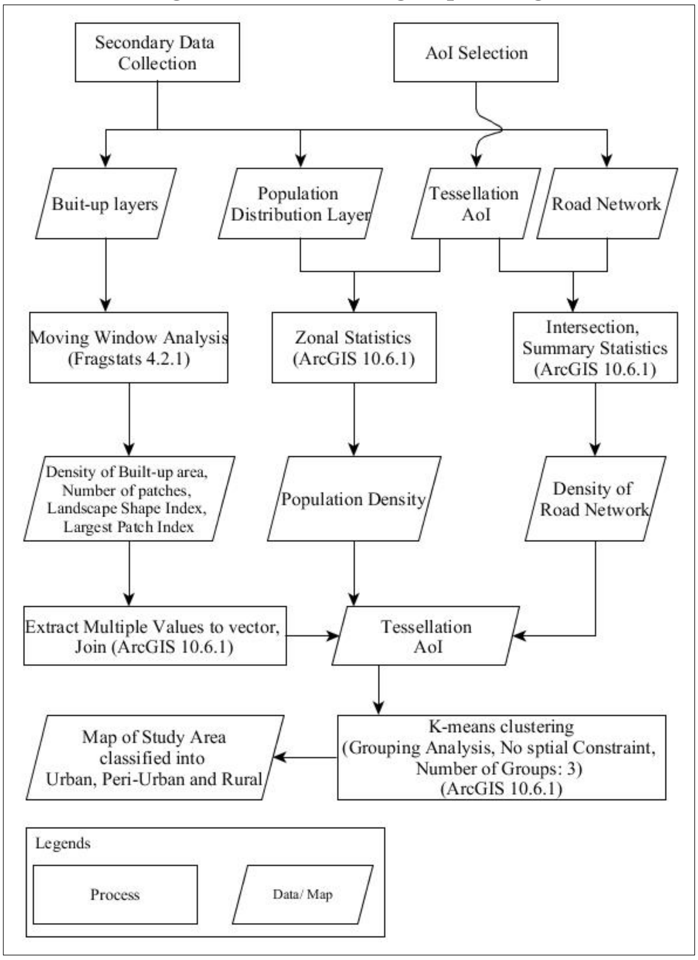



*Figure 3:1* Method applied to classify the study area into Urban, Peri-Urban and Rural

This procedure was followed for two scenarios- 2011 and 2016, and two maps were produced. The cells which changed from rural to peri-urban were identified as the location of peri-urbanisation. However, to understand the impact of cell size, this method was repeated for five different cell sizes. The cells chosen were square cells with 100 meter, 300 meter, 500 meter, 800 meter and 1000 meter sides. Hence, five maps of peri-urbanisation locations were produced. The following sub-sections will further discuss the important steps of the method.

### 3.1.1. Extent of the area of Interest

The data requirement of K-means clustering analysis dictated the determination of the AoI. The K-means algorithm categorises cells according to the nature of the provided data. Hence, it is critical to provide observations from each category. It implies that the AoI should extend in such a way to include the urban, peri-urban and rural areas around the city of Hyderabad. The literature suggests that the peri-urban areas lie in-between the urban and rural areas. Therefore, an area which starts from the urban core and extends up to the rural areas in all directions would also include the peri-urban areas.

Recent satellite images around the city of Hyderabad were analysed using Google Earth, to select such an area. It was observed that the density of built-up areas gradually decreases from the urban core towards the outskirts. Furthermore, it was observed that the areas outside the outer ring roads have a lower built-up density. Regular shaped green areas were observed in the areas beyond outer ring road; these resemble the pattern of agricultural land. Therefore, a boundary was drawn taking the non-built-up agricultural lands as the edge and used as AoI. Figure 3.2 presents the extent of the area of interest. It covers an area of 8,365 square Kilometres.

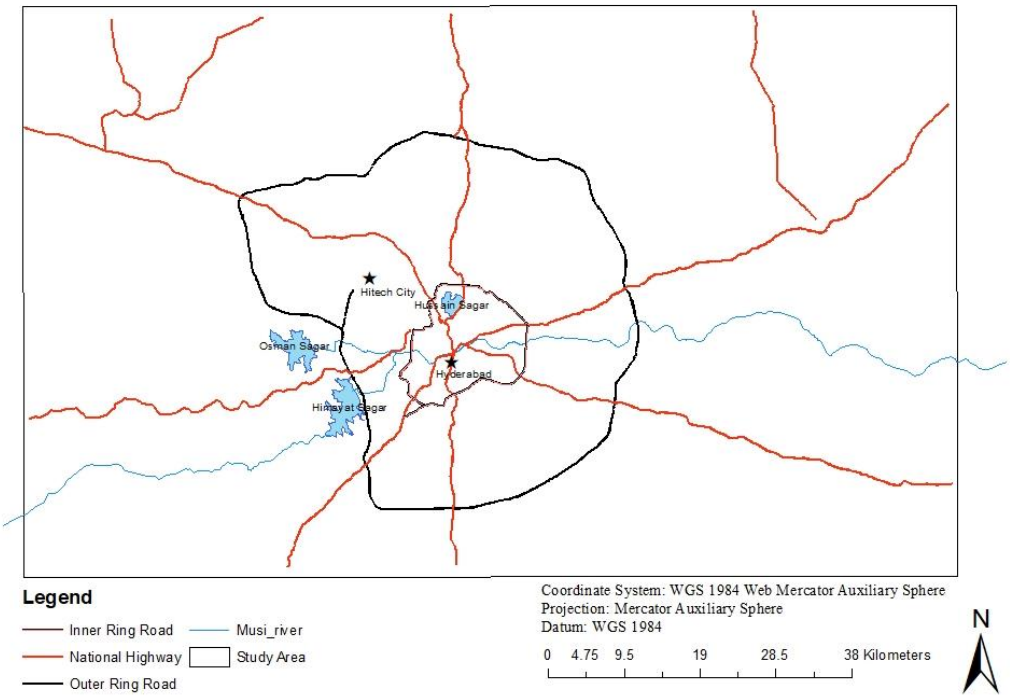



*Figure 3:2* Extent of the area of interest for specific-objective 1 (Data Source: OpenStreetMaps)

### 3.1.2. Secondary Data

The preliminary concern related to the method was the availability of secondary data and the selection of a suitable spatial unit of analysis. The majority of the indicators used in the previous studies are derived from census data (see table 2.1). As a consequence, a significant portion of the past studies has used the administrative or census unit as a spatial unit of analysis. Such analysis generates a list of administrative units or census tracts identified as peri-urban.

However, the use of census data and administrative units or census tracts does not meet the requirements of the objective of this research. First, the census data is not sufficient to map a recent scenario. The latest census of India was conducted in the year 2011 and has not been updated yet. Second, the time and financial resource required to study a large area such as a ward or a "mandal", which are the census tracts in India, exceeds the practical scope of this study.

Therefore, an extensive search for updated secondary data was conducted. It was found that three types of recent secondary data were available. A population distribution layer is available for the year 2011 and 2015 in raster format. A raster layer of built-up areas is available for the year 2011 and 2016; and the road network vector layer is available only for the year 2018.

**Population Distribution Layers:**

The population distribution layers were collected from the WorldPop project[2]. The WorldPop project has estimated and produced a high resolution gridded population map for the world. They distributed the number of population of a census tract into equally sized square cells or pixels. The size of the pixels is approximately 100m x 100m at the equator. This distribution is done by using a Random Forest model, which incorporates the census data and a wide range of open access remotely-sensed and geospatial datasets such as settlement locations, settlement extents, land cover, roads, building maps, vegetation and topography (Lloyd, Sorichetta, & Tatem, 2017). Thus the number of people in each pixel for the year 2011 is estimated. Besides, the project also estimates population grid maps for the year 2015 and 2020 (Stevens, Gaughan, Linard, & Tatem, 2015). Figure 3:3 shows the population distribution in the AoI for the year 2011 and 2015.

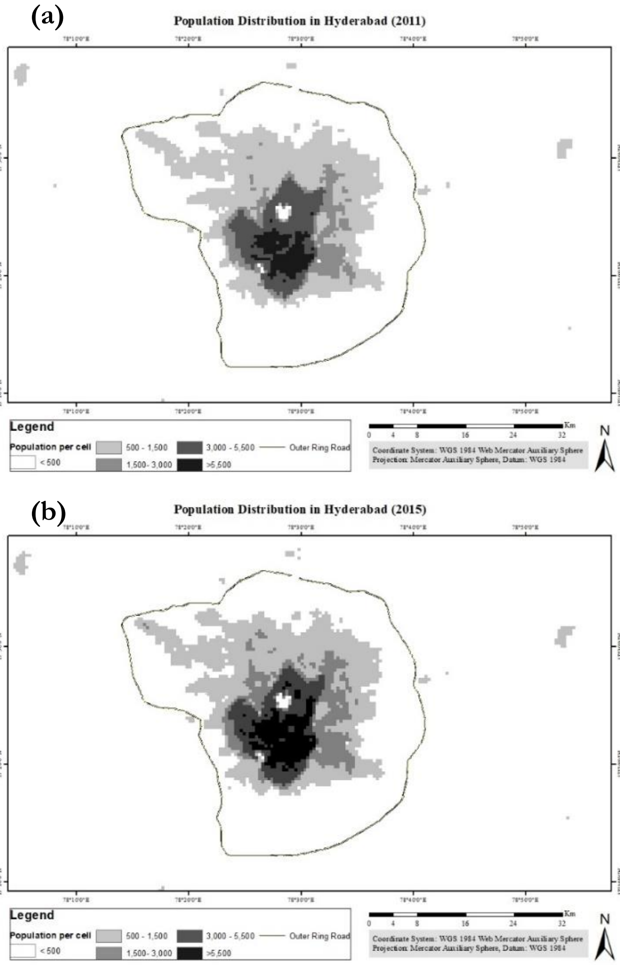



*Figure 3:3* Population distribution of the study area (a) 2011 and (b) 2015 (cell size 500m x 500m) (Data source: worldpop.org.uk)

[2] WorldPop website: www.worldpop.org

**Layers of built-up areas:** Two different layers of built-up areas were collected for the study. The global urban footprint (GUF) layer produced by the German Aerospace Center (DLR) was collected for the year 2011. The built-up layer generated by the Joint Research Centre (JRC) of the European Commission, which is known as Global Human Settlement (GHS) layer was collected to measure the indicators of 2016.

**Global Urban Footprint (GUF) Layer:** This layer has been claimed as the most detailed and consistent map of human settlement or built-up areas for the year 2011 (Esch et al., 2017). DLR developed an Urban Footprint Processor (UFP) which consists of five modules namely data management, feature extraction, unsupervised classification, mosaicking and post-editing. The input data of this UFP are the RADAR (radio detection and ranging) images collected through two satellites named TerraSAR-X and TanDEM-X (Esch et al., 2017).

A Radar satellite sends microwave signals or pulses towards the earth. These waves travel to the earth surface, get reflected by the objects on the earth surface and travel back to the satellite, where an antenna receives the wave. This reflected or backscattered signal is stored by the sensor installed in the satellite and an image is generated. The pixels of such an image store information of the backscattered wave(Bakker et al., 2013).

The elevation of a building in a built-up area is higher than the roads or open land. Therefore, the radar wave reflected by the top of a building travels a different distance than the waves reflected by roads or non-built-up areas. Hence, the urban footprint processor is built on the theory that the characteristics of the backscattered radar waves from the built-up areas, settlements and buildings, are heterogeneous than the non-built-up areas (Esch et al., 2017). The processor classifies the backscattered radar data and determine whether a class is built-up or not based on reference data such as OpenStreetMap settlement layers. The final product is a binary raster map which has a resolution of approximately 12 meters, meaning each pixel represent an area of 12m x 12m. The values of the pixels are either built-up or non-built-up. In a global context, 85 percent of the pixels of this layer are accurate, albeit the accuracy varies from city to city. It has been claimed that this layer can be used to analyse the peri-urbanisation patterns (Esch et al., 2017).

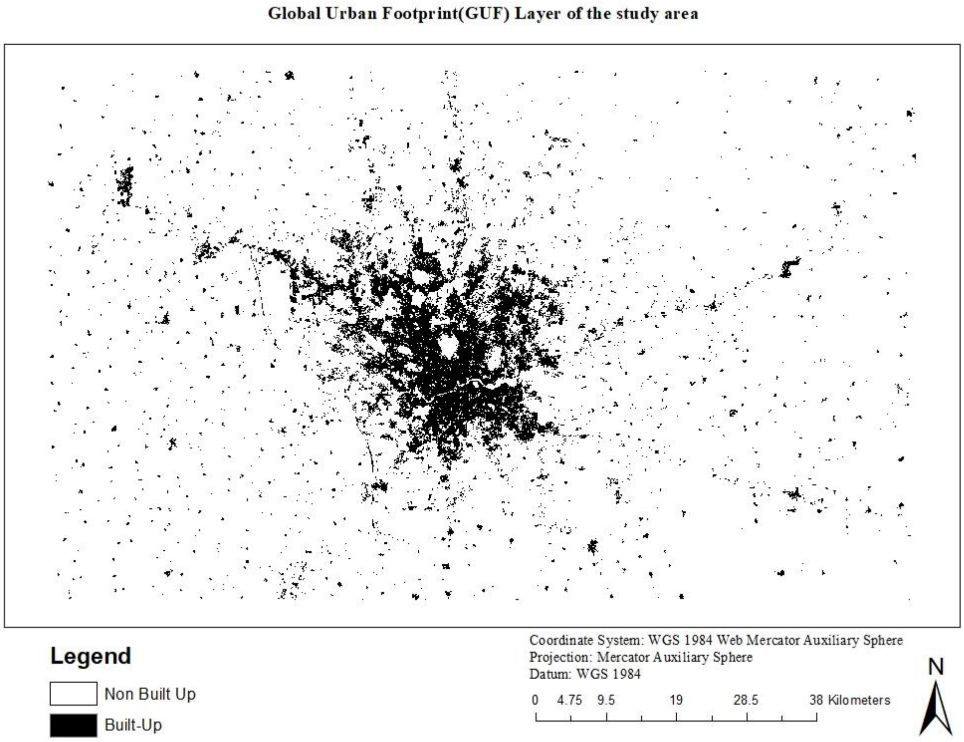



*Figure 3:4* Built-Up layer of AoI (2011) (Data source: German Aerospace center-DLR)

**Global Human Settlement (GHS) Layer:** This open and free data shows the extent of the built-up areas for different years around the world. In this study, the GHS built-up sentinel-1 grid was used as it is derived from the images from 2016 and is the latest layer of built-up areas. This layer was produced by using the Sentinel-1 radar images. A symbolic machine learning technique (SML) was applied to Sentinel-1 backscatter intensity data to identify the built-up areas. The output layer is a binary raster map, similar to the GUF layer (Corbane et al., 2018). Figure 3:4 and 3:5 shows the built-up layers of AoI in the year 2011 and 2016 respectively.

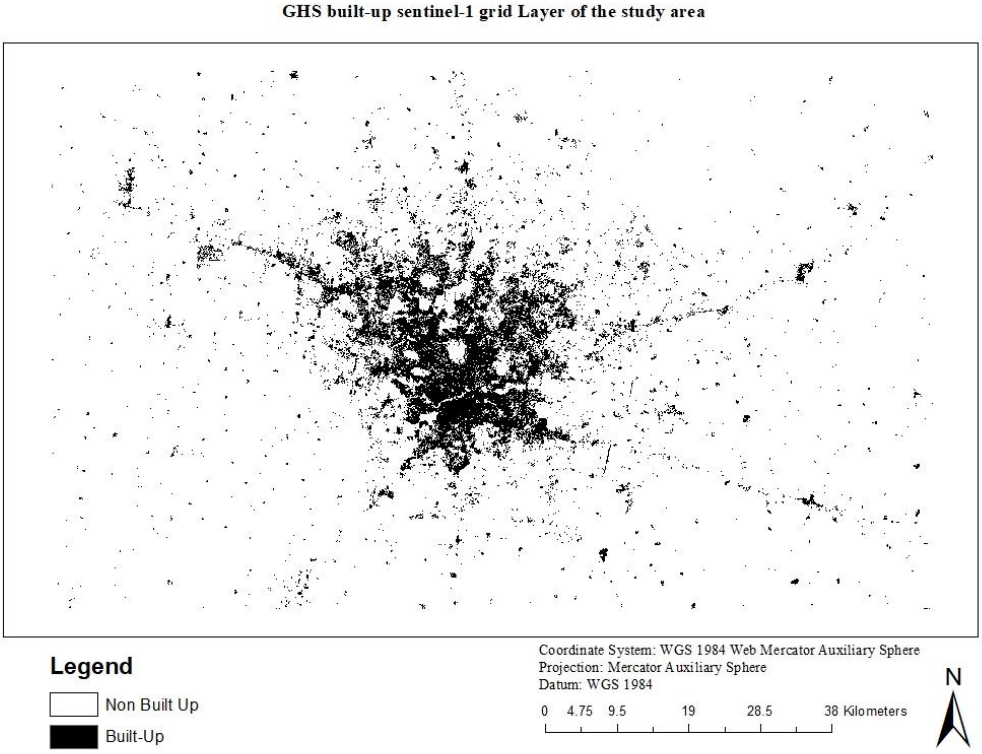



*Figure 3:5* Built-Up layer of AoI (2016) (Data source: European Commission)

**Road Network layer:** OpenStreetMap provides free to use spatial layers such as road network, waterways, and places of interest. For this study, all the spatial data of AoI were downloaded from the OpenStreetMap data extract server (http://download.geofabrik.de/).

The temporal and spatial properties of the secondary data determined two key aspects of this study. First, it is possible to identify peri-urbanisation for Hyderabad between the year 2011 and 2016 using the available data. It was assumed that the road network has not changed significantly since 2016 and population distribution has not changed significantly between 2015 and 2016. Second, the area of interest could be modelled using a tessellation of square cells.

### 3.1.3. Calculating the Indicators

Six indicators, namely population density, density of built-up area, number of patches, landscape shape index, largest patch index and road network density were calculated in this study. These indicators were calculated for each cell.

In addition, to explore the impact of scale, five different cell sizes were used. For that purpose, five tessellations of different sizes (as mentioned in section 3.1) were generated using the extent of the AoI. It is relevant to mention that five different cell sizes are used to test the effect of scale of analysis on the result. Huang, Zhou, and Wu (2016) emphasise the importance of analysis scale in delineating peri-urban areas.

They argue that peri-urban areas show distinct land-use heterogeneity and the built-up areas in the peri-urban areas are scattered compared to the urban core. To capture the heterogeneity, it is crucial to select an appropriate scale of analysis in this case cell size. A smaller cell size is not able to capture the heterogeneity of an area. On the other hand, larger cell size will find heterogeneity or scattered development pattern even in an urban core. Motivated by this claim, this study attempts to explore the effect of scale using five different cell size. The following segment of this sub-section explains the procedure of calculating the indicators.

**Population Density:** Each pixel of the population distribution layer contains the number of people residing in that pixel. Adding up the pixel values within one cell will represent the total population of that cell. As all the cells have equal area, this total population can be used as the population density. This indicator was calculated using the zonal statistics tool of ArcGIS, where the fishnet cells were selected as the zone and the sum operation was selected as the statistics type.

**Landscape Metrics:** The landscape metrics were measured using the moving window analysis in *Fragstats*[3] (version 4). The moving window analysis[4] calculates the landscape metrics from the centre of each pixel of a raster layer taking either a circular or square sized window. In this study square shaped windows were used.

**Density of Built-up Areas**: Sum of the areas of all built-up pixels within each cell (window) was calculated in hectares. As all the cells have equal size, this value was directly used as the density of built-up areas.

**Number of Patches:** Moving window analysis calculates the number of patches in each window. At the urban core where the window is fully covered by built-up areas the value of this indicator is 1. On the contrary, the value of this indicator increases where the built-up area is scattered.

**Landscape Shape Index (LSI):** The landscape shape index is calculated using the following equation in *Fragstats*. The value of this indicator increases when the built-up area becomes scattered and the edges become irregular.

$$LSI = \frac{0.25 \sum_{k=1}^{i} e_{ik}^{*}}{\sqrt{A}}$$

Where, $e_{ik}^{*}$=total length (in metre) of edges in sub-landscape between class type i and k

A=total area of sub-landscape (in square metre)

**Largest Patch Index (LPI):** *Fragstats* measures this index for each cell using the following equation. In the urban core, where the entire window is covered by a single patch of built-up area, the indicator shows a value of 100.On the contrary, in a scattered area, where the largest patch in a window is smaller, the value of this metric decreases.

$$LPI = \frac{max\ a}{A}(100)$$

Where, a= area (in square metre) of the patch
A=area of the sub-landscape

[3] Fragstats calculates various landscape metrics using categorical maps.

[4] Moving window is one of the exhaustive sampling strategy provided by Fragstats. A user specified window is passed over every pixel of the map. Desired landscape metrics are calculated taking the window as the landscape and the value is returned to the focal pixel. Finally, output grids are generated separately for each landscape metrics (Mcgarigal, 2015).

**Road Network Density:** This indicator is quantified by the length of total road network in each cell. A GIS overlay function- intersection- was performed between the road network layer and the fishnet of the AoI. The output feature is a line layer where the roads are separated based on the overlaying cells. The database of this output layer was summarised where the length of roads inside each cell was summed up and the value was used as road network density.

#### 3.1.4. Identification of Urban, Peri-Urban and Rural Areas using Cluster Analysis

After the calculation of the indicators, the indicator values were joined with the corresponding cells as attributes. For example, to classify the study area for the scenario of 2011 using 100m x 100m cells, the values of population density, density of built-up area, number of patches, landscape shape index and largest patch index were calculated using the population distribution layer of 2011, the built-up layer of 2011 (GUF) and the 100m x 100m tessellation of the AoI. Next, the indicator values were joined with the tessellation layer. The cells of the resultant layer are used as the observations for K-means algorithm and the indicators are used as variables.

The grouping analysis tool of *ArcGIS,* categorises points or polygons based on the attribute values following a K-means clustering algorithm. The K-means cluster algorithm is the most popular partitional cluster algorithm. It recognises the pattern of the provided observations, creates clusters of similar observations based on data pattern and separates the observations into pre-specified number of groups. The observations within a group have minimum within group variance. On the contrary, observations from different groups have maximum dissimilarity (A. K. Jain, 2010).

Figure 3:6 (taken from A. K. Jain (2010) shows a simple k-means clustering analysis which classifies the input data based on two variables and three clusters. First, the algorithm creates a two-dimensional space, as there are two variables. At the next step, all the input data are plotted in the two-dimensional space (figue 3:6-a). The co-ordinate of an input data in this space is determined by the values of the two corresponding variables. The algorithm arbitrarily determines three seed points, as the number of clusters is three (represented by circles in the Figure 3:6-b). These seed points are used to initialize the first iteration.

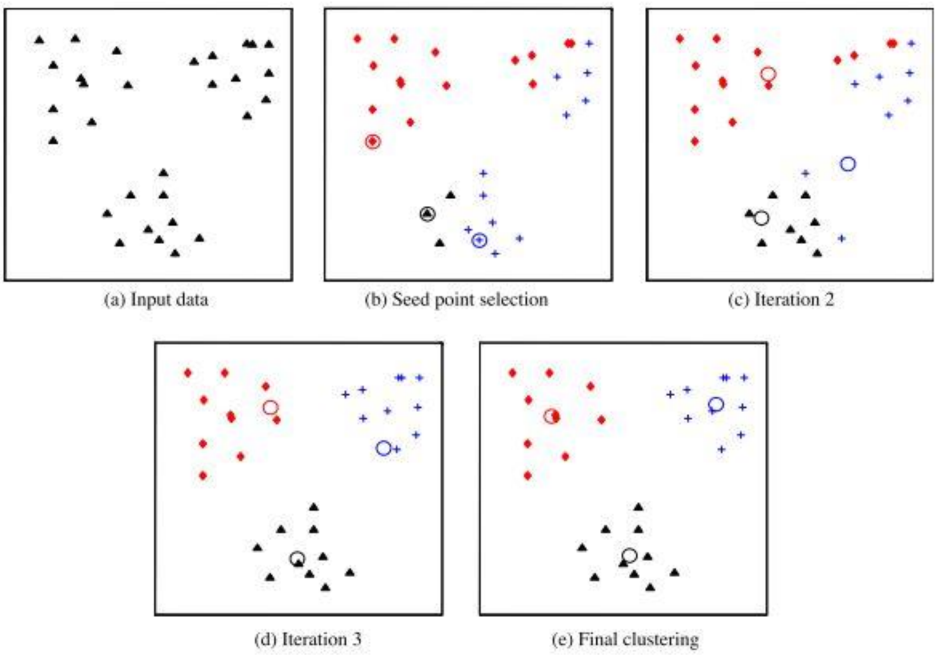



*Figure 3:6* Graphical representation of K-means algorithm (A. K. Jain, 2010)

After the initial iteration the input data are divided into three clusters and the means of the clusters are determined (marked as circles of three different colours: Figure 3:6-c). The next iteration begins by constructing a new cluster by reassigning the data based on its nearest cluster (Figure 3:6-d). For instance, in Figure 3:6-c it can be seen that, there are some red dot data near the blue cluster mean (blue circle). Hence, these red dots are assigned to the group blue plus and a new cluster mean is calculated based on this assignment (Figure 3:6-d). This iteration method stops when two subsequent iteration generates same cluster means.

In this study, the tessellation layer with indicators was used as the input for grouping analysis where the indicators were selected as variables. As three different groups are required the value of parameter-*number of groups*-was given a value of 3. The output of the grouping analysis is a feature class similar to the input feature (tessellation of the AoI). However, an additional attribute is generated named as SS_GROUP. Each cell gets a value of either 1,2 or 3, in the attribute SS_GROUP, which indicates the group membership of a particular cell. In addition, an analysis report is generated where the descriptive statistics of each indicator of each group are described. The output layer was mapped and the group statistics were explored. Based on the location and mean group statistics, the group of cells having the same SS_GROUP value were identified as either urban, peri-urban and rural. A similar procedure was repeated for the scenario of 2016. Furthermore, the analysis was repeated for all five tessellations.

#### 3.1.5. Identification of the Peri-urbanisation locations

As mentioned in chapter 1, peri-urbanisation process transforms the rural areas into peri-urban. Therefore, the cells which are categorised as rural in 2011 and peri-urban in 2016 are the areas of peri-urbanisation between 2011 and 2016. To identify the desired cells a query was performed to select the cells which are labelled as 'Rural' in 2011. The corresponding cells of the 2016 map were selected using an overlay function named "select by location". The selected cells are the areas of scenario 2016 which were rural in 2011. Finally, a second query analysis was performed to extract the peri-urban cells from the previously selected cells of 2016 map. The final selection contains those cells, which transformed from rural to peri-urban between 2011 to 2016. The procedure was repeated for five tessellations.

### 3.2. Result of Cluster Analysis

As explained earlier, the AoI was modelled using five tessellations of five different cell sizes. Furthermore, each tessellation was populated for two scenarios. Hence, total 10 tessellations were analysed using grouping analysis, which generated 10 maps. Each map shows the extent of urban, peri-urban and rural areas of AoI for a certain scenario and certain cell size. The maps are presented as Figure 3.7 to 3.11. In addition, a summary of the analysis is presented as Table 3-1.

*Table 3-1* Share of urban, peri-urban and rural areas in AoI (in percentage)

| | Urban | | Peri-Urban | | Rural | |
|---|---|---|---|---|---|---|
| **Cell Size** | **2011** | **2016** | **2011** | **2016** | **2011** | **2016** |
| 100m X 100m | 1.87 | 1.92 | 8.81 | 10.87 | 89.32 | 87.21 |
| 300m x 300m | 2.04 | 2.19 | 15.95 | 20.25 | 82.02 | 77.56 |
| 500m x 500m | 2.06 | 3.71 | 23.08 | 27.73 | 74.86 | 68.57 |
| 800m x 800m | 2.13 | 5.60 | 34.42 | 39.31 | 63.45 | 55.10 |
| 1000m x 1000m | 2.19 | 6.48 | 40.81 | 44.62 | 57.01 | 48.90 |

Table 3-1 shows that for each cell size, the shares of urban and peri-urban areas have increased from 2011 to 2016. On the contrary, for every cell size the share of rural areas has decreased. Such an increase in urban and peri-urban areas suggests that there is a trend of urban expansion and peri-urbanisation in and around Hyderabad from 2011 to 2016. This analysis is done using population layer, built-up layer and road network layer. Previous studies have claimed that the city has experienced rapid growth of population, expansion of built-up areas and road network over the last few decades (Das, 2015; Franco, Mandla, & Ram Mohan Rao, 2017; Gumma et al., 2017; Wakode et al., 2014). Such increment of population, built-up areas could lead to the increase of urban and peri-urban areas as found in this study.

The spatial distribution of urban, peri-urban and rural areas shown in figure 3:7 to figure 3:11 shows that the urban areas are majorly concentrated in the areas close to the inner ring road, which has a higher population density and higher density of built-up areas (see figure 3:3, 3:4 and 3:5). The peri-urban areas are located just outside the urban areas. However, the spatial extend of these peri-urban areas are not equally spread from the urban core. It is seen that a large portions of peri-urban areas are located in the northern direction from the urban core. Furthermore, the maps indicate that the peri-urban areas extend farther from the urban core along all the national highways.

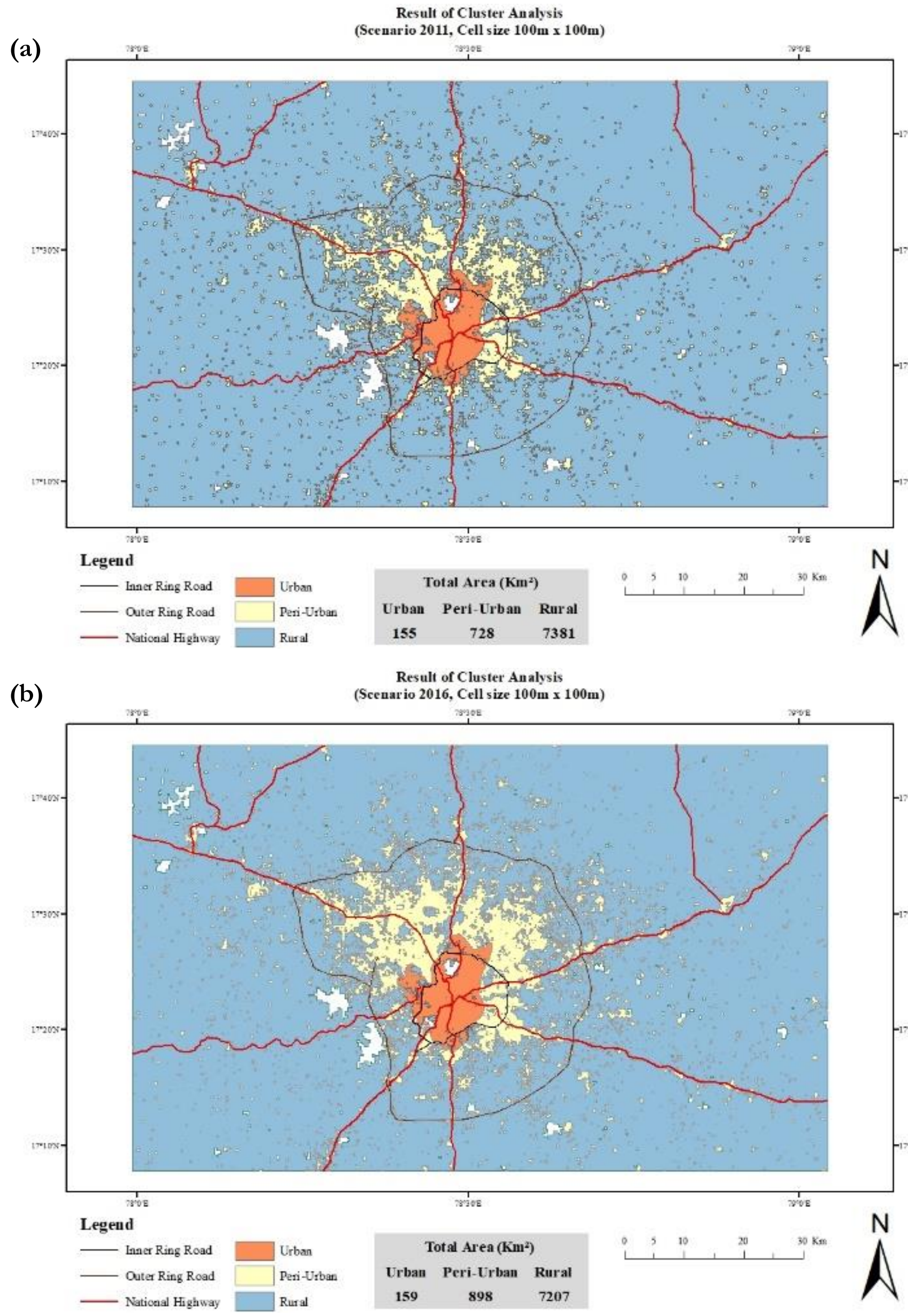
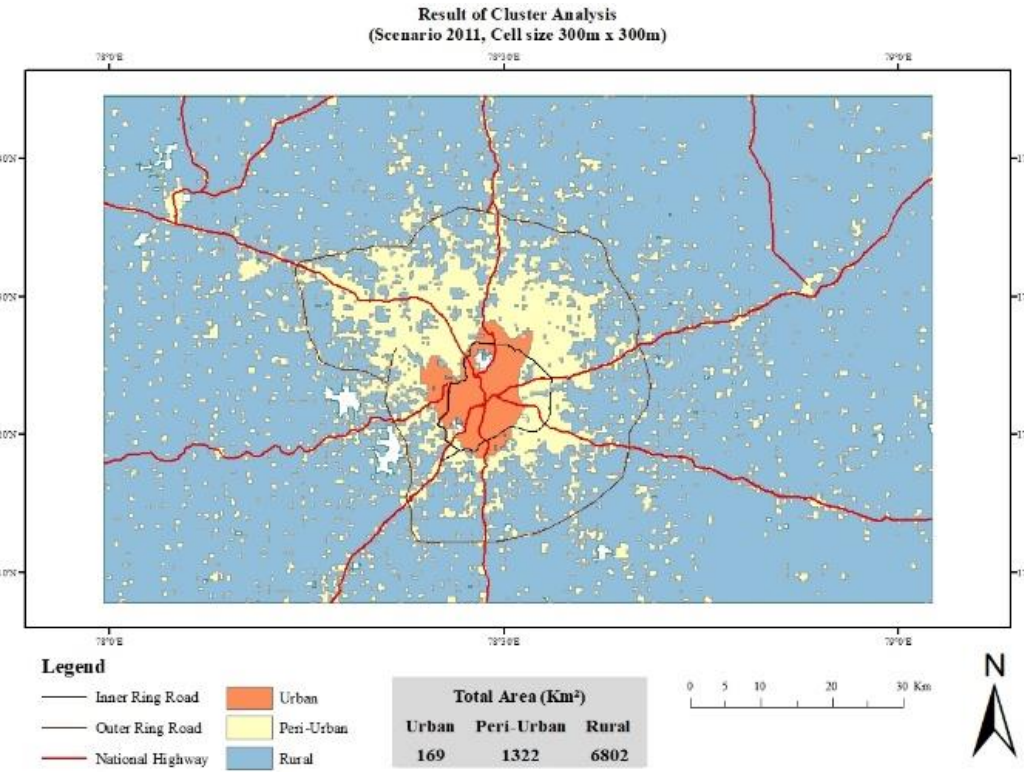



*Figure 3:7* Result of cluster analysis using cell size 100m x 100m, (a) scenario 2011, (b) scenario 2016

(a)




(b)

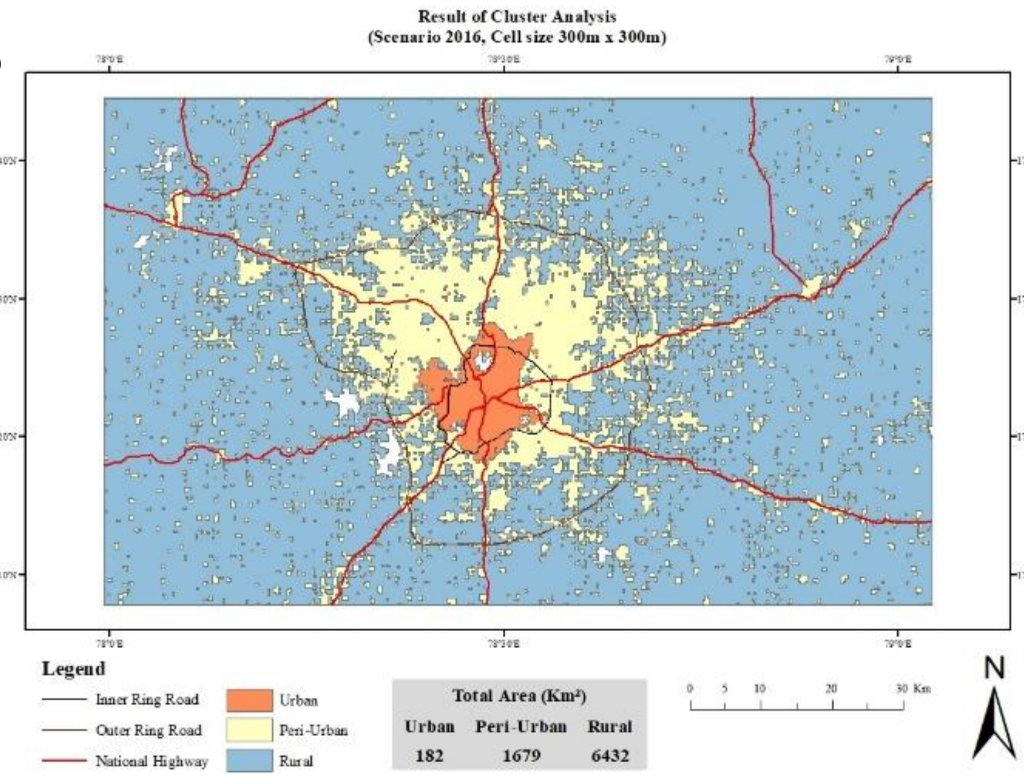



*Figure 3:8* Result of cluster analysis using cell size 300m x 300m, (a) scenario 2011 (b) scenario 2016

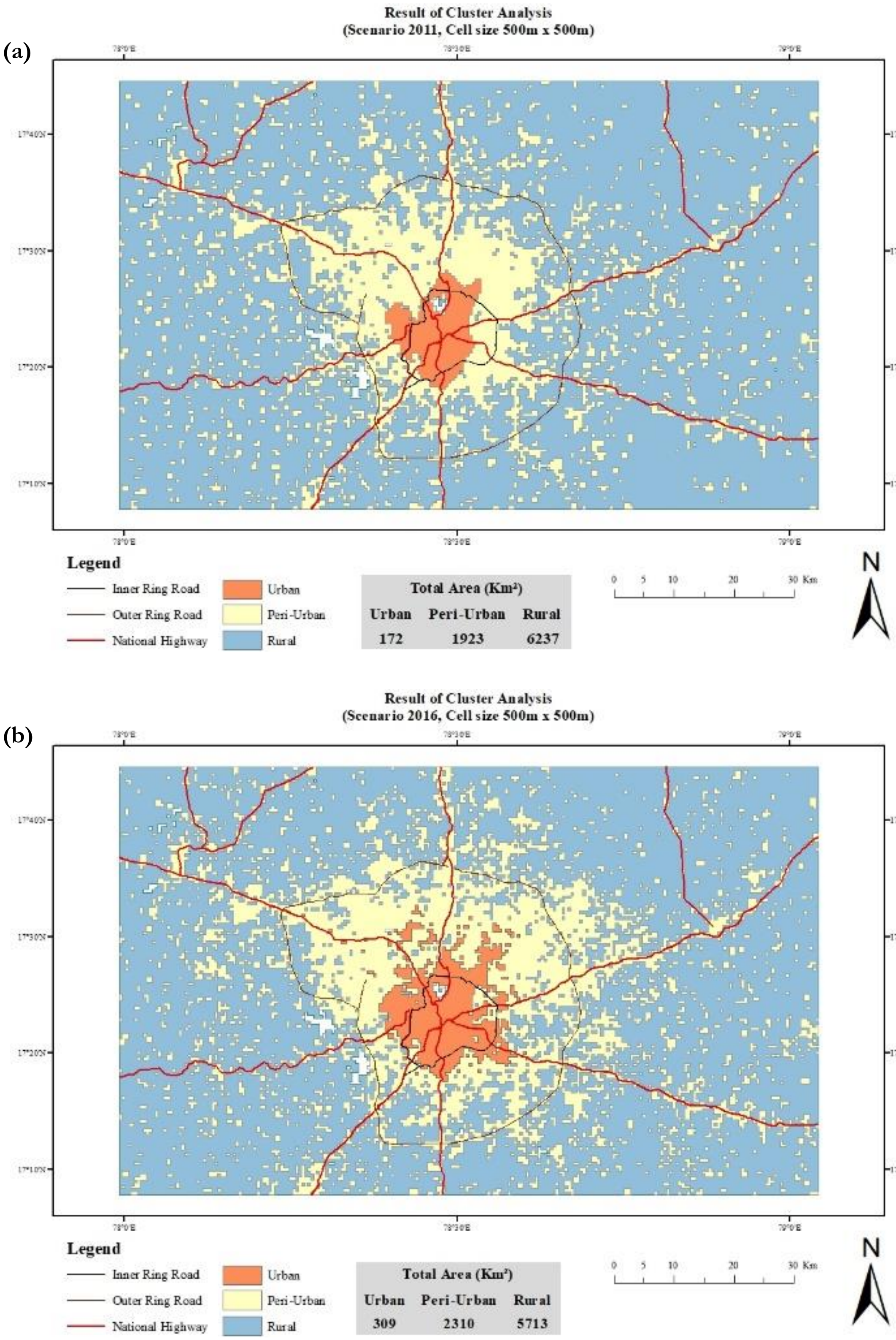



*Figure 3:9* Result of cluster analysis using cell size 500m x 500m, (a) scenario 2011 (b) scenario 2016

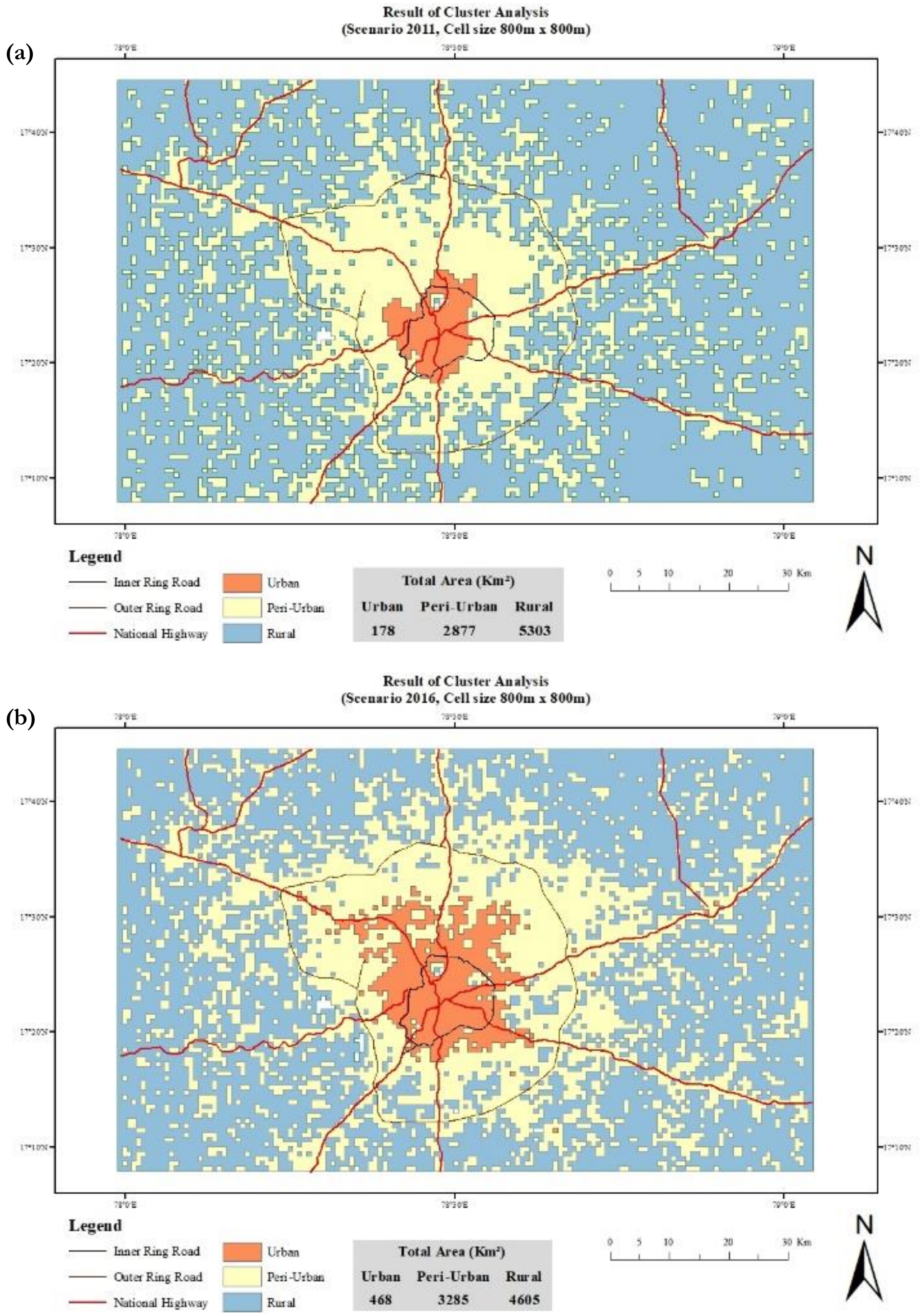
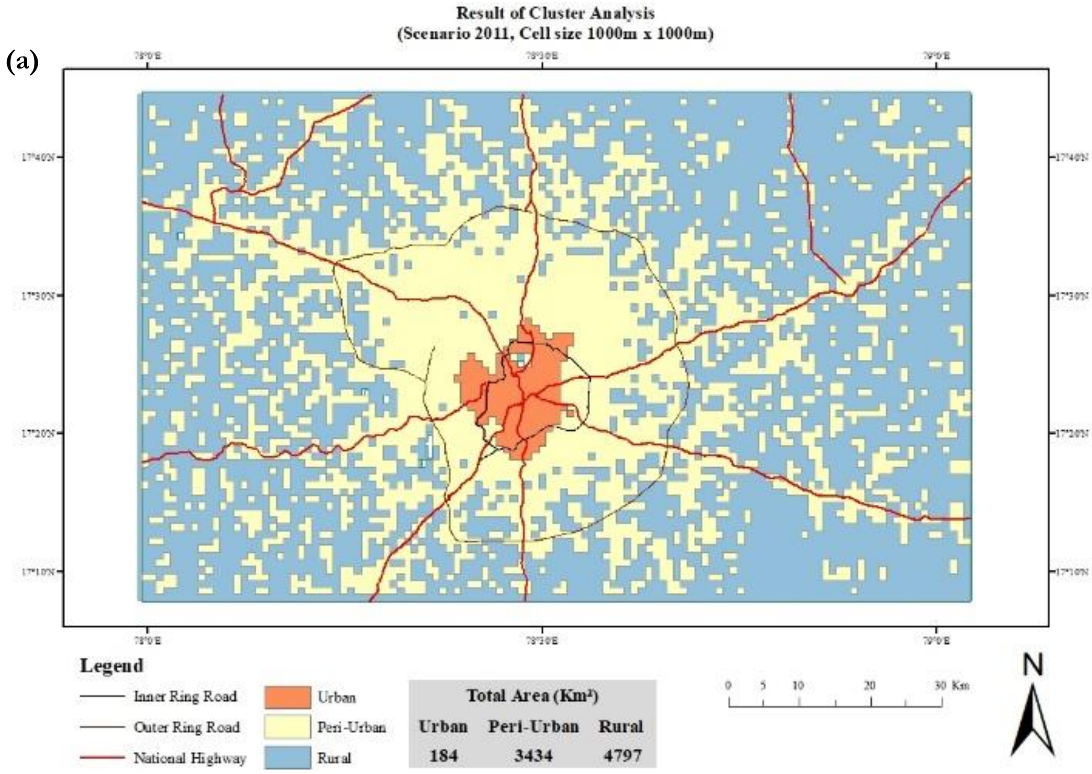



*Figure 3:10* Result of cluster analysis using cell size 800m x 800m, (a) scenario 2011 (b) scenario 2016



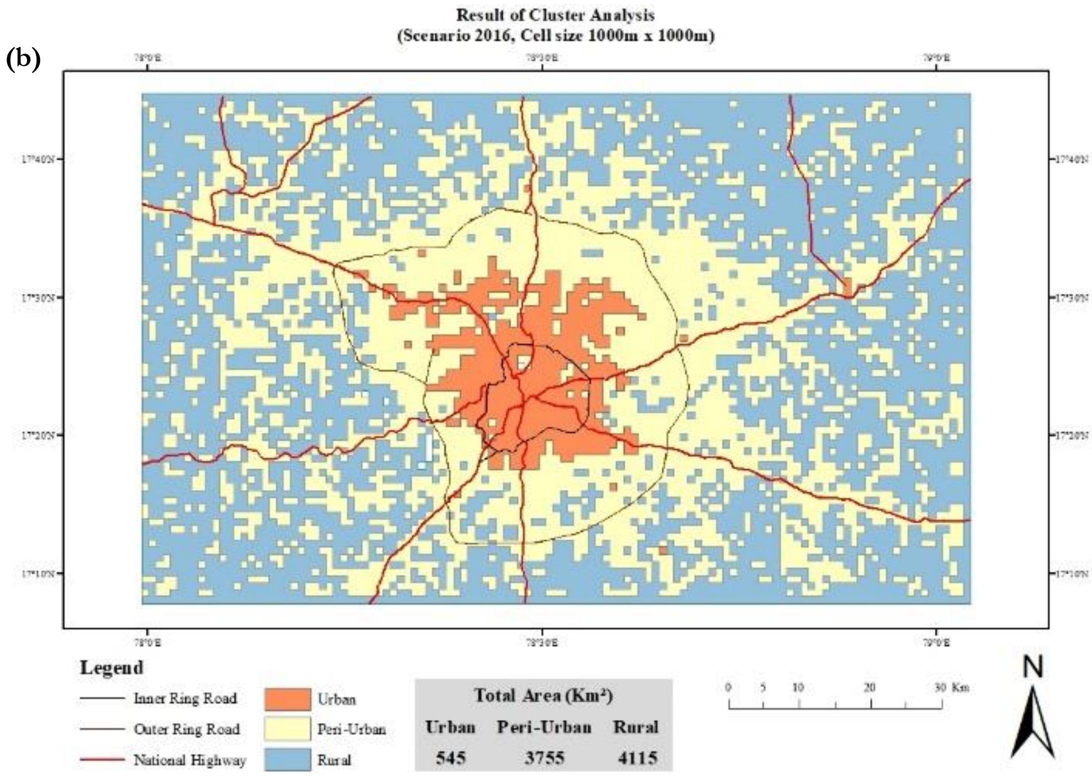




*Figure 3:11* Result of cluster analysis using cell size 1000m x 1000m, (a) scenario 2011 (b) scenario 2016

### 3.3. Discussion of results

Though the maps produced by the cluster analysis indicates a pragmatic trend, it is critical to explore the values of the indicators of each cluster. Table 3-2 enumerates the minimum and maximum values of the indicators for each cluster. At first, the indicator values of three clusters for each scenario are explored.

Table 3-2 shows that the values of population density of rural cells lie between 59 to more than 20 thousand people per square Km in 2011, when a 100m x 100m tessellation is used. The value of built-up density is zero in the rural areas. This indicates the rural areas, defined by the cluster analysis are the cells where the GUF layer (this layer is used as the built-up layer for the year 2011) shows zero built-up areas. This is further realised by the values of other landscape metrics (landscape shape index, largest patch index and number of patches). It is observed that these three indicators in the rural cells have the same value (-999). Fragstat returns a value of -999, when a cell does not contain any built-up pixel. As a summary, the rural areas according to cluster analysis, are those areas which are non-built-up and have a population density between 59 to 20361 people per square kilometre. The upper threshold of population density seems impractical as it exceeds the average population density of Hyderabad in 2011 (18,480/sq. Km) (Gurijala & Asadi, 2019). Moreover, the value suggests that this large number of people resides in an area which has no high rise buildings. Presence of such large number of population in a non-built-up areas seems unrealistic and thus make the result unreliable. Similar impractical threshold values of rural cells are also observed for scenario 2011 and 2016, when tessellations of 300m and 500m are used. However, for cell size 800m and 1000m the threshold values of the population density display a pragmatic condition.

Surprisingly, the minimum built-up density value of urban cells is found to be null in four scenarios (year 2011 and 2016, cell size 100m and 500m). However, the minimum population density values of the urban cells are notably higher (least value is 5647 per square kilometre, scenario 2016, cell size 300m). This finding implies that the cluster analysis suggested some cells as urban, which do not have any built-up pixels but holds a significant amount of population.

The methodology applied in developing the population layer is reviewed to explore the possible explanation of such mismatch. The population distribution layer used in this study was produced by distributing the census population over a built-up area. The extent of built-up areas was derived from four global land cover layers, namely AVHRR land cover classification, MODIS land cover classification, Global land cover 2000 and GlobCover Land Cover product (Linard, Gilbert, & Tatem, 2011). All of these four layers are generated from optical satellite images. The fundamental principles of optical satellite image and radar image are different (Bakker et al., 2013). It is possible that a location defined as built-up by an optical image, might not be detected as built-up in GUF or GHS layer. In such a case, the population distribution layer would estimate the presence of population on that pixel, but the GUF or GHS layer would show it as a non-built-up area.

However, a comparatively pragmatic result is observed when tessellations of 800m and 1000m are used. For instance, when a cell size of 1000m x 1000 m is used, the population density in rural cells varies between 3 to 3525 in scenario 2016. The maximum estimated population density is around one-fifth of the value estimated by 100m x 100m tessellation. For peri-urban cells the values range from 10 to 8951 and the range is 878 to 31807 in urban cells. Besides, the minimum and maximum values of the built-up areas appear to be large enough to accommodate the minimum and maximum values of population density. It is assumed that the use of a larger cell size might negate the mismatch between two layers. Nevertheless, using larger cell size could be criticised for aggregation bias as it loose detailed information.

The products used in this study (population layers and built-up layers) are generated based on two-different types of remote sensing technology. Therefore, combining these incongruent layers poses a risk of error propagation and hence not recommended.

*Table 3-2* Threshold values from the cluster analysis

| | | | Rural | | Peri-Urban | | Urban | |
|---|---|---|---|---|---|---|---|---|
| Scenario | Cell Size | Indicator | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 2011 | 100m x 100m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 1.00 | 0.00 | 1.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 2.14 | -999 | 2.14 |
| | | Largest Patch Index* | -999 | -999 | 4 | 100 | -999 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 4 | -999 | 4 |
| | | Population Density (per sq. Km) | 59 | 20361 | 116 | 11848 | 11851 | 31836 |
| 2016 | 100m x 100m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 1.00 | 0.00 | 1.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 2.75 | -999 | 2.85 |
| | | Largest Patch Index* | -999 | -999 | 4 | 100 | -999 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 6 | -999 | 5 |
| | | Population Density (per sq. Km) | 62 | 22658 | 69 | 14152 | 6914 | 34197 |
| | | Road Network Density (Km/sq. Km) | 0.00 | 93.60 | 0.00 | 118.60 | 0.00 | 96.77 |
| 2011 | 300m x 300m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 9.00 | 0.04 | 9.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 2.94 | 1.00 | 2.68 |
| | | Largest Patch Index* | -999 | -999 | 0 | 100 | 0 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 6 | 1 | 5 |
| | | Population Density (per sq. Km) | 13 | 15393 | 102 | 11136 | 11151 | 31021 |
| 2016 | 300m x 300m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 9.00 | 0.00 | 9.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 5.16 | -999 | 4.88 |
| | | Largest Patch Index* | -999 | -999 | 0 | 100 | -999 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 17 | -999 | 11 |
| | | Population Density (per sq. Km) | 14 | 17710 | 27 | 13714 | 5647 | 33329 |
| | | Road Network Density (Km/sq. Km) | 0.00 | 45.90 | 0.00 | 50.80 | 0.00 | 62.25 |

| | | | Rural | | Peri-Urban | | Urban | |
|---|---|---|---|---|---|---|---|---|
| Scenario | Cell Size | Indicator | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 2011 | 500m x 500m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 25.00 | 0.04 | 25.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 3.36 | 1.00 | 3.17 |
| | | Largest Patch Index* | -999 | -999 | 0 | 100 | 0 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 7 | 1 | 6 |
| | | Population Density (per sq. Km) | 6 | 14010 | 28 | 10770 | 10826 | 30733 |
| 2016 | 500m x 500m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 25.00 | 0.08 | 25.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 7.00 | 1.00 | 7.07 |
| | | Largest Patch Index* | -999 | -999 | 0 | 100 | 0 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 26 | 1 | 27 |
| | | Population Density (per sq. Km) | 7 | 10453 | 10 | 11385 | 2930 | 33164 |
| | | Road Network Density (Km/sq. Km) | 0.00 | 0.03 | 0.00 | 0.04 | 0.00 | 0.05 |
| 2011 | 800m x 800m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 67.24 | 0.80 | 67.24 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 4.86 | 1.00 | 3.85 |
| | | Largest Patch Index* | -999 | -999 | 0 | 100 | 1 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 11 | 1 | 8 |
| | | Population Density (per sq. Km) | 2 | 3862 | 33 | 10345 | 10426 | 29421 |
| 2016 | 800m x 800m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 59.00 | 0.36 | 64.00 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 10.76 | 1.04 | 10.67 |
| | | Largest Patch Index* | -999 | -999 | 0 | 88 | 1 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 60 | 1 | 49 |
| | | Population Density (per sq. Km) | 9 | 4219 | 2 | 9228 | 969 | 31809 |
| | | Road Network Density (Km/sq. Km) | 0.00 | 27.57 | 0.00 | 24.68 | 5.39 | 46.25 |

| | | | Rural | | Peri-Urban | | Urban | |
|---|---|---|---|---|---|---|---|---|
| Scenario | Cell Size | Indicator | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 2011 | 1000m x 1000m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 102.72 | 7.24 | 103.96 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 5.06 | 1.03 | 4.45 |
| | | Largest Patch Index* | -999 | -999 | 0 | 99 | 4 | 100 |
| | | Number of Patches* | -999 | -999 | 1 | 16 | 1 | 10 |
| | | Population Density (per sq. Km) | 3 | 3247 | 120 | 9770 | 7824 | 10167 |
| 2016 | 1000m x 1000m | Built-up Area per cell (in Hectare) | 0.00 | 0.00 | 0.04 | 81.96 | 1.96 | 103.24 |
| | | Landscape Shape Index* | -999 | -999 | 1.00 | 12.48 | 1.32 | 11.88 |
| | | Largest Patch Index* | -999 | -999 | 0 | 79 | 0 | 99 |
| | | Number of Patches* | -999 | -999 | 1 | 76 | 1 | 68 |
| | | Population Density (per sq. Km) | 3 | 3525 | 10 | 8951 | 878 | 31807 |
| | | Road Network Density (Km/sq. Km) | 0.00 | 26.42 | 0.00 | 22.58 | 6.04 | 47.68 |

* Fragstat returns -999 for windows without any built-up area

It is realised that the cluster analysis using cell size of 100m, 300m and 500m shows substantial anomaly. Hence, only the results of cluster analysis using 800m and 1000m cells are compared across scenario 2011 and 2016. It is observed that maximum values of built-up density (Hectare per cell) has decreased from 2011 to 2016 for the case of peri-urban and urban cell (table 3-2). The maximum density of built-up area for peri-urban cells has decreased from 67.24 to 59 hectare when a cell size of 800m x 800m is used. For the same cell size, the maximum built-up density dropped from 67.24 to 64 hectare in case of urban cells. Moreover, the minimum value of built-up density also decreased (0.80 to 0.36 hectare) between 2011 to 2016. A similar decrease in built-up area is observed for 1000m x 1000m tessellation. Such decrease in built-up areas contradicts the findings of recent studies who reports a growth of built-up areas in Hyderabad. Gumma et al. (2017) report that the extent of built-up lands in their study area, which covers the AoI of this study, increased from 68 thousand hectares to 80 thousand hectares.

To explain the anomaly, the GUF and GHS layers used in this study were carefully reviewed. It was found that the extent of built-up areas is less in 2016 (GHS Layer) than that in 2011 (GUF layer). To explore the anomaly a raster calculation was conducted which shows that there are pixels covering a total area of 174 square kilometres, which are built-up in 2011 according to GUF layer but represented as non-built-up in 2016 according to GHS layer.

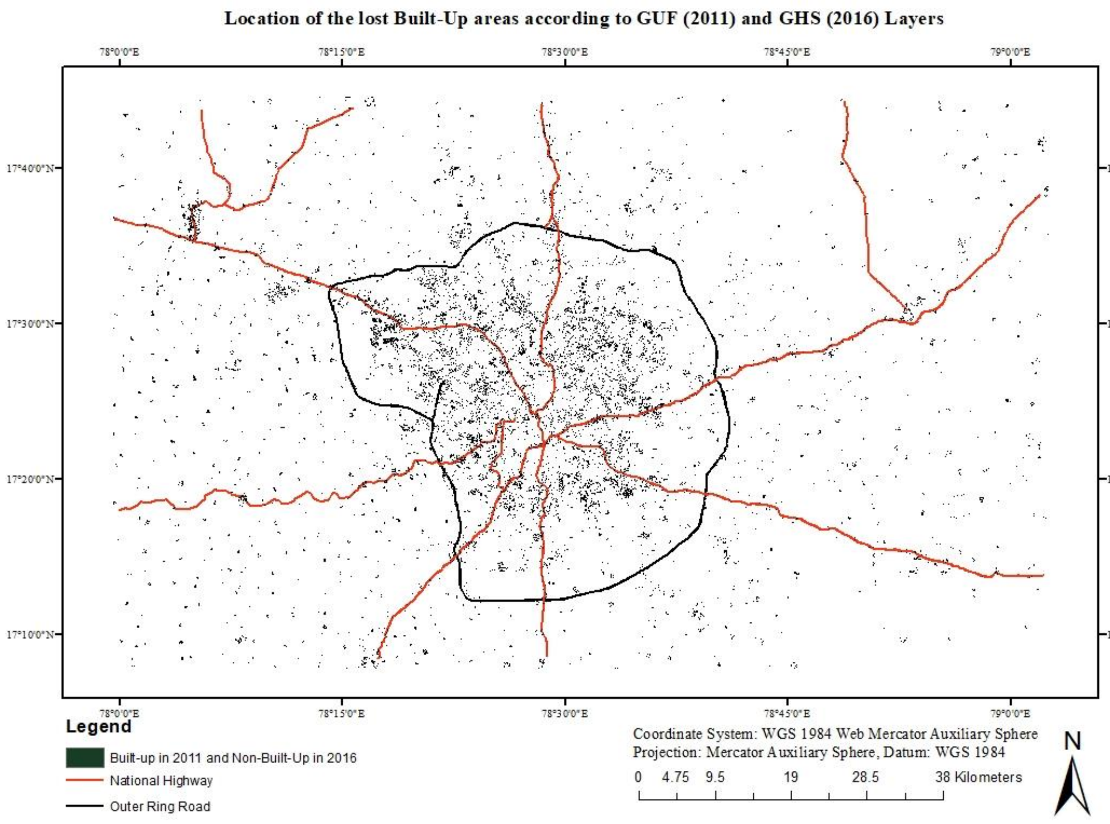



*Figure 3:12* Loss of built-up areas calculated from GUF and GHS layer

Figure 3:12 shows the distribution of such pixels which indicates a loss of built-up areas between 2011 and 2016. These pixels are approximately 2% of the study area. To validate the findings those locations were analysed using *Google Earth* satellite images. However, no conclusive evidence of demolition or similar loss of built-up area was observed on those locations.

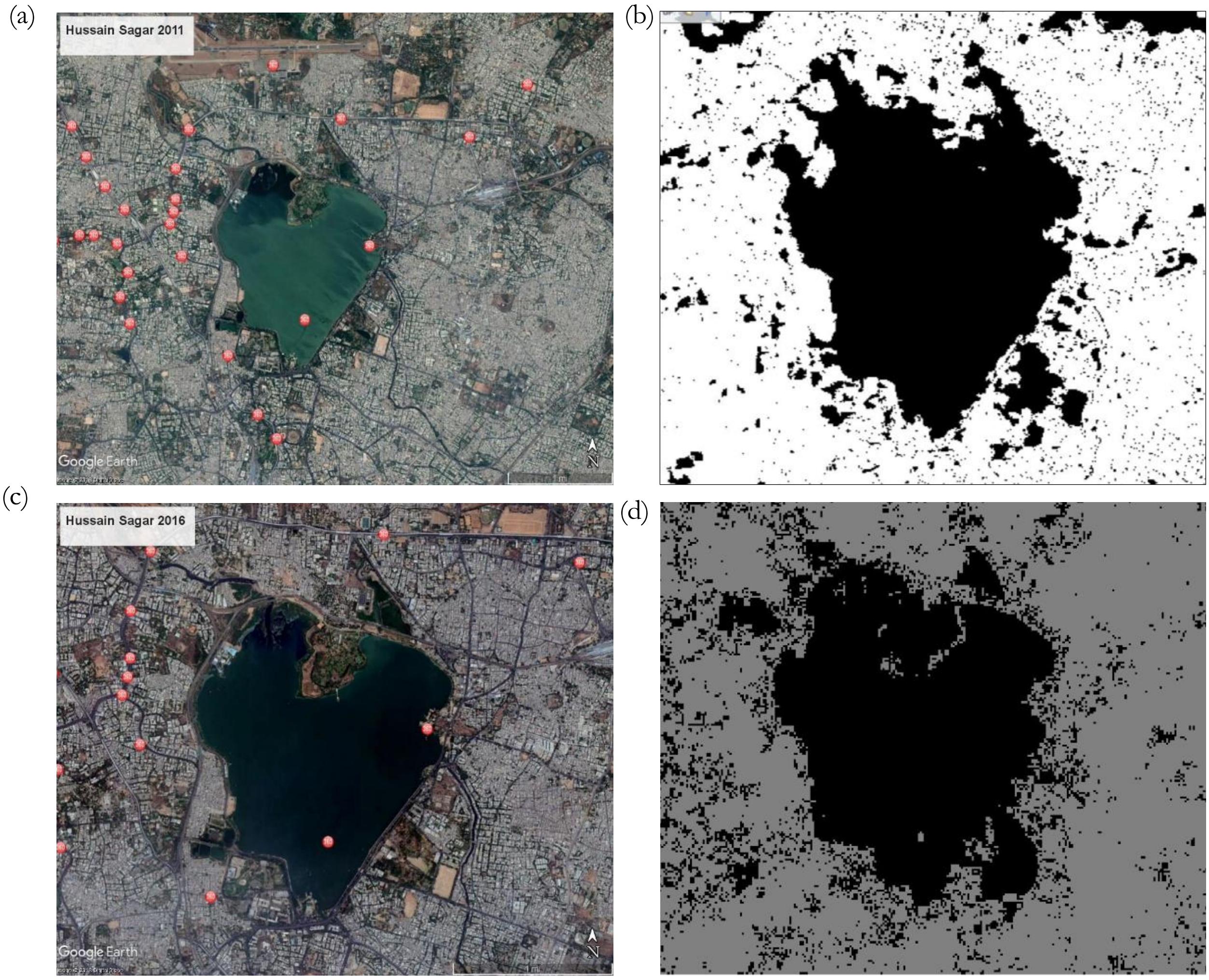



*Figure 3:13* Difference of accuracies between GUF and GHS layers around the areas near Hussain Sagar (a) satellite image of area around Hussain Sagar -2011, (b) GUF layer around Hussain Sagar-2011, (c) satellite image of area around Hussain Sagar -2016, (d) GHS layer around Hussain Sagar-2016

Figure 3:13 shows the actual extend of built-up areas around Hussain Sagar in 2011 and 2016 from Google Earth images and the extend estimated in GUF and GHS layers. It shows that GHS layer has under-estimated some of the built-up areas in the south-eastern edge of the lake. Corbane et al. (2018) mention that the GHS layer has been challenged for the under-detection of sparse built-up areas, particularly in rural settlement. Therefore, the loss of built-up densities between 2011 and 2016 could be associated with the limited accuracy of GHS data.

The above findings of the cluster analysis suggest that the applied method in this study for detecting peri-urbanisation largely depend on the accuracy and compatibility of the used data. The maps produced by cluster analysis look representative at a first glance. However, the threshold values suggested by the analysis are deemed as impractical. Furthermore, use of two different built-up layers from two different sources limits the comparison across two points of time. Therefore, the results obtained from this analysis could not be used to detect the areas of peri-urbanisation between 2011 to 2016.

However, the results could be improved by using two built-up layers from two different times, which are estimated by the same methodology. For instance, the Gumma et al. (2017) prepare Land use land cover (LULC) maps of Hyderabad for different years using a specific method. Their method is successful to detect the growth of built-up areas over time. Using such land cover maps of different points in time could overcome the limitation of the results of this research.

Moreover, LULC maps could be used to find the optimum cell size for such type of analysis. Huang et al. (2016) propose a method, which uses the landscape information entropy value known as "Shannon Diversity Index" (see table 2-1, entry 9), to find the optimum cell size. This information entropy value is calculated from a LULC map. In their study Huang et al. (2016) calculate information entropy for different cell size and plot an average entropy value versus cell size curve. The stationary point of that curve is calculated and the corresponding scale (or cell size) is selected as the optimum scale (referred as $S_0$ in Figure 3:14).

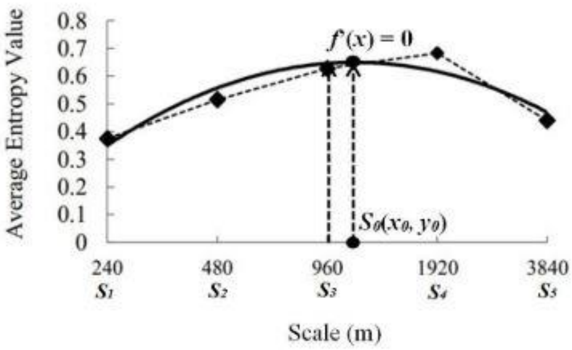



Figure 3:14 Determination of optimum scale using average entropy value (Huang et al., 2016)

It is concluded that the available layers of population distribution and built-up areas suffer from data compatibility. Moreover, the errors in these layers make it unsuitable for longitudinal study. Therefore, such a study should consider that there is a risk of error multiplication when data from different sources are combined.

Using land-use land cover (LULC) maps might overcome the risk of error propagation and the challenge of scale selection. However, the accuracy of such LULC maps should be carefully reviewed before analysis. Furthermore, it is also crucial to examine the compatibility of population layer and built-up layers. Presence of significant amount of population in a non-built-up pixel indicates a possible mismatch between population and built-up layers.

The areas which transformed from rural to peri-urban are identified using the method explained in section 3.1.5. However, due to lack of reliability, the results were not used in the later steps of the study. The results of the analysis are included in this report as Annex-I.

# 4. STUDY AREA: GOWLIDODDY AND GOPANAPALLY

This chapter provides an overview of the study area, which consists of two localities, Gowlidoddy and Gopanapalli. The first section discusses the key aspects which were considered for study area selection. The next section discusses the features of the selected area. and justifies the selection

## 4.1. Selecting an area for detail study: Selection criteria

The discussion of chapter 3 concludes that the identification of peri-urban areas based on available data have limited applicability in this research. Therefore, expert suggestions from Hyderabad Urban Lab (HUL) were solicited for selecting a study area for detail study. It was revealed that HUL considers certain areas in the periphery of Hyderabad as peri-urban. The study area for detail study was selected based on four criteria namely change in land-use, change in transportation infrastructure, change in population structure and finally ease of conducting primary data collection.

**Change in the land-use**: This study aims to explore the travel behaviour dynamics in the context of land use dynamics. Therefore, the study area should have gone through a substantial change in land-use since 2011. Areas which were predominantly agricultural or rural in 2011, but later changed into residential, commercial or industrial were considered as potential study area.

**Change in transportation infrastructure**: Areas which were introduced by public transport service, bus-stop or metro stations or new roads after 2011were deemed as relevant for the study as these developments affect the travel behaviour of the residents.

**Change in the population structure**: Peri-urbanisation brings change in the social structure of an area. One of the processes that stimulate such socio-economic change is migration. Hence, areas which have received new residents in recent years were prioritised. However, to understand the change in the travel behaviour, it is critical to understand the travel patterns of residents living in the area since 2011. Therefore, for the pragmatic reason it was considered that the area should have a significant portion of residents who are living there since 2011.

The cited three aspects were important to select the study area. However, the most critical criterion for selecting an area was the practical aspect of the primary data collection. A review of the Comprehensive Transportation Study (2011) reveals that achieving a desired level of response from the residents of Hyderabad is a major challenge (Hyderabad Metropolitan Development Authority, 2012). As the success of this study depends on the successful primary data collection, HUL selected those areas where they have an established social network and previous research experience.

## 4.2. Features of the selected Area - Gowlidoddy and Gopanapally

Considering the criteria discussed in the previous section a study area was selected for travel survey. The study area consists of two localities namely, Gowlidoddy and Gopanapally. They are located in the North-West direction from the city centre (Figure 4:1). The study area is situated in close proximity from Hitech city and Financial District of Nanakramguda. These two large-scale industrial projects have attracted international investment in the area and thus influenced the peri-urban dynamics of the study area (Kennedy & Sood, 2019).

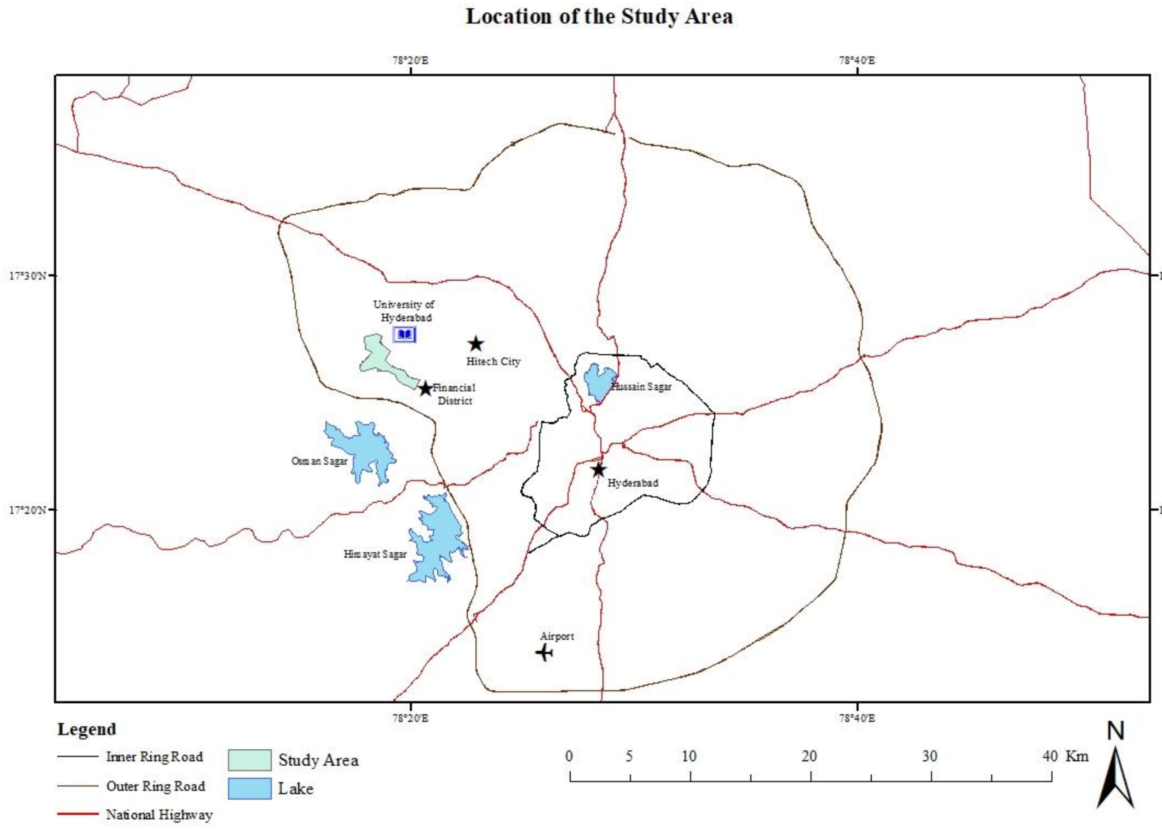



*Figure 4:1* Location of the study area

According to HUL, these two localities were predominantly rural in 2011. The majority of the population in Gowlidoddy were dairy farmers, who were engaged in cattle breeding and milk production. On the other hand, the dominant occupation of the people of Gopanapally was agriculture. They used to cultivate the agricultural fields close to Gopanapally. However, at present the area exhibits features which are analogous to the common features of peri-urban areas such as loss of agricultural land, diverse land use, heterogeneous population, heterogeneous residential structures. The agricultural lands and the grazing lands of cattle have been converted into built-up areas. The newly constructed structures are being used for residential and commercial purpose, thus changing the land-use diversity in the area. Even in 2018 several large infrastructure projects such as IT parks and apartment complex are ongoing.
Establishment of IT-parks and financial district have attracted skilled IT and white-collar professionals in this area. On the other hand, the ongoing real estate projects have introduced job opportunities for less skilled people in the area. As a result, unskilled marginal people from other parts of Telangana and several other states of India, such as Uttar Pradesh, Jharkhand, Bihar and Chhattisgarh have migrated to the area. Therefore, a heterogeneous population structure is observed in the study area.

The two localities offer living space for two different classes of people. As a result, the residential buildings in the area shows a mixture of different types. The area has ill serviced slums, modern apartment buildings and old village houses.

The transportation infrastructure of the area has changed too. The construction of two roads namely outer ring road and ISB road have been completed after 2011. ISB road connects the study area to the outer ring road. Outer ring road is a toll road which surrounds the greater Hyderabad and connects the peripheries with the urban core through a network of radial roads (Figure 4:1). A new bus route has also been introduced in the area, which starts from Gowlidoddy and goes to Kothi Terminal. However, HUL reports that the frequency of buses in this route is extremely low and the schedule is not reliable. Therefore, the bus service is not popular among the residents.

# 5. CHANGE IN TRAVEL BEHAVIOUR AND URBAN FORM

This chapter discusses the methods and results associated with the major focus of the study- change in travel behaviour and urban form. The first section of this chapter explains the methods deployed in this study to collect the primary and secondary data. It also explains how the variables related to travel behaviour and urban form were calculated. The subsequent sections illustrate the changes in travel behaviour and urban form in the study area.

## 5.1. Methodology

### 5.1.1. Primary Data Collection: Questionnaire Survey

The major aim of the primary data collection was to collect the past (2011) and present travel behaviour of the residents of Gowlidoddy and Gopanapally. Variables such as origin of the trip, destination of the trip, mode of transportation, starting time, duration, end time, chosen route, trip frequency etcetera helps to comprehend the different aspects of the travel behaviour of a trip maker. However, in this study three key information were collected namely origin of the trip, destination of the trip and mode of transportation. Other variables such as the starting time, trip duration, frequency etcetera were not considered as it is difficult for a person to accurately recollect these variables of a past trip. Furthermore, collecting data of past and present origin, destination and mode does not require complex survey instrument such as travel diary or additional tools such as GPS tracker or stop-watch. These variables could be collected by administering a cross-sectional questionnaire survey with retrospective questions.

Therefore, the primary data collection of this study was done through a face-to-face questionnaire survey, administered by HUL. A face-to-face administration method was applied as it provides higher response rate than pick and drop method, online survey and telephone interview, particularly in Indian context (Manoj & Verma, 2015).

Due to the absence of current population data, a sampling frame could not be formulated. A total of 254 participants were interviewed. In terms of geographical extent, it was decided that some areas within the study area could not be covered in the survey. There are two gated communities in the study area named Jayabheri and Aparna Shangri-La, which were inaccessible due to strict access control. Moreover, there are apartments, hostels and guest houses, which were also inaccessible due to access control.

The questionnaire survey was structured using 25 closed-ended questions (Annex-II). The questionnaire had two parts; the first part collected socio-demographic information (age, gender, employment status, personal income, household composition, and vehicle ownership) while the second recorded respondent's travel patterns (travel mode for home-based work trips, origin and destination of the trips). These variables were collected for two points in time- present and past (reference year 2011). Retrospective questions were used to collect the past travel behaviour and past socio-demographic information.

To collect the present travel behaviour data, the respondents were asked to recall their latest trip to work from home. This was done to ease the response of the participants as well as to ensure better accuracy. However, for the past travel behaviour the respondents were requested to recall the most frequent trip to work from home that they used to made in the year 2011.

The information related to mode of transportation was collected through a series of questions. The first question asks whether the respondent have walked to the destination or used a single mode or multiple modes for the trip. Respondents who used only one mode selected the used mode from a list of options. However, the multiple mode users were asked to report the modes in sequential order. Finally, the respondents were asked to locate the access and egress locations if they took public transportation such as bus, metro or train. To decrease the burden, respondents were requested not to consider a walk of less than 50 metres as an individual segment of the trip, as suggested by Clifton and Muhs (2012).

The locations of trip origin and destinations for present and past travels were collected in the form of geographic coordinates (latitude and longitude). The location of current residence was calculated with higher accuracy, as most of the participants were interviewed at their residence. However, the locations of the destination could not be collected with similar accuracy. It was found that the participants are more comfortable to answer the destinations by referring to some landmarks. Some of the land-marks are well-known structures such as Wipro building, which could be located accurately. However, some of the respondents answered the destination by referring to a larger locality such as Mehedipatnam or Khajaguda. For these locations HUL applied their local knowledge to ensure the maximum accuracy.

The options provided for the employment status were motivated from the census of India 2011 (Office of the Registrar General & Census Commissioner India, 2011). Similarly, the income ranges were selected based on the Comprehensive Transportation Study (CTS) 2011 (Hyderabad Metropolitan Development Authority, 2012). Household size, number of household members per age group and number of vehicles owned were the questions related to household characteristics. For personal attributes the respondents were asked to report their gender, age, highest level of education and their position in the household.

Finally, a set of life events which could influence the change in travel behaviour was provided. The list of the events was motivated from the work of Lee et al. (2017). In addition, a discussion with HUL was conducted to identify the most relevant events in the context of the study area. Reports of these events were later used to validate the responses pertinent to household composition and socio-economic attributes.

#### 5.1.2. Secondary Data

The urban forms and their change from 2011 were calculated using three types of secondary data, namely land-use maps, map of built-up areas and map of bus-routes and bus-stops. Land-use maps and bus-route maps were collected from HUL. Two maps of built-up areas within the study area were prepared by digitising the satellite images of 2011 and 2018 in *Google Earth***.**

#### 5.1.3. Calculation of Variables

**Calculation of Travel Distance:** For each survey respondent, two travel distances-for 2018 and 2011, were calculated using the origin and destination locations of the trips. The travel distances were calculated using the distance calculation tool of Google Maps. ArcGIS network analysis tool is another option to calculate travel distance. However, the data collected from OpenStreetMaps (OSM) server was not sufficient to model a network dataset, at least for Hyderabad. To construct a network dataset in ArcGIS, it is critical to define “one-way” roads and their direction. In principle, the line feature of the one-way roads should be digitised according to the direction of the vehicle flow. After examining the OSM road network, it was found that the unidirectional roads were digitised without following a uniform method. Hence, it was not possible to define an appropriate “one-way” attribute for the network dataset.

On the contrary, the distance calculation service provided by Google Maps calculates the actual travel distance considering the actual road network, direction of flow and barriers. Moreover, this open source service allows to calculate the routes, travel distance, travel time for different modes. A script in Java language (Annex-III) was developed, which extracts the distance travelled for the fastest route between the origin and destination. It is important to mention that the fastest route calculated by Google Maps may not be the shortest route between two locations. Moreover, the suggested fastest route may change for the different time of the day depending on the actual traffic condition. However, the distances provided by the service offers a pragmatic route and travel distance.

Nevertheless, the distances calculated by Google Maps were further examined. This was done by comparing the travel distances with the Euclidean distances between origin and destination locations. The calculated travel distances were examined further for cases where the calculated travel distance had a significant difference from the Euclidean distance. These travel routes were corrected individually by examining the suggested routes of Google Maps service.

The distances calculated for the present trips are more realistic than the distances of travel in 2011. It was found from the satellite images that several roads around the study area were not in operation in 2011. Hence, the routes suggested by Google Maps for the trips made in 2011 were further analysed using the satellite images of 2011. The routes which passed through the newly constructed outer ring road and ISB road were discarded. Only those routes which passed through the existing roads in 2011 were selected and the travel distances of those routes were considered for the variable distance travelled in 2011.

**Calculation of urban form related indicators**: Several studies report that a change in the urban form influences the travel behaviour of an individual (Ewing & Cervero, 2010). Scholars use five different types of indicators, known as 5-D's to quantify the changes in built-environment (Cervero, 2013; Ewing & Cervero, 2010). The 5-D's are density, diversity, design, distance to transit and destination accessibility (Cervero, 2013). The land-use maps and maps of built-up areas were used to calculate two indicators of 5-D's, density and diversity. Other indicators were not calculated due to lack of secondary data.

**Density:** Scholars use population density, density of dwelling units, employment density, density of building floor area as the indicators of density. In this study, density of built-up area was calculated as the measure of density. Secondary data required for calculating population or employment density was not available. The indicator was calculated using the following formula:

$$Density\ of\ built\ up\ area = \frac{total\ built\ up\ area}{total\ study\ area} x\ 100$$

**Diversity:** Diversity of an area reflects the heterogeneity of land-use. In this study, the indicator used for diversity is entropy or land-use diversity index. This indicator was calculated using the following equation (Singh, Fard, Zuidgeest, Brussel, & Maarseveen, 2014):

$$LU_d(i) = \frac{-\sum_i \left(Q_{lu_i}\right) x\ \ln Q_{lu_i}}{\ln n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$Q_{lu}(i) = S_{lu}(i)/S_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Here, $LU_d(i)$= Entropy or land use diversity index
$Q_{lu}(i)$= share of a specific land-use in the study area calculated by equation (2)
$S_{lu}(i)$= total area of the specific land-use
$S_i$ = total study area
n= number of land-use types

When the study area is composed of only one land-use the calculated value of the index is zero. A higher value of this index indicates higher land use diversity.

## 5.2. Change in Travel Behaviour

### 5.2.1. Characteristics of the sample

Table 5-1 presents an overview of the 254 interviewed respondents. The sample has a dominant representation of male respondents. A calculation of female share in workforce participation was made following the CTS 2011 report. The report claims that the areas outside the Greater Hyderabad Metropolitan Corporation (GHMC) had a ratio of 966 females per 1000 males in 2011. Workforce participation rate among the male was 85% and 13.4% of the female were engaged in work (Hyderabad Metropolitan Development Authority, 2012). Hence, the share of female workforce in 2011 is calculated as 13.2 percent. It is assumed that the male-female ratio of this sample is close to the actual ratio in workforce participation.

Around one-fourth of the respondents have in-migrated to this area after 2010. However, no reference value of migration in peri-urban Hyderabad was available to triangulate the sample composition from the perspective of migration.

A significant portion (44.9%) of the sample has never attended any education. This value exceeds the share of illiterate residents in Hyderabad calculated from CTS 2011 report (29.63%). The residents of gated communities, apartment complex, hostels and guest houses who are supposed to have some level of education, were not covered in the survey. This exclusion might have led to the over-representation of people with no education in the sample.

*Table 5-1* Sample's socio-demographic characteristics

| | | Statistics | Percent of total sample |
|---|---|---|---|
| | Total Number of participants | 254 | |
| Gender | Male | 206 | 81.10% |
| | Female | 48 | 18.90% |
| Age | Mean Age (years) | 40.82 | |
| | Minimum Age (years) | 20 | |
| | Maximum Age (years) | 69 | |
| | Number of participants between age 15-34 years | 86 | 33.90% |
| | Number of participants between age 35-59 years | 157 | 61.80% |
| | Number of participants aged 60 and above | 11 | 4.30% |
| Duration of residence in study area | Average duration of residence in study area (years) | 27.07 | |
| | Number of long-term resident | 190 | 74.80% |
| | Number of new-migrants | 64 | 25.20% |
| Education level | Never attended | 114 | 44.90% |
| | 5 years of schooling | 56 | 22.00% |
| | 8 years of schooling | 44 | 17.30% |
| | 10 years of schooling | 36 | 14.20% |
| | More than 10 years of schooling | 4 | 1.60% |
| Role in the household | Household head | 122 | 48.00% |
| | Other role | 132 | 52.00% |

Table 5-2 presents the present (2018) and past (2011) socio-economic and household characteristics of the sample. At present (column 2018, table 5-2), the majority of the respondents are daily wage earner. The next largest group consists of respondents engaged in full-time permanent job. Census of India defines these respondents as employed (main worker) (Office of the Registrar General & Census Commissioner India, 2011). More than seventy percent of the respondents earn between 10 to 15 thousand Indian Rupees (INR) per month. Only one respondent has reported earning between 40 to 60 thousand INR, which is the highest reported monthly income.

*Table 5-2* Descriptive statistics of socio-economic and household related variables (value represents percent unless mentioned otherwise)

| Variable | Level | 2011 | 2018 |
|---|---|---|---|
| Employment Status | Employed (Main worker)* | 29.91 | 37.8 |
| | Employed (Marginal Worker)* | 0.98 | 1.18 |
| | Self Employed (Main Worker)* | 14.70 | 12.99 |
| | Self Employed (Marginal Worker)* | 0.49 | 0.39 |
| | Daily Wages* | 53.92 | 47.64 |
| | Student/Unemployed** | 19.6 | - |
| Monthly Income (in INR) | No Income | 18.9 | - |
| | Up to 5 thousand | 7.48 | - |
| | 5 to 10 thousand | 50.79 | 11.81 |
| | 10 to 15 thousand | 18.9 | 70.87 |
| | 15 to 20 thousand | 1.97 | 12.6 |
| | 20 to 40 thousand | 1.97 | 4.33 |
| | 40 to 60 thousand | - | 0.39 |
| Vehicle ownership | No vehicle owned | 70.50 | 53.54 |
| | Only Two-wheeler | 24.40 | 32.28 |
| | Only Auto-rickshaw | 5.10 | 7.09 |
| | Two-wheeler and Auto | - | 4.72 |
| | Two wheeler and Car | - | 2.36 |
| | Number of Auto rickshaws/1000 HH member | 12 | 32 |
| | Number of Two-wheelers/1000 HH member | 84 | 126 |
| | Number of Cars/1000 HH member | - | 6 |

** Calculated as percent of total employed respondents in 2011*
*** Calculated as percent of total sample size*
**** 23 respondents do not remember the number of members per age group in 2011. The presented result is calculated based on the valid responses.*

A comparison between the past (2011) and present (2018) values of socio-economic and household characteristics of the sample indicates changes over time (table 5-2). The share of full time employees (Employed- main worker) has increased and share of daily wage earners has decreased since 2011. HUL claims that the recent development in and around the study area have triggered a change in employment structure. IT parks, commercial services, gated communities and dormitories are offering permanent employment related to housekeeping, cleaning, security and so on. HUL claims the creation of these types of jobs has caused a shift in the employment structure in the study area. HUL also reports that the majority of the self-employed residents, who are mainly dairy farmers or “Gowala” are experiencing difficulties with their present occupation. Conversion of grass land into residential buildings have decreased the space for cattle grazing. Moreover, the encroachment of the nearby lakes and walled residential areas have limited their access to waterbodies, which are critical for dairy farming. Hence, there is a possibility that more people from self-employment occupation will shift to other occupation. This sample already shows a small drop in the percentage of self-employed respondent from 2011 to 2018. However, these claims are qualitative and made based on the field-work observation. Therefore, this study does not claim any causal relationship between the change in employment structure and peri-urban dynamics.

Changes are also observed in the variable "monthly income". In 2011, the income range 5 to 10 thousand INR has the highest frequency. However, in 2018 the income group having the highest frequency is 10 to 15 thousand INR. It is also observed that the percentage of respondents for the income groups 0 to 5 thousand, 5 to 10 thousand have decreased in 2018. On the contrary, the share of respondents earning 10 thousand or more has increased since 2011 (Table 5-2 and Figure 5:2). Furthermore, more than eighty-five percent (85.8%) of the respondents have reported a rise of income since 2011 and the rest of the participant have reported that their income has not changed between 2011 and 2018. These observations suggest an overall rise in income of the respondents.

Winarso et al. (2015) explored the change in income taking the peri-urban Jakarta as a case study and found a similar pattern. In peri-urban Jakarta, the proportion of households earning less than 1250 thousand Rupees decreased from 1991 to 2006. However, the share of households earning between 1250 to 2499 thousand rupees increased sharply. The proportion of other higher income groups also increased, albeit in a less steep manner (Figure 5:1). The pattern of income change in this sample imitates the findings from peri-urban Jakarta (Figure 5:2).

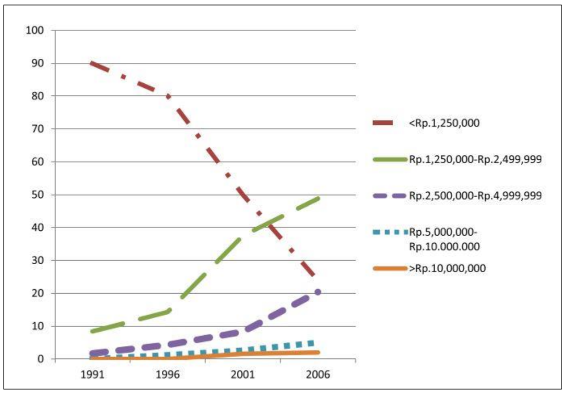



*Figure 5:1* Change in household income in peri-urban Jakarta (1991-2006) (Winarso et al., 2015)

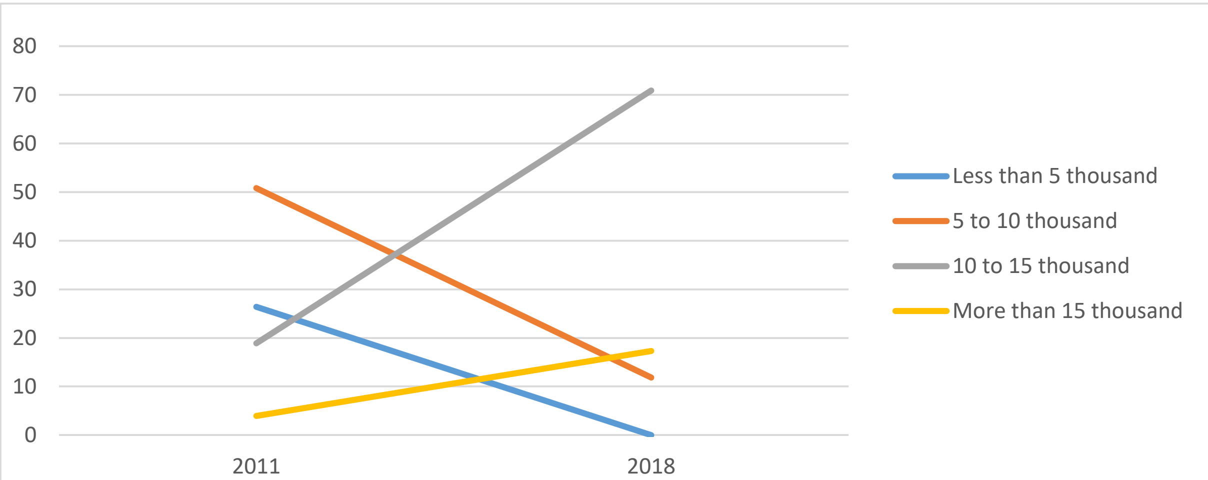



*Figure 5:2* Change in household income in the study area (2011-2018)

However, these findings are not sufficient to establish a causal relationship between the peri-urban dynamics and change in the socio-economic characteristics. The increase in income of the respondents could be associated with other macro-economic factors. It has been reported that India has been experiencing a rise in GDP in recent years (The World Bank, 2019). The rise in income in the study area could be a reflection of nationwide economic growth instead of peri-urban dynamics. Furthermore, factors such as inflation, increased price of commodities influence the value of money over time. Therefore, an increase in income might not indicate an economic development of an individual. Nevertheless, it is concluded that the sample shows an increase in income and change in employment structure which resembles the reported trend in peri-urban areas.

Cervero (2013) argue that the rapid economic development and rising income in the global South has stimulated the motorisation rate. Such rapid motorisation is one the major catalyst for reducing the share of walk, NMT and public transport trips in urban areas (Cervero, 2013). This study provides an opportunity to explore the rate of motorisation from a peri-urban perspective.

Table 5-2 illustrates the pattern of vehicle ownership in 2011 and 2018 for the sample. It is observed that the majority of the respondents (70.50%) did not own any vehicle in 2011. Around one-fourth respondents of the sample (24.40%) used to own two-wheelers and around 5 percent of respondents had auto-rickshaw in 2011. However, the pattern of vehicle ownership in 2018 indicates a rise in motorisation. The percentage of respondents who do not own any vehicle decreased to 53.54 percent. Approximately one-third of the respondent (32.28%) own at least one two-wheeler. Percentage of respondent having an auto-rickshaw increased by around 2 percent. New patterns of vehicle ownership (two-wheeler and auto-rickshaw, two-wheeler and car) are observed. Interestingly, none of the respondents reported to own a bicycle in 2018 and there is only one respondent who used to own bicycle in 2011. Table 5-2 further shows that the number of vehicles per 1000 household member has increased between 2011 to 2018 for all types of vehicles. The result of the exploratory analysis suggests that the sample exhibits an increasing trend of motorisation. Cervero (2013) mention this trend as one of the key challenges for sustainable transport planning in the context of India and other developing countries.

#### 5.2.2. Change in Travel Behaviour

**Change in Destination:** The coordinates of the trip destinations (job locations) in 2011 and 2018 are mapped and presented as Figure 5:3 and 5:4. Visual interpretation of the maps indicates that the locations of destination in 2018 are comparatively less scattered than in 2011. However, these maps do not show the percentage of trips attracted by different locations.

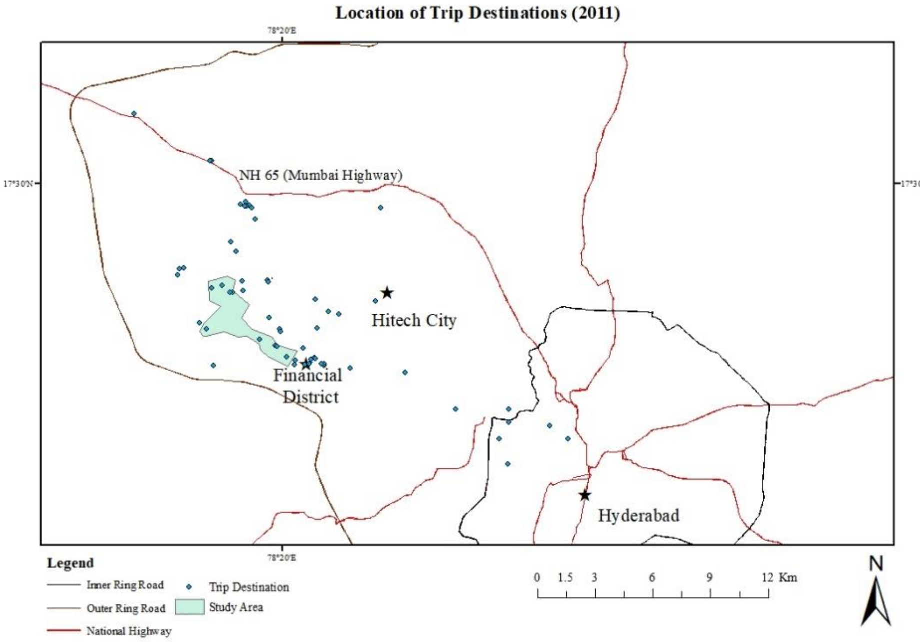



*Figure 5:3* Destinations of HBW trips (2011)

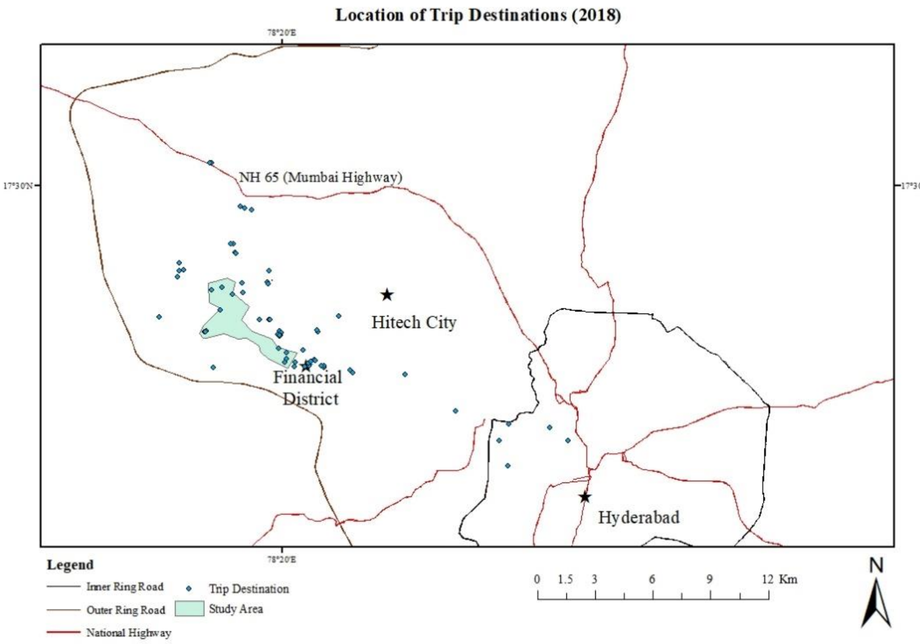



*Figure 5:4* Destinations of HBW trips (2018)

To explore the relative attractiveness of the job locations, the number of trip destinations were accumulated in 500m x 500m cells and the percentage of trips attracted by each cell was calculated. Figure 5:5 and 5:6 show the shares of trips at each destination cell. Furthermore, the percentages are compared across two points in time-2011 and 2016. Figure 5:7 shows how the relative attractiveness of these cells have changed from 2011.

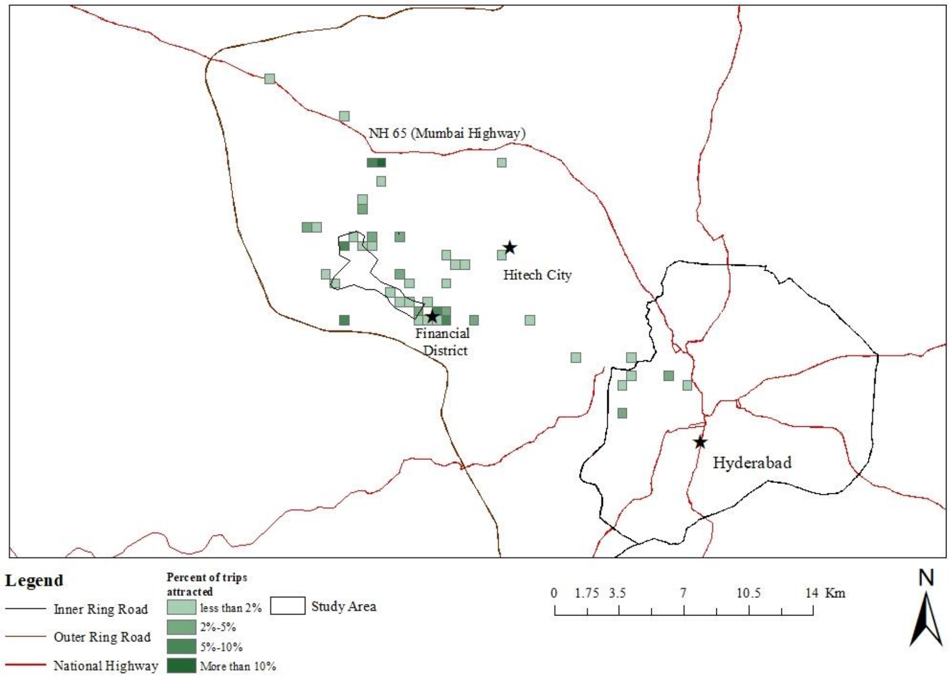



*Figure 5:5* Distribution of trips (2011)

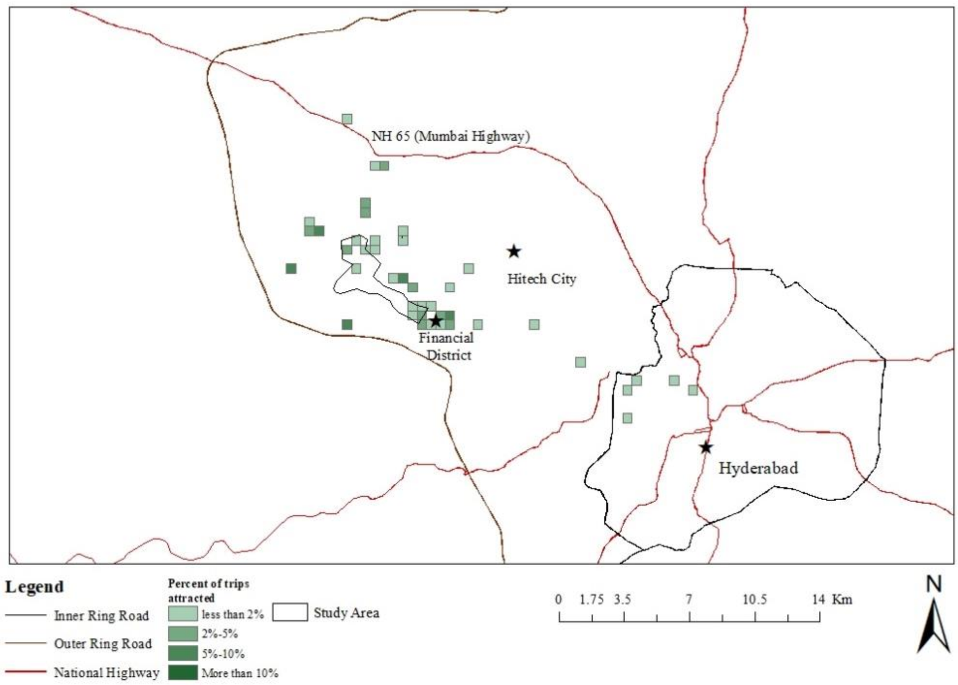



*Figure 5:6* Distribution of trips (2018)

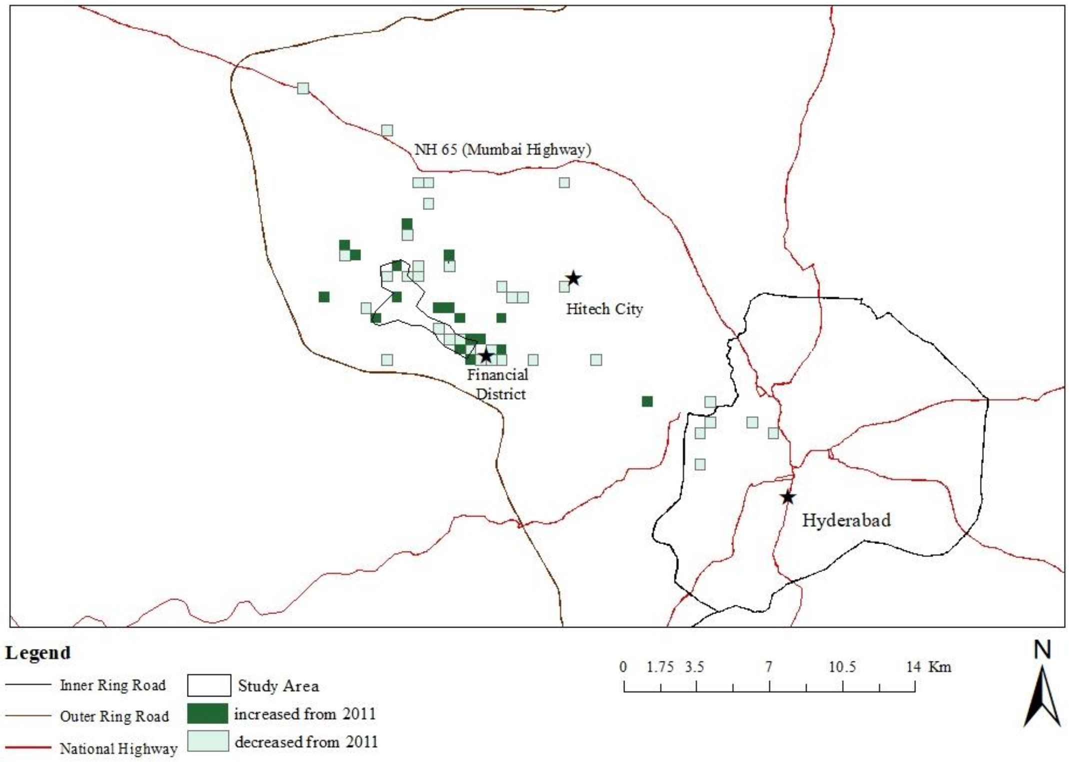



*Figure 5:7* Change of trip distribution (2011 to 2018)

Figure 5:7 illustrates that the cells closer to inner ring road and urban core, along the NH 65 national highway, near the Hitech city attract less percentage of HBW trips. On the contrary, majority of the cells which shows increased trip attraction are located near the study area, where the trip makers reside. Such distribution indicates that more respondents are travelling in areas close to the study area and areas which are comparatively farther from the study area are attracting less respondents in 2018.

However, the findings from the maps (Figure 5:5 to 5:7) do not prove any significant change in trip distribution. The percentages that are calculated based on 500m x 500m, might change if a different cell size is used. A hot spot analysis was performed to explore the statistically significant hot-spots and cold spots. However, this analysis could not produce significant hot-spots and cold-spots, as the minimum required number of destinations (30 points per cell) were not achieved for most of the destinations.

**Change in Travel Distance:** A comparison between the distances travelled in 2011 and 2018 was done to explore the statistical significance of the change in travel behaviour. Figure 5:7 indicates that the destinations of respondents in 2018 are relatively compacted around the study area than the trips in 2011. Therefore, it is expected the travel distance in 2018 will show lower values than that in 2011. First the hypothesis is tested using descriptive statistics as presented in table 5-3. It can be seen that the mean of travel distances decreased from 2011 to 2018 for all the trips. The comparison of median value indicates that in 2011 half of the respondents used to travel more than 5.58 Km, whereas in 2018 the median value has decreased to 3.75 Km. The decreased value of standard deviation also indicates that the distances travelled in 2018 are relatively less dispersed than in 2011. A similar pattern is observed when the distances were compared separately for each mode of transportation. For every mode the mean, median and standard deviation values in 2011 are greater than the corresponding statistics in 2018 (Table 5-3).

*Table 5-3* Descriptive Statistics- distance travelled

| Mode | Statistics | 2011 | 2018 |
|---|---|---|---|
| All | Mean | 6.46 | 4.85 |
| | Median | 5.58 | 3.75 |
| | Minimum | 0.23 | 0.76 |
| | Maximum | 22.21 | 20.5 |
| | Standard Deviation | 4.52 | 4 |
| Walk and Bicycle | Mean | 2.18 | 1.16 |
| | Median | 1.45 | 1.17 |
| | Standard Deviation | 1.57 | 0.08 |
| Two-Wheeler | Mean | 9.65 | 8.01 |
| | Median | 9.18 | 5.81 |
| | Standard Deviation | 6.62 | 6 |
| Shared Auto Rickshaw | Mean | 5.57 | 4.45 |
| | Median | 5.47 | 4.05 |
| | Standard Deviation | 2.56 | 1.83 |
| Vehicles provided by employer | Mean | 4.77 | 3.53 |
| | Median | 4.77 | 3.52 |
| | Standard Deviation | 2.08 | 0.93 |
| Other | Mean | - | 3.45 |
| | Median | - | 3.47 |
| | Standard Deviation | - | 0.17 |

Figure 5:8 further strengthens the assumption that there is a decrease in travel distance from 2011 to 2018. It shows that the frequencies of relatively shorter trips have increased since 2011 and the share of trips longer than 6 Km have decreased within this period. For instance, 7 percent of the total trips in 2011 are made for a travel within 1.5 Km. In 2018, the share of such trips of less than 1.5 Km is increased to 19 percent. On the contrary, for the distance group 6 to 9 Km, the share of trips decreased from 24 percent (in 2011) to 12 percent (in 2018). The findings of Table 5-3 and Figure 5:8 and the findings from change in destination indicate a decrease of overall travel distance of the respondent between 2011 and 2018.

The change in travel distance for each long-term residents was measured too. It was found that 44 percent of long-term residents travel the same distance at present as they used to in 2011. 40 percent of them travel shorter distances for job and the average depletion of travel distance is 3 Km. However, 16 percent of the long-term residents travel longer distance in 2018. Average increase in travel distance for this group is 2 Km.

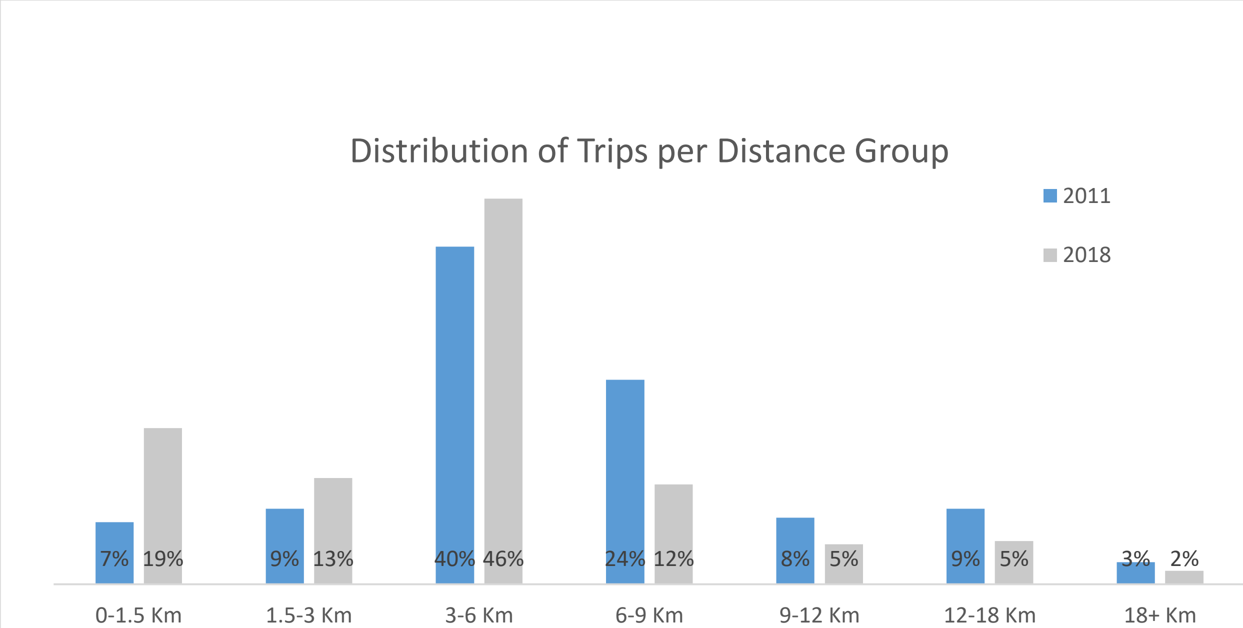



*Figure 5:8* Frequency of trip (percentage) for each distance group

The statistical significance of the change in travel distance is tested through a non-parametric test named "related samples Wilcoxon signed rank test". This test is used to compare two conditions of the same sample, when the distribution of these conditions are not normal (Field, 2013). It is found that the travel distances in 2011 and 2018 are not normally distributed.

"Related samples Wilcoxon signed rank test" measures the significance of change in travel distance by comparing the medium values. The null hypothesis ($H_0$) for this test is:

*"the median of differences between distance travelled in 2018 and distance travelled in 2011 equals zero."*

The test result shows that the median of decrease in travel distance (2.44 Km) is significantly higher than the median of increase in travel distance (1.47 Km). The value of test statistics is 4303.5 and most importantly the p value calculated is .000. Such p value implies that the difference between two medians are significant and not occurred by chance. Therefore, the null hypothesis is rejected. Therefore, it is concluded that the travel distances of the respondents have significantly decreased from 2011 to 2018.

**Change in Travel Mode:** The respondents were given 10 options of transport modes (see Appendix II). However, the respondents chose only a few transport modes namely walk, bicycle, two-wheelers, shared auto-rickshaw, car, bus from office. In addition, some respondent reported that they use vehicles provided by their employers such as truck, tractor. HUL reports that the primary purpose of these vehicles are to carry construction materials. However, these vehicles are used to pick the employees (mainly the daily wage earners) to the job locations.

The shares of each mode in 2011 and 2018 are presented as table 5-4. In 2011, the majority of the respondents who used to live in the study are, used to take shared auto rickshaw for HBW trips. Two-wheelers and walk are the second and third dominant more in 2011. In 2018, the order of modes based on use changes slightly. The highest share is for shared auto rickshaw. Two-wheelers, employer provided vehicles and walking are the second, third and fourth frequently used mode. However, the percentage of trips made by shared auto rickshaw has decreased from 2011 to 2018. Share of trips made by two-wheeler, walk and employer provided vehicle has increased within this period.

*Table 5-4* Modal split in 2011 and 2018

| Mode | 2011(%) | 2018(%) |
|---|---|---|
| Walk | 5.3 | 12.60 |
| Bicycle | 0.50 | - |
| Two-wheelers | 26.80 | 27.17 |
| Personal Car | - | 0.40 |
| Shared Auto Rickshaw | 65.80 | 44.09 |
| Bus from office | 0.50 | 0.40 |
| Vehicles provided by the employer | 1.10 | 15.35 |

Figure 5:9 compares the modal splits (percentage of trips by a mode) of two scenarios for different distance groups. It is observed that majority of the shorter trips (less than 1.5 Km) are made by two-wheelers (50%) and non-motorised alternatives (walk and Bicycle-42%) in 2011. However, in 2018, such short trips are predominantly made on foot. The share of two-wheeler in the distance group 0-1.5 Km decreased in 2018. It indicates that more respondents are walking in 2018 for HBW purpose trips.

Figure 5:9 further shows that majority of the trips falling under the distance groups 1.5-3 Km, 3-6 Km and 6-9 Km are made by shared-auto rickshaw. In fact, the shared auto-rickshaw is the most frequently used mode in 2011 and 2018 for trips between 1.5 to 9 Km. However, the percentage of shared auto-rickshaw have decreased from 2011 to 2018 for all of the distance groups. This decrease in modal split of shared auto-rickshaw is caused by the increase of two-wheeler use. Furthermore, for the trips longer than 18 Km the respondents use only two-wheeler. The share of employer provided vehicles have around a quarter share in the distance groups 1.5 to 3 Km and 3 to 6 Km.

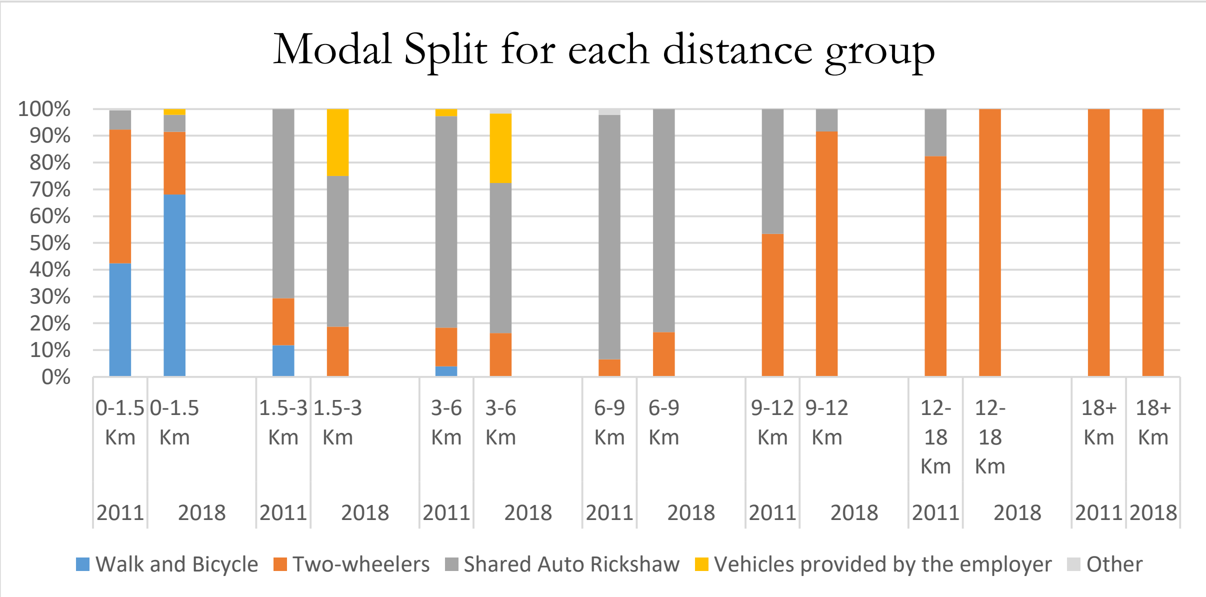



*Figure 5:9* Share of modes for each distance group

Above discussion concludes that the overall use of non-motorise transport options (walk and bicycle) have increased from 2011 to 2018. However, all the trips on foot are within a distance of 1.5 Km. The shared auto rickshaw is the most dominant mode in the sample for both the scenaios-2011 and 2016. However, there is a decrease in the overall use of shared auto-rickshaw and such drop of share is observed in all distance groups. On the contrary, the overall use of two-wheelers has increased. The share of two-wheeler use decreased only for the shorter trips.

## 5.3. Change in Urban Form:

Figure 5:10 shows the land use pattern of the study area in 2011 and 2018 and table 5-5 shows the total areas of each type of land uses for both the year. In 2011, a significant portion of the study area was natural or semi natural lands. Besides a fair amount of land was being developed by the real estate investors at that time. Residential and agricultural lands were observed, albeit in small extents.

Between 2011 to 2018, the study area experienced the emergence of new land-use type. The areas which were under real estate development in 2011 have converted into residential and commercial areas. Besides more agricultural, natural and semi natural lands are being developed by real estate investors. As a consequence, the total amount of agricultural and natural, semi natural lands have decreased. On the contrary, the amount of residential areas has grown. New type of land use such as commercial and recreational have emerged.

*Table 5-5* Total Area of different land uses (in hectare)

| Land Use | 2011 | 2018 |
|---|---|---|
| Agricultural | 43 | 6 |
| Natural or semi natural | 209 | 162 |
| Commercial | 0 | 82 |
| Construction/ Real estate development | 157 | 78 |
| Institutional | 88 | 96 |
| Recreational | 0 | 2 |
| Residential | 55 | 125 |
| Water | 12 | 12 |
| Entropy* | 0.67 | 0.74 |

* Unit less indicator

The development of new built-up areas has caused significant growth in built-up density. The percentage of built-up areas was approximately 15 percent (14.72%) in 2011. In 2018, the value of built-up density has increased more than two-times (31.32%). The value of land diversity index has increased too (table 5-5). The emergence of new land-use type, such as commercial, recreational has induced this growth of land use diversity.

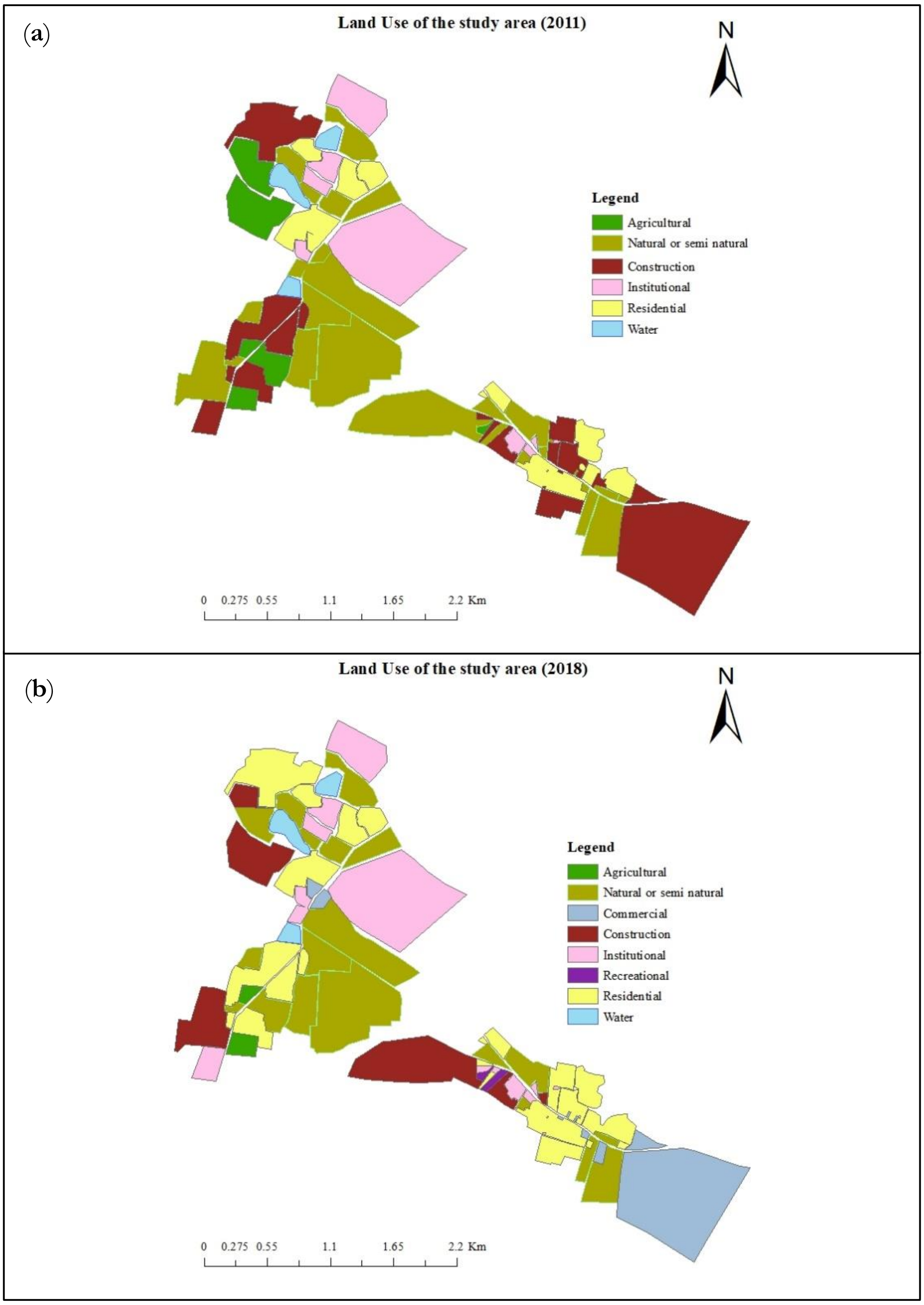



*Figure 5:10* Land use maps of the study area (a) 2011, (b) 2018

# 6. DISCUSSION

This chapter discusses the changes in travel behaviour and urban form in the study area since 2011 and compares the findings with the previous studies. It also discusses the limitation of the study.

## 6.1. Change in Travel Distance and Urban Form

Several studies claim that the built environment features have a direct association with travel distance (Ewing & Cervero, 2010). Locations with higher density and increased land-use diversity generate shorter trips in terms of travel distance (Ewing & Cervero, 2010; Sun, Ermagun, & Dan, 2017). It is believed that increased density and mixed land-use generates more activity destinations (Etminani-Ghasrodashti & Ardeshiri, 2016). Consequently, increased density and land-use diversity around the residential location tend to motivate shorter travel distance.

The results of this study show a similar pattern as discussed above. The respondents who have been living in the study area since 2011 have significantly decreased their travel distance to employment. Besides, the construction of new residential and commercial buildings has increased the built-up density and land-use diversity in the study area. These new buildings have created new employment opportunities in the area. Hence, the long-term residents of the study area have shifted their job location nearer to the study area, which might have reduced the travel distance.

Further analysis was done to explore the relation between urban change and job relocation. It was found that 75 respondents have reduced their travel distance between 2011 to 2018. The present job locations of these 75 respondents were mapped over satellite images of 2011 and 2018. It reveals that 57 percent of those locations are residential or commercial buildings which were constructed between 2011 to 2018. Also, 17 percent of these job locations are ongoing construction projects. This result indicates that the creation of new employment opportunities around the study area has a negative effect on travel distance. However, such a relationship between the urban form change and the decrease in travel distance was not tested statistically.

## 6.2. Change in Travel Mode and Urban Form

Results show that the share of non-motorised trips has increased in the sample from 2011 to 2018. Such increase of NMT for HBW purpose and increase in density and diversity have been reported in literature (Etminani-Ghasrodashti & Ardeshiri, 2016; Sun et al., 2017). However, other indicators of urban form related to design features such as street network characteristics, average block size, proportion of intersection have larger influence on choice of non-motorised trips (Cervero, 2013; Ewing & Cervero, 2010). This study was unable to study the influence of design features due to lack of secondary data of 2011. Hence, the increase of NMT in this sample could not be associated with the change in urban form.

It was found that, the increased share of NMT is contributed by the new-migrants. Majority of the respondents who make non-motorised trip in 2018 are new-migrants, who moved into the study area after 2011. Moreover, the majority of the respondents who used to walk to their job locations in 2011 have switched to shared-auto rickshaw. The above findings raise a concern regarding the interpretation of NMT increase and its relationship with the change in urban form. First, the mode choice after residential relocation has association with several factors other than the urban form (Ewing & Cervero, 2010). Second, the share of new-migrants in the sample could be different from the actual composition of the population. Therefore, the results of this study do not contribute any insight into the relationship between change in NMT and urban form.

However, the change in modal split could be associated with the change in income and motorisation. In the global South, the rapid economic growth and rising income have led to a rise in vehicle ownership (Cervero, 2013). The rate of motorisation in terms of cars, two-wheelers and auto-rickshaws shows an increasing trend in this sample. However, the share of two-wheeler increased in a small margin when the mode share is calculated for the total sample and the percentage of trips made by shared-auto-rickshaw decreased, which is contrary to the change in vehicle ownership.

Further analysis reveals that measuring the modal share for the long-term residents show an expected trend of change (Table 6-1). The share of two-wheeler users among the long-term residents increased, though the percentage of shared auto decreased. It is relevant to mention that all the respondents who possess new two-wheelers after 2011 are long-term residents.

*Table 6-1* Modal split for long-term residents (2011 to 2018)

| Mode | 2011(%) | 2018(%) |
|---|---|---|
| Walk | 5.3 | 2.6 |
| Bicycle | 0.50 | - |
| Two-wheelers | 26.80 | 36.3 |
| Personal Car | - | 0.40 |
| Shared Auto Rickshaw | 65.80 | 55.8 |
| Bus from office | 0.50 | 0.50 |
| Vehicles provided by the employer | 1.10 | 4.20 |

Table 6-2 illustrates the distribution of mode choice for new-migrants. Both the shares of walk and vehicles provided by the employer are more than 40 percent. Such a pattern of distribution has eventually effected the calculation of modal split for the total sample.

*Table 6-2* Modal split for new migrants (2018)

| Mode | 2018(%) |
|---|---|
| Walk | 42.2 |
| Shared Auto Rickshaw | 9.4 |
| Vehicles provided by the employer | 48.4 |

## 6.3. Limitation of the study

The findings of the study could not be interpreted for the whole study area because of a biased sample. Due to methodological limitation, the residents from the gated communities, apartment building were not included in the sample. People from middle-class income group, who lives in these areas are supposed to have different economic characteristics and different vehicle ownership pattern. Moreover, the representation of new-migrants could not be validated. It is realised that the inclusion of new-migrants in the sample have a significant impact on the interpretation of results.

# 7. CONCLUSION

## 7.1. Key Findings

This research explores the peri-urban dynamics from the perspective of travel behaviour dynamics. The primary objective of the research was to investigate the changes in travel distance and modal split in a dynamic peri-urban area.

First, an attempt was made to identify the areas which have gone through peri-urban transformation since 2011 around Hyderabad, India. A list of indicators used in previous studies to map peri-urban areas was prepared. It was found that most of these indicators are measured by census data, using census tracts as the spatial unit of data organisation and aggregation. Two major challenges limit the use of census data in this study. First, the latest census data do not reflect a recent situation in the peri-urban areas. Second, using large spatial units such as census tracts would result in a large sample size. Therefore, high resolution population layer, built-up layer and road network data was used to detect the location of peri-urban transformation. However, it was found that there is a lack of compatibility among the secondary data. Use of secondary data from different sources produced unreliable delineation of peri-urban areas. It was concluded that a reliable mapping of peri-urban areas largely relies on data availability and compatibility.

Therefore, study area for a detailed questionnaire survey was selected based on local experts' suggestion and a questionnaire survey was administered. Exploratory analysis of primary data revealed a significant decrease in travel distance since 2011. This reduction in travel distance could be associated with the increased in built-up density and increased land-use diversity. The recent development of residential and commercial areas has created employment opportunities for the residents in the study area. Moreover, the ongoing construction of real estate projects has attracted new migrants in the study area, who live near their work place. Therefore, the emergence of job opportunities in proximity could be one of the factors of reduced travel distance. Such a pattern of reduced travel distance is reported in the literature. Moreover, the pattern suggests a shift towards sustainable travel behaviour.

Analysis of modal split or mode share reveals that the majority of the respondents in 2011 and 2018 use shared-auto rickshaw for home-based work trips. However, a drop in the mode share for shared-auto rickshaw was observed between 2011 and 2018. Share of trips made on foot increased and share of two-wheeler users also increased since 2011. A rise in the share of employer provided vehicles was also observed.

An increase in non-motorised trips (NMT) use after land-use diversification have been reported in the literature. However, in this study, it was found that the majority of the respondents who used to walk in 2011 have shifted their mode of transportation. Majority of the respondents who walk to their job destination in 2018 are new-migrants. These new-migrants have not experienced the change in urban form that happened in the study area since 2011. Therefore, it was not possible to present any strong relationship between change in urban form and rise in NMT use. However, the increase in two-wheeler ownership and modal share of two-wheeler indicate that the economic growth in the peri-urban areas is likely to motivate higher use of personal vehicles. As a result, the overall travel behaviour in a peri-urban area might become less sustainable. However, due to the probable bias in the sample the observed changes in mode share did not provide any conclusive insight.

Though the study fails to describe the change in modal split in the study area, it reflects some key issues regarding sustainable transport planning and the development of the study area. First, the absence of reliable public transportation system has forced the residents to use two-wheeler and shared auto-rickshaw. These vehicles cause noise pollution, air pollution and have negative effect on road safety (Cervero, 2013). Second, the construction of new toll roads such as outer ring roads is not inclusive and pro-poor. A sustainable integration of land-use and transportation planning is desired to be pro-poor (Cervero, 2013). Finally, the increased income and increased rate of motorisation in the peri-urban area might lead to less sustainable travel behaviour, congestion, pollution and increased fuel consumption. The policy makers should pay attention to such changes in socio-economic factors and their impact on peri-urban travel pattern

## 7.2. Recommendations for Future Study

This study explored the change in travel behaviour from the perspective of urban density and land-use diversity. The results suggest that the change in urban form due to peri-urbanisation does not provide any conclusive evidence of mode choice dynamics. Therefore, future research could explore the effects of other socio-economic changes on mode choice dynamics. Such research could be further enriched by accommodating life-cycle events and change in household composition as associated information has been gathered.

# LIST OF REFERENCES

Aguilar, A. G., & Ward, P. M. (2003). Globalization, regional development, and mega-city expansion in Latin America: Analyzing Mexico City's peri-urban hinterland. *Cities*, *20*(1), 3–21. https://doi.org/10.1016/S0264-2751(02)00092-6

Aljoufie, M., Zuidgeest, M., Brussel, M., & van Maarseveen, M. (2013). Spatial–temporal analysis of urban growth and transportation in Jeddah City, Saudi Arabia. *Cities*, *31*, 57–68. https://doi.org/10.1016/j.cities.2012.04.008

Allen, A. (2003). Environmental planning and management of the peri-urban interface: Perspectives on an emerging field. *Environment and Urbanization*, *15*(1), 135–148. https://doi.org/10.1177/095624780301500103

Bakker, W., Bakx, W., Bijker, W., Lucas, K. G., Horn, J. J., Huurneman, G., … Woldai, T. (2013). Sensors. In *The Core of GIScience* (pp. 125–166). Enschede, the Netherlands: Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente.

Beynon, M. J., Crawley, A., & Munday, M. (2016). Measuring and understanding the differences between urban and rural areas. *Environment and Planning B: Planning and Design*, *43*(6), 1136–1154. https://doi.org/10.1177/0265813515605096

Bohte, W., Maat, K., & van Wee, B. (2009). Measuring attitudes in research on residential self- selection and travel behaviour: A review of theories and empirical research. *Transport Reviews*, *29*(3), 325–357. https://doi.org/10.1080/01441640902808441

Buchanan, N., Barnett, R., Kingham, S., & Johnston, D. (2006). The effect of urban growth on commuting patterns in Christchurch, New Zealand. *Journal of Transport Geography*, *14*(5), 342–354. https://doi.org/10.1016/j.jtrangeo.2005.10.008

Budiyantini, Y., & Pratiwi, V. (2016). Peri-urban typology of Bandung metropolitan area. *Procedia - Social and Behavioral Sciences*, *227*, 833–837. https://doi.org/10.1016/j.sbspro.2016.06.152

Cervero, R. (2013). Linking urban transport and land use in developing countries. *Journal of Transport and Land Use (JTLU)*, *6*(1), 7–24. https://doi.org/10.5198/jtlu.v1.425

Chidambaram, B., Janssen, M. A., Rommel, J., & Zikos, D. (2014). Commuters' mode choice as a coordination problem: A framed field experiment on traffic policy in Hyderabad, India. *Transportation Research Part A: Policy and Practice*, *65*, 9–22. https://doi.org/10.1016/j.tra.2014.03.014

Clifton, K., & Muhs, C. D. (2012). Capturing and Representing Multimodal Trips in Travel Surveys. *Transportation Research Record: Journal of the Transportation Research Board*, *2285*(1), 74–83. https://doi.org/10.3141/2285-09

Corbane, C., Lemoine, G., Pesaresi, M., Kemper, T., Sabo, F., Ferri, S., & Syrris, V. (2018). Enhanced automatic detection of human settlements using Sentinel-1 interferometric coherence. *International Journal of Remote Sensing*, *39*(3), 842–853. https://doi.org/10.1080/01431161.2017.1392642

Danielaini, T. T., Maheshwari, B., & Hagare, D. (2018). Defining rural–urban interfaces for understanding ecohydrological processes in West Java, Indonesia: Part I. Development of methodology to delineate peri-urban areas. *Ecohydrology & Hydrobiology*, *18*(1), 22–36. https://doi.org/10.1016/j.ecohyd.2017.11.006

Das, D. (2015). Hyderabad: Visioning, restructuring and making of a high-tech city. *Cities*, *43*, 48–58. https://doi.org/10.1016/j.cities.2014.11.008

Douglas, I. (2006). Peri-Urban ecosystems and societies: Transitional zones and contrasting values. In D. McGregor, D. Simon, & D. Thompson (Eds.), *The peri-urban interface: Approaches to sustainable natural and human resource use* (pp. 18–29). London: Taylor & Francis.

Dupont, V. (2007). Conflicting stakes and governance in the peripheries of large Indian metropolises – An introduction. *Cities*, *24*(2), 89–94. https://doi.org/10.1016/j.cities.2006.11.002

Dutta, V. (2012). Land use dynamics and peri-urban growth characteristics. *Environment and Urbanization*

*ASIA*, *3*(2), 277–301. https://doi.org/10.1177/0975425312473226

Esch, T., Heldens, W., Hirner, A., Keil, M., Marconcini, M., Roth, A., … Strano, E. (2017). Breaking new ground in mapping human settlements from space – The Global Urban Footprint. *ISPRS Journal of Photogrammetry and Remote Sensing*, *134*, 30–42. https://doi.org/10.1016/j.isprsjprs.2017.10.012

Etminani-Ghasrodashti, R., & Ardeshiri, M. (2016). The impacts of built environment on home-based work and non-work trips: An empirical study from Iran. *Transportation Research Part A: Policy and Practice*, *85*, 196–207. https://doi.org/10.1016/j.tra.2016.01.013

Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association*, *76*(3), 265–294. https://doi.org/10.1080/01944361003766766

Field, A. (2013). Non-parametric models. In *Discovering Statistics Using IBM SPSS* (4th ed., pp. 213–261). SAGE Publications Ltd.

Franco, S., Mandla, V. R., & Ram Mohan Rao, K. (2017). Trajectory of Urban Growth and Its Socioeconomic Impact on a Rapidly Emerging Megacity. *Journal of Urban Planning and Development*, *143*(3), 04017002-0-04017002-10. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000378

Gonçalves, J., Gomes, M. C., Ezequiel, S., Moreira, F., & Loupa-Ramos, I. (2017). Differentiating peri-urban areas: A transdisciplinary approach towards a typology. *Land Use Policy*, *63*, 331–341. https://doi.org/10.1016/j.landusepol.2017.01.041

Gonçalves, J., Gomes, M., & Ezequiel, S. (2017). Defining mobility patterns in peri-urban areas: A contribution for spatial and transport planning policy. *Case Studies on Transport Policy*, *5*(4), 643–655. https://doi.org/10.1016/j.cstp.2017.07.009

Gopal, S., Tang, X., Phillips, N., Nomack, M., Pasquarella, V., & Pitts, J. (2016). Characterizing urban landscapes using fuzzy sets. *Computers, Environment and Urban Systems*, *57*, 212–223. https://doi.org/10.1016/j.compenvurbsys.2016.02.002

Gumma, M. K., Mohammad, I., Nedumaran, S., Whitbread, A., & Lagerkvist, C. J. (2017). Urban sprawl and adverse impacts on agricultural land: A case study on Hyderabad, India. *Remote Sensing*, *9*(11), 1–16. https://doi.org/10.3390/rs9111136

Gurijala, A., & Asadi, S. S. (2019). Analysis and estimation of hazardous components in drinking water in and around of Hyderabad : A model study. *International Journal of Mechanical Engineering and Technology*, *8*(12), 1048–1056.

Hahs, A. K., & McDonnell, M. J. (2006). Selecting independent measures to quantify Melbourne's urban–rural gradient. *Landscape and Urban Planning*, *78*(4), 435–448. https://doi.org/10.1016/j.landurbplan.2005.12.005

Harrison, P. (2006). On the edge of reason: Planning and urban futures in Africa. *Urban Studies*, *43*(2 SPEC. ISS.), 319–335. https://doi.org/10.1080/00420980500418368

Hilal, M., Legras, S., & Cavailhès, J. (2018). Peri-urbanisation: Between residential preferences and job opportunities. *Raumforschung Und Raumordnung | Spatial Research and Planning*, *76*(2), 133–147. https://doi.org/10.1007/s13147-016-0474-8

Hu, L. (2014). Changing job access of the poor: Effects of spatial and socioeconomic transformations in Chicago, 1990–2010. *Urban Studies*, *51*(4), 675–692. https://doi.org/10.1177/0042098013492229

Huang, J., Zhou, Q., & Wu, Z. (2016). Delineating urban fringe area by land cover information entropy—An empirical study of Guangzhou-Foshan metropolitan area, China. *ISPRS International Journal of Geo-Information*, *5*(5), 59. https://doi.org/10.3390/ijgi5050059

Hugo, G., Champion, A., & Lattes, A. (2003). Toward a new conceptualization of settlements for demography. *Population and Development Review*, *29*(2), 277–297. https://doi.org/10.1111/j.1728-4457.2003.00277.x

Hyderabad Metropolitan Development Authority. (2012). *Report on Data Compilation and Statistical Analysis Volume I : Household Interview Survey Analysis*. Hyderabad. Retrieved from http://ctshma2011.finnaclle.com/downloads.php

Jain, A. K. (2010). Data clustering: 50 years beyond K-means. *Pattern Recognition Letters*, *31*(8), 651–666. https://doi.org/10.1016/j.patrec.2009.09.011

Jain, M., Siedentop, S., Taubenböck, H., & Namperumal, S. (2013). From Suburbanization to Counterurbanization?Investigating urban dynamics in the National Capital Region Delhi, India. *Environment and Urbanization ASIA*, *4*(2), 247–266. https://doi.org/10.1177/0975425313510765

Joh, K., Boarnet, M., Nguyen, M., Fulton, W., Siembab, W., & Weaver, S. (2008). Accessibility, travel behavior, and new urbanism: Case study of mixed-use centers and auto-oriented corridors in the South Bay region of Los Angeles, California. *Transportation Research Record: Journal of the Transportation Research Board*, *2082*(1), 81–89. https://doi.org/10.3141/2082-10

Kamat, S. (2011). Neoliberalism, urbanism and the education economy: producing Hyderabad as a 'global city.' *Discourse: Studies in the Cultural Politics of Education*, *32*(2), 187–202. https://doi.org/10.1080/01596306.2011.565639

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2013). Residential dissonance and mode choice. *Journal of Transport Geography*, *33*, 12–28. https://doi.org/10.1016/j.jtrangeo.2013.09.004

Kennedy, L. (2007). Regional industrial policies driving peri-urban dynamics in Hyderabad, India. *Cities*, *24*(2), 95–109. https://doi.org/10.1016/j.cities.2006.06.001

Kennedy, L., & Sood, A. (2019). Outsourced urban governance as a state rescaling strategy in Hyderabad, India. *Cities*, *85*, 130–139. https://doi.org/10.1016/j.cities.2018.09.001

Khan, K., & Munir, A. (2017). Delineation of rural-urban fringe: A case study of Aligarh city. *Forum Geografic*, *XVI*(1), 70–79. https://doi.org/10.5775/fg.2017.021.i

Kitamura, R. (1990). Panel analysis in transportation planning: An overview. *Transportation Research Part A: General*, *24A*(6), 401–415. https://doi.org/10.1016/0191-2607(90)90032-2

Kuffer, M., Pfeffer, K., & Sliuzas, R. (2016). Slums from Space—15 Years of Slum Mapping Using Remote Sensing. *Remote Sensing*, *8*(6), 455. https://doi.org/10.3390/rs8060455

Lee, J. H., Davis, A. W., & Goulias, K. G. (2017). Triggers of behavioral change: Longitudinal analysis of travel behavior, household composition and spatial characteristics of the residence. *Journal of Choice Modelling*, *24*, 4–21. https://doi.org/10.1016/j.jocm.2017.01.001

Lerner, A. M., & Eakin, H. (2011). An obsolete dichotomy? Rethinking the rural-urban interface in terms of food security and production in the global south. *The Geographical Journal*, *177*(4), 311–320. https://doi.org/10.1111/j.1475-4959.2010.00394.x

Linard, C., Gilbert, M., & Tatem, A. J. (2011). Assessing the use of global land cover data for guiding large area population distribution modelling. *GeoJournal*, *76*, 525–538. https://doi.org/10.1007/s10708-010-9364-8

López-Goyburu, P., & García-Montero, L. G. (2018). The urban-rural interface as an area with characteristics of its own in urban planning: A review. *Sustainable Cities and Society*, *43*(July), 157–165. https://doi.org/10.1016/j.scs.2018.07.010

Manoj, M., & Verma, A. (2015). Design and administration of activity-travel diaries: A case study from Bengaluru city in India. *Current Science*, *109*(7), 1264–1272.

Mcgarigal, K. (2015). *Fragstats Help. Fragstats*. https://doi.org/10.1016/S0022-3913(12)00047-9

Office of the Registrar General & Census Commissioner India. (2011). *Metadata*.

Pucci, P. (2017). Mobility behaviours in peri-urban areas. The Milan Urban Region case study. *Transportation Research Procedia*, *25*, 4229–4244. https://doi.org/10.1016/j.trpro.2017.05.227

Rauws, W. S., & de Roo, G. (2011). Exploring transitions in the peri-urban area. *Planning Theory & Practice*, *12*(2), 269–284. https://doi.org/10.1080/14649357.2011.581025

Ravetz, J., Fertner, C., & Nielsen, T. S. (2013). The dynamics of peri-urbanization. In K. Nilsson, S. Pauleit, S. Bell, C. Aalbers, & T. A. Sick Nielsen (Eds.), *Peri-Urban Futures: Scenarios and Models for Land use Change in Europe* (pp. 13–44). Berlin, Heidelberg: Springer Berlin Heidelberg.

https://doi.org/10.1007/978-3-642-30529-0

Rojas-Caldelas, R., Ranfla-González, A., Pena-Salmon, C., Venegas-Cardoso, R., Ley-Garcia, J., Villegas-Olivar, O., & Leyva-Camacho, O. (2008). Planning the rural-urban interface under sustainable principles: A methodological proposal. *WIT Transactions on Ecology and the Environment*, *117*, 641–649. https://doi.org/10.2495/SC080601

Saxena, A. M., & Vyas, S. (2016). Delimitation of peri-urban area: Various approaches. *International Journal of Combined Research & Development (IJCRD)*, *5*(9), 691–698. Retrieved from www.ijcrd.com

Schenk, H. (2005). India's urban fringe. In V. Dupont (Ed.), *Peri-urban dynamics: Population, habitat and environment on the peripheries of large Indian metropolises, A review of concepts and general issues* (pp. 121–145). Pondicherry: French Research Institutes in India. https://doi.org/10.1109/ICEELI.2012.6360664

Schneider, A., & Woodcock, C. E. (2008). Compact, Dispersed, Fragmented, Extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. *Urban Studies*, *45*(3), 659–692. https://doi.org/10.1177/0042098007087340

Shaw, A. (2005). Peri-urban interface of Indian cities: Growth, governance and local initiatives. *Economic and Political Weekly*, *40*(2), 129–136. Retrieved from http://www.jstor.org/stable/4416042

Shaw, R., & Das, A. (2017). Identifying peri-urban growth in small and medium towns using GIS and remote sensing technique: A case study of English Bazar urban agglomeration, West Bengal, India. *The Egyptian Journal of Remote Sensing and Space Science*. https://doi.org/10.1016/j.ejrs.2017.01.002

Simon, D., McGregor, D., & Nsiah-Gyabaah, K. (2004). The changing urban-rural interface of African cities: definitional issues and an application to Kumasi, Ghana. *Environment and Urbanization*, *16*(2), 235–248. https://doi.org/10.1177/095624780401600214

Simon, D., McGregor, D., & Thompson, D. (2006). Contemporary perspectives on the peri-urban zones of cities in developing areas. In D. McGregor, D. Simon, & D. Thompson (Eds.), *The peri-urban interface: Approaches to sustainable natural and human resource use* (pp. 2–17). London: Taylor & Francis.

Singh, Y. J., Fard, P., Zuidgeest, M., Brussel, M., & Maarseveen, M. Van. (2014). Measuring Transit Oriented Development : A Spatial Multi Criteria Assessment Approach for the City Region Arnhem and Nijmegen. *JOURNAL OF TRANSPORT OF GEOGRRAPHY*, *35*, 130–143. https://doi.org/10.1016/j.jtrangeo.2014.01.014

Sun, B., Ermagun, A., & Dan, B. (2017). Built environmental impacts on commuting mode choice and distance : Evidence from Shanghai. *Transportation Research Part D*, *52*, 441–453. https://doi.org/10.1016/j.trd.2016.06.001

Wakode, H. B., Baier, K., Jha, R., & Azzam, R. (2014). Analysis of urban growth using Landsat TM/ETM data and GIS—a case study of Hyderabad, India. *Arabian Journal of Geosciences*, *7*(1), 109–121. https://doi.org/10.1007/s12517-013-0843-3

Wandl, D. I. A., Nadin, V., Zonneveld, W., & Rooij, R. (2014). Beyond urban–rural classifications: Characterising and mapping territories-in-between across Europe. *Landscape and Urban Planning*, *130*, 50–63. https://doi.org/10.1016/j.landurbplan.2014.06.010

Webster, D. (2002). *On the edge: Shaping the future of peri-urban East Asia*. Stanford, California: Asia/Pacific Research Center, Stanford University.

Winarso, H., Hudalah, D., & Firman, T. (2015). Peri-urban transformation in the Jakarta metropolitan area. *Habitat International*, *49*, 221–229. https://doi.org/10.1016/j.habitatint.2015.05.024

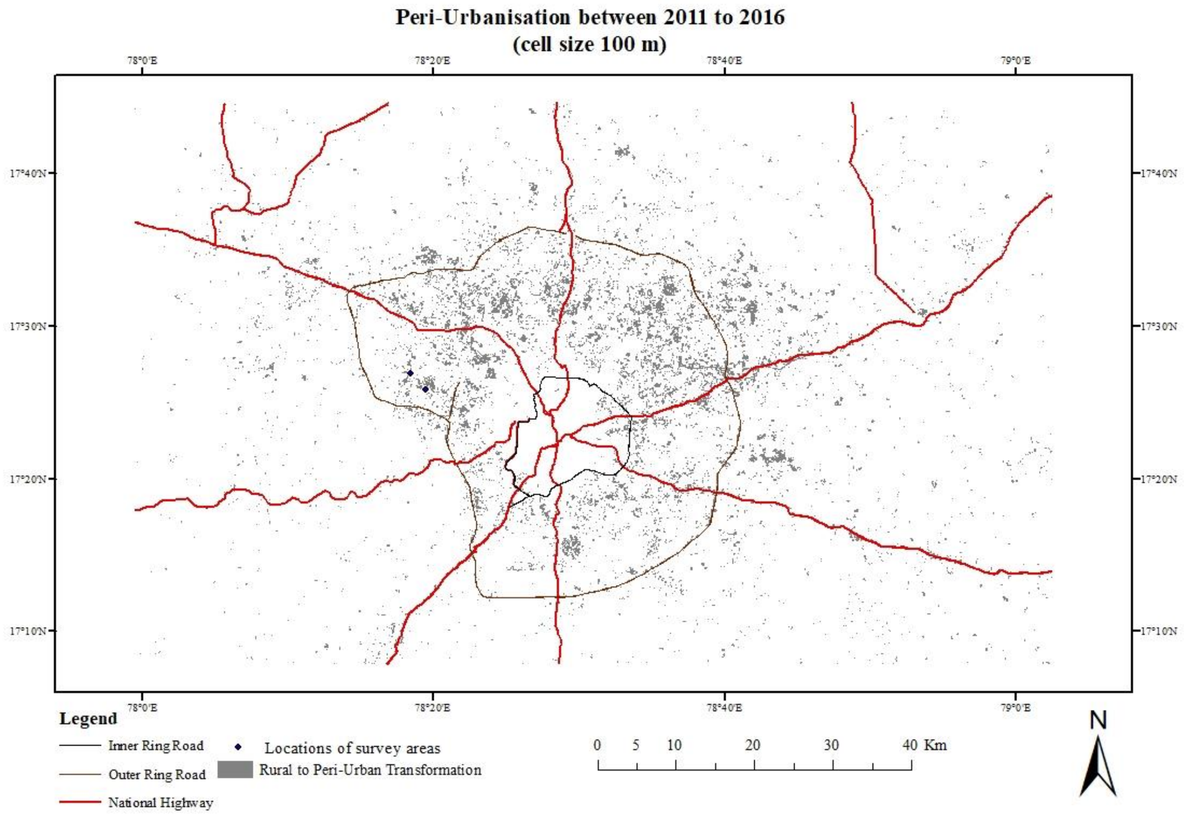
Woltjer, J. (2014). A global review on peri-urban development and planning. *Jurnal Perencanaan Wilayah Dan Kota*, *25*(1), 1–16. https://doi.org/10.5614/jpwk.2014.25.1.1

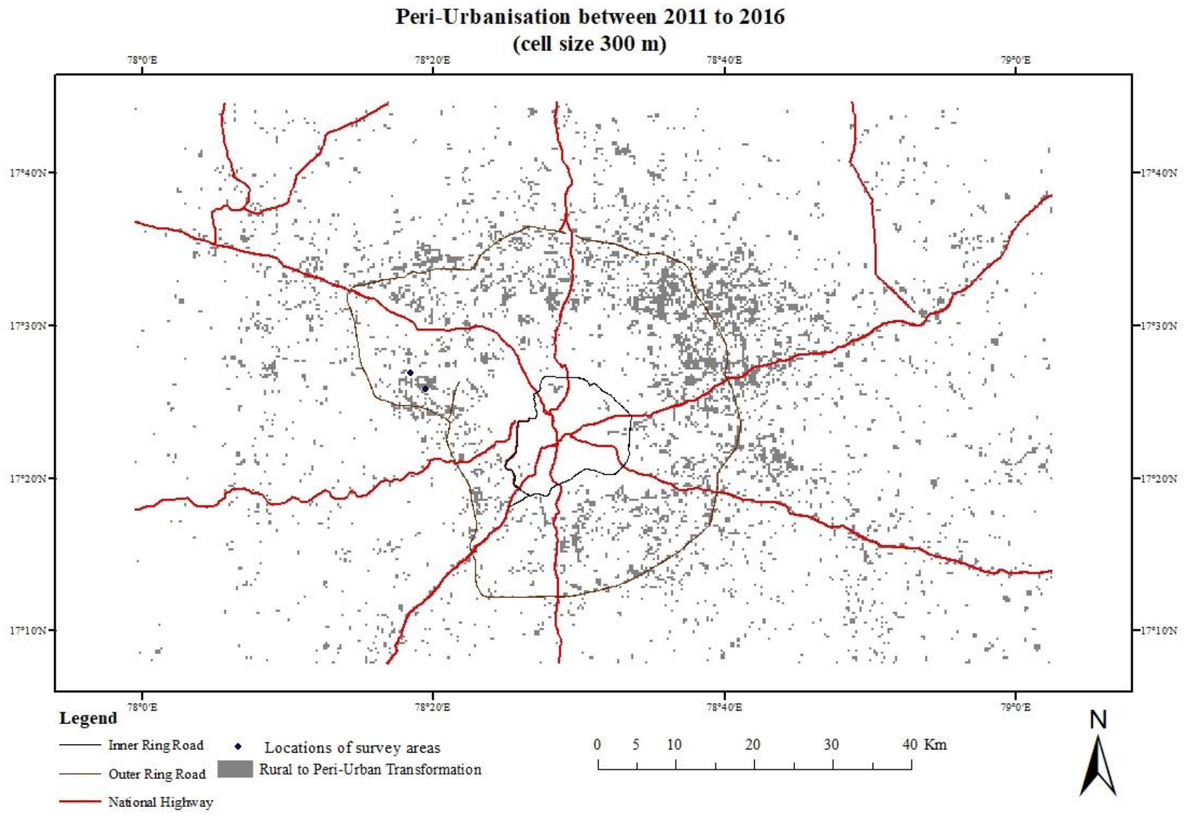
Zhou, J. (2012). Sustainable commute in a car-dominant city: Factors affecting alternative mode choices among university students. *Transportation Research Part A: Policy and Practice*, *46*(7), 1013–1029. https://doi.org/10.1016/j.tra.2012.04.001

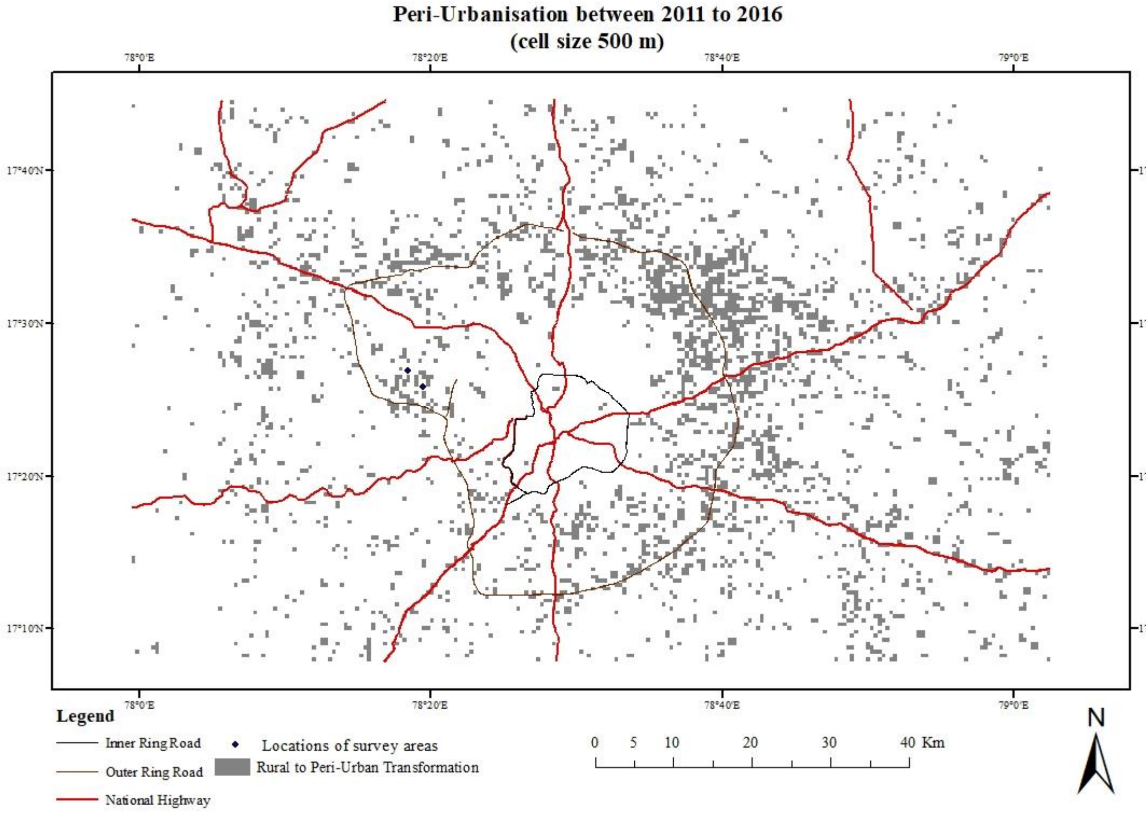
Zoomers, A., van Noorloos, F., Otsuki, K., Steel, G., & van Westen, G. (2017). The rush for land in an urbanizing world: From land grabbing toward developing safe, resilient, and sustainable cities and landscapes. *World Development*, *92*, 242–252. https://doi.org/10.1016/j.worlddev.2016.11.016

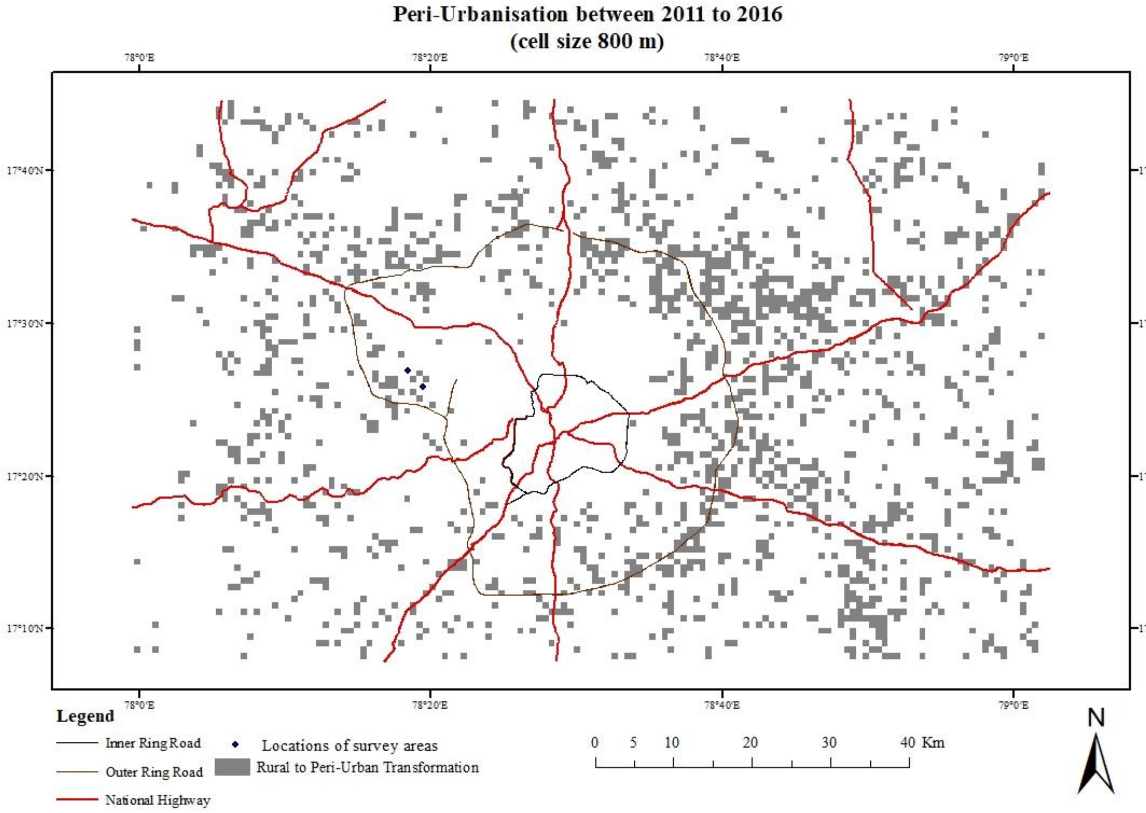
# APPENDIX

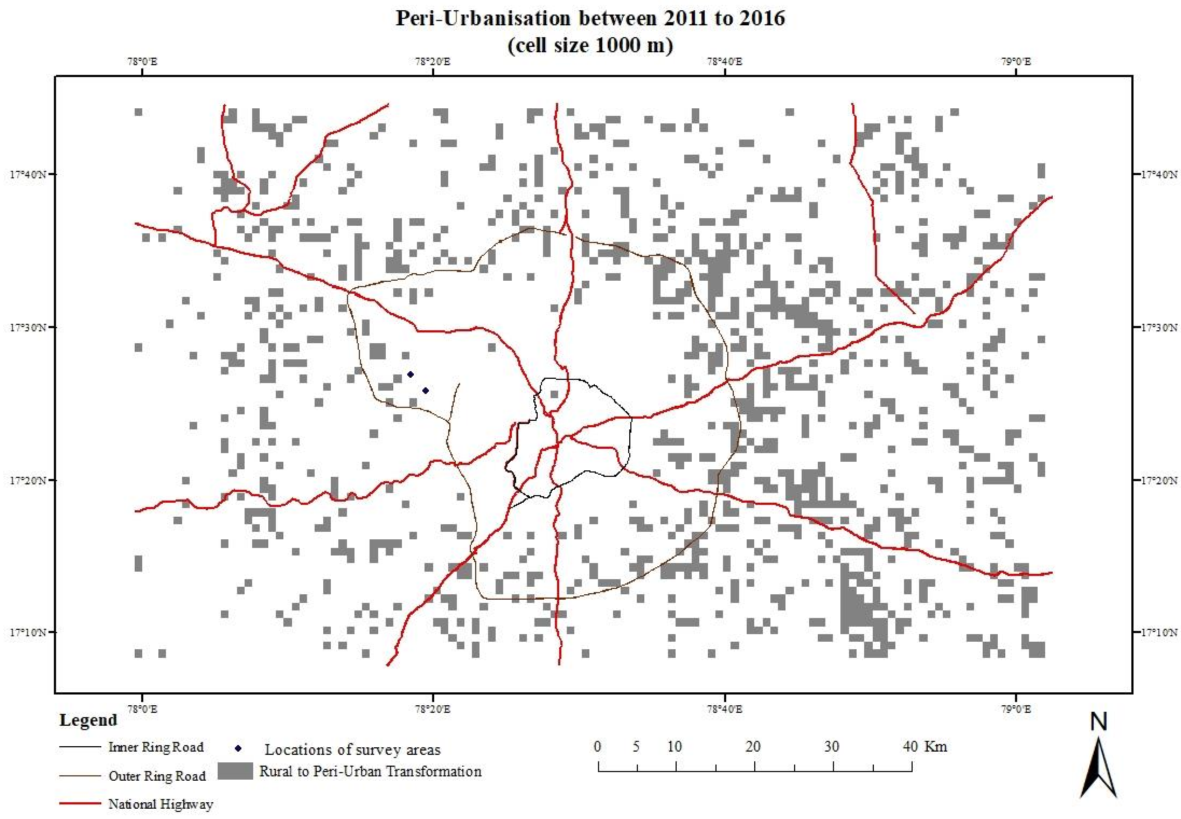
## Annex-I: Locations of peri-urbanisation between 2011 to 2016




Peri-Urbanisation between 2011 to 2016
(cell size 500 m)
78°0'E
78°20'E
78°40'E
79°0'E
17°40'N
17°30'N
17°20'N
17°10'N
Legend
Inner Ring Road
Outer Ring Road
National Highway
Locations of survey areas
Rural to Peri-Urban Transformation
0 5 10 20 30 40 Km
N


Peri-Urbanisation between 2011 to 2016
(cell size 800 m)
78°0'E
78°20'E
78°40'E
79°0'E
17°40'N
17°30'N
17°20'N
17°10'N
Legend
Inner Ring Road
Outer Ring Road
National Highway
Locations of survey areas
Rural to Peri-Urban Transformation
0 5 10 20 30 40 Km
N


Peri-Urbanisation between 2011 to 2016
(cell size 1000 m)
78°0'E
78°20'E
78°40'E
79°0'E
17°40'N
17°30'N
17°20'N
17°10'N
Legend
Inner Ring Road
Outer Ring Road
National Highway
Locations of survey areas
Rural to Peri-Urban Transformation
0 5 10 20 30 40 Km
N

**Annex-II: Questionnaire Survey**

**<u>Travel Survey Form</u>**

**<u>Introduction</u>**

Greetings. I am_________ (name of the surveyor). I am working at Hyderabad Urban Lab foundation, as a Research Assistant. This is a non-profit private organisation, which explores different issues related to the urban life of greater Hyderabad. The Hyderabad Urban Lab is currently conducting a research in this area with the collaboration of University of Twente, the Netherlands, titled "Change in travel behaviour in a dynamic peri-urban area: A case study of Hyderabad, India". The purpose of this research is to understand how the recent changes in the social structure and surrounding environment in and around this area has changed the way people travel to their work. We invite you to participate in this study. You can contribute to this research by answering few questions about your travel behaviour, household and personal attributes. It will take approximately 20-25 minutes to complete the survey. We might need to record the audio of the interview for data validation. You have the right to discontinue answering the question whenever you desire.

***Please select the appropriate box***

*I (the participant) have read the introduction section of this survey form or it has been read to me. I understand that the information collected through this survey will be used only for research purpose. I also understand the terms and conditions explained in the introduction document. Having understood them, I consent voluntarily to be a participant in this study.*

- ☐ Yes
- ☐ No

**This questionnaire is meant for the adult residents of Gowlidoddy and greater Gopanapalli, who regularly travel from their houses to be engaged in economic activities.** In the past, this area had lot of open spaces and the majority of the population was farmer. But now this area has new buildings. The construction of the outer ring road and ISB road has been completed. There are new job opportunities in IT firms and business. More people have moved into the area. We want to see how your travel behaviour and personal attributes have changed along with the changes in the area. **Questions 1 to 5 are to ensure your eligibility.**

**Q1 Are you a resident of Gowlidoddy/ NTR Nagar/ Gopanapalli Thanda/ Gopanapalli village?**

- ☐ Yes
- ☐ No [Terminate]

**Q2 How long have you been living in this area?**

___________ years

**Q3 Are you older than 14 years?**

- ☐ Yes
- ☐ No [Terminate]

**Q4 Do you regularly travel from your house to an economic activity such as farming, manufacturing, construction, business, selling products, to do house-maid's job, formal office job etc.?**

- ☐ Yes
- ☐ No [Terminate]

**Q5 What is the address of your residence?**

Area Name: ______________________________,

Landmark: ______________________________,

House Number: ______________________________,

Street Name: ______________________________,

Next section of the questionnaire (questions 6 to 9) is for understanding your travel behaviour. Particularly, we want to know about the journey to your place of work. At the beginning of this section we would like to know about your employment status.

**Q6 What is your employment status?**

- ☐ Employed (Main worker)
- ☐ Employed (Marginal worker)
- ☐ Self Employed (Main worker)
- ☐ Self Employed (Marginal worker)
- ☐ Daily Wages

Now we are going to ask you some questions about your regular travel. Please answer these questions based on a recent normal working day. It can be the latest day when you travelled outside of your house for work/income/economic activity. Or y**ou can choose any recent day** for which you remember the details of your journey.

**Q7 Date of the journey/ Day of the week (optional)**

____________

**Q8 The address of your main activity**

Company Name: ______________________________,

Area Name: ______________________________,

Landmark: ______________________________,

House Number: ______________________________,

Street Name: ______________________________,

Ward Name: ______________________________

We are interested to know about your way of travelling to the location you just answered. The next question is to know about the transport mode you used for the journey. **Transport modes are motorised, non-motorised vehicles such as Bus, Metro, Auto-rickshaw (7- seaters, 4-seaters), Car, Cycle, Two-Wheelers etc.**

Q9 **How did you travel to those locations from your house?**

a) **Please select**:

i. You used only one transport mode

ii. You used more than one transport modes, you changed transport modes to reach the destination

iii. You walked to the destination

***b) (For those who selected option i. in question 9a)***

The only transport mode you used is:

i. Bicycle,

ii. Two-wheelers,

iii. Shared Auto Rickshaw (4-seaters, 7 seaters)

iv. Car

v. Public Bus

vi. Bus (from office)

vii. MMTS

viii. Metro

ix. Uber/Private cab

x. Other, (please specify) ________________________________________

**c) For those who selected option ii. in question 9 a)**

i. You started from home by ___________ (walking / bicycle/ two-wheelers/ shared auto-rickshaw/ Car/ Uber/ Cab)

ii. The next mode you took is __________ (walking/ bicycle /two-wheelers /shared auto-rickshaw / Car / Uber / Cab /Public Bus / Office Bus/ MMTS/ Metro)

iii. You took off from that mode and took _________ (walking/ bicycle /two-wheelers /shared auto-rickshaw/ Car/ Uber/ Cab/Public Bus / Office Bus / MMTS/ Metro)

iv. You took off from that mode and took _________ (walking/ bicycle /two-wheelers /shared auto-rickshaw/ Car/ Uber/ Cab/Public Bus / Office Bus / MMTS/ Metro)

**d) (For those who selected Public Bus/ Metro/ MMTS in Question b) or c)**

i. You board the transit (Bus/Metro/MMTS) at location ________________ (name of the stop)

ii. You left the transit (Bus/Metro/MMTS) at location __________________ (name of the stop)

**The next section of this questionnaire (questions 10 to 13) is about your household attributes which influence your travel behaviour.**

**Q10 Total Number of persons living in household including yourself *(Please do not include temporary guests /roommates, but please include house-maids/ caretakers)***

______________________

**Q11 Number of household members according to the age group**:

Below 5 years: _____ persons

5-14 years: _____ persons

15-34 years: _____ persons

35-59 years: _____ persons

60+ years: _____ persons

**Q12 How many vehicles do you own as a household?**

i. None,

ii. Number of Bicycle: __________,

iii. Number of Two-wheeler: __________,

iv. Number of Auto-rickshaw: _________,

v. Number of Car: _________.

**Q13 What is your total monthly income (in Rupees)?**

☐ Up to 5,000

☐ 5,001-10,000

☐ 10,001-15,000

☐ 15,001-20,000

☐ 20,001-40,000

☐ 40,001-60,000

☐ 60,001-1,00,000

☐ Above 1,00,000

**In the next section of this survey, we would ask you some questions about your past travel behaviour. We are particularly interested in the year 2011 or before.**

**Q14** What was the address of your residence in 2011?

Area Name: ____________________________________________________________,

Landmark: ____________________________________________________________,

House Number: ____________________________________________________________,

Street Name: ____________________________________________________________, Ward Name: ______________________________________________,

**Q15 What was your employment status in 2011?**

- ☐ Employed (Main worker)
- ☐ Employed (Marginal worker)
- ☐ Self Employed (Main worker)
- ☐ Self Employed (Marginal worker)
- ☐ Daily Wages
- ☐ Student
- ☐ Unemployed/ Searching for employment

Next question is for understanding your past travel behaviour. We know that it is difficult to remember the exact detail of your past travel behaviour. Also, you might have used different modes in different days. Here, we request you to recollect the most frequent type of journeys to your work/ education. Please answer these questions based on the most common/most regular journey.

**Q16 On a normal day in 2011 you used to travel to:**

Company Name/School Name: ______________________________________,

Area: ______________________________________________,

House Number: ______________________________________________,

Street Name: ______________________________________________,

Zip code: ______________________________________________,

Ward Name: ______________________________________________,

Landmark: ______________________________________________.

**Q17 How did you use to travel to those locations from your house in 2011?**

**a) Please select:**

i. You used only one transport mode

ii. You used more than one transport mode

iii. You walked to your destination

b) **(For those who selected single mode)** The only transport mode you used:

i. Bicycle,

ii. Two-wheelers,

iii. Shared Auto Rickshaw (4-seaters, 7 seaters)

iv. Car

v. Public Bus

vi. Bus (from office/ school/ college)

vii. MMTS

viii. Metro

ix. Uber/Private cab

x. Other, (please specify) ___________

c) **For those who selected multiple mode-the respondent will select from a drop down list**)

i. You started from home by ___________ (walking / bicycle/ two-wheelers/ shared auto-rickshaw/ Car/ Uber/ Cab)

ii. The next mode you took is __________ (walking/ bicycle /two-wheelers /shared auto-rickshaw / Car / Uber / Cab /Public Bus / Bus from office, school or college / MMTS/ Metro)

iii. You took off from that mode and took _________ (walking/ bicycle /two-wheelers /shared auto-rickshaw/ Car/ Uber/ Cab/Public Bus / Bus from office, school or college / MMTS/ Metro)

iv. You took off from that mode and took _________ (walking/ bicycle /two-wheelers /shared auto-rickshaw/ Car/ Uber/ Cab/Public Bus / Bus from office, school or college / MMTS/ Metro)

**d) (For those who selected bus/metro/MMTS in Question b) or c)**

i. You board the transit (Bus/ Metro/ MMTS) at location ________________________

***ii.*** You leave the transit (Bus/ Metro/ MMTS) at location _________________________

**The next section of this questionnaire is about your past household attributes.**

**Q18 Total Number of persons living in the household including yourself in 2011**

________________

**Q19 Number of household members according to the age group in 2011**:

Below 5 years: _____ persons

5-14 years: _____ persons

15-34 years: _____ persons

35-59 years: _____ persons

60+ years: _____ persons

**Q20 How many vehicles did you own as a household in 2011?**

**i.** None,

**ii.** Number of Bicycle: ____,

**iii.** Number of Two-wheeler: ____,

**iv.** Number of Auto-rickshaw: ____,

v. Number of Car: _____.

**Q21 What was the total monthly income in 2011 (Rupees)?**

- ☐ No income
- ☐ Up to 5,000
- ☐ 5,001-10,000
- ☐ 10,001-15,000
- ☐ 15,001-20,000
- ☐ 20,001-40,000
- ☐ 40,001-60,000
- ☐ 60,001-1,00,000
- ☐ Above 1,00,000

This part of the questionnaire will collect some of your personal information. It is found in the research that these factors influence the way people travel to their work.

**Q22 You are:**

- ☐ Female
- ☐ Male
- ☐ Other

**Q23 Year of Birth/ Age**

________

**Q24 Highest Educational Level Achieved (passed)**

- ☐ Bachelor's and above
- ☐ Diploma/Vocational
- ☐ Class 12
- ☐ Class 10
- ☐ Class 8
- ☐ Class 5
- ☐ Never attended

**Q25 Are you the head of this household?**

- ☐ Yes
- ☐ No

Finally, we would like to understand the changes in your personal and household attributes which have been happened since 2011. As you have seen, we have not collected your name, these answers will be anonymised. Please select the statements which are appropriate for you (you can select as many as you want):

- ☐ I got married in or after 2011
- ☐ I was in a joint family/ with my parents, now I live in a single family
- ☐ My children were born in or after 2011
- ☐ My children started school in or after 2011
- ☐ My children started earning in or after 2011
- ☐ My spouse departed after 2011
- ☐ My role in the household changed
- ☐ I have new /changed job
- ☐ I got a promotion/salary raise in my job
- ☐ The household bought a new house/flat/apartment
- ☐ The household standard of living improved
- ☐ The household standard of living worsened
- ☐ Any other event which might influence the change in your travel behaviour

(Please specify in this box)

**The survey ends here. We thank you for your kind cooperation and participation.**

**Annex III: Code used to extract network distance from GoogleMaps service**

```
//This function calculates the travel distance between two locations. The
// latitude and longitude of origin and destination locations are needed
// to be arranged in separate column in a “Google Sheet”


function GoogleMaps(origin_lat,origin_lon,destination_lat,destination_lon)
{


  var mapobj= Maps.newDirectionFinder();
  mapobj.setOrigin(origin_lat,origin_lon);
  mapobj.setDestination(destination_lat,destination_lon);
  var directions= mapobj.getDirections();
  var distance= directions["routes"][0]["legs"][0]["distance"]["value"];
  return distance
}
```