INVESTIGATION OF URBAN FORM AND PUBLIC TRANSPORT USE IN LAHORE CITY

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بسم الله الرحمن الرحيم

DEDICATION

I dedicated this work to my honorable and worthy parents and teachers withou whom; I could have never achieved so much in my life.

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In the name of Allah Almighty, the most Merciful, by the grace of Whom, I am able to complete this research with courage and serenity.

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ABSTRACT

Lahore, the most populated city of Punjab is expanding particularly on southern side due to migration of people from all over the province. Along with other different problems; Traffic problems are also generating due to expansion of city. Literature from worldwide suggest that city should be planned in such a way that promotes public transport usage which offers more capacity and eventually result in lower traffic problems. The aim of this research is to investigate urban form of Lahore and its relationship with public transport usage. Urban form refers to density, diversity and design of an area or a city. For this, different urban form variables were computed for the city of Lahore and maps at town and union council level to explore the urban form of Lahore were generated. To develop the relationship for urban form and social variables with public transport usage in Lahore, Ordinary Least Square and Simultaneous Auto regression have been used. After assessment of all urban form variables by using maps, it is concluded that Lahore is monocentric at town level whereas bridging towards sprawl at union council level. Further investigation has been made at union council level. A significant relationship was also found to exist between urban form and social variables with public transport usage of the city. Out of six urban form variables, Entropy Index, Employment Density and Accessibility Index to Employment found statistically significant to explain the public transport usage. On other side, households having no car, households having size less than 6, young females having age less than 30 years and households having transport expense less than 5,000 are social variables which have significant effect on usage of public transport at union council level. Further, Spatial lag parameter was found to be statistically significant which shows that public transport usage in the city has neighborhood influence at Union Council

level. Overall, the research shows that there is a strong relationship between urban from variables and public transport usage in Lahore yet the analysis of many more cities at union council level is needed in support of order to validate this claim in local context.

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Chapter 1

1 INTRODUCTION

1.1 PROBLEM STATEMENT

Lahore has population of around 9 Million in year 2010 and expected to have 15 Million approximately in 2030 (Government of Punjab, 2012). The city has an area of about 1,772 km^2. It is second highest populated city of Pakistan and the most populated city of Punjab. Due to better education, health facilities and economic opportunities, people from all over of the province are migrating to Lahore. Due to this fact, the population of the city is increasing day by day. Increase in population and high prices of land closer to city center forces people to live in the suburb areas of the city. As a result, city is expanding in all directions mainly towards southern side. Inhabitants tend to move towards their destination for different purposes including work, education, shopping etc. Due to such increase in population and expansion of city, travel demand of inhabitants is increasing. Expansion of city has resulted longer commuting distance. The number of vehicles has also increased in recent years, which eventually resulting congestion, environmental degradation and safety threats. Highly congested roads also results in high travel time of commuters. Concerned authorities including Local Government, Lahore Development Authority and Communication and Works Department have executed a large number of projects to cater this increasing travel demand. Improvements in public transport system have also been done by providing the new busses and optimizing the routes of public transport vehicles. Despite of all these measures, the issues related to sustained and smooth mobility in the city still persist. One of the possible reasons of such failure is linked to land use planning. Literature from worldwide suggest that land use should be planned in a way that encourages public transport usage, offers more capacity and hence less congestion on roads, and decreases automobile use. Studies conclude that land-use patterns do impact commuting, while others simply do not (Giuliano and Small, 1993; Badoe and Miller, 2000).

In Pakistan no research has been done to investigate the relation between land use planning and its impacts on the transport usage. There is need to develop the relation between land use and public transport use. In case, the Land use affects the public transport use in local context, the improvement in land use will increase the use of public

transport. Due to increase in use of public transport system, the congestion on road will decrease which eventually control the fuel losses and environment degradation. Urban form refers to the spatial imprint of transport system and adjacent physical infrastructure in an area (Rodrigue, 2013). Urban form includes density, diversity and design of an area.

1.2 RESEARCH OBJECTIVES

The aim of this research is to explore urban form of Lahore and its effect on public transport usage and eventually on transport system of the city. The specific research objectives are as follows:

1. To investigate the urban form of Lahore
2. To determine the relation between urban form variables and public transport usage in Lahore
3. To find specific urban form variables which effects the usage of public transport for Lahore

1.3 THESIS OUTLINE

Thesis consists of five chapters.

- Introduction
- Literature Review
- Method of Analysis
- Results and Discussion
- Conclusion and Recommendations

Chapter one begins with the problem statement followed by the research objectives. Chapter two starts with discussion of theoretical context of the topic. Discussion includes urban form and development of its model with public transport usage. This chapter also briefed about the already conducted studies in this context. Appraisal of variables and techniques used in previous studies also part of this chapter. Chapter three outlines the methods used to investigate the urban form and to develop the relationship between urban form and public transport usage. All urban and socio economic factors identified and used to develop the model are also explained in this chapter. Chapter four presents the results which includes investigation of urban form and model formulation and

development. It also includes discussion about Ordinary Least Squares (OLS) and Simultaneous Auto-Regressive (SAR) modeling. In chapter five, the conclusions are made and followed by recommendations for future research work.

Chapter 2

2 Literature Review

2.1 INTRODUCTION

The spatial locations of urban transport system and associated land use at a point in time determines the urban form of a geographical area (Rodrigue, 2013). It mainly refers to the design of an area or a city. An unexpected change in urban form around the world, happened in twentieth century when invention of automobile entered in the market which led to the heavy investments in road network to increase the accessibility to previously inaccessible locations (Maoh and Kanaroglou, 2007). Invention of automobile and increase in accessibility relocated the pattern of housing and job. Opportunity to travel on public vehicle and lower cost of land in suburb encouraged people to live in suburb. Expansion in cities occurred and importance of a central core or CBD decreased gradually which resulting in polycentric and distributed type of urban forms. This type of spatial growth is generally termed as urban sprawl which is held responsible for many problems included traffic congestion, increase in travel time, high fuel consumption, high prices of housing near CBD, environmental degradation etc. by many research analysts (Behan, *et al.,* 2008). In south Asian countries, such type of change in urban form was observed due to the poor quality of public transport owned by Government. (Imran, 2009).

Before the inception of car traffic, Street networks were mainly comprise of arterial and local streets converted into grid system as a result of street car transportation. In 1950s, curvilinear type of road network shift to cul-de-sac type of network as result of increase in urban mobility. Which become responsible for lower density of land use and private car became the most favorable mode of transportation, especially in North America (Rodrigue, 2013).

The traditional compact cities have the advantage of mix land use enabling residents to perform multiple tasks in a single journey, use car less and have a potential of reducing the total number of trips which results in reducing congestion (Friedman, *et al.,* 1994 and Stover and Koepke, 1991). These urban forms also promote the trips on foot, cycling and public transport (Cervero, 2002). Residents of suburb areas have more car-ownerships than the residents of compact areas (Stead, 2001). Examples of such monocentric cities

exist in Europe, China and Japan metropolitan areas where public transport is encouraged. North American urban areas – American and Canadian, in contrast, are mostly decentralized and low density neighborhoods (Rodrigue, 2006).

Transportation problems motivated researchers to study the integration of transportation with land-use planning to explore the suitable solutions. This could be done by understanding the relationship between travel behavior and land-use (Acker and Witlox, 2011). According to Chen *et al*. (2008), population and employment density are significant variables of urban form which have impact on public transport usage because higher densities reduce the travel time. Areas having low densities would result in longer travel times by public transport and it promotes private vehicle usage which is ineffective system (Behan, *et al.,* 2008). Dense urban areas with better public transport facilities, limited parking spaces and access to employment and commercial land-uses encourage public transit usage and therefore a policy implementation of simply increasing density (in previously low-density areas) without improving transit services would not yield a lower car use (Manaugh, *et al.,* 2010). One advantage of using density as an explanatory variable for public transport use is that it is very easy to calculate and most of the times is significant (Sadek, *et al.,* 2011). Acker and Witlox (2011) strongly suggested that the use of both population and employment density to identify the impact on transit use because workplace land-use patterns help to explain how commuting distances influence the mode choice.

Another important variable that have an impact on public transport usage is diversity. It can be divided into two types: job-housing mix and mixed land use. Job-housing mix is the measure of balance in employment and residential densities in a geographical area which reduces the congestion by decreasing the number of trips and distances and travel times (Potoglou and Kanaroglou, 2008). A previous study, however, suggested that the influence of job-housing mix on commuting is very general and a balanced job-housing doesn't impact on commuting behavior (Giuliano, 1991). An area having several type of land uses e.g. residential, recreational, employment, commercial, water bodies, Graveyard, agriculture, gardens etc. has a mixed-land use which encourages public transport usage and decreases single-occupancy vehicle usage (Frank and Pivo, 1994). Third, more complex and difficult to analyze, variable of urban form is urban design

(Axisa, 2009). It includes the above two variables and includes features like layout, design, pedestrian/Bicycle paths etc. Grid road network design facilitates faster transit network and results in more transit users due to higher accessibility (Messenger and Ewing, 1996). This is confirmed by Handy (1996) who also reported lower automobile use in pedestrian-oriented designs. This emphasizes the importance of researching the impact of urban design.

Research on urban form and public transport usage has mostly been done on American cities using urban form variables and non-urban form variables e.g. income, age, car ownership and employment status (Axisa, 2009). By using non-urban form variables as control variables, the focus of research can be put on urban form variables (Frank and Pivo, 1994). Different methods have already been identified and used to research of this type. Job-house mixing can be determined by computing Mixed Density Index (MDI) which compares the employment with population density in an area (Giuliano, 1991). A higher MDI value means higher job-housing balance, higher density and more transit usage (Behan, *et al.,* 2008). Mixed-use development or the heterogeneity of an area in terms of its land use could be determined by Entropy Index (EI). Entropy is a concept received from statistical sciences which is used to describe the uncertainty in distributions. In context of land-use and urban form, the same concept is applied to explain the diversity of land-uses (Sadek, *et al.,* 2011). EI ranges from 0 to 1. An even distribution of all land uses will have an EI closer to 1, implying spatial heterogeneity, and 0 for a single type of land use, implying spatial homogeneity (Potoglou and Kanaroglou, 2008). Accessibility to population and employment can be determined by using gravity formula of trip distribution to develop Accessibility Index (AI). Areas with higher job accessibility were found to have lesser car ownership by residents (Gao, *et al.,* 2008).

2.2 CASE STUDIES

Differences in past studies about developing the relationships between transportation and urban form variables might be due to the differences in study methodologies (cross-sectional versus longitudinal) and the different study levels used (metropolitan vs census tract level) etc. (Acker and Witlox, 2011).

To develop the relationship between urban form and Public transport usage, researchers have been used Ordinary Least Squares (OLS) method, Simultaneous Auto-Regressive method (SAR) (Axisa, 2009).

The spatial trends in transit usage might be due to the correlation of urban form variables with themselves in a number of census tracts. This spatial autocorrelation could be described by a statistic called Global Moran's I which varies from -1 to +1. A higher positive value means positive correlation meaning neighboring census tracts attributes influence the attributes of census tract under consideration, zero means no autocorrelation but randomness and a negative value means dispersed trend (Tsai, 2005).

2.3 METHODOLOGIES USED IN PAST RESEARCH

2.3.1 Exploration Techniques

To study the relationship between urban form and public transport usage, different methodologies depend upon the type of urban form were used by different researchers.

Following are the techniques used in the past:

- Mixed Density Index (MDI). The balance between population density and employment density within an area can be computed through this index (Giuliano, 1991). A higher value of this index refers to higher job housing balance which eventually resulted in to shorter commuting distances and increased transit use (Behan *et al*., 2008; and Chu, 2002).
- The Entropy Index (EI). Heterogeneity or homogeneity within a specific geographic area can be determine by this index. (Cervero and Kockelman, 1997; Chu, 2002; Frank and Pivo, 1994; and Messenger and Ewing, 1996). This Index ranges between 0 and 1. Single type of land use in an area implies 0 while 1 indicating an even distribution of all land use types. An EI closer to 1 indicates increased usage of active transportation types such as: public transport usage, walking and cycling as trips are often shorter in nature (Potoglou and Kanaraglou, 2008).
- The Global Moran coefficient. Spatial autocorrelation is measured by Global Moran Coefficient. (Tsai, 2005). Compactness/Sprawl can be determined by

this coefficient and its value ranges from -1 and +1. Higher positive values indicate clustering (monocentric form), values close to zero indicate randomness (polycentric form) and lower negative values indicate a checkerboard pattern (decentralized sprawl) (Tsai, 2005).

- Accessibility index to Population and Employment. These indexes expressed in a gravity model form and has been used by Cervero and Kockelman (1997), and Chu (2002) in past when computed accessibility index to population and employment within a zone. Larger values indicate higher accessibility for that particular zone. Travel time between two zones is also required to determine this index.

2.4 PAST MODELING EFFORTS

Different techniques of regression most commonly used when developing the model between urban form and transportation. Common regression modeling techniques are mentioned in Table: 2-1.

Multiple regression is technique for modeling numeric data consisting of a dependent variable and multiple independent variables. This type of regression model attempts to develop the relationship between the dependent variable and independent variables (Ortuzar and Willumsen, 2001). Socioeconomic variables allow for comparisons between similar trip makers. This allows the analyst to tease out the impact of urban form on transportation after controlling for all other factors that explain the variability in the generated trips (Frank and Pivo, 1994).

Logistic (Logit) regression models are also very popular within the literature. Logit models are mode choice models where independent variables are used to determine a population's modal split. The most important independent variables used for explaining mode choice are related to: residential density, car ownership and socio-economic characteristics (Ortuzar and Willumsen, 2001).

Table 2-1: Types of Regression Model used in Previous Studies

Empirical studies of Urban Form and Travel since 1990		
Study	**Study Area**	**Regression Model**
Wang and Chai (2009)	Beijing (China)	Multiple Regression
Chen *et al*. (2008)	New York Metropolitan Region, New York (USA)	Binomial Logit Analysis
Handy *et al*. (2005)	San Francisco Bay Area, California (USA)	Multiple Regression
Schwanen and Mokhtarian (2005)	San Francisco Bay Area, California (USA)	Multinomial Logit Analysis
Cervero (2002)	Montgomery County, Maryland (USA)	Binomial Logit Analysis
Crane and Crepeau (1998)	San Diego County, California (USA)	Multinomial Logit Analysis
Cervero and Kockelman (1997)	San Francisco Bay Area, California (USA)	Binomial Logit Analysis
Levinson and Kumar (1997)	Numerous cities across the USA	Multiple Regression
Dunphy and Fisher, 1996	Numerous cities across the USA	Multiple Regression
Messenger and Ewing (1996)	Dade County, Florida (USA)	Stepwise Regression Analysis
Frank and Pivo (1994)	Puget Sound Region, Washington (USA)	Multiple Regression

3 Methodology

3.1 STUDY AREA

A comprehensive study has already been conducted in Lahore and its surrounding for the Transport Master Plan 2030 by the JICA (Government of Punjab, 2012). In this study, different types of traffic and Household surveys were conducted for the study area. Data required to investigate the urban form and development of its relationship with public transport usage is only available in this study. For this research, encoded data sheets of household interview survey from JICA Study was taken. All required data was extracted and computed from the encoded data sheets. Lahore comprises of 10 towns and 188 union councils having Tehsil Ferozewala, Sharaqpur, Pattoki, Muridkey and Kasur in its neighbors. List of towns exist in Lahore are mentioned in following table: 3.1.

Table 3-1: List of Towns in Lahore

Sr. No.	Town
1.	Ravi Town
2.	Data Gunj Baksh Town
3.	Shalimar Town
4.	Gulberg Town
5.	Nishtar Town
6.	Wagha Town
7.	Allama Iqbal Town
8.	Samnabad Town
9.	Aziz Bhatti Town
10.	Cantonment

Ravi town exist in northern side of city whereas Nishter town falls on the southern side. Gulberg, Data Ganj Baksh and Cantonment exist within the center of the city. Although, Wagah and Aziz Bhatti town exist on the eastern side and Iqbal town on western side of the city.

List of union councils fall in each respective town of Lahore are mentioned in following tables from 3.2 to 3.11.

Table 3-2: List of union councils in Ravi town

Sr. No.	Union Council	Town
1	Begum Kot	Ravi Town
2	Kot Mohibbu	Ravi Town
3	Aziz Colony	Ravi Town
4	Faisal Park	Ravi Town
5	Qaiser Town	Ravi Town
6	Qaiser Town	Ravi Town
7	Dhair	Ravi Town
8	Shahdara	Ravi Town
9	Shahdara	Ravi Town
10	Jia Musa	Ravi Town
11	Qila Lakshman Singh	Ravi Town
12	Fruit Mandi	Ravi Town
13	Siddiquepura	Ravi Town
14	Bangali Bagh	Ravi Town
15	Siddiqia Colony	Ravi Town
16	Bhamman	Ravi Town
17	Farooq Ganj	Ravi Town
18	Dehli Gate	Ravi Town
19	Rang Mahal	Ravi Town
20	Androon Bhaati Gate	Ravi Town
21	Androon Texali Gate	Ravi Town

21 Union councils exist in Ravi town.

Table 3-3: List of union councils in Data Ganj Baksh town

Sr. No.	Union Council	Town
1	Kasurpura	Data Gunj Baksh Town
2	Ameenpura	Data Gunj Baksh Town
3	Kareem Park	Data Gunj Baksh Town
4	Ganj Kalan	Data Gunj Baksh Town
5	Bilal Gunj	Data Gunj Baksh Town
6	Anarkali	Data Gunj Baksh Town
7	Gawalmandi	Data Gunj Baksh Town
8	Sarai Sultan	Data Gunj Baksh Town
9	Qila Gujjar Singh	Data Gunj Baksh Town
10	Race Course	Data Gunj Baksh Town
11	Mozang	Data Gunj Baksh Town
12	Jinnah Hall	Data Gunj Baksh Town
13	Riwaz Garden	Data Gunj Baksh Town
14	Islampura	Data Gunj Baksh Town
15	Chohan Park	Data Gunj Baksh Town
16	Sanda Kalan	Data Gunj Baksh Town
17	Sanda Khurd	Data Gunj Baksh Town
18	Shadman	Data Gunj Baksh Town

18 union councils exist in this town.

Table 3-4: List of union councils in Samnaabad Town

Sr. No.	Union Council	Town
1	Abu Bakar Siddique Colony	Samanabad Town
2	Sham Nagar	Samanabad Town
3	Gulgasht Colony	Samanabad Town
4	Gulshan-e-Ravi	Samanabad Town
5	Babu Sabu	Samanabad Town
6	Rizwan Park	Samanabad Town
7	Sodiwal	Samanabad Town
8	Bahawalpur House	Samanabad Town
9	Ichhra	Samanabad Town
10	New Samanabad	Samanabad Town
11	Shah Kamal	Samanabad Town
12	Pakki Thatti	Samanabad Town
13	Kashmir Block	Samanabad Town
14	Nawan Kot	Samanabad Town
15	Samanabad	Samanabad Town
16	Rehmanpura	Samanabad Town
17	Gulshan-e-Iqbal	Samanabad Town
18	Sikandar Block	Samanabad Town
19	Muslim Town	Samanabad Town
20	Muslim Town	Samanabad Town

20 union councils exist in this town.

Table 3-5: List of union councils in Shalamar Town

Sr. No.	Union Council	Town
1	Bhaghatpura	Shalamar Town
2	Gujjarpura	Shalamar Town
3	Rehmatpura	Shalamar Town
4	Begumpura	Shalamar Town
5	Chah Miran	Shalamar Town
6	Bilal Park	Shalamar Town
7	Makhanpura	Shalamar Town
8	Kot Khawaja Saeed	Shalamar Town
9	Shad Bagh	Shalamar Town
10	Wassanpura	Shalamar Town
11	Faiz Bagh	Shalamar Town
12	Crown Park	Shalamar Town
13	Madhu Lal Hussain	Shalamar Town
14	Muhammad Colony	Shalamar Town
15	Baghbanpura	Shalamar Town
16	Angori Bagh	Shalamar Town
17	Mujahidabad	Shalamar Town

17 union councils exist in this town.

Table 3-6: List of union councils in Gulberg Town

Sr. No.	Union Council	Town
1	Railway Colony	Gulberg Town
2	Railway Colony	Gulberg Town
3	Daras Barey Mian	Gulberg Town
4	Bibi Pak Daman	Gulberg Town
5	Garrhi Shahu	Gulberg Town
6	Garrhi Shahu	Gulberg Town
7	Al-Hamra	Gulberg Town
8	Zaman Park	Gulberg Town
9	Zaman Park	Gulberg Town
10	Gulberg	Gulberg Town
11	Mecca Colony	Gulberg Town
12	Naseerabad	Gulberg Town
13	Garden Town	Gulberg Town
14	Model Town	Gulberg Town
15	Faisal Town	Gulberg Town
16	Liaqatabad	Gulberg Town
17	Kot Lakhpat	Gulberg Town
18	Pindi Rajputan	Gulberg Town

18 union councils exist in this town.

Table 3-7: List of union councils in Aziz Bhatti Town

Sr. No.	Union Council	Town
1	Harbanspura	Aziz Bhatti Town
2	Harbanspura	Aziz Bhatti Town
3	Rashidpura	Aziz Bhatti Town
4	Fateh Garh	Aziz Bhatti Town
5	Nabipura	Aziz Bhatti Town
6	Mughalpura	Aziz Bhatti Town
7	Mian Meer	Aziz Bhatti Town
8	Mustafabad	Aziz Bhatti Town
9	Ghaziabad	Aziz Bhatti Town
10	Taj Bagh	Aziz Bhatti Town
11	Tajpura	Aziz Bhatti Town
12	Al-Faisal Town	Aziz Bhatti Town
13	Guldasht Colony	Aziz Bhatti Town
14	Bhangali	Aziz Bhatti Town

14 union councils exist in this town.

Table 3-8: List of union councils in Wagah Town

Sr. No.	Union Council	Town
1	Muslimabad	Wagah Town
2	Sultan Mehmood	Wagah Town
3	Shadipura	Wagah Town
4	Salamatpura	Wagah Town
5	Daroghawala	Wagah Town
6	Lakhodher	Wagah Town
7	Bhaseen	Wagah Town
8	Dograi Kalan	Wagah Town
9	Manawan	Wagah Town
10	Minhala	Wagah Town
11	Barki	Wagah Town
12	Hadiara	Wagah Town

12 union councils exist in this town

Table 3-9: List of union councils in Nishtar town

Sr. No.	Union Council	Town
1	Kamahan	Nishtar Town
2	Hair	Nishtar Town
3	Dhaloke	Nishtar Town
4	Bostan Colony	Nishtar Town
5	Ismail Nagar	Nishtar Town
6	Sittara Colony	Nishtar Town
7	Farid Colony	Nishtar Town
8	Keer Kalan	Nishtar Town
9	Green Town	Nishtar Town
10	Maryam Colony	Nishtar Town
11	Attari Saroba	Nishtar Town
12	Dullo Khurd Kalan	Nishtar Town
13	Chandrai	Nishtar Town
14	Chandrai	Nishtar Town
15	Halloke	Nishtar Town
16	Gajju Matta	Nishtar Town
17	Kahna Nau	Nishtar Town
18	Jia Bagga	Nishtar Town
19	Pandoki	Nishtar Town
20	Kamahan	Nishtar Town

20 union councils exist in this town

Table 3-10: List of union councils in Iqbal town

Sr. No.	Union Council	Town
1	Awan Town	Iqbal Town
2	Saidpur	Iqbal Town
3	Sabzazar	Iqbal Town
4	Dholanwal	Iqbal Town
5	Bakar Mandi	Iqbal Town
6	Johar Town	Iqbal Town
7	Hanjarwal	Iqbal Town
8	Niaz Beg	Iqbal Town
9	Shahpur	Iqbal Town
10	Shahpur	Iqbal Town
11	Ali Razabad	Iqbal Town
12	Chung	Iqbal Town
13	Chung	Iqbal Town
14	Maraka	Iqbal Town
15	Maraka	Iqbal Town
16	Shamke Bhattian	Iqbal Town
17	Shamke Bhattian	Iqbal Town
18	Sultanke	Iqbal Town
19	Manna	Iqbal Town
20	Township	Iqbal Town
21	Township-II	Iqbal Town
22	Pajian	Iqbal Town
23	Pajian	Iqbal Town
24	Raiwind	Iqbal Town
25	Raiwind	Iqbal Town

25 union councils exist in this town.

Table 3-11: List of union councils in Cantonment

Sr. No.	Union Council	Town
1	Airport	Cantonment
2	Askari Housing	Cantonment
3	Aziz Bhatti	Cantonment
4	Basti Chiragh Shah	Cantonment
5	CMA Colony	Cantonment
6	Chung Khurd	Cantonment
7	DH01a	Cantonment
8	DH01b	Cantonment
9	DH03	Cantonment
10	DH04	Cantonment
11	DH05	Cantonment
12	DH08	Cantonment
13	Dher Pindi	Cantonment
14	Gulshan1	Cantonment
15	Gulshan2	Cantonment
16	Gulshan3	Cantonment
17	Iqbal Camp	Cantonment
18	Madina	Cantonment
19	Mian Mir	Cantonment
20	New Nishtar	Cantonment
21	Nishat Colony	Cantonment
22	Park View	Cantonment
23	Pir Colony	Cantonment
24	Raza Colony	Cantonment

24 union councils exist in this town.

3.2 METHODOLOGY

Methodology of this research has been developed by considering the objectives of the research and by consulting the past studies.

3.2.1 Data collection

Different kinds of datasets including urban form variables (Population density, employment density, mix density index, entropy index, accessibility index to population and accessibility index to employment) and social variables (Households having income less than 20,000, households having transport expense less than 5,000, households having no car, household having size less than 6, males having age less than 30 years, females having age less than 30 years, households having employed residents) are required to carry out the research. All social variables were extracted from encoded data sheets of Household interview survey. Land use data and road network dataset for Lahore was also required to compute urban form variables. Employment data is not directly available in the surveys conducted for Lahore Urban Transport Master Plan (LUTMP) 2011 by JICA. In absence of that travel log diary available in Household interview survey for above mentioned study is used to extract the employment opportunities data.

3.2.2 Data Analysis and Model Development

In the analysis, Mix Density Index, Entropy Index and Accessibility Index were computed to determine the urban form as a first step. After extracting/computing all required urban and social variables, a shape file including all variables was developed in GIS software. The same shapefile was further used in investigation and model development. Investigation of Urban Form was done at Town and Union council level by generating maps on GIS whereas, model development was done by using software Geoda. To develop the model between urban form and public transport usage, two types of regression analysis were done including Ordinary Least Square regression and Simultaneous Auto regression.

3.2.3 Model Validation

After analysis, different models will be developed. Validation of these models will also be done by conducting the questionnaire survey from one union council of each town. Flow diagram of methodology is attached as Figure 3-1 as follows:

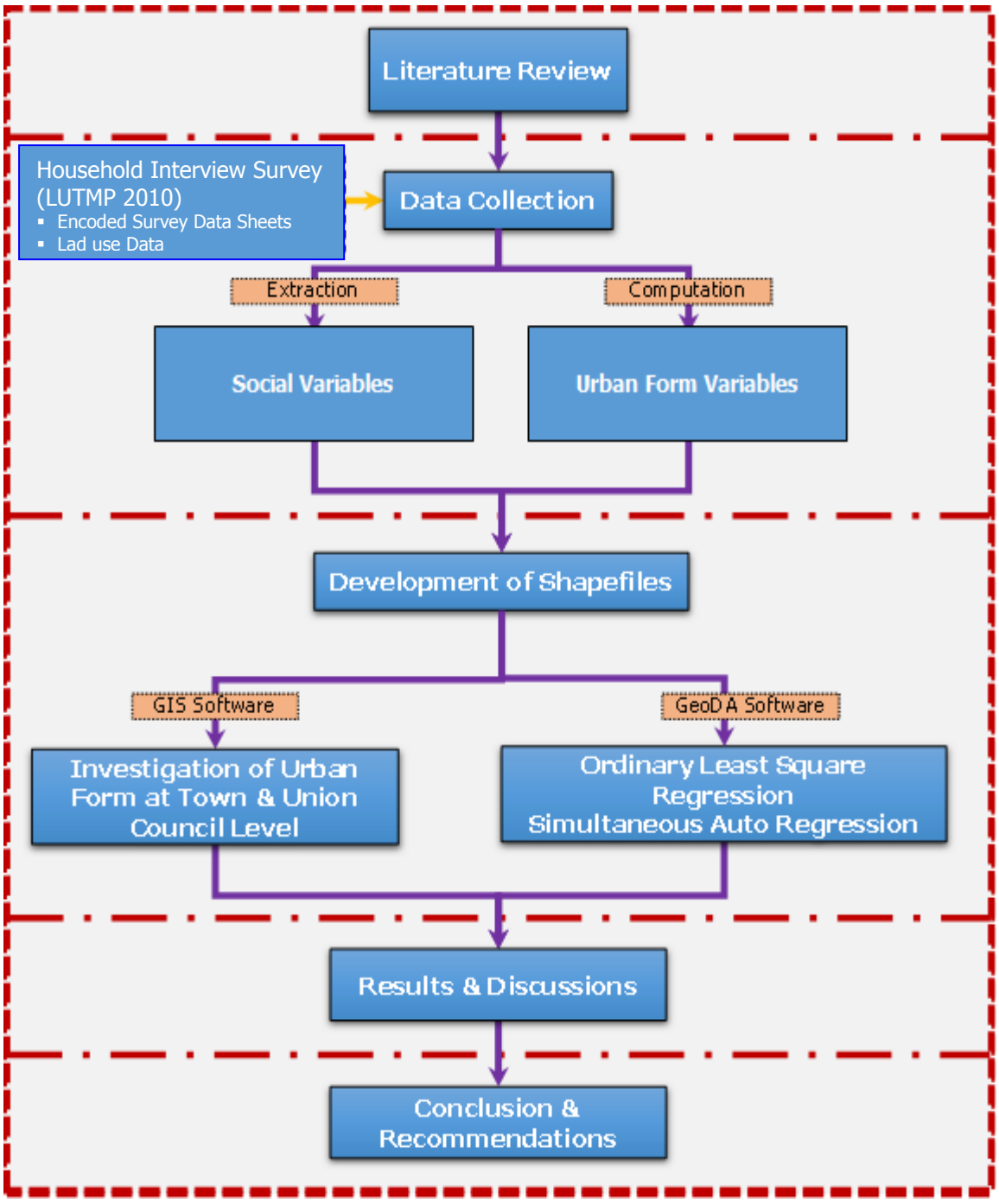

Figure 3-1: Framework Methodology

3.3 METHOD OF ANALYSIS

3.3.1 Investigation of Urban Form

Six different urban form variables have been used in this research to investigate the urban form of the city. These six urban form variables are as follows:

- Population Density
- Employment Density
- Mix Density Index
- Entropy Index
- Accessibility Index to Population
- Accessibility Index to Employment

Population Density

Number of people living in a unit area is known as population density. If total area including agriculture, open, water body etc. considered for the density calculations then it would be known as gross population density whereas only built up area is considered then it would be called as net population density. For this research gross population density is computed and written in this thesis as population density.

$$Population\ density = \frac{number\ of\ persons \text{in unit area}}{\text{total area}}$$

Unit of this variable is persons per hector

Employment Density

Number of employment in a unit area is known as employment density. For this research, gross employment density is computed and written in this thesis as employment density.

$$\text{Employment } density = \frac{number\ of\ \text{employments in unit area}}{\text{total area}}$$

Unit is persons per hector

Mix Density Index

It is job housing mix index. Mix density index is the combination of population density and employment density.

$$Mix\ density\ index = \frac{\text{Population Density } * \text{ Employment Density}}{\text{Population Density } + \text{ Employment Density}}$$

Unit is persons per hector.

Higher value of this index showed the higher job housing mix whereas the lower values associated with lower mixing.

Entropy Index

Mixing of land use in an area is known as entropy index. If high number of land uses exist in an area at a definite proportion, the entropy index is closer to 1 and in case of one type of land use the value falls closer to 0.

$$Entropy\ index = -\sum \frac{p_k . \ln p_k}{\ln k}$$

p_k=proportion of land use in k^{th} land use category

k= Number of land uses

The land-uses used were: Commercial, Industrial, Open Space, Water body, Residential, Parks & Recreation, Educational, Hospitals, Government, Institutional etc.

Accessibility Index to Population

Accessibility Index to population is known as how much population of an area is accessible from different areas of that city.

$$Accesibility\ Index\ to\ population = \sum \frac{P_J}{T_{IJ}^2}$$

P_j=Population in destination zone j

T_{ij}=Travel time in minutes from origin centroid to destination centroid along the network

Accessibility Index to Employment

Accessibility Index to employment is known as the employment of an area is accessible from different areas of that city.

$$Accesibility\ Index\ to\ employment = \sum \frac{Q_J}{T_{IJ}^2}$$

Q_j= employment in destination zone j

T_{ij}=Travel time in minutes from origin centroid to destination centroid along the network

3.3.2 Types of Urban Form

Urban form can be investigated by using three parameters density, diversity and design (Tsai, 2005). Density includes population and employment density; diversity includes mix density index and entropy index whereas design include accessibility index to population and employment. Urban form usually has three types:

- Monocentric
- Polycentric
- Decentralized Sprawl

Monocentric Urban Form:

In this type of Urban Form, higher values of each urban form variable associated to one zone. CBD has more importance and all trips terminate there. Monocentric cities focused around the CBD. Pictorial representation is attached as Figure: 3-2.

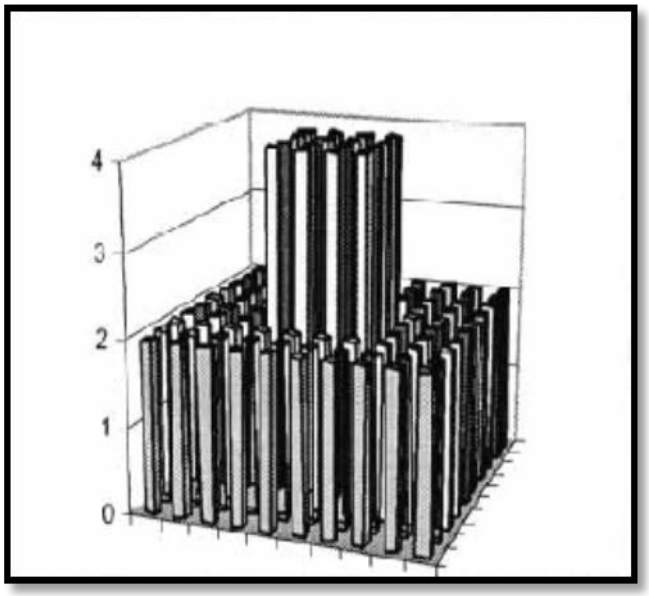

Figure 3-2: Monocentric Urban Form (Adapted from Tsai, 2005)

Polycentric Urban Form

Higher values of each variable associated to more than one zone lead to polycentric type of urban form. Importance of CBD is not as much as in monocentric type of urban form. Figure is shown below as Figure 3-3.

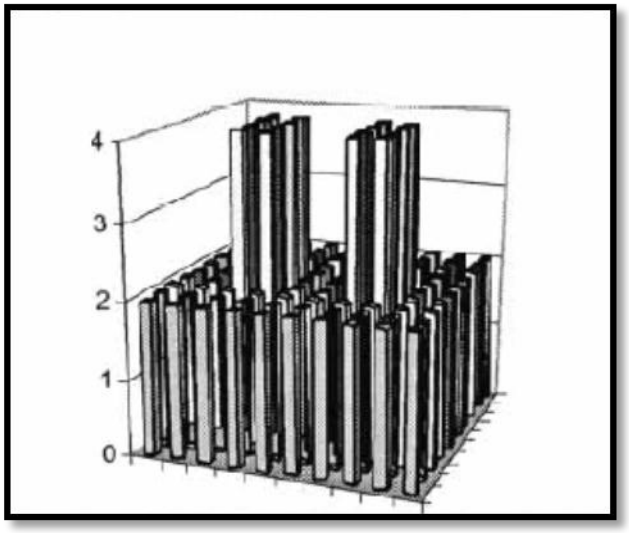

Figure 3-3: Polycentric Urban Form (Adapted from Tsai, 2005)

Decentralized Sprawl

When each urban form variable has higher values in different zones of city, then the urban form lead to sprawl nature. This type of urban form has different characteristics regarding living, employment, transportation etc. People prefer to live in suburbs. Pictorial representation is attached as Figure 3-4.

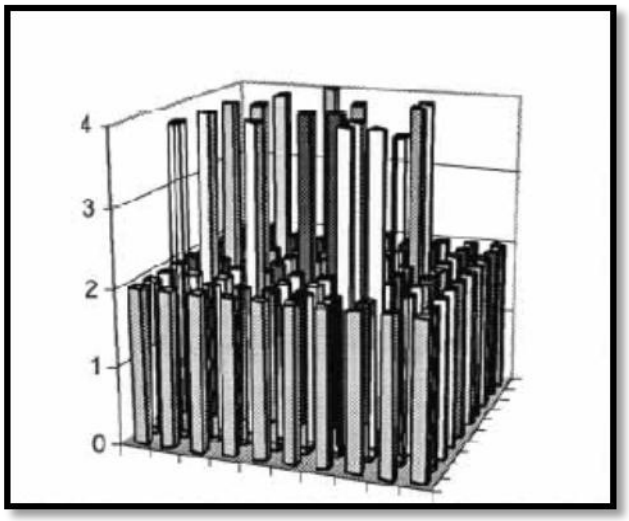

Figure 3-4: Decentralized Sprawl Urban Form (Adapted from Tsai, 2005)

After computing all urban form variables, maps of each variable were developed. Investigation of urban form can be investigated by reviewing the maps of each urban form variable.

Global Moran's I is another variable used to explore the urban form. It measures the level of spatial auto correlation and clustering within a specific area (Tsai, 2005). Its value ranges from -1 to +1. A positive higher value closer to 1 depicts the monocentric type of urban form, relative positive lower value represents polycentric type of urban form. Similarly value closer to zero indicates decentralized sprawl and negative value represents chess board development (Tsai, 2005). This urban form variable will be computed through using software GIS.

3.3.3 Relation development between Urban form and Public Transport Usage

To develop the relationship between urban form and public transport usage in Lahore, two types of regression was done.

- Ordinary Least Square Regression
- Simultaneous Auto Regression

In these types of regression public transport usage was considered as dependent variable whereas one urban form variable and different socioeconomic variables were considered as independent variables.

$$Y = m_i x_i + m_{ii} x_{ii} + m_{iii} x_{iii} + m_{iv} x_{iv} + \cdots + C$$

Y is the dependent variable which is Public Transport usage. X is the independent variable and m is coefficient of each independent variable. C is the constant computed as result of regression analysis.

In ordinary Least Square regression, there are two basic assumptions that are as follows:

i. Dependent variable of each zone should be independent to other zones
ii. Each independent variables in one model should independent to each other

Public transport usage as dependent variable could not remain independent as usage in one zone have an impact on neighboring zones.

To cater this neighborhood impact phenomena, Spatial Log parameter was considered to run the Simultaneous Auto Regression. Simultaneous Auto Regression was done on Geo da software with Rook Model. Shape file having all urban and social variables used in Geo da software to generate the model.

$$Y = mx + pw(Y - mx) + c$$

In above equation, ρ is spatial lag parameter, w is weighted matrix indicates spatial relationship between zones (Bailey and Gatrell, 1995).

Different socioeconomic variables including households having income less than 20,000, households having transport expense less than 5,000, household size less than 6, employed Resident, males having age less than 30 years, females having age less than 30 years and households having no car were used for the model development. Socioeconomic variables used for this research were taken from the studies already conducted or to develop the relation for specific variable. Age barrier of 30 years was considered by keeping in view the fact that most of individuals got settled in their lives till this age bracket.

3.3.4 Model Specifications

Data availability and Literature review was used to specify urban form and social variables for the development of models. Public transport usage being the dependent variable and all urban and social variables considered as independent variables. Hypothesis of each urban and social variable with dependent variable was developed. All urban and social variables along with their expected signs are mentioned in Table 3-12.

Table 3-12: Hypothesis of Urban and Social Variables

Variables	Hypothesis	Expected Sign
Urban Form Variables		
Population Density	As population density increase, public transport use will increase	+
Employment Density	As employment density increase, public transport use will increase	+
Mix Density Index	As Mix Density Index increase, public transport use will increase	+
Entropy Index	As Entropy Index increase, public transport use will increase	+
Accessibility Index (Population)	As Accessibility Index(Population) increase, public transport use will increase	+
Accessibility Index (Employment)	As Accessibility Index(Employment) increase, public transport use will increase	+
Social Variables		
Rented houses	Public transport use increases with increase in houses on rent	+
Households having income less than 20,000	Household having income less than 20,000 will increase, public transport use will increase	+
Households having transport expense less than 5,000	Increase in transport expense will decrease the public transport use	+
Household size less than 6	Household size increase will decrease the public transport use	-
Employed Resident	Increase in employed residents will increase the public transport use	+
Males having age less than 30 years	Increase in Males having age less than 30 will increase the public transport use	+
Females having age less than 30 years	Increase in Females having age less than 30 will increase the public transport use	+
Households having no car	Households having no car will use more public transport	+

3.3.5 Model Formulation

To develop the model between urban from and public transport usage in Lahore. Six different models were developed by considering one urban form variable and multiple social variables. Details of each model is summarized in Table 3-13.

Table 3-13: Model Formulation

Model	Urban Form Variable	Social Form Variable
Model-1	Entropy Index	Households having transport expense less than 5,000, Household having no car, Female residents having age less than 30 years
Model-2	Net Population Density	Households having income less than 20,000, Household size less than 6, Male having age less than 30 years
Model-3	Net Employment Density	Households having income less than 20,000, Households having no car, Male having age less than 30 years
Model-4	Mix Density Index	Households having income less than 20,000, Household size less than 6, Male having age less than 30 years, Number of Employed residents
Model-5	Accessibility Index to Population	Households having income less than 20,000, Number of Rented Houses, Male having age less than 30 years, Number of Employed residents, Household size less than 6
Model-6	Accessibility Index to Employment	Households having income less than 20,000, Number of Rented Houses, Male having age less than 30 years, Household having no car

In model-1, Entropy Index as urban form variable has been considered whereas for socioeconomic variables: households having transport expense less than 5,000, household having no car and female residents having age less than 30 years were considered. In model-2, net population density as urban form variable has been considered whereas for socioeconomic variables: households having income less than 20000, household size less than 6, male having age less than 30 years. In model-3, net employment density as urban form variable has been taken whereas for socioeconomic variables: households having income less than 20,000, households having no car, male having age less than 30 years were used. In model-4, mix density index as urban form variable whereas socioeconomic variables: households having income less than 20,000, household size less than 6, male having age less than 30 years, number of employed residents were taken. In model-5, accessibility index to population as urban form variable has been considered whereas for socioeconomic variables: households having income less than 20,000, number of rented houses, male having age less than 30 years, number of employed residents, household size less than 6 were considered. In model-6, accessibility index to employment as urban form variable whereas socioeconomic variables: households having income less than 20,000, number of rented houses, male having age less than 30 years, household having no car were used. One urban form variable has been considered in each model whereas, more multiple socioeconomic variables have been considered in one model.

3.3.6 Model Validation

For Model Validation, one union council from each Town was selected and Questionnaire survey was carried out. Union councils selected for questionnaire survey are described in following Table 3-14:

Table 3-14: Selected Union Council of Each Town

Sr. No.	Union Council	Town
1.	Shahdara	Ravi Town
2.	Bilal Ganj	Data Gunj Baksh Town
3.	Bhaqwalpura	Shalimar Town
4.	GarhiShahu	Gulberg Town
5.	Gajjumatta	Nishtar Town
6.	Daroghawala	Wagha Town
7.	Sabzazar	Allama Iqbal Town
8.	Shah Kamal	Samnabad Town
9.	Taj Pura	Aziz Bhatti Town
10.	Gulghan Colony	Cantonment

4 RESULTS AND DISCUSSION

4.1 INVESTIGATION OF URBAN FORM OF LAHORE AT TOWN LEVEL

To investigate the urban form on Town level, urban form variables mentioned in previous chapter are computed.

4.1.1 Population Density

Population density was computed for all towns of Lahore. Shalamar Town had the highest population density whereas Nishtar Town had the lowest value in Lahore. The potential reason may the existence of high proportion of agriculture area in this Town. Whereas Data GanjBaksh Town, Ravi Town and Samnabad Town had higher values of Population density. Town wise population density is mentioned in Table 4-1.

Table 4-1: Town wise Population Density

Sr. No.	Town Name	Net Population Density
1	Samnabad Town	414.55
2	Nishter Town	79.46
3	Iqbal Town	69.73
4	Gulberg Town	218.71
5	Data GunjBaksh Town	442.41
6	Aziz Bhatti Town	257.06
7	Wagah Town	126.32
8	Shalamar Town	594.15
9	Ravi Town	555.17
10	Cantonment	100.94

4.1.2 Employment Density

Employment density was computed and its map was generated. Employment opportunities found the highest for the Data Ganj Baksh and Shalamar Town due to

existence of business hub. Likewise, population density, employment density was also lowest in Nishtar Town. Ravi Town also fall under the higher employment density category. Employment density of each town is mentioned in Table 4-2.

Table 4-2: Town wise Employment Density

Sr. No.	Town Name	Employment Density
1	Samnabad Town	67.23
2	Nishter Town	12.91
3	Iqbal Town	18.31
4	Gulberg Town	79.27
5	Data Gunj Baksh Town	181.02
6	Aziz Bhatti Town	31.73
7	Wagah Town	21.13
8	Shalamar Town	79.04
9	Ravi Town	148.41
10	Cantonment	20.69

4.1.3 Mix Density Index

Mix Density Index computed on the basis of population and employment density. Likewise, population and employment densities, mix density index also found highest for Data Ganj Baksh Town whereas Nishtar Town had the lowest value of this index. Town wise detail is summarized in Table 4-3.

Table 4-3: Town wise Mix Density Index

Sr. No.	Town Name	Mix Density Index
1	Samnabad Town	57.85
2	Nishter Town	11.11
3	Iqbal Town	14.50
4	Gulberg Town	58.18
5	Data Gunj Baksh Town	128.46
6	Aziz Bhatti Town	28.24
7	Wagah Town	18.10
8	Shalamar Town	69.76
9	Ravi Town	117.11
10	Cantonment	17.17

4.1.4 Entropy Index

Higher value of entropy index shows the heterogeneity of land uses in definite proportion. Towns including Shalamar, Data Gunj Baksh etc had entropy index value closer to 1 and contrary to these Wagah Town had index value on lower side which showed the existence of limited type of land use in high proportion. Entropy index of each town is mentioned in Table 4-4.

Table 4-4: Town wise Entropy Index

Sr. No.	Town Name	Entropy Index
1	Samnabad Town	0.666
2	Nishter Town	0.227
3	Iqbal Town	0.382
4	Gulberg Town	0.608
5	Data Gunj Baksh Town	0.668
6	Aziz Bhatti Town	0.391
7	Wagah Town	0.145
8	Shalamar Town	0.603
9	Ravi Town	0.553
10	Cantonment	0.587

4.1.5 Accessibility Index to Population

Towns which had high population and lower travel time with other towns eventually had higher value of this index. Data Ganj Baksh Town had the highest value of this index which showed that this town is highly approachable from other towns. Iqbal Town had the lowest accessibility index. Accessibility index to population of each town is mentioned in Table 4-5.

Table 4-5: Town wise Accessibility Index to Population

Sr. No.	Town Name	Accessibility Index(A.I) to Population
1	Samnabad Town	62,693,978
2	Nishter Town	10,216,992
3	Iqbal Town	6,019,015
4	Gulberg Town	64,132,621
5	Data Gunj Baksh Town	84,886,553
6	Aziz Bhatti Town	11,298,943
7	Wagah Town	13,061,095
8	Shalamar Town	46,058,655
9	Ravi Town	62,976,646
10	Cantonment	31,114,407

4.1.6 Accessibility Index to Employment

Same as A.I (pop), higher opportunity to employment increases the A.I (emp). Likewise, accessibility index to population, this index had the highest value in Data GanjBaksh Town and lowest in Iqbal Town. Following Table 4-6 summarized the town wise distribution. Higher travel time also leads towards lower A.I(emp).

Table 4-6: Town wise Accessibility Index to Employment

Sr. No.	Town Name	Accessibility Index(A.I) to Employment
1	Samnabad Town	17,203,918
2	Nishter Town	2,786,625
3	Iqbal Town	1,643,318
4	Gulberg Town	17,596,076
5	Data Gunj Baksh Town	23,904,112
6	Aziz Bhatti Town	3,094,499
7	Wagah Town	3,219,103
8	Shalamar Town	12,859,856
9	Ravi Town	17,188,742
10	Cantonment	8,593,186

Population density observed higher in Shalimar Town, Ravi Town, Samanabad Town and Data Ganj Baksh Towns which fall in the Central part of the city and people prefer to live near commercial hubs therefore population density found more near the city center and as we go away from the center, population density becomes lower gradually in middle and suburb parts. Employment density was also observed higher in towns where population density found higher. The potential reason might be existence of business center in and around these towns. Higher employment opportunity found more in these towns due to existence of main business hub. Entropy index found higher in Ravi Town, Samanabad Town, Shalimar Town, Data Ganj Baksh Town and Gulberg Town. Each type of land use exists in these towns in definite proportion. Wagah Town and Nishtar Town had lesser E.I value having existence of large proportion of agriculture area in these town.

MDI found higher in Shalimar Town, Ravi Town, and Cantonment which showed higher balance of employment and population. With increase in distance from city center, MDI gradually decreased. Lower value of MDI leads to longer commuting distances, a characteristic of non-contiguous urban form (Kockelman, 1997; Wang and Chai, 2009).

A.I(Pop) found higher in Data Ganj Baksh Town Ravi Town, Shalimar Town, Gulberg Town. These towns had more population and lower travel time with other towns therefore found more accessible from other towns. A.I (emp) found higher in towns where A.I (Pop) found higher due to the lower travel time. Road network density in higher accessible areas found higher as compare to lower accessible area.

Maps of all urban form variables on Town level are attached from Figure: 4-1 to 4-6.

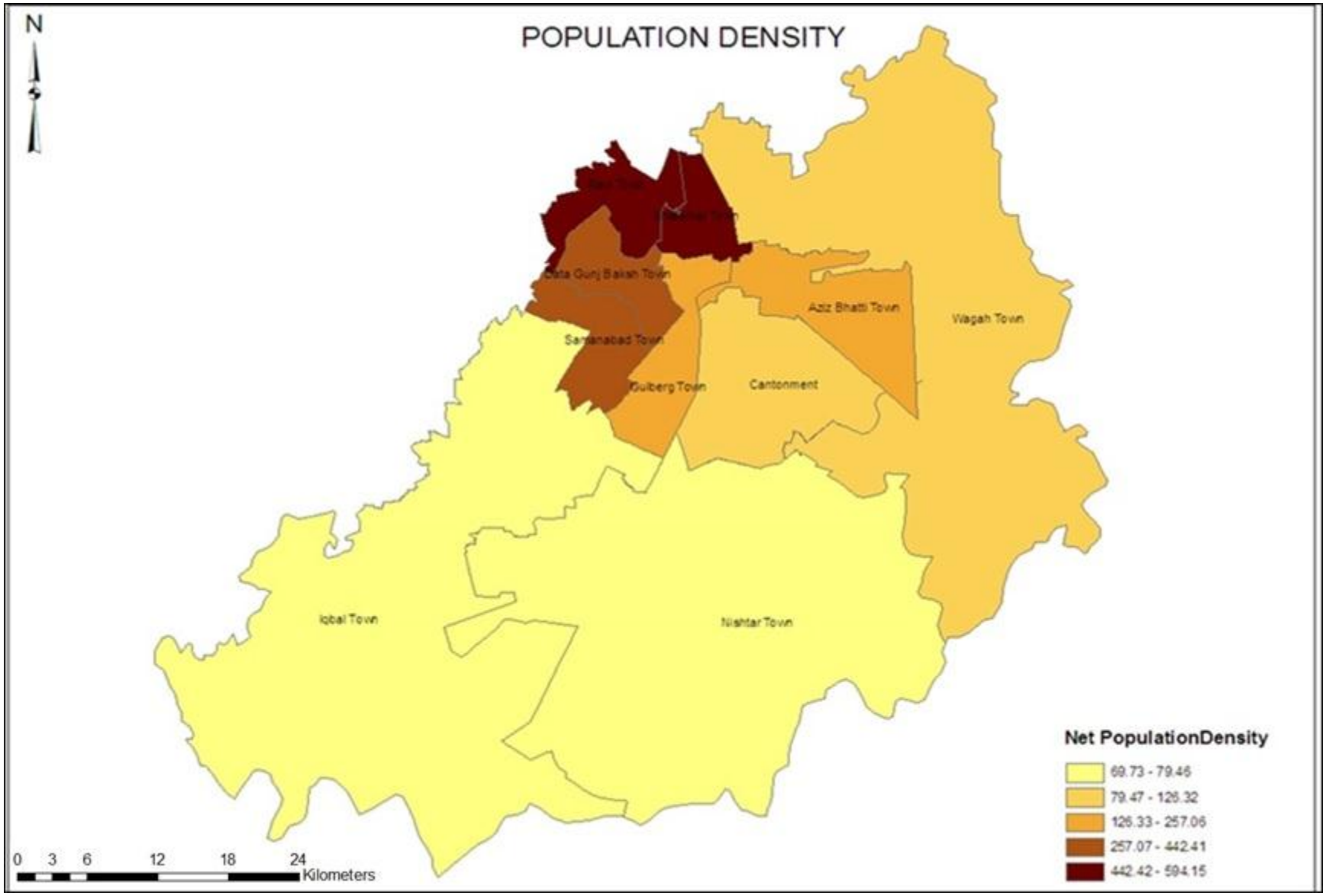

Figure 4-1: Population Density Map of Lahore at Town level

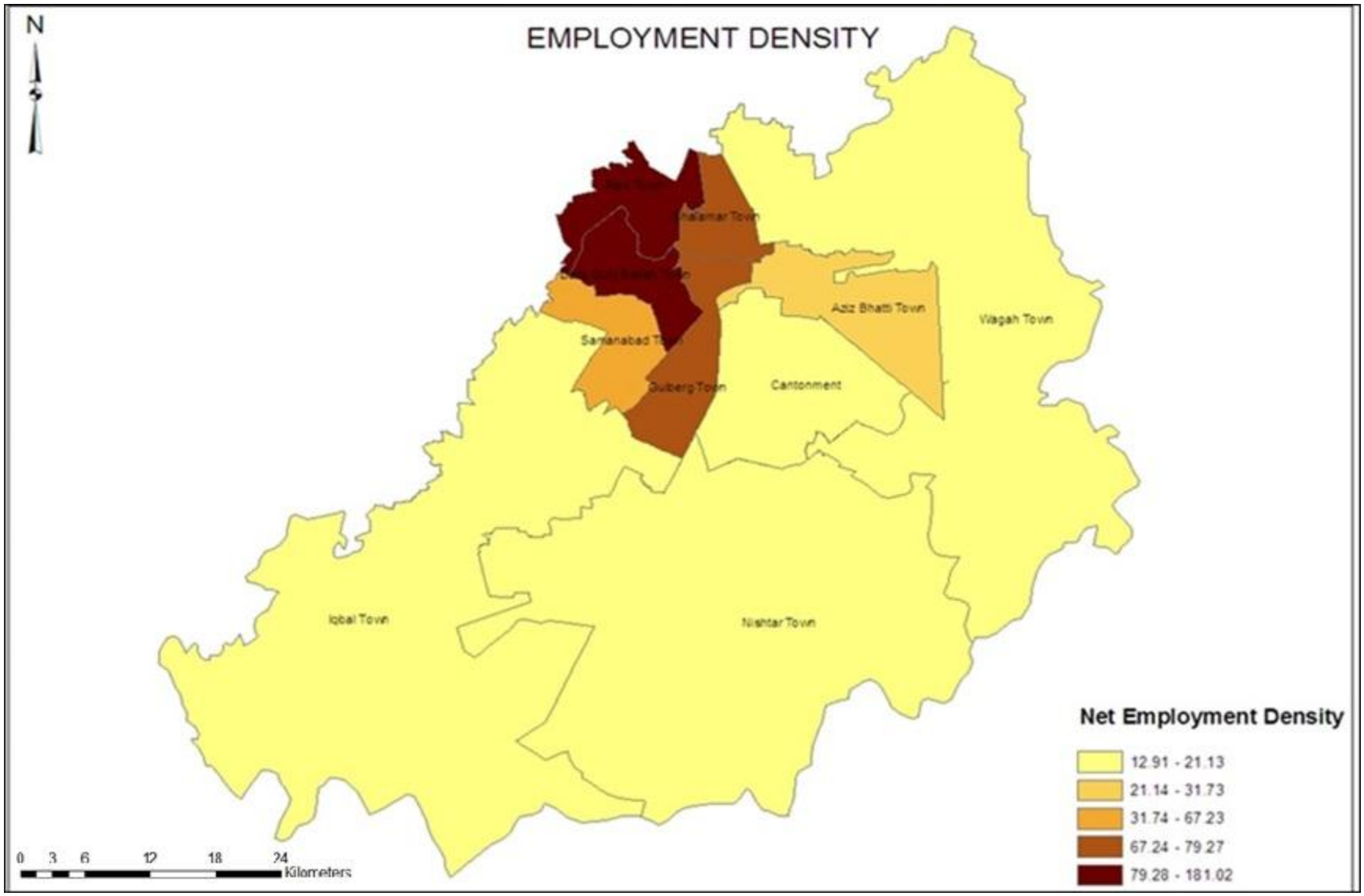

Figure 4-2: Employment Density Map of Lahore at Town level

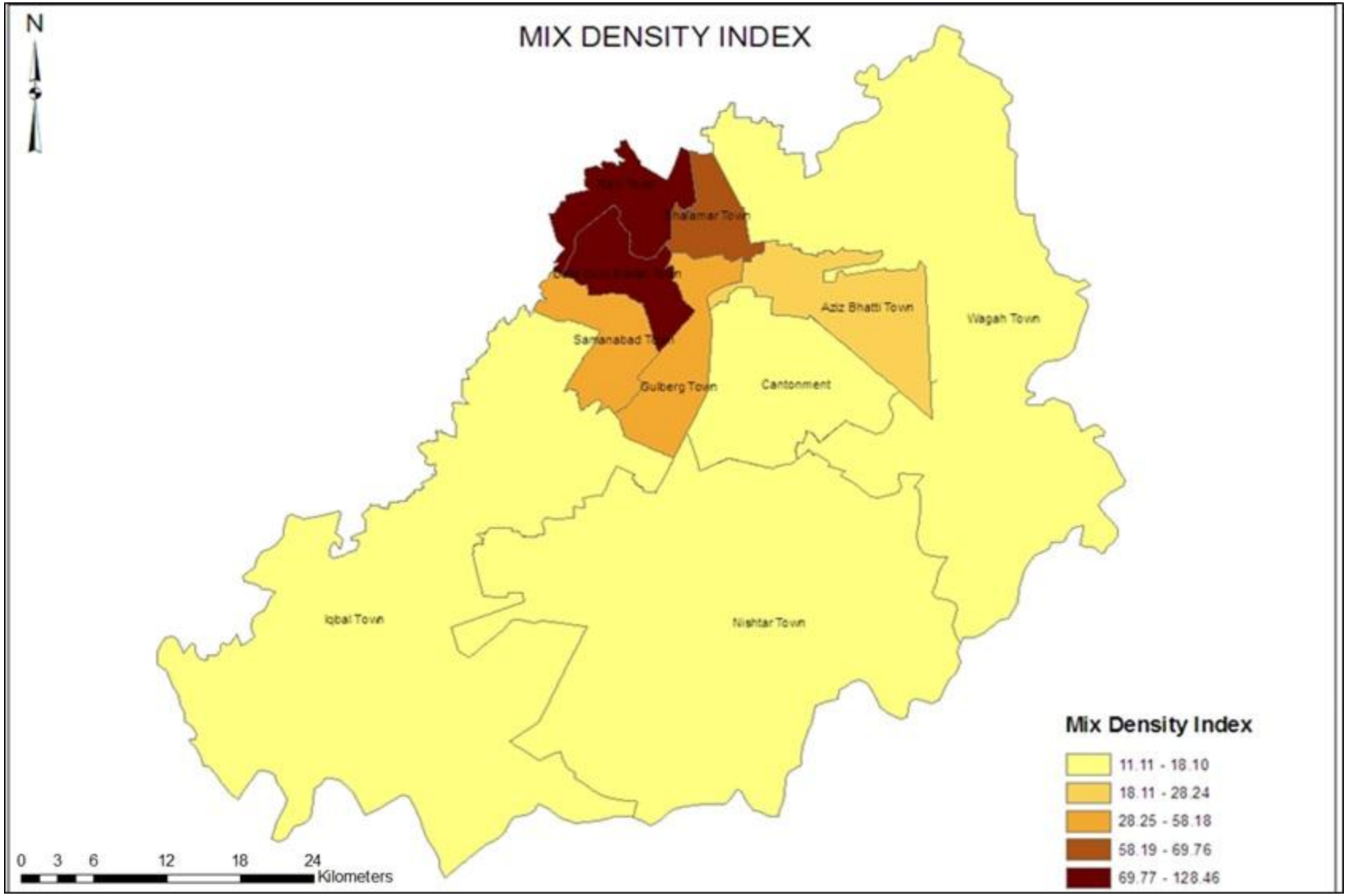

Figure 4-3: Mix Density Index Map of Lahore at Town level

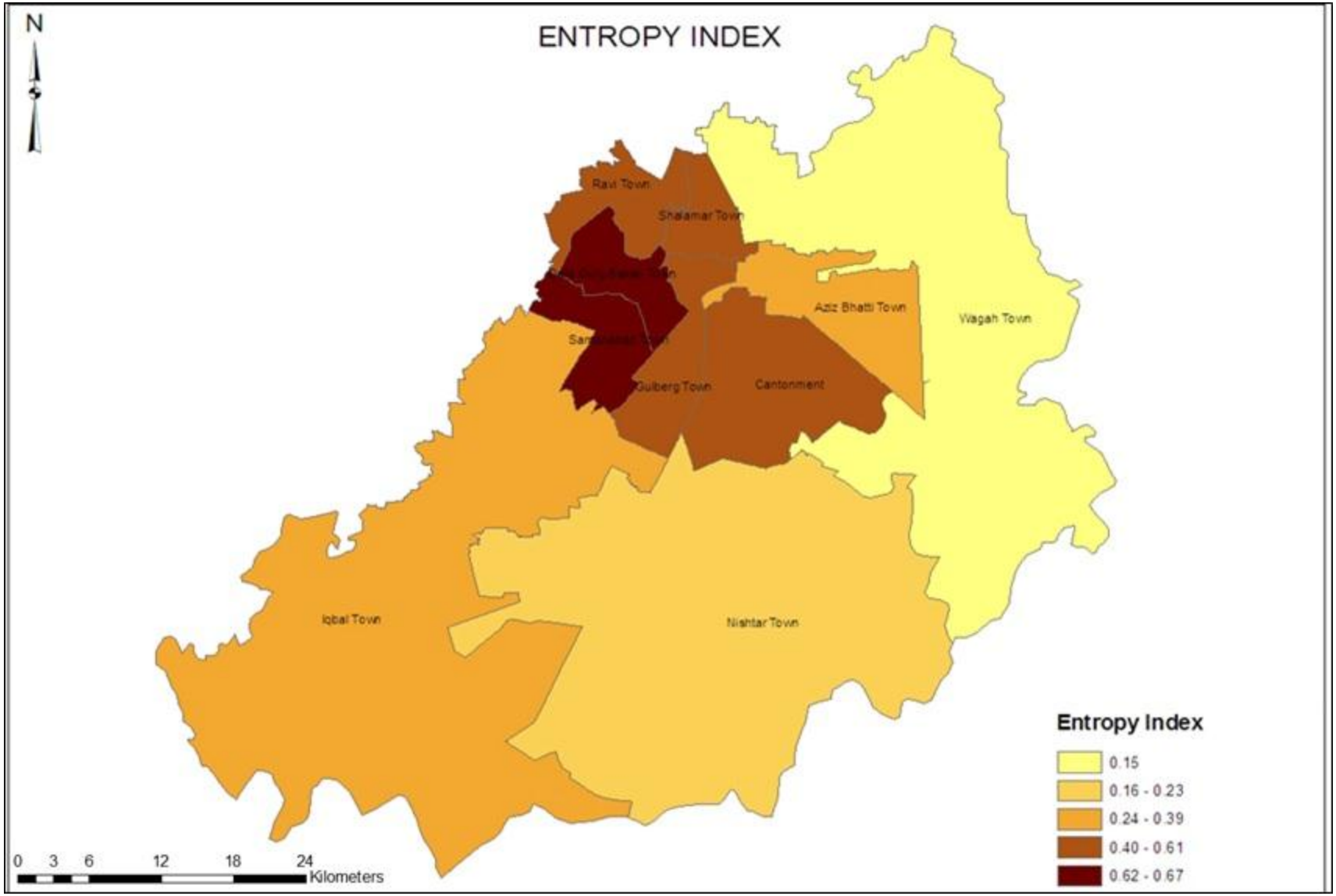

Figure 4-4: Entropy Index Map of Lahore at Town level

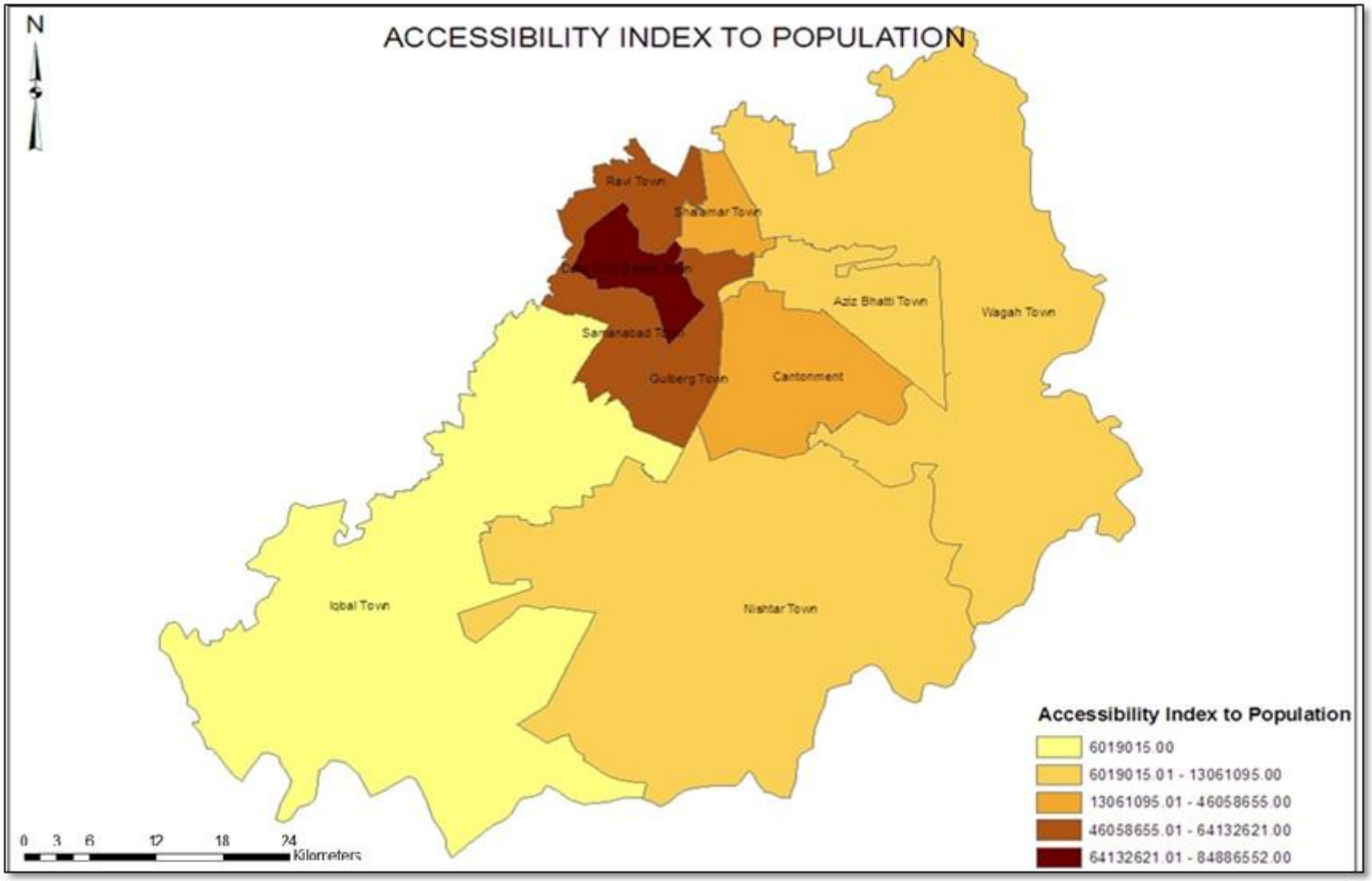

Figure 4-5: Accessibility Index to Population Map of Lahore at Town level

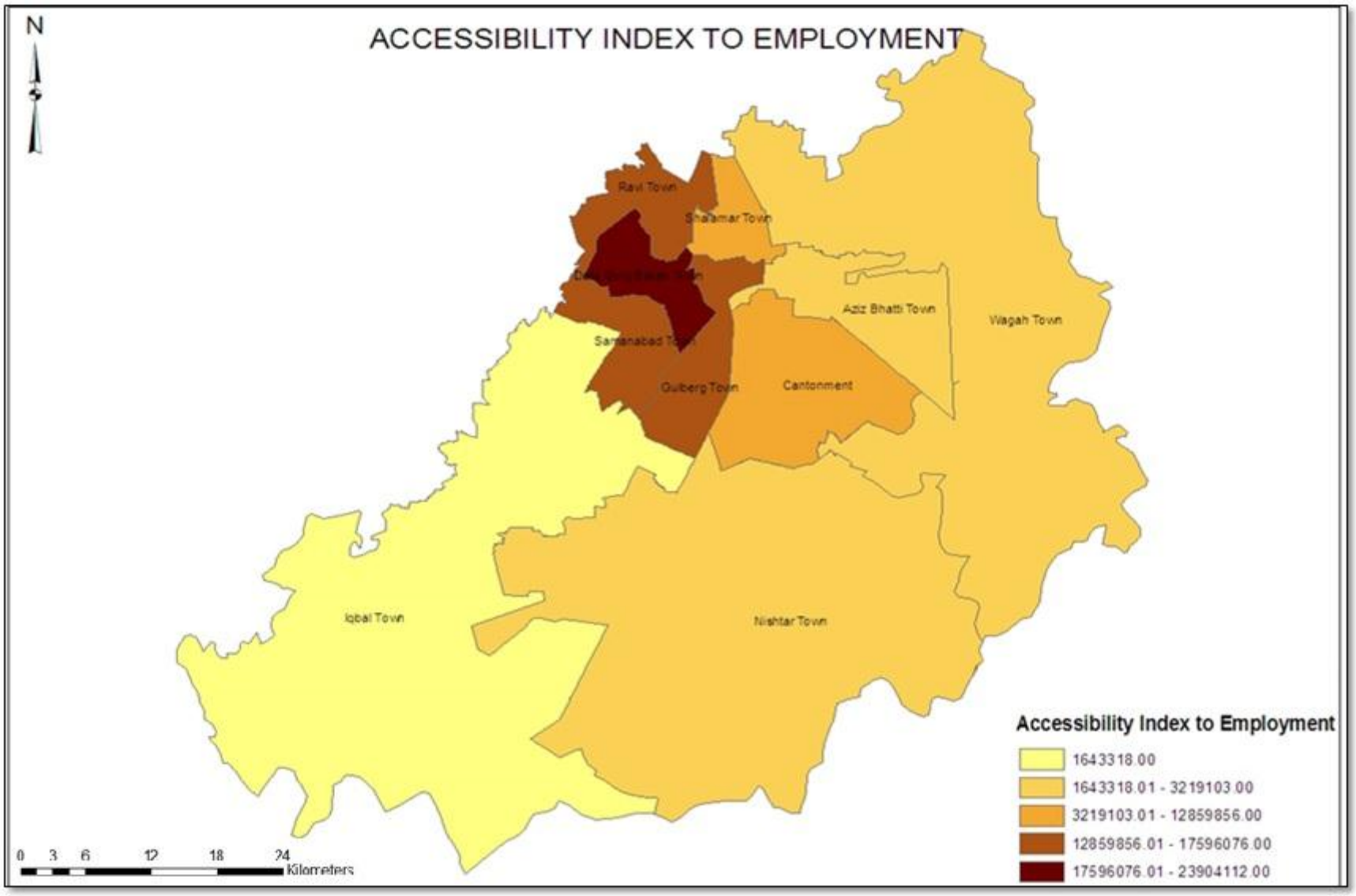

Figure 4-6: Accessibility Index to Employment Map of Lahore at Town level

Salient features including maximum, minimum, average and Moran's I value of each urban form variable is mentioned in Table 4-7.

By keeping in the all computed urban form variables it can be seen that higher intensity of each variable found within the centre of the city and gradually decrease as move towards the south and eastern part of city. Same trend exist for all variables which concludes that Lahore had monocentric type of urban form when investigated on Town level. Investigation of urban form on Town level computed coarser nature of results which need to be computed on lower level i.e: Union council or Census level.

Investigation of urban form at Town level is courser in nature. It needs to be investigated on some basic level therefore the investigation was done on Union council level.

Table 4-7: Salient Features of Urban Form Variables at Town Level

Sr. No	Urban form Variable	Maximum	Minimum	Average	Moran's I Value
1	Population Density (Persons/hector)	594.15	69.73	285.85	0.28
2	Employment Density (Persons/hector)	181.02	12.91	65.97	0.24
3	Mix Density Index	128.46	11.11	52.05	0.29
4	Entropy Index	0.67	0.15	0.48	0.26
5	Accessibility Index to Population	84,886,552	6,019,015	39,245,890	0.34
6	Accessibility Index to Employment	23,904,112	1,643,318	10,808,944	0.34

4.2 INVESTIGATION OF URBAN FORM OF LAHORE AT UNION COUNCIL LEVEL

After computation of urban form variables on Town level, all urban form variables were again computed to investigate the urban form on union council level.

By moving from investigation of Urban form on Town level, the same salient features including Maximum, Minimum, Average and Moran's I value of all urban form variables on union council level are mentioned in Table: 4-8.

4.2.1 Population Density

Population density was computed on union council level for the study area and found that the union councils having higher values of population density exist spatially scattered. Higher proportion of union councils exist within the city center whereas only few exist along the canal. Some union councils also exist away from canal. In outer part of Lahore union councils had lower values of population density less than 30 persons per acre.

The reason of high population density within city centre is existence of major markets. People having employment in these major markets prefer to live near their employment area to minimize the travelling cost. But the trend to live in the suburb areas is also increasing due to poor infrastructure including water, sewer, drainage, traffic etc. in the city.

4.2.2 Employment Density

Distribution of employment density on union council level was calculated and shown in Figure: 4.8. Employment density had also the same distribution as observed for population density in the city centre. Existence of major markets which are source for the whole province not only for city. These areas have the retail market for clothes, grocery, food items, shoes etc. Also including fruit and vegetable market, timber market, market for auto spare parts and existence of Larri Adda in the vicinity. Religious sentiments also exist for this area by the people of whole province. High proportion of employment opportunities associated with the city centre union councils but exist spatially scattered. Union councils exist away from the city centre, had reasonable value of employment density. All offices, shopping

markets, shops etc. exist in different parts of the city which generates the employment. Union councils exist in the outskirts of the city also had equitable employment density.

4.2.3 Mix Density Index

MDI was calculated by using population and employment density on union council level. Higher values of union council associated with city centre except few only. Only one union council which had the higher value exist in eastern part of city. Existence of definite proportion of population and employment within the union council contribute towards the higher value of MDI. As we go away from city center, this variable decreases in all directions. In the outskirts, a few union councils had reasonable value of Mix density Index which showed people live in the outskirts of city prefer to have employment in the same area. Existence of factories in the suburb also contribute towards higher MDI.

4.2.4 Entropy Index

Entropy index is the measure of mixed land use within an area. This index had the higher values within the city centre and decreases as we go away from the centre. E.I had lower values in the eastern part of city whereas on western and Sothern part of city E.I had definite value. Existence of open area and agriculture area in eastern part of Lahore contribute towards lower E.I whereas development of new societies and allied infrastructure encourage towards higher index.

4.2.5 Accessibility Index to Population

Accessibility Index to population after computing on Town level further calculated on union council level. This index shows the ease of population to approach a particular zone as destination of trip. Higher values of this index associated with the centre core part of city and decreases as get away from the centre. Union councils exist from city centre to canal had higher values of this accessibility index to population. Union councils exist away from canal towards southern side and on eastern and western part of city had comparatively lower values. Comparative to other urban form variables this index had the gradually decreasing type of pattern in all directions from the city center.

4.2.6 Accessibility Index to Employment

The index was computed on union council level after town level. This index is based upon the employment and travel time. Only few union council exist in or around the city center and one union council exist away from canal had the higher values of this index. Reason of this higher value may the higher employment opportunities in these union councils. This index had gradual decrease in all directions from the center. Some union councils exist spatially scattered had the lower values. Some union councils also exist in the suburbs. Eastern suburb of the city had not the lowest value of this index.

Salient features of each urban form variable at union council level are summarized in Table 4-8.

Table 4-8: Salient Features of Urban Form Variables at Union Council Level

Sr. No	Urban form Variable	Maximum	Minimum	Average	Moran's I Value
1	Population Density (Persons/hector)	3,563.94	1.28	444.782	0.21
2	Employment Density (Persons/hector)	1,057.55	1.68	96.67	0.23
3	Mix Density Index	1,351,684.11	8.06	72,699.91	0.13
4	Entropy Index	0.9	0.01	0.5	0.21
5	Accessibility Index to Population	173,385.45	137.66	42,065	0.59
6	Accessibility Index to Employment	124,924.11	160.39	10,311	0.28

Maps of each urban form variable was generated and attached from Figure 4-7 to 4-12.

By investigating all urban form variables, the urban form of Lahore is bridging towards sprawling. Some Canadian cities had also similar type of urban form as Lahore had (Axisia, 2009).

4.3 COMPARATIVE ASSESSMENT OF PUBLIC TRANSPORT USAGE

4.3.1 Public Transport Usage at Town level

Public Transport Usage of each town was extracted from Household interview survey conducted by JICA in year 2011. Map for distribution of public transport usage town wise in Lahore was developed and placed in Figure: 4-13. Data Ganj Baksh and Gulberg Town has the highest public transport usage in comparison to all other towns of Lahore. Whereas inhabitants of Wagah, Aziz Bhatti and Nishter Town have the lowest tendency to use public transport. Following Table 4-9 summarizes the town wise public transport usage.

Table 4-9: Town wise distribution of Public Transport Users

Sr. No.	Town Name	Public Transport Users
1	Samnabad Town	326,650
2	Nishter Town	186,891
3	Iqbal Town	323,826
4	Gulberg Town	439,407
5	Data Gunj Baksh Town	419,500
6	Aziz Bhatti Town	205,335
7	Wagah Town	152,548
8	Shalamar Town	252,564
9	Ravi Town	295,198
10	Cantonment	280,752

4.3.2 Public Transport Usage at Union Council level

After computing public transport usage and its map at town level, the same map is developed at union council level. It is found that this variable is spatially scatter at union council level. Map of public transport usage at union council level is placed in Figure: 4-14.

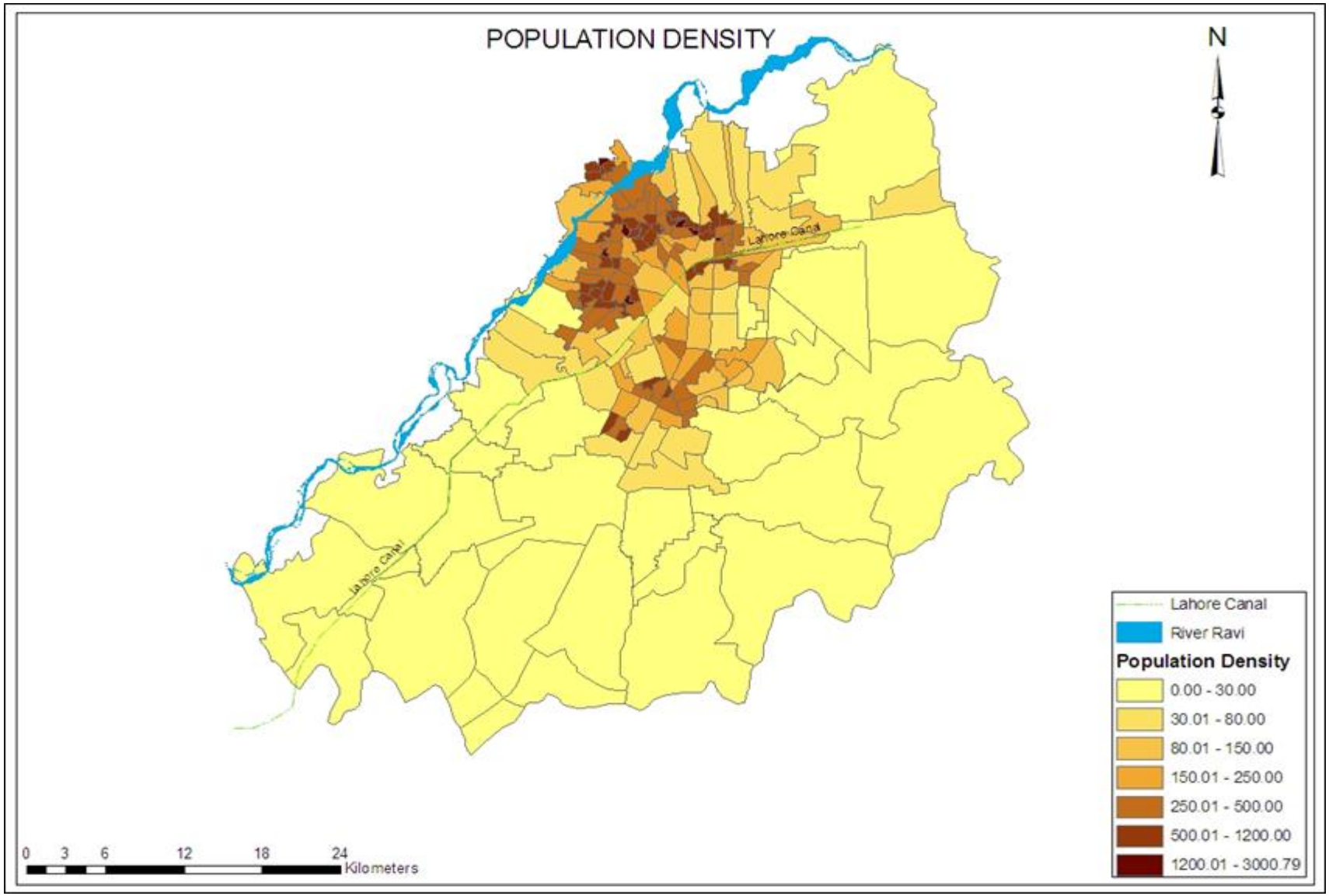

Figure 4-7: Population Density of Lahore at Union Council Level

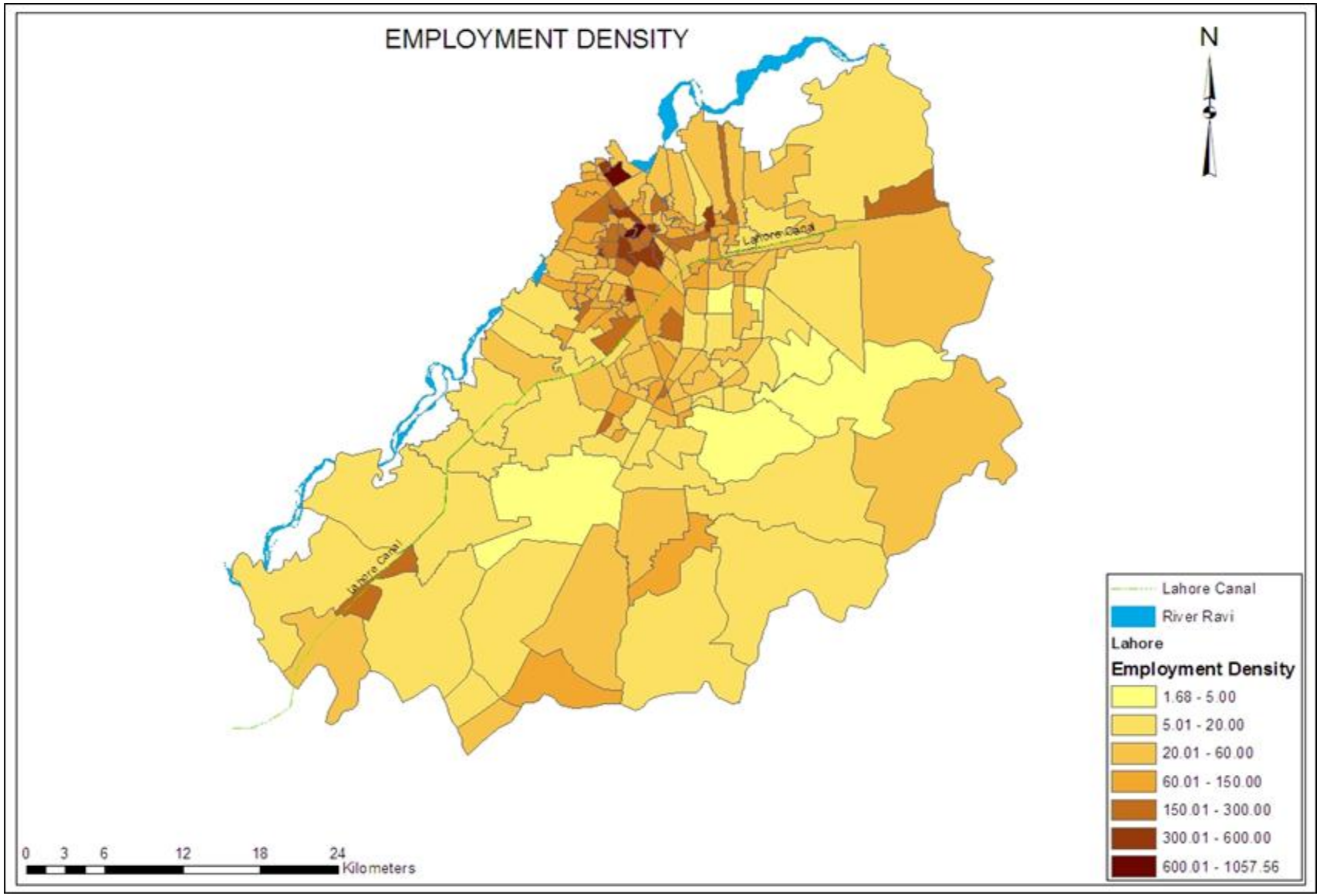

Figure 4-8: Employment Density of Lahore at Union Council Level

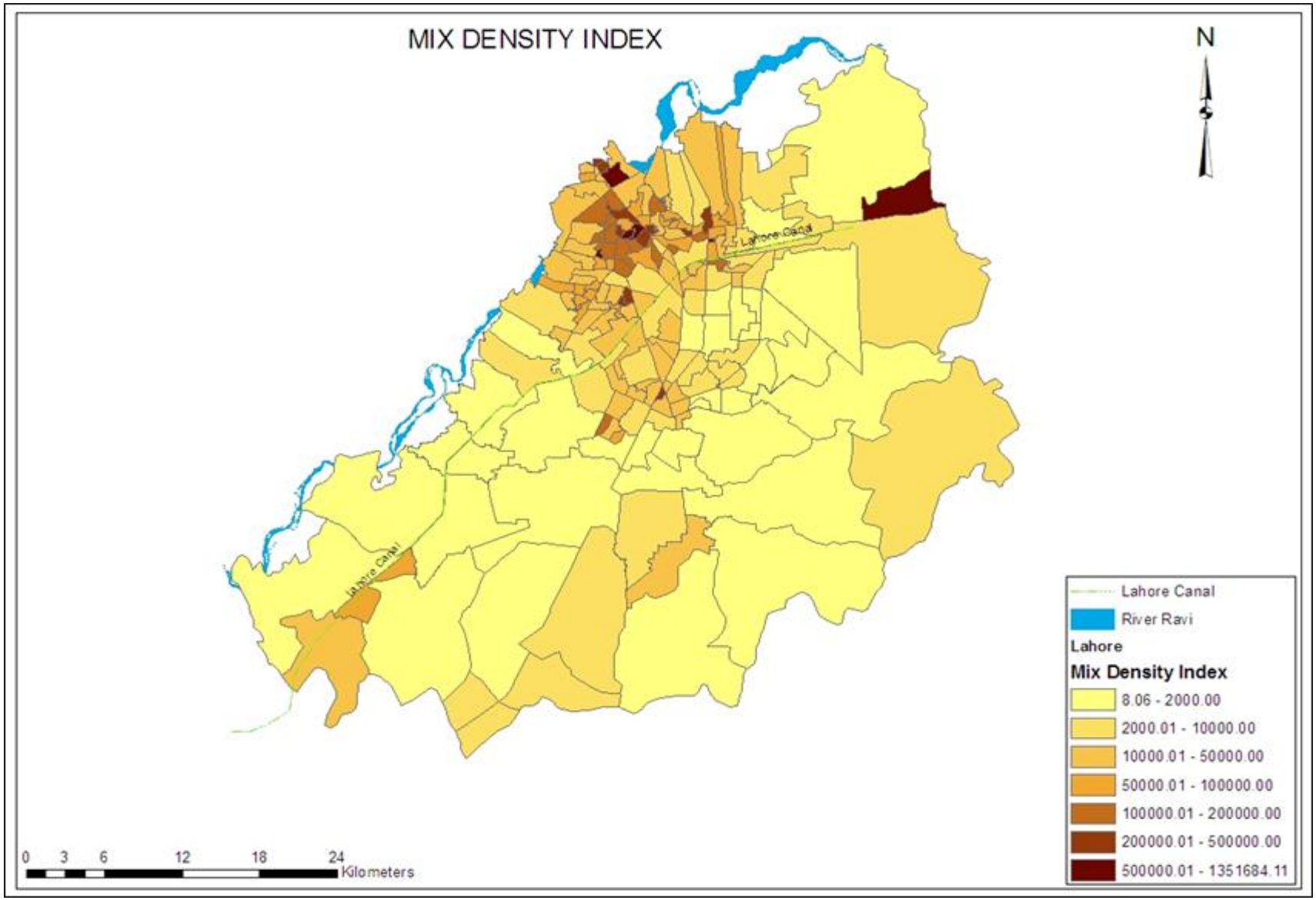

Figure 4-9: Mix Density Index of Lahore at Union Council Level

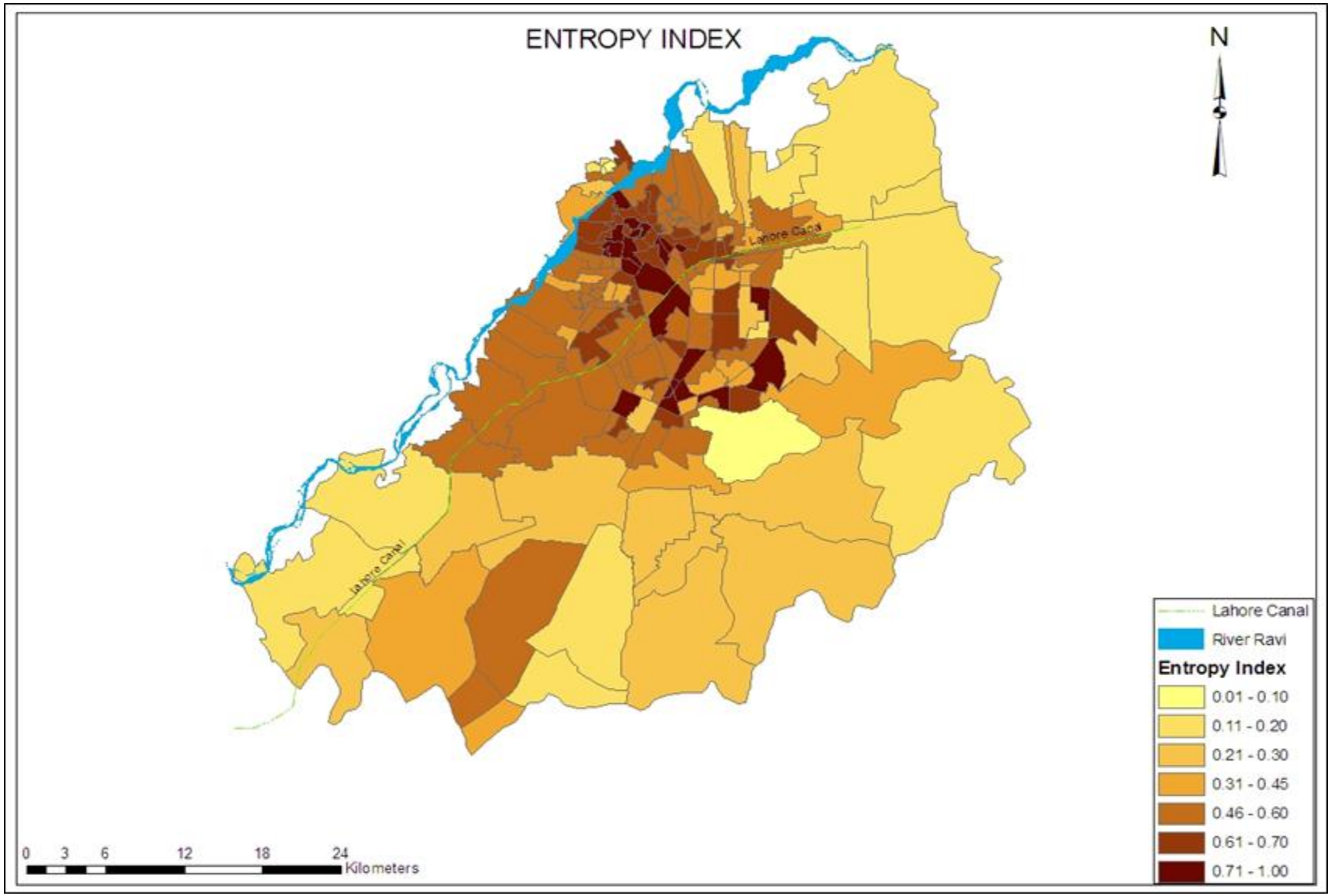

Figure 4-10: Entropy Index of Lahore at Union Council Level

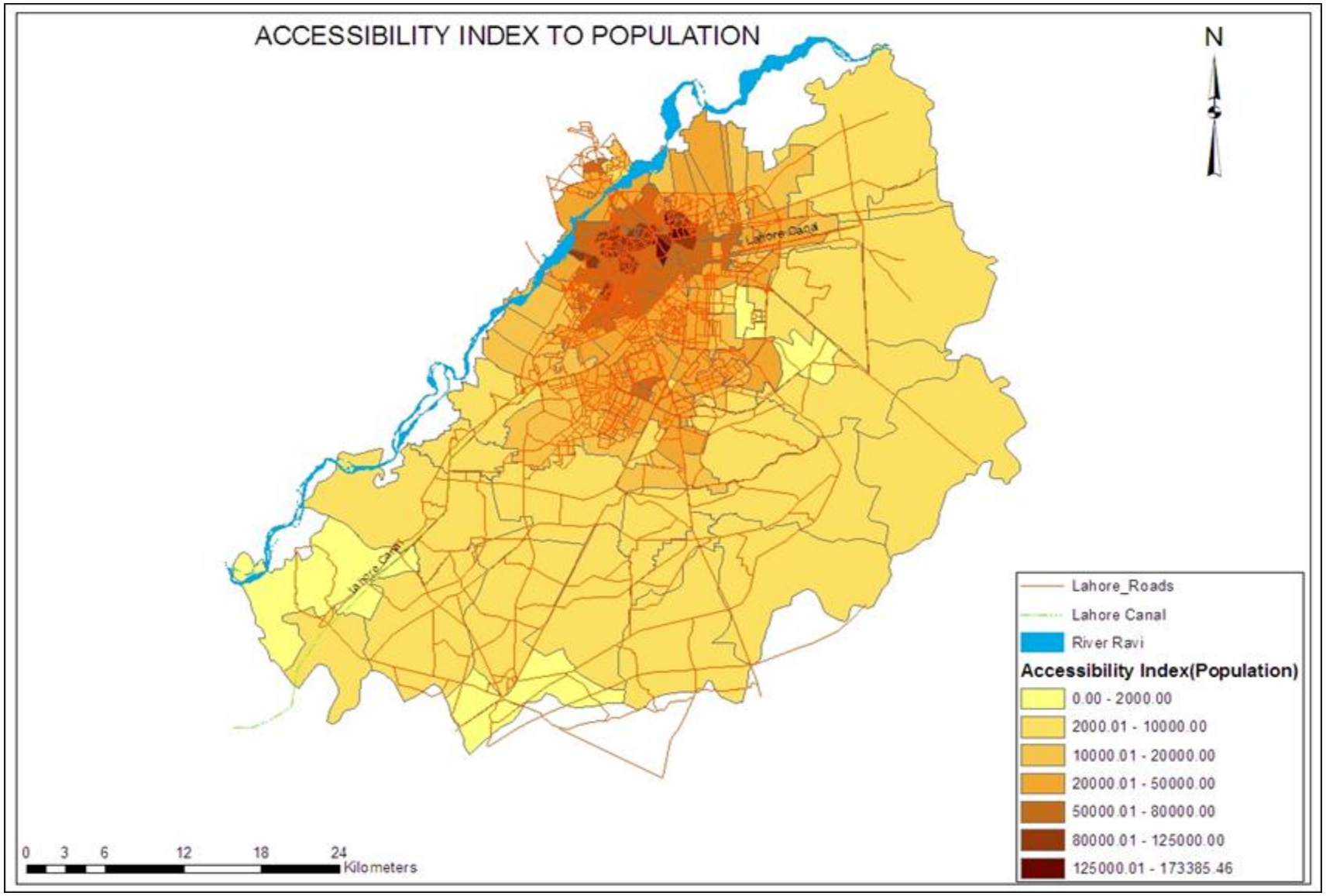

Figure 4-11: Accessibility Index to Population of Lahore at Union Council Level

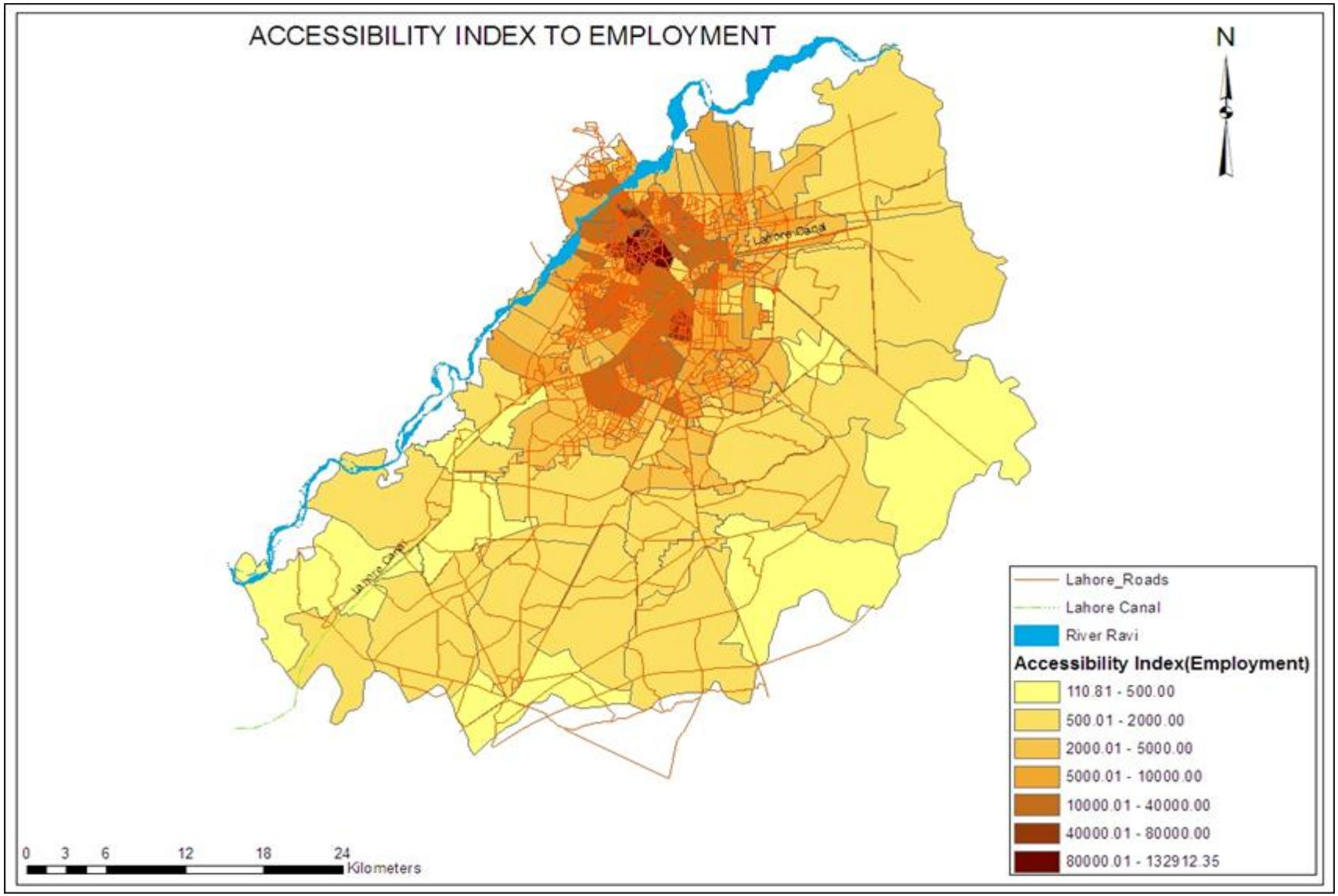

Figure 4-12: Accessibility Index to Employment of Lahore at Union Council Level

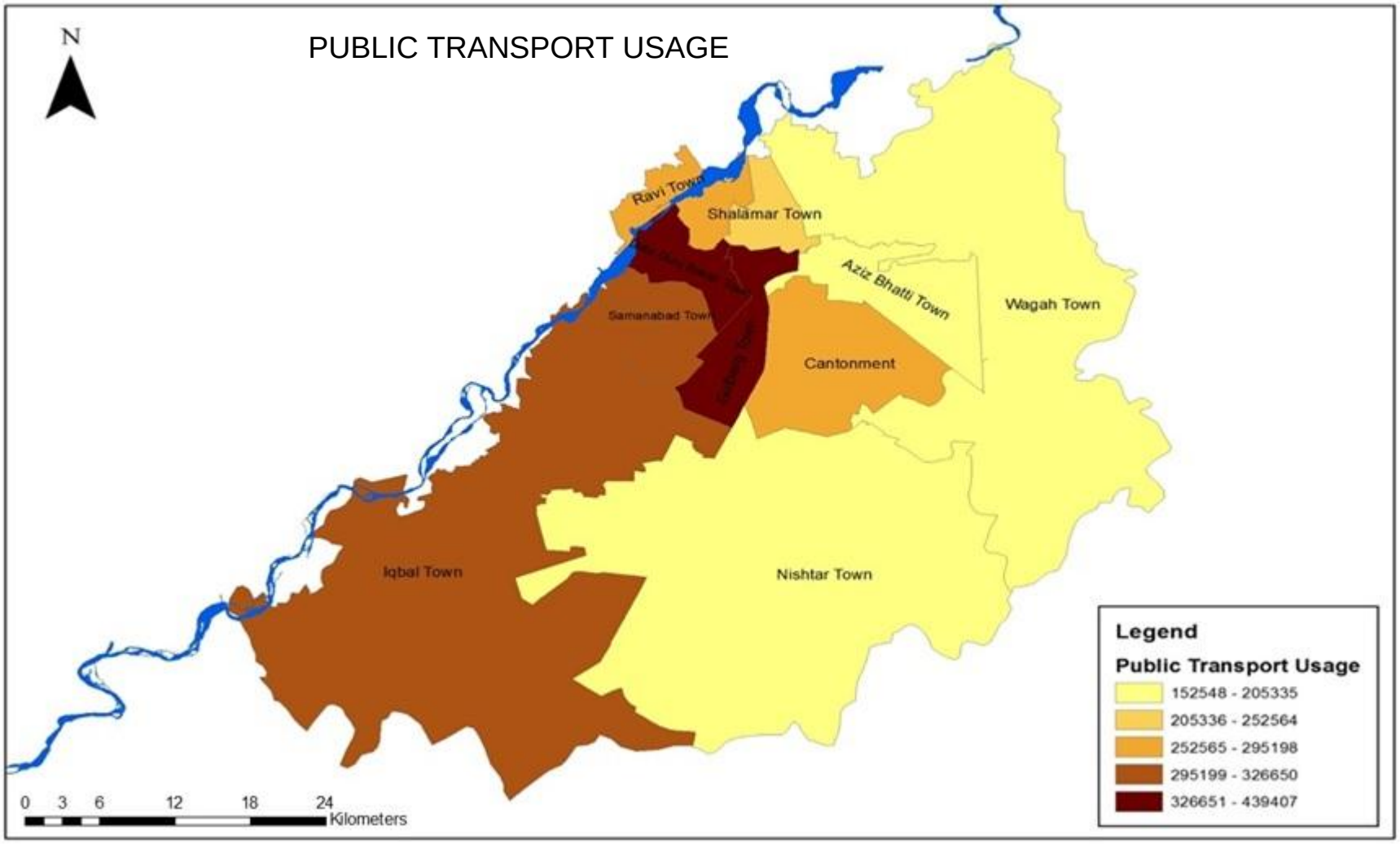

Figure 4-13: Public Transport Usage of Lahore at Town Level

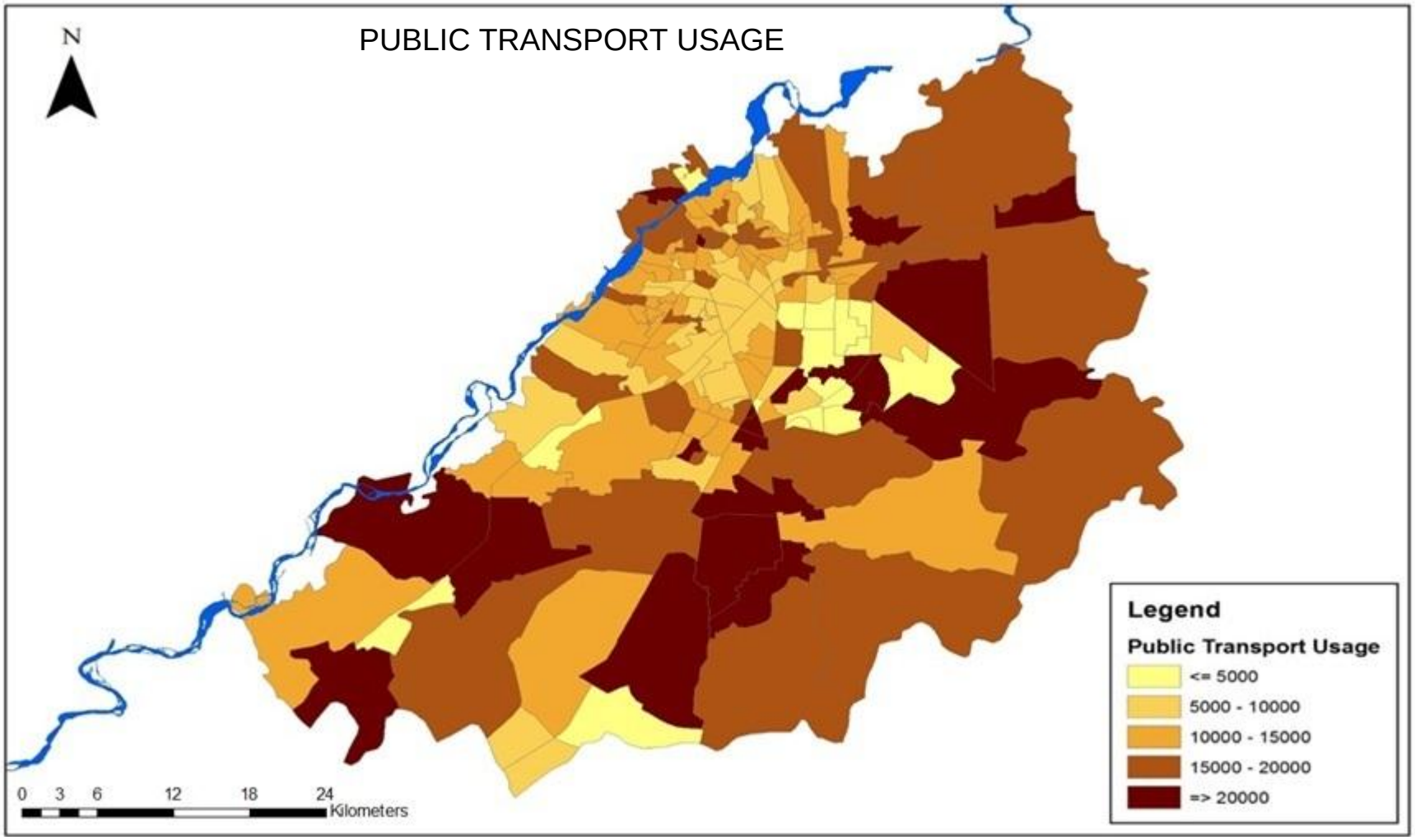

Figure 4-14: Public Transport Usage of Lahore at Union Council Level

4.4 MODEL DEVELOPMENT BETWEEN URBAN FORM AND PUBLIC TRANSPORT USAGE

Geo-Da spatial analysis software was used to develop the relationship between urban form and Public Transport usage in Lahore by using Ordinary Least Square (OLS) and Simultaneous Auto Regression (SAR) methods. One urban form along with different socio-economic variables were used to develop the model. Results from Ordinary Least square regression and Simultaneous Auto regression are discussed below.

Six different types of models were developed by considering one urban form and different social variables with an independent variable: public transport use. In model-1 adjusted R^2 value computed as 0.67 which showed that the model fit to explain the relationship. Entropy Index and all selected socio-economic variables: household transport expense, females having age less than 30 years and household having no car in this particular model found highly significant. The sign of urban form variable found opposite as expected. It showed that if entropy index of a union council increases the public transport usage will decrease. In Model-2, adjusted R^2 value was 0.67. The population density was not found statistically significant along with household income variable but the household size and males having age less than 30 years were found statistically significant in this model. Employment density, household income, households having no car, employed residents and males having less than 30 years were considered as dependent variable and not found significant as the adjusted R^2 value was 0.67. Households having no car and males having age less than 30 years were found significant and employment density was found un-significant for Lahore city at union council level.

By moving towards Model: 4, the adjusted R^2 value computed as 0.67. Mix density Index, household having income less than 20,000, household size less than 6, employed Residents and males having age less than 30 years were considered for this model. Males having age less than 30 years and household size less than 6 were found significant in this model whereas other selected variables found insignificant which had probability more than 0.05. Adjusted R^2 found as 0.68 which showed the model is fit to explain the dependent variable. Accessibility Index to population, rented houses, household income and employed residents were insignificant whereas household size less than 6 and males have age less than 30 years were found significant in this particular model. By considering the urban form variable of accessibility index to employment,

and social variables: rented houses, household income less than 20000, household having no car and males having age less than 30 years, adjusted R^2 was computed as 0.64 which considered as fit model. Accessibility index to employment along with rented houses and households having no car were found statistically significant variables in this model-6. Results of each model are shown in Table 4-11.

The same models which have been developed on Geoda software by Ordinary Least Square regression were also developed on Excel software. All models developed having R^2 and adjusted R^2 Value more than 0.5. In case of urban form variables, both variables entropy index and Accessibility index to employment found statistically significant same as in case of results generated through Geoda software. Households having size less than 6 is the only social variable which was not computed statically significant when models developed on Excel software. Households having income less than 20,000 is the social variable which computed statistically significant, contradictory to the previously developed regression of Geoda software. Results of regression of all 6 models done on excel software is summarized in Table: 4-13.

Spatial Auto correlation for public transport usage was checked and found positive. Models by using Simultaneous Auto Regression were developed with the same parameters. The models developed for OLS were also generated on SAR. Spatial Lag Parameter found positive and highly significant having probability less than 0.05 which indicated the existence of spatial autocorrelation for public transport usage. R^2 value for all models were found improved on SAR. Results of each model has been summarized in following Table: 4-12.

Out of six urban form variables, two urban form variables: Entropy Index and Accessibility Index to Employment found statistically significant to explain the public transport use on OLS Regression. With spatial autocorrelation, employment density was also found significant for Lahore city at Union council level. Population density found statistically insignificant which was contradictory to Chen. *et al.,* 2008 who stated that population density impacts on transport use. Entropy Index was statistically significant which was not in line what Axisia found in 2009 but the inverse relation was same as Axisia found. Mix density index was also found statistically insignificant and negative which opposes the past research of Messenger and Ewing's (1996). Employment density was also found statistically significant with SAR. Employment density had negative impact on public transport usage in Lahore which means union councils with high

employment density had low public transport usage. Different past studies concluded both relations direct and indirect relation of employment density with public transport usage. Household size, household with no car, young people having age less than 30 years were socioeconomic variables which found statistically significant whereas the other selected socioeconomic variables found statistically insignificant to explain the public transport use in Lahore at union council level. Cervero in 2002 also concluded that public transport use is high in households which have no car. Spatial autocorrelation found statistically significant as in line with the study conducted by Axisia in 2006.

A comparison has been developed between the expected sign, computed sign after regression analysis and results based upon the other studies and are mentioned in following Table 4-10.

Table 4-10: Comparison of Variables

Variables	Expected Sign	Computed Sign	Result from other studies
Urban Form Variables			
Population Density	+	-	+
Employment Density	+	-	-
Mix Density Index	+	-	+
Entropy Index	+	-	-
Accessibility Index (Population)	-	-	+
Accessibility Index (Employment)	-	-	
Socio-economic Variables			
Rented houses	+	+	+
Households having income less than 20,000	+	-	-
Households having transport expense less than 5,000	+	-	
Household size less than 6	-	+	-
Employed Resident	+	+	
Males having age less than 30 years	+	+	+
Females having age less than 30 years	+	+	+
Households having no car	+	+	

Lahore being the developing city, has different urban and social dynamics in comparison to other developed cities where this study have already been done. Developed countries have well defined land use patterns, specific road and route classifications and definite laws to be obeyed by the residents. Whereas, the study area, Lahore has different urban and social conditions due to absence of well-defined laws and legislations for land use and other areas which impact on urban and social variables. However, a comparison was also done to show the difference between the results of statistical analysis done for Lahore in comparison to other cities of the world. Potential reason of this variation could be trend of residents towards mode choice which may be further explored in future researches.

Table 4-11: Results of Ordinary Least Square Regression

Description	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Constant	3857.469 (0.000)	1393.480 (0.088)	1374.137 (0.095)	1303.524 (0.112)	1408.742 (0.086)	1680.367 (0.047)
Population Density		-0.616 (0.249)				
Employment Density			-2.111 (0.306)			
Mix Density Index				-0.001 (0.439)		
Entropy Index	-6442.984 (0.000)					
Accessibility Index (Population)					-0.012 (0.117)	
Accessibility Index (Employment)						-0.041 (0.003)
Rented House					0.511 (0.183)	-0.769 (0.055)
Households having income less than 20,000		-0.198 (0.245)	-0.201 (0.246)	-0.191 (0.269)	-0.292 (0.125)	-0.463 (0.0200)
Households having Transport Expense less than 5000	-0.739 (0.006)					
Households having no car	2.191 (0.000)		1.970 (0.000)			1.982 (0.000)
Households size less than 6		1.979 (0.000)		1.979 (0.000)	1.954 (0.000)	
Employed Residents			0.013 (0.583)	0.004 (0.842)	0.009 (0.661)	
Males having age less than 30 years		0.273 (0.000)	0.261 (0.000)	0.259 (0.000)	0.269 (0.000)	0.073 (0.378)
Females having age less than 30 years	0.259 (0.011)					
R^2 Value	0.677	0.679	0.678	0.678	0.683	0.652

Table 4-12: Results of Spatial Auto Regression

Description	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Constant	699.376 (0.581)	-579.150 (0.618)	-1888.968 (0.075)	-720.739 (0.534)	-783.096 (0.501)	-1613.427 (0.137)
Spatial Lag Parameter	0.208 (0.002)	0.160 (0.025)	0.298 (0.000)	0.164 (0.022)	0.176 (0.014)	0.260 (0.000)
Population Density		-0.627 (0.226)				
Employment Density			-4.038 (0.048)			
Mix Density Index				-0.001 (0.355)		
Entropy Index	-5276.40 (0.00)					
Accessibility Index (Population)					-0.011 (0.144)	
Accessibility Index (Employment)						-0.036 (0.007)
Rented House					0.675 (0.069)	-0.446 (0.240)
Households having income less than 20,000		-0.112 (0.503)	-0.492 (0.004)	-0.107 (0.5288)	-0.238 (0.197)	-0.369 (0.049)
Households having Transport Expense less than 5,000	-0.543 (0.037)					
Households having no car	2.000 (0.000)		1.829 (0.000)			1.882 (0.000)
Households size less than 6		1.882 (0.000)		1.882 (0.000)	1.860 (0.000)	
Employed Residents			0.012 (0.605)	0.007 (0.720)	0.0123 (0.554)	
Males having age less than 30 years		0.270 (0.000)	0.048 (0.539)	0.255 (0.000)	0.253 (0.000)	0.052 (0.503)
Females having age less than 30 years	0.233 (0.016)					
R^2 Value	0.693	0.689	0.675	0.688	0.699	0.680

Table 4-13: Results of Regression on Excel software

Description	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Constant	4019.16 (0.000)	1484.40 (0.079)	558.34 (0.461)	1390.17 (0.101)	1509.48 (0.075)	606.79 (0.420)
Population Density		-0.62 (0.246)				
Employment Density			-2.24 (0.26)			
Mix Density Index				-0.001 (0.433)		
Entropy Index	-6497.41 (0.000)					
Accessibility Index (Population)					-0.012 (0.113)	
Accessibility Index (Employment)						-0.025 (0.065)
Rented House					0.513 (0.183)	-0.348 (0.341)
Households having income less than 20,000		1.97 (0.000)	1.48 (0.000)	1.97 (0.000)	-0.292 (0.125)	1.33 (0.000)
Households having Transport Expense less than 5000	-0.755 (0.005)					
Households having no car	2.19 (0.000)		0.001 (0.94)			0.87 (0.000)
Households size less than 6		-0.206 (0.229)		-0.200 (0.25)	-0.304 (0.115)	
Employed Residents			0.724 (0.001)	0.005 (0.812)	0.010 (0.630)	
Males having age less than 30 years		0.271 (0.000)	0.062 (0.413)	0.257 (0.000)	0.267 (0.000)	0.069 (0.363)
Females having age less than 30 years	0.255 (0.012)					
R^2 Value	0.67	0.670	0.689	0.669	0.674	0.690

4.5 MODEL VALIDATION

Questionnaire survey was conducted from each selected union council of town and encoded data sheets were developed for regression analysis. Only socio-economic variables has been taken for model validation process. Six different model same as used for model developments were developed to validate the results. Households having no income and households having no car are the only social variables having relatively better significance to explain the public transport usage.

5 CONCLUSION AND RECOMMEDATIONS

This thesis has explored the urban form of Lahore along with its relationship with public transport usage.

5.1 SUMMARY OF FINDINGS

Urban form is investigated by computing different urban form variables. All computed variables were analyzed at Town and Union council level. At Town level, urban form of Lahore found monocentric whereas at Union council it is bridging towards sprawl. This variation in results indicates that urban form depends upon the level of investigation.

The urban form and social variables are modeled with public transport usage for Lahore. The modeling begins with Ordinary Least Square regression and after that the same models are developed by using Simultaneous Auto Regression. Spatial autocorrelation is found statistically significant for public transport usage in Lahore which shows the influence of neighborhood exist for public transport usage. Entropy Index, Employment density and Accessibility Index to employment found statistically significant urban form variables to explain public transport usage in Lahore. Whereas, households having no car, households having size less than 6, households having transport expense less than 5,000 and young females having age less than 30 years found statistically significant social variables. All other urban form variables including in this research population density, mix density index and accessibility index to population computed statistically insignificant for Lahore city. Young males having age less than 30 years, employed residents, and households having income less than 20,000 are social variables which does not have statistically significance on public transport usage. All urban form variables have the inverse relation with public transport usage which shows that increase in urban form variable decrease the public transport usage in Lahore. Social variables including households having income less than 20,000, employed resident, males having age less than 30 years, females having age less than 30 years and households having no car have positive impact on the use of public transport at Union council. Whereas households having transport expense less than 5,000 and household size less than 6 found opposite relation with public transport usage.

5.2 RECOMMENDATIONS

Following are the recommendations of this research:

- Validation of models developed under this research may be done in future researches.
- Exploration of some urban and social variables found opposite relation with public transport usage in comparison to the expected result which may further be explored.
- Simultaneous Auto Regression in place of Ordinary Least Square Regression is recommended to be adopted to develop the relationship between urban form and public transport usage for future researches.
- Furthermore, this research was done by using available data of year 2011. However, major developments in transport sector have been done after that time spectrum. Therefore, the same study may also be repeated by using the latest data to investigate the impact of new development on urban form and relation of its variables with public transport usage.
- For making policy decisions related to planning in Pakistani cities, it is recommended to conduct a thorough study of urban form variables for all other cities and somehow control the future urban forms and relation of its variables with public transport usage.
- It is also recommended that all major developments regarding public transport including provision of new routes or its optimization, establishment of mass transit lines may be planned by keeping in view the variables computed statistically significant in this research.

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