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Assessing the Impact of Urban Streets Networks Connectivity on Vehicular Movement and Urban Air Quality for Lahore City, Pakistan

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Summary

Urban environment is considered as a complex system comprised of physical, social, economic and environmental features and activities. With the passage of time, after realising its contribution in changing the function and morphological pattern of cities, researchers are keenly interested to explore the relationship of its physical component among social, economic and environmental activities. Among all physical components, buildings and street networks are considered as main morphological elements of urban cities.

By keeping in view, the above illustrated importance of urban environment: different component, this research study has been planned to carry out for a city of Lahore, Pakistan by focusing physical built environment, particularly urban street networks and its associated impacts on vehicular movement in addition to urban air quality. Street networks are being considered as facilitator of the human movement in a city based on its capability to join or to segregate different parts/areas of city and this feature of urban street networks is strongly dependent on degree of accessibility of street networks. As accessibility is very vast concept and have different definitions which are used according to research objectives of the study. For this research study, accessibility is considered in terms of integration (closeness of one street to another street) and choice (street which is likely to pass through while moving in a city) of urban street networks. These accessibility measures are used as a determinant to describe the extent of urban street networks connectivity of a city, measured through axial lines (number of turns: topological point of view) using space syntax as a measuring tool. From applications of space syntax in different field like crime, land particularly in transportation sector, it is considered a good predictor of pedestrian as well vehicular movement. In this research, it is used to investigate the extent of influence of urban street connectivity on vehicular movement as well as on urban air quality by finding out relationship of integration and choice with vehicular movement first, and then determining the relationship of vehicular movement with urban air quality through research model 1 (Urban Street Connectivity and Vehicular Movement) and research model 2 (Air Pollution with Urban Street Connectivity in terms of vehicular Movement) by using multiple regression and simple linear regression as a statistical analysis methods.

From the results of first part of research study, it is examined that there is a significant relationship exists between vehicular movement and urban street connectivity shows that approximately 48-50% of the variance in traffic flows is accountable by the urban street connectivity for the city of Lahore, Pakistan. Outcomes of the statistical analysis also demonstrate that choice_Nor has a slightly greater impact on vehicular movement as compared to integration. Furthermore, second part of the research study based on research model 2, in this case urban street connectivity is taken in account in terms of vehicular movement and PM10 as indicator of urban air quality. Results explained that only 20% variance is occurred in PM10 concentration due to vehicular movement which shows a very weak relationship between urban street connectivity in terms of vehicular movement and urban air quality.

Due to unavailability of data for controlled variables they are not taken in account during analysis and considered as a limitation of research study. Therefore, it is recommended to do the same research for same city under similar circumstances by collecting the data of control variables to analyses how significantly other variables have an influence on vehicular movement and on urban air quality along with urban street connectivity. It is also suggested to perform the same research by taking in account geometric analysis for urban street connectivity to explore the difference in results among both type of analysis and discover which analysis best fits to describe the vehicular movement flow.

Keywords

Urban Environment, Space Syntax (Integration, Choice), vehicular movement, urban air quality,

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Abbreviations

ADDT	Average Annual Daily Traffic
CAIT	Climate Analysis Indicator Tool
CD	Conventional Design
EDF	Empirical Distribution Function
EIA	Environmental Impact Assessment
ERGES	Environment Resettlement and General Engineering Services
GoPb	Government of the Punjab
GSM	Google Street Map
HH	Integration
H&TED	Highway and Transportation Engineering Division
IHS	Institute for Housing and Urban Development
IPCC	Intergovernmental Panel on Climate Change
ISUF	International Seminar on Urban Forum
JICA	Japan International Cooperation Agency
K-S	Kolmogorov-Smironov
LDA	Lahore Development Authority
LWMC	Lahore Waste Management Company
M2	Motorway 2
MCA	Multiple Centrality Assessment
ND	Neotraditional Design
NFP	Netherlands Fellowship Programme
NESPAK	National Engineering Services Pakistan
Nor	Normal
OECD	Organisation for Economic Co-operation and Development
PM	Particulate Matters
QGIS	Quantum Geographic Information System
r	Radius
SAARC	South Asian Association for Regional Cooperation
SPSS	Statistical Package of Social Sciences
SS	Space Syntax
TEPA	Traffic Engineering and Transport Planning Agency
TIA	Transportation Impact Assessment

WHO	World Health Organization
WRI	World Resource Institute
UN	United Nations
USPMU	Urban Sector Planning and Management Services Unit

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Chapter 1: Introduction

1.1 Introduction

Sustainable development is concerned of today's world for everyone especially for the developer, policymakers and planners. Sustainable development is defined as "to fulfil the need of the present without compromising on the ability of future generations to fulfil their own needs" (Moran, Wackernagel, et al., 2008, p.470). In order to make cities more sustainable, three aspects of development should be considered in an integrated way i.e. environment, social and economic. Therefore, researchers are looking at cities urban environment as a complex system and giving immense attention to study the configuration of its physical features by taking in account urban street networks as an important component which influences the people's movement and associated social activities within it. From research studies conducted in past, there is correlation evidence found between urban street networks morphological properties and movement of human beings carried out either by foot or by vehicles (Hiller 1984; Hiller and Hanson 1984). The ability of urban street networks to join and segregate different parts/area of the city is strongly dependent on degree of accessibility (integration, choice) of street networks. Hence, urban street networks accessibility (integration and choice) is important to taken in account while doing city planning for sustainable future development.

This research aims to examine the relationship between connectivity of urban street network and vehicular movement. Connectivity means how well is one street physically linked with all the other adjoining streets. Hillier (2007), Charalambous and Mavridou (2012) and many other authors has given importance to street connectivity due to its influence on human movement which is demarcated in their research studies. Besides this, vehicular movement is one of the important sources among many other pollutant sources (i.e. industrialization, combustion of fossil fuels, biomass burning, and deforestation etc) which have an influence on the urban air quality (IPCC, 2014). In perspective of developing countries particularly, the contribution of road transport sector is higher among all other sources (Shrivastava, Neeta, et al., 2013). Hence, Relationship between vehicular movement and urban air quality will also be examined in this research study.

1.2 Background

"We shaped our Dwellings and afterwards our dwellings shape our live".
(said by Winston Churchill, (Edussuriya, Chan, et al., 2011, p.3)

Urbanization is the ongoing process and one of the key factors to determine economic growth of any country all over the world. According to OECD report, "By 2050, 70% of world population –and 86% for OECD Countries—will live in urban areas"(OECD, 2010, p.17). Majority of the world's population is living in urban areas because people are migrating from rural to urban areas in search of employment, education, better health and transportation services in fact to improve their quality of life.

It is reviewed that built environment has a greater contribution in changing the function and morphological pattern of the cities. Buildings and street networks are considered as main morphological elements of urban cities (Edussuriya, Chan, et al., 2011). Focus of this study is on physical built environment, particularly urban street networks and its associated impacts on vehicular movement in addition to urban air quality. Street networks are being considered actually facilitator of the movement in a city which is strongly dependent on degree of integration of street networks. Hence, direct impact of this physical build environment feature has been observed on habitat, water quality, ecosystem while they indirectly influences the air and noise quality as well as global climate(Tang and Wang, 2007).

Batty, elaborated the importance of the street networks by considering them as an integral part to shape the cities because of the influence on the movement of human beings carried out either by foot or by using motorized vehicles(Batty, 2008). To explain, how street networks shape the cities, he considered "street networks as an excellent example to see the city growth (bottom up) for they represent the skeleton which all else in the city hangs" (Batty, 2008, p.8). As when we look in patterns of cities growth, it is analysed that most of the social and economic activities are visible along accessible (integrated) streets which is also a determinant of relationship among street networks, city shape formulation and people movement as well as their social activities. He has also presented the example of inner city of London in figure "Where streets are coloured according the energy they transport, in fact using the proxy of road traffic volumes which give some index of both capacity and congestion or saturation. This is also highly correlated with patterns of accessibility which mirror the proximity of places to each other" (Batty, 2008, p.7-8).

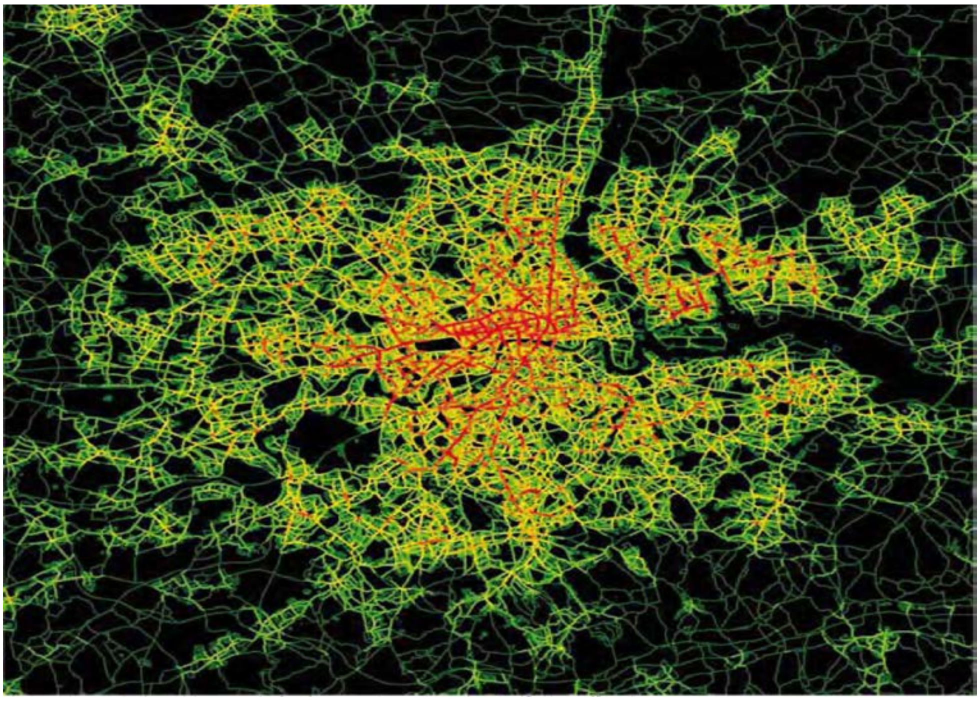

Figure 1: Organically evolve networks of surface street in London classified by traffic volume

Source: (Batty, 2008, p.8)

Therefore, morphological and spatial analysis of the street networks is very significant in the transportation sector to analyse the traffic flow. Since, it gives the information not only about evolution and transformation of street networks but also about their integration through spatial analysis means how one street is integrated with the other streets. The concept of integration of the street networks is defined by Hiller in terms of accessibility (accessibility means proximity of spaces; in this study accessibility is considered in terms of integration and choice based on number of turns). Integration is described as how easy is for individuals to access one street from all other adjoining streets to perform their function (Hillier, 2009). It means the shorter is the path, few number of turns required to take and higher will be the integration value of that street. Choice describes street which is most likely to visit while moving in city. The core of these two concepts is shortest path in axial line analysis, it means few number of turns (topological) one should have to take to reach at other point/destination. In addition, Hillier also describes connectivity (in space syntax it refers as number of axial lines touches directly to a given line) of the streets with respect to different distances types (metric, topological, geometric) and at various scales in the form of closeness (mean how close one street with the other neighbouring streets) (Hillier, Penn, et al., 1993) and Betweenness (refers to "calculates how many distance-minimising paths between every pair of segments lies on under different definitions of distance" (Hillier, 2009, p.4)). It is generally considered that streets having high connectivity are more popular among other streets and supposed to attract more vehicular movement. By using space syntax analysis, the configuration of the urban street networks can be visualized. Roads, motorways linkages as well as internal connectivity exhibit the accessibility (integration, choice) level of the city. Although, more spatially integrated street/road networks have taken more traffic movement[1]. These interconnected streets interreact with each other at different scale and can be characterized in to two types "background networks" and "foreground networks" (refer: section 2.4 for detail description) and provide space for mobility and accessibility. These networks served as a base of traffic and pedestrian movement in a city and indicates that among all spaces, some are frequently accessed due ease of accessibility (in terms of integration and choice) as compared to others (Hillier, 2009).

Therefore, influence of the street networks higher in shaping social, transportation and environmental aspects of the cities. Consequently, researchers are more focused to study topological characteristics of these networks. According to Pereira, et al., it is explored that highly compact and integrated roads in terms of topology and geometry, are contributed towards efficient flow of motorized vehicles with minimum travel time due to appropriate street configuration, which makes them economically efficient and less perilous to contribution towards air pollution (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011).

Reduction of air pollution by improving the transport infrastructure (mainly street networks) used by vehicles for commutation is a challenging task because of unprecedented increase in private vehicle and due to inadequate urban street connectivity. While, most of the roads don't have adequate capacity to cope with this issue of increasing vehicular movement in most of the developing and in very limited number of developed countries. This situation leads towards increase in congestion and travel time; consequently, greater is contribution to intensify the air pollution in this area. This situation can be seen by considering the example of UK, according to Patterson, "Passenger cars in the UK emitted 63% of all greenhouse emissions from road transport in 2009 and the number of vehicle miles travelled by cars and taxis in the UK has increased fivefold in the last 60 years, accounting for 80% of traffic on UK roads"(Patterson, 2016, p.1163).

As urban street networks are considered as facilitator of the vehicular movement which is directly associated with air pollution; therefore, urban street connectivity should be taken in account in transportation projects design to minimize air pollutants at city, regional and global level. According to Patterson, "in most cities, a degree of reorganization of the existing built environment and the associated infrastructure is likely to be necessary to create a more sustainable transport system" (Patterson, 2016, p.1).

Different studies have been conducted to show the relative importance of street network connectivity and design with urban air quality assessment. Barrington et al., has conduct study for an American city to show the influence of urban street networks connectivity on quality of air. Which associates increased number of vehicles due to higher streets integration, travel time with greater is the emission of harmful pollutants in air. It is also identified that gridded street networks having more connections, less distance to travel which is good to maintain the urban

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[1]https://www.slideshare.net/tstonor/tim-stonor-predictive-analytics-using-space-syntax-technology

air quality. Hence, urban street network pattern study for new road transportation development projects is very significant to enhance transport efficiency and reduce GHG emission as move for better urban air quality (Barrington-Leigh and Millard-Ball, 2017).

Since, they are concerned with movement of vehicles which is increasing day by day particularly in developing countries due to poor street networks integration, higher dependency on motorized vehicles and less cycling and walkable lanes. It gives new horizon to urban planner as well as transportation engineers to look for better urban street networks design, land use planning and integrated transportation system to reduce air pollution. However, these measurements will be a move towards sustainable and synergic cities development to protect urban air quality particularly.

Problem Statement

"*Road transport is particularly suited to the conditions and requirements of Pakistan … the motor vehicle is more adaptable than the railways to varying degrees of traffic intensity and permits a greater degree of speed and efficiency in haulage over short distance … there is close relationship between the volume of transport and the level of economic activity because each depends upon the other (Govt. of Pakistan, Planning Commission 1960)*" (Imran, 2009, p.9)

In Pakistan roads are the basic mode of transportation among air, railways, ports and shipping modes. So, road development is one of the important segments in urban transportation and covered "96% inland freight and 92% of Passenger Freight" (SAARC Energy Center, 2015, p.18), in cities. Lahore is second largest city of Pakistan having population approximately 10 million which is increasing with annual growth rate of 3.1% (UN Population Division, 2016). This population bulge requires well connected urban street networks and functioned services like transportation, health and good planning to make city sustainable, integrated and resilient along with reduction of global warming impact and air pollution. Urban streets accessibility issue rises due unavailability of adequate integrated intracity and intercity road infrastructure in the research study area (Lahore) which has increased private vehicle usage. These sub-sequential private vehicles ultimately amplify traffic congestion, commuting time and air pollution day by day which delimit the urban air quality of city and region at global scale. This growing transportation demand not only raises the question of urban street network integration but also seeks an integrated planning of sustainable environment and transport development.

In Lahore, according to the JICA study (conducted in 2008), major urban street networks are composed of primary, secondary and local roads having a flow of around 2 million vehicles all over the city. This study also reported that traffic volume on roads of Lahore is beyond the "worldwide standard limit of roads i.e. 8000 vehicles per road" (Rathore and Ali, 2015, p.138). These statistics shows that the road transport infrastructure of the Lahore city is not capable to fulfil the present and future needs of the city in all aspects social, economic and environment. Therefore, Government of Punjab has initiated several transportation infrastructure development projects by introducing signal free corridors, Bus Rapid Transit system etc to improve current transportation for reduction of congestion, travel time, commutation distance and air pollution which is also a move to improve both quality of life and economic productivity (Rathore and Ali, 2015).

By having such a huge investment on road infrastructure development projects to accommodate the increased number motorized and non-motorized vehicle, there is a need to focus on urban street connectivity to shorter the travel distance, reduce the congestion and ultimately these measures will be beneficial to improve the urban air quality. Previously, no handful work has been carried out to assess the quality of urban street connectivity in a city and its impact on vehicular movement and air pollution which is going to increase day by day having a largest contribution of road transport sector. “According to the World Resources Institute’s Climate Analysis Indicator Tool (WRI CAIT), energy contributes 46% of Pakistan’s total annual GHG emissions, of which 26% is attributed to electricity consumption, 25% to manufacturing, 23% to transportation and the remaining 25% to other energy subsectors”(CAIT, W., 2015).

Although, ambient air quality standards have been announced in 2007, to measure the air quality and monitoring station has been developed in Lahore along with other four cities(Colbeck, Nasir, et al., 2011). According to the results, it is cleared that air quality of the city is degrading rapidly having greater contribution of road vehicles, less accessibility and poor quality of public transport system. From different studies, it is identified that current concentration of the air pollutants i.e. CO, PM, SO_2, NO_2 and Pb are higher than the prescribed standards of the WHO guidelines (Colbeck, Nasir, et al., 2011) which is deteriorating the urban air quality of the city.

Therefore, a challenge remains for planners to harness effective and efficient transport infrastructural design for mass accessibility through integrated urban street network planning that reduce congestion, travel time and minimize air pollutant concentration in Lahore.

1.3 Research Objective

This main objective of this research is twofold, first one is to assess the spatial configuration of urban street networks in Lahore city in terms of accessibility (integration and choice) in order to analyse its contribution in identify vehicular flows patterns as well as in reduction of traffic congestion. Second objective is to determine how urban air quality is getting an influence of urban street connectivity.

1.3.1 Main Research Question

To what extent does urban street networks connectivity have an impact on the vehicular and urban air quality, for city of Lahore?

1.3.2 Sub Questions

i. Which urban street connectivity factor have significant influence on vehicular movement, specifically for Lahore City?
    - Integration (Mathematical_Closeness)
    - Choice (Mathematical_Betweenness)

ii. At what extent vehicular movement impact the urban air quality, for Lahore city?

1.4 Significance of the Study

This research study of existing street network infrastructure in Lahore will be helpful in many perspectives to analyse:

a) At what extent, this spatial urban street connectivity facilitates the vehicular flows and how this vehicular movement impacts the urban air quality. The academic benefit of this research is that it will add knowledge by making relationship between environment and urban street networks that how urban street networks accessibility contribute to reduce the air pollution. According to Matthew Barth, there are several technologies which can be used to minimize the emissions of CO_2 and PM from vehicles in atmosphere include use of environmental friendly fuel, improving and managing operations of traffic but all of the above there is need to make road infrastructure integrated to reduce the traffic congestions and make the traffic flow continuous.

b) The other most important benefit of this research study is that it will facilitate as well as integrate both sectors in planning and decision-making process of the transportation infrastructure development authority which will be a move towards the sustainable development. It will provide a new horizon to incorporate the environmental issues of the development projects. However, change in vehicle manufacturing technologies for less fuel consumption, promotion of environment friendly fuels, use of Intelligent transportation system, and make road signal process well-organized seems very efficient solutions but all of them required good human resources and technology management skills to curtail congestion and air pollution issues as well as having higher economic cost. Although among these stated technologies, if one system collapses or not functioning well then it will create a bulk traffic congestion, increased commutation time and deteriorate the environmental quality as a whole. So, among all these technologies, integrated street network formation and development is the core long term solution to increase the capacity of the existing infrastructure by making some modifications and for new project development to absorb traffic volume increase on roads and improve air quality of the city.

1.5 Scope and limitations

The scope of this study focuses on examination of the urban street networks connectivity influence on vehicular movement and urban air quality for the city of Lahore, Pakistan. The focus of the thesis is determination of how topological features of the urban street networks impacts the vehicular movement particularly. In addition, how vehicular movement contribute to degrade the urban air quality. In this dissertation impact of urban street connectivity on urban air quality is determined by taken in account vehicular movement, as relationship between urban street connectivity and urban air quality is due to movement of vehicular flows in urban streets. Moreover, narrowing down the study scope focuses on trunk (highways and motorways), primary, secondary and local roads of the Lahore city. Therefore, the results of this research are only specific to this context and cannot be generalized for any other city.

Due to limited time and unavailability of the data, only 20% of trunk, primary, secondary and local roads (street networks) have been considered as sample size to check the road integration (accessibility) and choice for vehicular movement as well as for particulate matter (PM10) measurement. For this whole big city, primary survey for vehicular count and PM10 measurement is not possible to conduct in such a short time period given for field work by the academic institute that leads the researcher to relay on secondary available data sets. However, secondary data sets are available for year 2015-2016 and 2016-2017 collected during different time periods because it is not possible to run survey for air quality and vehicular count at once for whole city at government level as well due to financial and human resource constraints. stated by Lahore Development Authority, Pakistan during secondary data collection. Air quality parameter (PM10) is also going to be study for this selected study area to analyse that either the highly integrated street networks have higher contribution in air pollution or not, due to vehicular movement.

As vehicular movement and urban air quality does not only dependent on the urban street connectivity but there are also several factors involved to formulate or envisage the vehicular movement while designing proper transportation system. Based on literatures written by different authors like Simuruganandam and Nagendra, (2010) and many other (refer: chapter 2 for details), enlisted below are factors/variables which also impact the dependent variable (vehicular movement and urban air quality) involved in this research study. But due to unavailability of the data on these variables they cannot be computed while performing inferential analysis to answer main and sub research questions. The unavailability of data on these control variables is one of the biggest limitation of this research study which might affect the analysis results.

- Land Use Pattern
- Origin-Destination Travel Time
- Vehicular Speed
- Vehicle Classification and Engine Types
- Number of Traffic Signals and Road Width
- Metrological Effect

Some limitations for this research study is based on the limitation of space syntax software, streets function (one way, two way, squares, roundabout, physical obstacles and road width) are not taken in account by the software: in addition, it consider each ‘turn' as a ‘step’ while performing space syntax analysis. Since, while doing analysis for choice and integration it only takes natural street as a straight line.

Another limitation for this research study is regarding generation of axial lines in QGIS because axial lines generation is a complex process which rise appearance of some isolated lines during mapping. This is due to phenomenon of axial line representation through straight lines so when there is curve path is adjusted to straight ones by dividing into number of segments as shown below therefore it is considered that spatial analysis based axial lines is not a significant representation of natural streets (Jiang Claramunt, (2002); Ratti, (2004)). To minimize this issue, great care has been taken while dealing with roundabouts, squares and other no straight structures during axial map formation. Although, for software limitations researcher have no control.

Chapter 2: Literature Review / Theory

2.1 Core Thesis Concepts

This chapter is contributing to understand the core theories involved in this research work. It provides a review of the significant theories used to show the relevance with this study. Urban Morphology, Space syntax, Depth Map, Spatial Integration Accessibility, Vehicular Movement, Air pollution are the basic core concepts included in the literature review for this research.

2.2 Urban Morphology

The word "Morphology" is originated from two Greek words "Morphe" means shape and "logy" mean study therefore it is defined as the study of shape and form. Urban Morphology is interdisciplinary term, defined by Vahid Ahmadi, et.al, "Urban morphology is the study of city appearance, its gradual formation, and the interaction among components of the tissue that defines specific compounds and urban faces, such as streets, squares, and other public spaces." (Ahmadi, Chi-Ani, et al., 2012, p.56). Moreover, 'form, resolution and time' are the basic components of morphological analysis. These three terms are demarcated by using book 'Planning and Urban Design Standards' are as follows; Resolution, "urban form can be understood at four level of resolutions, corresponding to the buildings/lot, the street/block, the city, and the region'; Time "urban form can only be understood historically because the elements of which it is comprised undergo continuous transformation and replacement", (American Planning Association, 2006, p.401). Furthermore, form is defined as the urban form of city physical components like land, buildings and their associated open spaces, streets, and plots etc. These three components are considered as basic components of morphological analysis because they demonstrate the way in which cities built and transformed with the passage of time (American Planning Association, 2006, p.401). Although, cities are considered as a "complex combination of humans, physical structures (road networks, building, etc) with agglomeration of different cultural, social as well as economic activities" (Moudon, 1997, p.3). Due to transformation and transition, cities are taking new shape as compared to old ones while this process is considered as an ongoing under different circumstances.

City morphological patterns is usually influenced by the many social and economic decisions. Since, economic growth of the city is contributed in overall progress of that respective country, gives birth to new infrastructure development projects and considered as a parameter to judge the economic growth potential respectively. Therefore, both social and economic aspects are the centre of attention for urban morphologists. However, land use planning and physical structures of the city act as living part and continuously changing with passage of time eliminated, transformed physically and used for other purposes due to economic, social and environmental pressure (Anne venze mouden, 1997). These factors modify the city planning process and cities are gradually taking new shapes according to the requirement of the economic growth, to accommodate population bulge, better utilization of space to fulfil the demand of basic needs i.e. housing, transportation, healthcare facilities, agriculture/food production and building infrastructure etc.

Modern city basically originated from old cities which were continuous, dense, and compact previously but now they changed into discontinuous, expended as well as loose. It has taken its new physical shape through radical changes which are visible not only in the form of territorial expansion but also in form of physical transformation. Traditional urban fabric phenomenon and its elements have been changed rapidly and moved from closed fabric to open peri-urban fabric. Street networks are most important city component among others which is considered as the good example of this change as they changed their morphological pattern from Conventional Design and Neotraditional Design in past many years (Alba and Beimborn, 2005a). In result of this transformation from old city, new modern city is polycentric having low density and no particular boundaries (Levy, 1999).

Although, new developments in cities are being carried out along major transportation lines i.e. roads, airports and motorways etc. Road transportation infrastructure is linked with the growing demand of mobility and economic growth to link urban centres and sub-urban areas in addition to fill available space in city. It is considered as significant component of the urban fabric and has taking a greater land space as compared to the other urban fabric elements. Charalambouset.al. has illustrated the importance of street networks by identify that the flow of people and vehicles in cities are highly outlined by street networks. That's shape the origin of city centres and sub centres. Moreover, morphological study helps us to understand how physical structures changed from their origin and what are the causes of this change. The type of changes not only provides a comfort and facilities to improve living condition and economic growth. But on the other hand, deteriorate the environmental quality and urban form as well as reduce open space and changed streets (social activity places) into transportation infrastructure (Levy, 1999). Consequently, the change in physical structure is depended on our decisions, thoughts, economic growth requirement and value of social interaction.

"How cities are formed and evolve, how we might best understand and then simulate them, and most importantly, how we should design plans which enable them to function in more efficient and equitable ways."(Batty, 2008, p.13)

From the above mentioned reviewed literatures, importance of urban morphology has been understood well to analyse physical structure (urban street networks) of the cities and their impacts on build environment. Space syntax analysis method which was first introduced by Hillier in 1984 is used as common tool in architectural and urban planning field for analysis of physical structure and to predict functional results (Hillier, 2009). Although, detailed description of space syntax is further illustrated under heading of space syntax analysis.

2.3 City

City is basically a complex mixture of millions of people, infrastructure, social and economic activities. There is no universal agreed definition of the city (Bettencourt, 2013) and can be defined in various form like garden city, cellular city, medeival city and roman city etc. The form and functions of the city is influenced by the decision of the human beings to make progress in economic, social and environmental aspects. Batty defined city formation as, "Cities develop by filling the space available to them in different ways, at different densities and using different patterns to deliver the energy in terms of people and materials which enable their constituent parts to function. We will demonstrate a simple diffusion model and then generalize it to grow city forms and structures, in silico" (Batty, 2008, p.2). Hiller describe city as an enormous collection of buildings/infrastructure combined by the large number of street networks which is deemed as the largest city component. All cities architecture has its specific topology, geometry and scaling which contribute to identify the integration of street networks, accessibility, human activities and mobility within a city (Hillier, 2009). Cities are transformed from its historic times gradually and had taken the shape in a response of social and economic requirement which is visible to everyone and properties of the cities are changing gradually. They are also classified according to the population size and availability of facilities. Here detailed discussion is carried out to clarify the concept of the reader about cities and their morphological pattern about physical components to get clear understanding of their importance and influence on human activities development patterns.

2.4 Urban Street Networks

Urban street networks have always been identified as complex web of roads, highways, motorways and streets to connect one part of the city with other neighbouring parts of the same city as well as with other cities and actually gives or determine shape of cities (Batty, 2008). Batty also identifies that traditional street networks are grown by itself without specific planning (bottom up) but their modification according to need is the top down approach comprised of many people decision. Therefore, it is not wrong to say that street networks represent the growing pattern of cities (Batty, 2008). However, from historic times, urban planner and transportation engineers are working hard to explain them in an integrated way for the betterment of cities economic state, well-being and environment condition through reducing congestion, travel time, and accommodating private as well as public vehicles. In developing countries particularly, dependency on private vehicles are going to be increased day by day due to population bulge, absence of well-connected street networks in addition to poor access to public transportation system.

While doing planning, transport engineers and architects emphasis to study the morphological pattern of the urban street networks to modify the existing street networks as well as for future street network development. Lynch highlighted the importance of the paths/ networks by considering them one of the important elements among nodes, edges, landmarks and districts which are generally used to build a city image. He defined path as a network used by the movers to approach destination point from origin point. Notion of path is used for all type of networks i.e. streets, railroads, and walkways etc. Organised set of paths are used to structure a city while intersections (connecting point of streets) acts as a tactical point for human decision of motion (Lynch, 1960).

Therefore, it is not wrong to say that urban street networks is the determinant of human movement either with or without vehicle. However, shape of the street is an important aspect which have an influence on urban form as well as on commutation behaviour of the traveller specifically between the selection of straight or winding route. For instance, there is a huge difference between the geometry of the ancient cities and European American's colonies. Former one is not covering long grids while later one has long grids spread to tens of kilometres: this difference in scale between two grids determines the human environment perception. While perception regarding space is related with spatial cognition and environmental psychology. The human perception regarding street shape varies from person to person in relation to their environment (environmental psychology), though spatial cognition highlights that physical space and mental space is different from each other. According to (Blanchard, Volchenkov, 2009) "perception of space and human thinking does not have a simple metric relationship" (D'Acci, 2016, p.3). A study has been conducted to describe that path having less direction change are preferable, also seems as shorter, against the path having larger number of change in direction. It is assumed, due to less complexity of route to remember or being afraid to get lost, human follows the path/streets having less number of turns, more integrated streets but study results shows different results. It showed that people preferred to travel along sinuous streets because it is generally less boring, having more characters, seems shorter instead of a very straight path having few turns only. It also a representation that physical environment and human physiological understanding about route selection differs from each other (D'Acci, 2016).As cities are combination of different physical structures, economic, cultural and social activities and urban street networks are considered as an important physical structure to facilitate all these activities by interconnecting different parts of cities at local and global scale. These interconnecting roads are categorized as "foreground networks" having "longer lines, linear lines, nearly straight connections and route continuity usually passing through the whole urban structure linking different areas of the city (Global scale); and the “background network” has shorter lines, right angle connections and more local grid-like structures that link at local scale” (Hillier, 2009, p.28). Both networks types influence the vehicular movement, as foreground networks tends to maximize the movement as it is driven by socio-economic factors while background networks shaped by “Socio-cultural” factors therefore it restricts and structure movement. Furthermore, research showed that structure of street network itself shapes the movement flows in streets. This doesn’t mean that space is a determined of individual movement but is an indicator that some spaces have more movement as compared to others because they are frequently visited by travellers. Usually, urban street networks that are connected well have high integration value and accepting frequent traffic as well as pedestrian flows as compared to the poorly integrated street networks (Hillier, 2009).

Different methods like Multiple Centrality Assessment (MCA) and Space Syntax is used to measure the urban street connectivity parameters (integration, depth, choice) particularly in transportation sector. “MCA allows for a metric calculation of distance, whereas space syntax calculations are relative. MCA reduces subjectivity; however, the creation of maps requires the use of very large information resources” (Patterson, 2016, 1164). While to run space syntax, there is no intensive data requirement and it is based on axial map formation as well as easy to use (for detail description of space syntax see section 2.6) (Patterson, 2016).

To conduct this research study various models has been studied as illustrated above, due to ease in use and less data requirement of space syntax software, it is selected to perform connectivity analysis of the urban street networks.

2.5 Spatial Integration and Accessibility

Owing to extensive urbanization, cities are getting bigger and bigger day by day. As we understood that cities are the complex units of people, structures, land, environment and activities of the human beings to gain the economic efficiency in order to compete with other cities in the world. Due to this phenomenon land use, topographical and structural pattern are changing continuously which transform the shape of the cities. Street network has always been considered one of the important elements to shape the different cities and to transport energy from one place to the other parts in terms of accessibility of street networks. Therefore, while doing planning for better future cities development, spatial aspects of street networks should be focused because of its strong influence on build environment.

“The basic factor that space syntax analysis relies on is the accessibility of each space from all the other spaces in the system” (Salheen, 2004, p.36.2). It is the spatial strength measurement of the network (itself). As it is already defined in chapter one that accessibility means proximity of spaces, here particularly for this research study accessibility is considered in terms of integration and choice measured through axial map formation by considering topological measurement analysis (number of turns). Moreover, “connectivity is defined as directness and availability of alternative routes from one point to another within a street network” (Handy, Boarnet, et al., 2002, p.66). In space syntax, it is described as number of axial lines touches directly to a given line and considered as one of the important variables of broader accessibility concept. Therefore, greater street networks connectivity refers to those networks which have fewer dead-ends, frequent intersections and short links. It helps to determine the accessibility and resilience of the transportation system as well as discourage the vehicular movement because higher connectivity let people move by foot to get access to their basic needs. Cities which have less street networks connectivity always have greater dependency on vehicles to access destination points which contribute in generating ample traffic flows, congestion, air and noise pollution. The example of such street networks is cul-de-sac streets pattern which are also called pedestrian unfriendly and car oriented streets (Cozens and Hillier, 2008). In space syntax, integration and choice as a accessibility measure to assess the connectivity of urban street networks and its influence on the vehicular movement (Hillier and Iida, 2005), (Hillier, Penn, et al., 1993). Integration is defined as closeness of a particular segment from the other segments. Moreover, choice of the route selection is based on traveller choice and integration of that street with the destination point. Higher the integration of the street, higher will be the accessibility and in result it will take high flow of pedestrians as well as vehicle (Charalambous and Mavridou, 2012).

2.6 Space Syntax

Space syntax method is first introduced by Hillier and Hanson at University College London. The word "space" has no single description; this word is used for many illustrations under different concept and circumstances. Here, Space can be used in conservative way and represent the social pattern in the form of spatial layout. According to Hiller, "It reflects the distinctive properties of cities as "*spatialized societies*" (Hillier, 2009, page.9). However, the syntax is used to express the relationship between "space and society" (Jiang and Claramunt, 2002, p.295). Therefore, space syntax is considered as a method to "analyse architectural and urban space and forecast functional outcomes" (Hillier, 2009, p.2). It is visualized from the above stated description that there is strong relationship of individuals social activities with the habitat/space. People activities and cities are always influenced by the spatial structure and layout. Spatial language is always source of attraction for researchers and used to carry out city spatial pattern analysis. This theory contributes to assess the human disarticulation pattern in city by considering the degree of integration and connection of urban areas(Jiang and Claramunt, 2002). Based on its ability to assess the connectivity of street pattern and vast applications in transportation sector as vehicular modelling, it is used in this research as a study method. Before going in depth to see how it helps transportation sector to find out which street is more integrated or having a more pedestrian as well as vehicular flow, it is necessary here to understand the space syntax model first and important terms used in it.

Cities now days are considered to be self-organized which make them most liveable place and space syntax have capability to highlight structures configuration at all scales global and local scale. Open spaces system can rationally be putrid into two spaces i.e. convex and axial.

According to Hillier, urban grid configuration is determinant of the routs that are more connected and having huge flow of masses (human and motorized vehicles) and create mobility pattern in the city. While topological characteristics of the streets network system have also a capability for identification of potential roads networks facilitating the movement of travellers by assigning numerical values to every space (called "integration value" (Patterson, 2016, p.1)).

2.6.1 Axial Lines

In the theory of space syntax, axial lines are defined as representation of all roads and street networks in the form of line or set of lines that follow the line of sight along a network (Patterson, 2016). Although, any alteration in direction or route inaccessibility is shown by the line breakage and addition of a new line as demonstrated in figure 2. The longest sight lines (visibility lines) cut across open public space and bulk of streetscapes of an urban environment to generate map of lines called "axial map"(Jiang and Jia, 2011) .

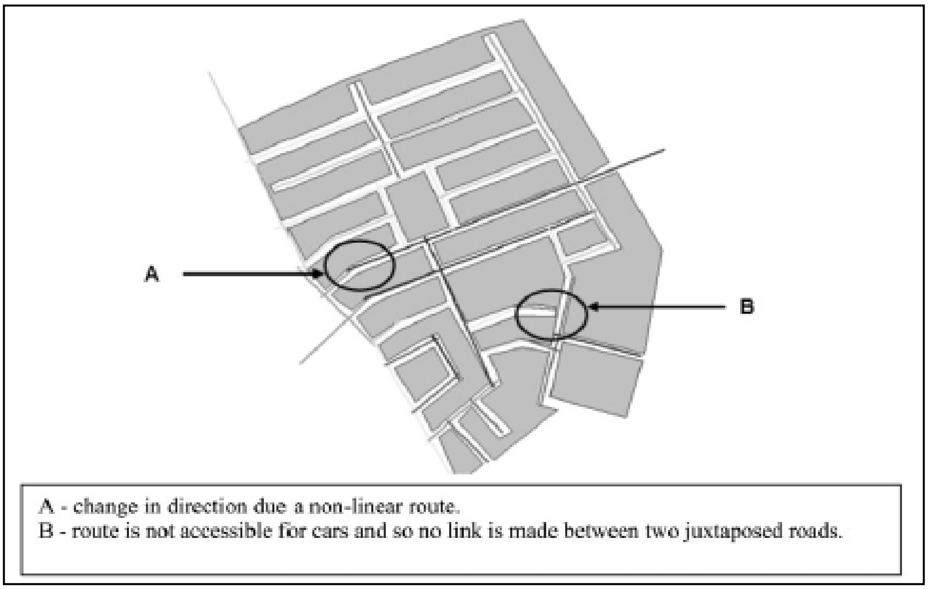

Figure 2: An axial lines demonstration in the form of axial map for traffic

Source: (Patterson, 2016, p.1166)

"Axial lines are used to represent direction of continuous movement and visibility; hence these lines represent the longest sight lines (visibility lines) in two-dimensional urban space" (Jiang and Claramunt, 2002, p.297). In past, this method has been applied in analysis of pedestrian and traffic flow movement (Patterson, 2016) along with having an application in the field of crime analysis and in many more fields (Hillier, 2009), (Jiang and Claramunt, 2002).Axial map can also be defined as a set of mutually intersecting axial lines which covers free space (Jiang and Claramunt, 2002). Different research studies illustrated empirically and theoretically that "i) long and central axes tend to be more integrated, with higher topological accessibility, than short and peripheral axes; and *ii*) more topologically integrated spaces tend be active centers, corresponding to urban areas where there is a greater quantity and diversity of uses and flows" (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011, p.10). Axial map serves as an input data for depth map software for analysis of urban street connectivity. Color branding is used to show highly integrated lines presentation in form of red and less integrated lines in form of blue.

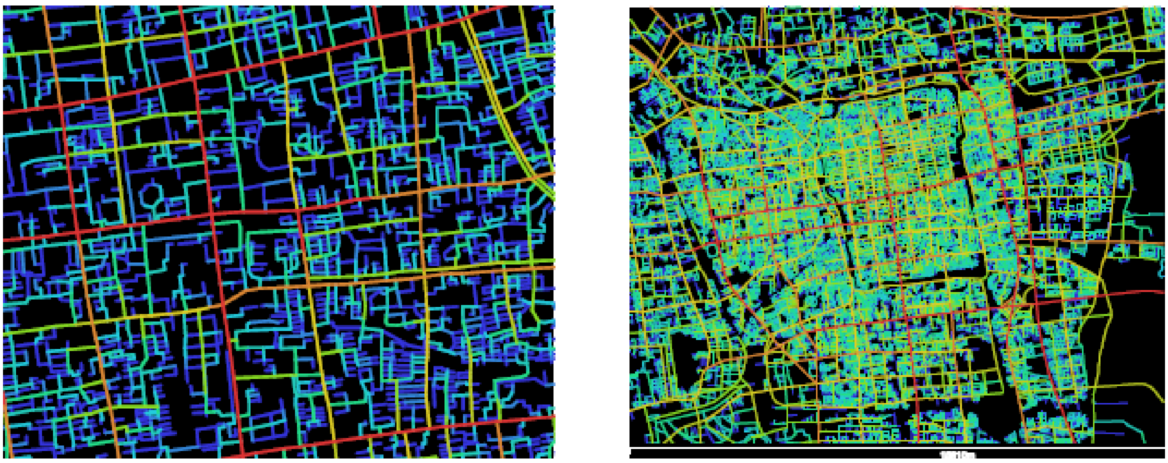

Figure 3: Network representation by colour according to values, from red for high connected streets through to blue for low connectivity of urban street networks

Source: (Hillier, 2014, p.20)

In this analysis, the word 'distance' is alter with 'axial line depth' and defined as less number of steps (turns or conversions) required to reach from one line to another. According to Medeiros, this depth measurement helps "to clarify the average degree of difficulty or ease of reaching an axis, and allows the comparison of means values between distinct road systems" (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011, p.20). So, it is concluded that space syntax analysis is friendly tool having axial lines as most important elements to check the integration of the street network and accessibility of people as well as vehicles.

2.6.2 Depth Map (Integration and Choice Measurements)

Depth Map is the software (computer program) which was created by the Alasdair Turner in University College London for the very first time in 1998 afterward it has been started to use for research and education purposes (Giannopoulou, Roukounis, et al., 2012). This is freely available on internet to calculate the connectivity of the street network at both scales i.e. local and global. Although connectivity is defined by Hillier, "it is clearly a property that can be seen from each space, in that wherever one is in the space one can see how many neighboring spaces it connects to"(Hillier, 2007, p.94). Three definitions of distances are used in space syntax (Hillier, 2009):

i) If the distance measurement of road networks and streets is based on shortest paths, is called *metric measurement* of a distance.
ii) *Topological* definition of the distance is stated in terms of fewest direction change (turns).
iii) The third definition of distance can be stated in *geometric* and defined as least angle change path system).

Syntactic integration or mathematical closeness can be calculated by using these definitions of the distance. The later one is the measurement of a segment in terms of its "closeness with all others under each definition of distance while syntactic choice/mathematical betweenness, "calculates how many distance-minimising paths between every pair of segments lies on under different definitions of distance" (Hillier, 2009, p.4). Integration and choice measurements are the strong pillars of the space syntax. Both of these measurements based on the concept of 'depth'. It is defined by Hiller and Hanson, "depth exists wherever it is necessary to go through intervening spaces to get from one space to another" (Hillier and Hanson, 1984, p.108). The concept of the depth can easily be understood in terms of steps, or distance which shows that how many steps a particular axial line is from the other axial line.

Integration describes the to-movement potential of segment and explains how easily this segment is accessible from all other neighboring segments. The axial line integration (I) is considered a function of its depth associated with all other axial lines, "It is calculated by giving depth value to every space according to how many spaces it is away from the original space, summing these values and dividing by the number of spaces in the system less one" (D'Acci, 2016, p.5). Motorized trips having shorter time span are supported by those street networks which have highly integrated configuration and supportive to increase the efficiency of transportation system (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011).

The equation used by the software to calculate this (I) value is stated by Mahbub R.

Equation 1: Integration (I) calculation formula

$$I_i = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right)-1\right)+1\right)/(n-1)(n-2)}{2\left(\left(\frac{\sum_{j=1}^{n} d_{ij}}{n-1}\right)-1\right)/(n-2)}$$

Source: (D'Acci, 2016, p.5)

In the above stated equation 'n' represent axial lines number in the considered urban street area while 'd_{ij}' shows the shortest/minimum number of steps between 'ij' ('ij' represent two axial lines). From this equation, inverse relationship between number of steps (d_{ij}) among axial lines (streets) and integration (I)is well represented.

Choice (betweenness) is defined as "measuring the through-movement potential" (Hillier, 2009, p.4) means how many times you likely to travel through this segment while moving all through the city so it shows the route potential of a segments to the all other segments. For any trip generation, selection of route and destination are the two important components and it is observed that humans mostly follow the segment/path having less angular turns so in Depth map software definition of least angular change is used as a default setting (Hillier and Iida, 2005). The formula used behind the calculation of the choice (C) is as follows:

Equation 2: Choice calculation formula

$$C_i = \sum_j \sum_k g_{jk}(i)/g_{jk}(j < k)$$

Source: (D'Acci, 2016, p.6)

Where $g_{ik}(i)$ represents the shortest path numbers between two lines j and k having i, while g_{ik} shows the number of all shortest path between j and k. This equation highlights, how determination of the numerical value of choice is based on the definition of shortest paths: greater the number of the axial lines in between means to take turn many times hence it is not considered as a shortest path. In fact, shortest path is only when there is minimum number of axial lines between i and j having minimum number of turns.

In this research study, depth map is used as software to measure integration and choice. Which helps us to visualize the relationship of street networks connectivity by using the integration and choice as parameters in order to identify how much is particular street taking the vehicular movement or traffic flow because of the theory explained by different authors i.e. Hillier, Patterson, 'greater the accessibility (Integration, choice) greater is the vehicular movement on it'.

2.7 Analysis of Vehicular Movement Patterns

Transportation engineering is very vast field of engineering sciences related to all modes of transportation that is land, air and water but for this research work our focused is at land transportation system specifically on vehicular movement on urban street networks. Day by day, due to increase in car dependency traffic flows on street networks are increasing that's becomes a cause of many transportation issues which are all discussed throughout this literature review. To understand the dynamics of traffic flow, the theory used mostly is "traffic flow theory, derived from statistical study in which traffic flows are measured by measuring actual vehicular movement (number of vehicles per hour) and velocities of observed vehicles" (Greenberg, 1959, p.79). Vehicular movement pattern along street networks can be measured in terms of traffic volume (Litman, 2003). Traffic volumes are not constant for all roads and varies from one road to other road even varies at hourly basis. It is used to control and define traffic flows/movement in field of transportation engineering and planning. For accurate prediction of traffic flow both integration and choice concept should be better to encountered in a same model along with other important elements like location (origin and destination point) and time due to their significant impact on vehicular movement. Therefore, in best suitable traffic model to predict traffic movement in terms of accessibility (integration and choice), they both are taken in account (Paul, 2012). Since, with change in time traffic volume varies like at peak hours frequently/mostly integrated or visited roads having educational institutes, offices, markets usually have higher volume of traffic as compared to others. Vehicular counts are the most important data source of this indicator (traffic volume) (Caltran, 1979).

There are two types of traffic counts in transportation engineering studies one is 'Short term traffic count' and other is 'long terms traffic count'. For short term traffic count the data of traffic volume is calculated by conducting minimum 48 hours survey of particular point at an interval of minimum 15minutes and maximum 1hour. While permanent traffic count usually represents the vehicular data collected for 24hours a day for a whole year. This type of data collection required large number of financial and human resources which is not available in general to carry out the traffic count for whole year. Therefore, due to these constraints, short term traffic data is extrapolated by using a factor to estimate average annual traffic count. ADDT. Average annual traffic count is defined as a yearly estimate of average number of vehicles passed through a traffic measurement point (data collection point) on any day of the year(Duddu and Pulugurtha, 2013).

2.8 Influence of Street Networks on Choice (Mathematical Betweenness) and Vehicular Movement/Flows

It has been studied (Hillier, 2007; Cozens and Hillier, 2008; Charalambous and Mavridou, 2012; Alba and Beimborn, 2005b), that connectivity of the urban street networks among buildings, land and activities have a high influence on the movement of the people and vehicles. It is giving the impression that topographical and geometric feature involved to shape human movement carried out either by foot or by vehicle navigate urban grids. But it is also a fact that human behaviour is unclear and unpredictable about their dependency on spatial decision and how distant they are from mathematically probable network effects (embryonic statistical effect on comprehensive movement) which is independent of navigational choice psychology. From the example given by Hillier (1999) which gives an idea that how street networks effect the movement. Network effects means the "emergent statistical effects on cumulative movement from the structure of the network itself' (Hillier, and Iida, 2005, p.554). Consider the figure below, it shows hypothetical grid with different types of street i.e. primary (main streets), side and back street as well as cross street. It is assumed that all streets are equally full of dwellings. People commute from their dwelling to all others by using notion of least distance (shortest) or fewest turn (simplest) routes. It is cleared, to commute from one part to any other part in this grid most of the commuters will pass through the primary street i.e. main street (horizontal one), and that the more people will use central part of the main street as compared to the peripheral parts. "This effects follows from structure of the network, since no one need to plan to pass through the spaces, and would hold under either assumption about distance" (Hillier, and Iida, 2005, p.554). it is also visible that main street is more integrated and easily accessible as compared to other parts. This property makes it preferable choice of the people to commute and to start their business activities. It is cleared from this example how street networks effect the vehicular and pedestrian movement.

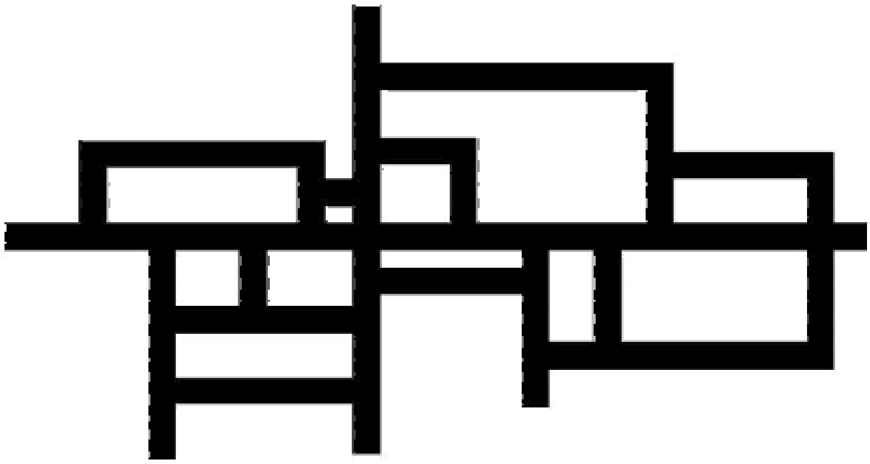

Figure 4: Hypothetical grid showing how network shape movement flows

Source: (Hillier and Iida, 2005, p.555)

As per hillier and lida, the networks effects have an influence on “to-movement (integration/closeness)” as well as “through-movement (choice/betweenness)”. The arrangements of nodes available between trip origin and destination point will frequently varies in accordance with definitions of distance but whichever distance definition we used the available arrangements are defined by the graph itself, here again the effect of network is visible. Therefore, network effects occur for both type of movement. It is explained by Hillier and Iida as, “First, every trip is made up of a pair of origin-destination, or to-movement nodes, and a variable number of through-movement nodes. But with increasing length of trip the to-movement pair will remain constant at two nodes while the through movement node count will increase. It follows that the longer the trip, the higher will be the ratio of through movement spaces to the origin destination pair, which of course always remain constant. We may expect then that the greater the graph length of the trip, the more it will reflect the choice, or betweenness, structure of the graph, rather than the integration, or closeness, structure” (Hillier and Iida, 2005, p.557).

To predict the choice of commutation is very difficult because it is influenced by many factors like aesthetics of street, shape of street (straight, zigzag), attractive spots, shops etc and also because of the human perception regarding space which is not pure metric. But in space syntax calculated integration and choice values are independent of this effect due to limitation of SS software. Hillier hypothesis was supported by Dalton (2003) that human most likely to travel the straight paths instead of zigzag routes because of fear of getting lost and reducing the complexity. However, this complexity minimizing technique is not mostly applicable to the resident of area who knew their area very well so they will not pay so much attention on how many turns they take but this strategy is applied to tourist who is not familiar with area very well and prefer short path having minimum turns (D’Acci, 2016). So the choice “likely pass through the street while travelling” varies from person to person but shows the potential of the street to have greater vehicular movement. While Ewing a Handy (2009) showed that there is a “negative relationship between long straight lines and urban street design qualities creating comfortable and pleasant feelings such as enclosure and human scale”: “the layout of the street network can influence the sense of enclosure. A rectilinear grid with continuous streets creates long sight lines. These may undermine the sense of enclosure created by the buildings and trees that line the street. Irregular grids may create visual termination points that help to enclose a space […] The sign of the coefficients in the model are as expected, with long sight lines […] detracting from the perception of enclosure […] [and] detract from the perception of human scale" (D'Acci, 2016, p.5). From the space syntax analysis, numerical value of choice (betweenness) can be determined easily which shows greater number of axial lines in between having several turns as well as less number of axial lines in between represent minimum turns (step or conversions). By keeping in view all the factors discussed above, it is stated that people usually follow the least angle change path instead of the shortest path so this definition of distance is used in depth map as a default setting.

The choice (mathematical betweenness) generally accelerates the more traffic flow in a street as compared to Integration (mathematical closeness) which likely to be passes through while commuting a street as in general curve streets have more segments as compared to straight ones and are taking more traffic flows (origin-destination trips) as compared to the straight streets of the same length (Turner, 2007). In this study, to explore the impact of urban street networks connectivity on vehicular flows/movements allows to look in depth that which streets permits efficient and smooth traffic movement to reduce congestion.

2.9 Spatial Urban Street Networks Connectivity and Vehicular Movement Influence at Urban Air Quality.

From the above reviewed literatures, it is easily understandable that the movement pattern of the masses and vehicles in a city has shaped by topographical and geometric features of the urban street networks. Through SS analysis the relationship between spatial connectivity with the focus on particularly on urban street networks and vehicular movement is determined. Hence, it is concluded that higher the street connectivity with neighbouring street, greater it has ability to capture traffic flow or pedestrian movement (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011).But on the other hand, it is studied by Alba and Beimborn that enhance street connectivity and accessibility (integration, choice) is a way to reduce traffic on street networks although increase accessibility also increases the traffic volume but it divert this traffic volume to neighbouring street networks and helps in reduction of congestion. This shows the difference between accessibility and mobility, mobility which is defined as, "measure of the vehicle-miles involved in travel" (Alba and Beimborn, 2005a, p.3) increased traffic congestion. Although, accessibility reduces the congestion by making better street connection, shorting the distance between origin and destination point which ultimately reduces the travel time and shorter the journey (Alba and Beimborn, 2005b).

As mentioned by Alba and Beimborn, there are two types of street network design available: Conventional Design (CD) and Neotraditional Design (NTD). "Neotraditional Design (NTD) is defined as an interconnected rectilinear grid patterns such as was commonly used before World War II in the U.S. and Conventional Design as a discontinuous pattern of cul-de-sacs common since the 1950s" (Alba and Beimborn, 2005a, p.3). It is highlighted by different authors that Neotraditional Design has greater traffic capacity in a given network based on its intersection availability. Greater the connectivity intersections, higher will be capability of the street network to uniformly distribute the traffic flow therefore small traffic volume concentrate at a specific junction. Figure below is the graphical representation of the NTD and conventional design, the former one has more connection which helps to reduce the turning vehicular load at a particular intersection and reduce congestion (access) (Alba, 2003).

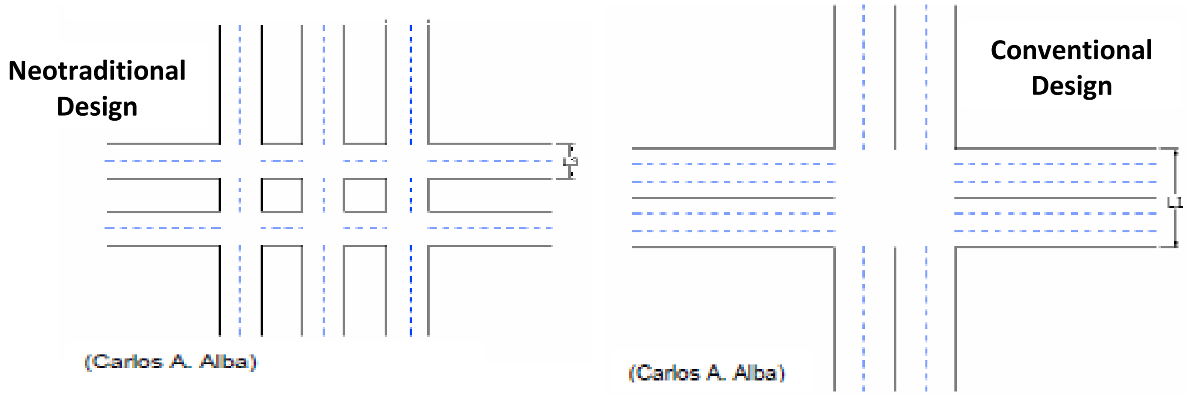

Figure 5: Conventional and neotraditional design.

Source: (Alba, 2003, p.6)

It is assessed that spatial structure of the urban areas has an influence on outdoor air pollution particularly due to road transport infrastructure. Spatial connectivity may not be a direct determinant of air quality but it linked with outdoor air quality in terms of vehicular movement on spatially integrated (connected) and separated road as well as it also dependent on the choice (betweenness). If the cities are planned properly and have less congestion due to more spatial connectivity mean less emission of air pollutants due to small quantity of burning fuel in result lesser will be the exhaust in atmosphere therefore it will not have greater contribution to degrade the outdoor air quality.

Except all of this there are several factors also influence the urban air quality such as spatial variations in land use is also going to impact the vehicular movement. It is highlighted by authors that spatial change bring change in vehicular flows. Commercial, industrial and areas having educational and professional institutes takes higher traffic volume during peak hours and contribute towards congestion which ultimately impact the urban air quality (Wang, Zhang, et al., 2015). Additionally, metrological factors i.e. wind and temperature also affects the air quality. Therefore, the concentration of PM10 is taking an effect of temperature and wind speed which is very prominent on stay time of PM10 matter in atmosphere. Particulate matter concentration is usually higher during winter as compared to summer due to increase in anthropogenic emissions (combustion of fossil fuels), burning of biomass, and unfavourable metrological condition (i.e. "more frequent occurrences of stagnant weather and temperature inversion during the cold period) for pollution dispersion"(Zhang and Cao, 2015, p.2) .

Although, from literatures reviewed in this section, it is assessed that air quality relates with vehicular movement directly and vehicular movement are facilitated by urban street connectivity. Therefore, if the road transport infrastructure is not well connected spatially it will received a high traffic volume which raise the congestion problem along with other causes of congestion like increased dependency on private vehicles instead of public vehicles, increased in number of vehicles as well as greater consumption of environment friendly fuels which impacts the urban air quality. "It is reported that, in London, UK, more than 80% of PM emission is from the road traffic (DoT, 2002) and in Athens, Greece, 66.5% is from the road traffic" (Srimuruganandam and Nagendra, 2010, p.184). By keeping in view such type of issues found in road transportation sector, IPCC (AR5) declared that roads are the highest contributor of greenhouse gases emission among other components of transportation sector and this concentration is increased from last ten years up to 80% as elaborated in figure 6(IPCC, 2014).

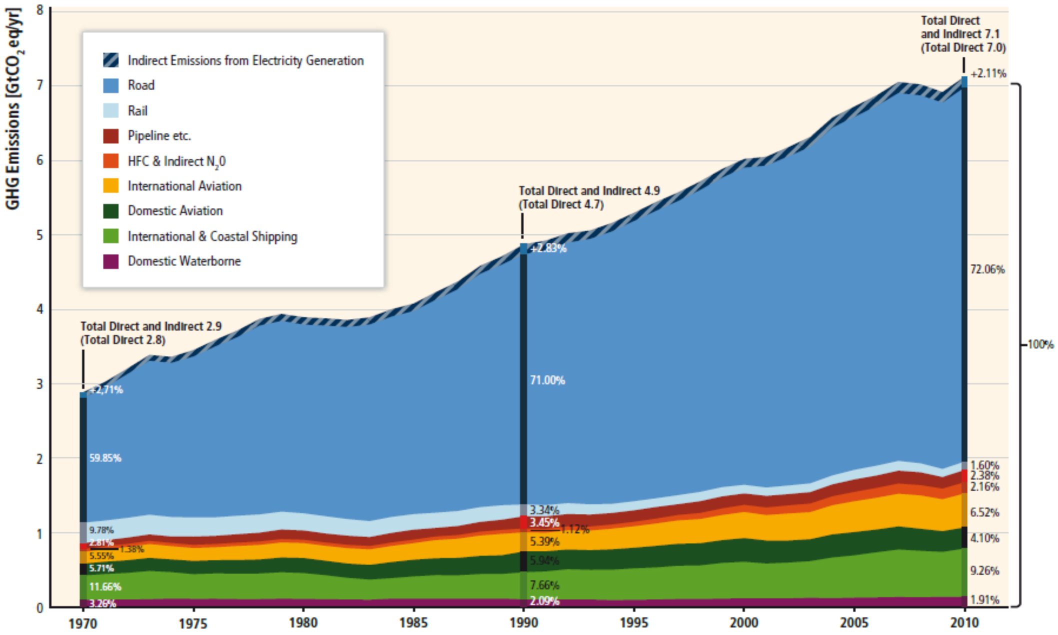

Figure 8.1 | Direct GHG emissions of the transport sector (shown here by transport mode) rose 250 % from 2.8 Gt CO_2eq worldwide in 1970 to 7.0 Gt CO_2eq in 2010 (IEA, 2012a; JRC/PBL, 2013; see Annex II.8).

Figure 6: Contribution of different components of transportation sector in GHG's emission

Source: (IPCC, 2014, p.606)

Hence, in most of the cities air pollution control is the biggest challenge for the city managers due to highest contribution of road transport sector (Modak, Jiemian, et al., 2011). GHG's emphases on the emission of CO_2 gases among many other air pollutant gases. While in air quality determination CO_2 emission is one among other outdoor air quality determinants like carbon monoxide (CO), Nitrogen dioxide (NO_2), Particulate Matters (PM2.5 and PM10) etc. These described in detail under heading of Air Quality Indicators.

2.10 Air Quality Indicators

Air quality of the cities is mortified by many anthropogenic activities due to gain in social and economic development activities. To maintain the air quality is the basic concern of city planner and environment professional worldwide particularly in developing countries. Since, it causes serious environmental and health issues. The contribution of road transport sector is the greatest to make the situation worst in developing countries particularly (Shrivastava, Neeta, et al., 2013). World health organization in 2005 updated its air quality guidelines to reduce the concentration of air pollutant emission in atmosphere. When the limits exceed above the WHO air quality guide lines then the emission of gases in the atmosphere becomes toxic for human health as well as degrade the quality of air (Krzyzanowski and Cohen, 2008). The basic air pollutants due to road transport sector are carbon monoxide (CO), Sulphur dioxide (SO_2), Particulate Matter (PM2.5 & PM10) and Carbondioxide (CO_2). Particulate matter (PM) is defined as 'the mixture of liquid droplet and solid particles suspended in air'(United States Environmental Protection Agency, 2017) They are divided into two types based on size i.e. PM2.5 (fine particles having diameter 2.5 micrometre or even smaller than 2.5 micrometre) PM10 (fine particles having diameter 10 micrometre smaller). It is measured in microgram/cubic meter. For this research study, our focus is to assess the influence of air pollutants i.e. PM_{10} in relation with connectivity of urban street networks (in terms of vehicular movement). Regression analysis will be used to find out that more connected roads have higher contribution in air pollution or not.

2.11 Lesson Learnt from Literature Review:

Vehicular movement is going to be increased all over the world in developing as well as developed countries due to haphazard increased in urbanization, population, not appropriate public transportation system as well as spatial configuration. Due to this, dependency on private vehicles is increased which is problematic for today as well as for future because it accelerates the issues like congestion, mobility, increased travel time in addition to have negative influence on the environment air quality. To resolve these highlighted issues which will be intense in future, it is better to think now and make strategy by doing research in this field is an appropriate way to fix them. This research provides the clear understanding how spatial configuration with a particular emphasis on urban street networks connectivity, influence the vehicular movement and urban air quality. All the three concepts have been studied in a comprehensive way by carried out literature review to demarcate the role and relationship among three of them. Urban street networks have an influence on vehicular movement as well as on the urban air quality because it is well stated by the Batty and Hillier that urban street networks actually shapes our city and movement.

While doing literature review, it is identified that attraction theory of movement: "movement is seen as bring to and from built form with differing degree of attraction and design is seen as coping with the local consequences of that attraction" , (Hillier, Penn, et al., 1993, p.29) talked less about spatial configuration of urban street network (which is independent of attractions). Whereas it has more focus on different degrees of attraction to attract the pedestrian and vehicular movement. Despite the fact, that alleys, street, squares, and so on when combined make global pattern. The effect of spatial configuration on choice (through movement) is determined when layout is deemed as possible route system. On the other hand, if layout is considered as system of origin destination then it is visible that configuration may also be concerned in to-movement (integration). It is very logical to say that presence of attractors plays vital role to attract pedestrian but don't have any impact on urban street connectivity. But for particularly vehicular movement as stated by Hillier that connectivity on of urban streets has a potential to attract trips or vehicular movement that is highly dependent on the street networks integration completely. This can be calculated by perform simple linear regression analysis -Ordinary least squares between number of cars motorized vehicles passing through these path ways and topological degree of the integration and choice of each urban street in a network (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011, p.12). Therefore, assessing the impact of urban street network connectivity on vehicular movement, it is determined that integration and choice are the most important parameters to be measured through space syntax analysis.

Space syntax analysis is a tool which gives insight knowledge of movement pattern in an urban area which are usually shaped according to the topology of the urban street networks. Axial map formation is the most important component of the space syntax analysis which is combination of longest and shortest intersecting axial lines and helps in doing vector analysis of urban street connectivity in terms of integration and choice. Highly integrated lines presented by red color while most segregated lines are shown by blue color on depth map.

Space syntax analysis is preferred for this research work due to ease of use and less data requirement. The result of the study will be represented in the graphical form. As for research study area, PM_{10} has been selected as an outdoor air quality indicator from guidelines developed by WHO due to availability of these emissions in greater concentration as compared to other outdoor air quality indicators. The technique use to analyse the impact of street connectivity on urban air quality is the simple linear regression analysis.

The interesting aspect of this research study is the presence of two dependent variables that going to be analysed against two variables in research model 1 and one independent variable in research model 2 which is shown in conceptual framework.

2.12 Theoretical Framework

Urban street connectivity is determinant of ease of vehicular movement and accessibility while have an impact on air quality indicators. Theoretical framework has been developed by keeping main research and sub research questions in mind to get the answers by following the right path provided by following framework:

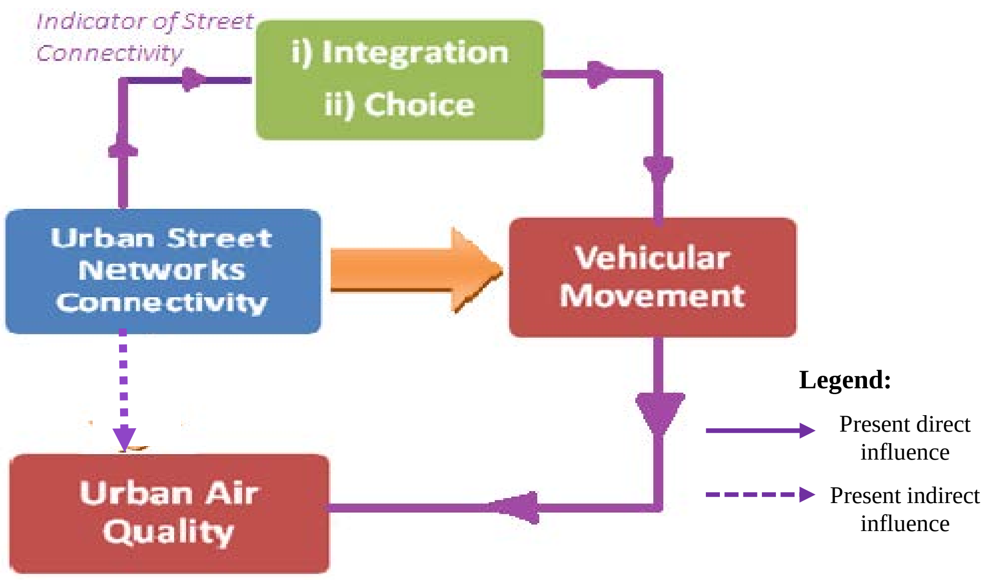

Figure 7: Theoretical conceptual framework.

Source: Author, (2017)

In this theoretical frame work two variables has been considered as dependent variable Vehicular Movement (y_1) and Air Quality (y_2) although having only one independent variable that is Urban Street Connectivity (x). Whereas, Integration (HH) and Choice (C) are considered as indicators of to measure urban street networks connectivity (x). On the other hand, to find out the impact of urban street connectivity (x) on air quality (y); vehicular movement, integration (mathematical_closeness), and choice (mathematical_betweenness) has been considered as an independent variable along with vehicular movement initially but from the literature it is determined that they only compliment to explain the higher flow of vehicular movement. Therefore, air pollution has direct relation with vehicular flows while indirect with urban street connectivity (facilitator of high traffic volumes). Therefore, it is decided to take the vehicular movement (x_1) as an indicator of urban street connectivity for this research part analysis.

Chapter 3: Research Design and Methods

This chapter is the representation of the research design, data collection and analysis methodology which is adopted to attain the research objectives.

3.1 Research Question

3.1.1 Main Research Question

To what extent does urban street networks connectivity have an impact on the vehicular movement and urban air quality, for Lahore City?

3.1.2 Sub Questions

i. Which urban street connectivity factor have significant influence on vehicular movement, specifically for Lahore City?
    - Integration (Mathematical_Closeness)
    - Choice (Mathematical_Betweenness)

ii. At what extent vehicular movement impact the urban air quality, for Lahore city?

3.2 Conceptualisation

Based on the conceptual framework, variables and indicators have been identified. The aim of this activity is to understand how independent variables influence the dependent variables. They are categorized in two types: Dependent variable and Independent variable. Dependent variables are those variables, influenced from the independent variables in a cause effect relationship. This influence could be positive or negative, stronger or weaker which could be realized by observing relationship among them. While independent variables are defined as input variable or shows the effect in a cause effect relationship (Van Thiel, 2014).

3.2.1 Dependent Variable (Y)

- **Vehicular Movement**

Most of the cities from the developing world are dependent on the vehicular mode of transportation particularly private transportation like cars, buses, motor-bikes due to inappropriate public transportation system or might be due to poorly urban street connectivity. It means that vehicular movement is highly dependent on urban street connectivity among all other factors which provide base for vehicles to move and connect different parts of the city. Therefore, vehicular Movement is considered as a dependent variable to analyse the traffic flow patterns for this research because "Lahore city" which is a part of developing country "Pakistan" having huge number of private motorized vehicles instead of good public transportation system. It creates problems like congestion, increased travel time, budget, and fuel consumption for commuter.

According to the literature the vehicle traffic volume is used as an indicator of the vehicular movement (Litman, 2003). Secondary data collected for this research work is annual average daily traffic count (AADT) to determine vehicle traffic volume flow for primary, secondary and local roads which has already been defined under the scope of this study. Traffic count data is obtained by the various traffic count survey reports which has been conducted in a city and available with Government Departments i.e. Lahore Development Authority (LDA), National Engineering Services Pakistan (NESPAK) and Traffic Engineering and Transport Planning Agency (TEPA).

- **Urban Air Quality**

From various studies and international reports like IPCC, it is identified that road transportation has the largest contribution to deteriorate the urban air quality. The parameters involved to make the condition worse is higher dependency on vehicular use, congestion, increase in commutation distance, as well as poorly integrated roads/ streets. This verify that urban air quality particularly depend on these parameters of the road transportation sector which makes it dependent variable for this research study.

With reference to chapter 2, Particulate matter (10) is considered as indicator of urban air quality. Selection of PM10 for this research study particularly for "Lahore" city is based on the findings of previous studies carried out to determine which air pollutants have comparatively greater contribution to deteriorate the urban air quality. It is highlighted by Colbeck, Nasir et.al in research study, carried out in "Lahore" city that particulate matters are one of the greater contributor of air quality among many other air pollutants due to vehicular movement along urban streets (Colbeck, Nasir, et al., 2011). Sample selected to find out this correlation is limited to a small area of the primary and secondary roads due to unavailability of air quality data for whole street networks of the Lahore, city.

Particulate matter (10) numerical data is collected by Environmental Protection Department, Lahore (EPD) as well as from the various environmental studies report conducted by NESPAK & TEPA.

3.2.2 Independent Variable (X)

For this study, Urban Street networks connectivity is considered as an independent variable with reference to literature view carried out in chapter 2. To measure this variable at global scale, integration (x_1) and choice (x_2) are selected indicators for this research work based on definition provided by Hillier and Iida, 'how close is one street with the other neighboring streets' (Integration) as well as' how likely you pass through the certain street while moving in a city' (choice) (Hillier and Iida, 2005). Hillier, somehow able to show that movement pattern is dependent on Integration value. Axial lines having greater integration values are mostly those lines through which topologically shortest path sprint (Steadman, 2004, p.484). Topological distance (steps/turns) value for integration and choice gives us the accessibility information as well and for this research study this topological measurement is not restricted to certain value of radius 2km and 3km but it is calculated for all values of "n" to do axial analysis at global scale.

3.3 Operationalisation

The objective of this activity is to transit theoretical concepts in to reality to show what will be studied or measured exactly. The brief overview of the concepts, variables, and indicators is shown in the following used to carry out research at this topic. It is also specified while operationalization that enlisted controlled variables (refer: chapter1, heading 1.6) are not being computed while performing analysis due to unavailability of data therefore they are not included in operationalization table and stated under limitation of the research study.

Table 1: Operationalisation of dependent and independent variables

Source: Author, (2017)

Concept	Variable	Indicator	Scale/ Units	Source
Dependent Variables				
Analysis of Traffic Flow Pattern	Vehicular Movement	Vehicle Traffic Volume [Average annual traffic count on each streets (roads)]	Continuous Numbers (0,1, 2....)	Secondary Data collected from TEPA, NESPAK, LDA, for Lahore Space Syntax
Environmental Quality	Urban Air Quality	PM_{10}	Continuous numbers µg/m^3	Secondary Data collected from EPD, TEPA, NESPAK, LDA, for Lahore.
Independent Variable				
Spatial Accessibility Analysis	Connectivity	Axial Integration (HH), (r=n at global scale) (calculate how integrated is street with others neighbouring streets in vicinity of "n" times topological change of direction Choice (r=n) (calculate the potential route, which is likely to pass through while moving in a city)	Continuous numbers From 0.000 to onwards	Space syntax Analysis using Depth Map ArcGIS for Axial map formation

3.4 Research Strategy

From the research questions stated in chapter 2, it is identified that this research study comes under the explanatory field of research. The basic objective of this study is to explain the influence of one course of action (urban street connectivity) on the other course of actions (vehicular movement and urban air quality). By keeping in view all of these points, it is easy to categorize this study under deductive research in which explanations can be made by using existing relevant theories. Therefore, this research objective is viable to fulfil by using secondary quantitative data analysis strategy as a core research strategy due to existing secondary data sets as well as existing theories defined in various literatures. This research study also known as desktop study, characterize with an approach in which existing data sets are collected by someone else for different purpose but used by researcher to carry out the his/her own research. This strategy is very common to adopt by researches these day due to time and financial constraints while on the other hand it facilitates the researchers due to availability of quality data sets through national and international data sources.

The scope of this study is limited to assessment of the urban street connectivity impact on vehicular movement and urban air quality. Further narrowing down the scope of study focuses trunk, primary, secondary and local urban street networks of Lahore city, including other variables of this study i.e. urban air quality and vehicular movement. Hence, this research study is considered as a city scale study, its results can be generalized for cities having similar city characteristics as Lahore city but for cities that have different characteristics, this research results are not applicable. For this research the data for vehicular count and urban air quality indicator (particulate matters PM10) is collected from various government departments like

TEPA, LDA, NESPAK and from EPD in the form of the traffic count survey reports which were conducted by these stated organizations under different time scenarios for years 2015-2016 and 2016-2017. As there is no development occur after 2015 as per LDA official statement.

As Lahore is the city of approximately 10 million habitants having a big network of urban streets comprised of complex urban street networks usually called ‘roads’ and divided into different types trunk (motorways, highways), primary, secondary and local roads. Therefore, within a given time frame the primary data collection is not a suitable case strategy for this research study to generate adequate results. However, secondary data collection is also somehow the difficult task in developing countries due to inadequate information and data up gradation. Although the data availability for these urban street networks make the selected research study suitable for this research study.

For desktop study, access to information is always a difficult task which is considered as a biggest limitation for the research study. Because most of the data which is available with government departments is not updated, incomplete and collected for different purpose (not relevant with research study purpose) which may sometimes be not able to fulfil the requirement of this research study. These factors may involve changing or reshaping the indicators of the research. However, the data collected by the departments of the Lahore city is having the same purpose which is collected to improve the urban street networks accessibility through improving connectivity by initiating new and improving existing road infrastructure development. So, the validity of the data is adequate for these existing data sets used for research purpose.

3.5 Data Collection Tools and Methods

Desktop study has already been identified as a research strategy for this quantitative study. It highlights that there are basic two types of data sources are available for this study. First one is the data collected from existing data sets and literature. Secondly, is from open street map.

3.5.1 Existing Data Sets and Literature Review:

Lahore city is second largest city of the Pakistan. In past few years, many road infrastructure development projects has been completed to make city more integrated, attractive as well as prosperous for its inhabitants. But with this development car or private vehicular dependency is not reduced. Hence, most of the data collected making correlation between variables like vehicular movement, air pollution is available in the form of traffic impact assessment reports and environmental impact assessment reports with the government departments like TEPA, EPD, NESPAK and LDA. These different reports have traffic count and PM10 details of most of the roads covered under those projects. These reports are prepared on the base of primary data collection through field surveys conducted by the respective department. In these reports data for trunk, primary, secondary and local streets is available but in all over the city streets are thousands in number and for all streets, vehicular count and air quality measurement data is not available.

As well as for whole city, traffic count and air quality data is very difficult to collect by researcher herself at a time is very difficult as a primary collection. Because it required large number of human resource, finance and time in a developing country like Pakistan in a given time frame. Therefore, literature review of the existing data sets, reports and surveys has been used for data collection. Around 20% of the roads (streets) has taken as a sample size to carry out this research study due unavailability of the required data for rest of the roads.

Summary of data sets:

- Research Area: Lahore City, Pakistan
- Project Scope: Trunk, Primary, Secondary and Local Streets
- Type of Data Collected: Traffic Count & PM_{10}
- Data Collection Year: 2015-2016, 2016-2017

3.5.2 Google Open Street Map

Google open street map is used as data tool in order to collect the data for urban street connectivity visualization. It is a free tool available and used by different researchers, companies, as well as by academic institutes for research and other purposes according to their need. From google open street map, boundary of the city is determined. The city map is then imported in QGIS (version 2.18.7 with Grass 7.2.0) by using this version axial lines are drawn to represent all urban street networks of the Lahore city. This data will contribute to analysis the indicators of urban street connectivity by using Depthmap software.

3.6 Data Analysis Techniques

Data analysis is the very important step in the research study. It shows the findings of the research study based on the results. This step serves as the base for the conclusion drawn from research study to analyse correlation between variables and their influence, either there is strong influence of independent variable on dependent variables or not. Figure below show the process of spatial analysis of urban street networks connectivity.

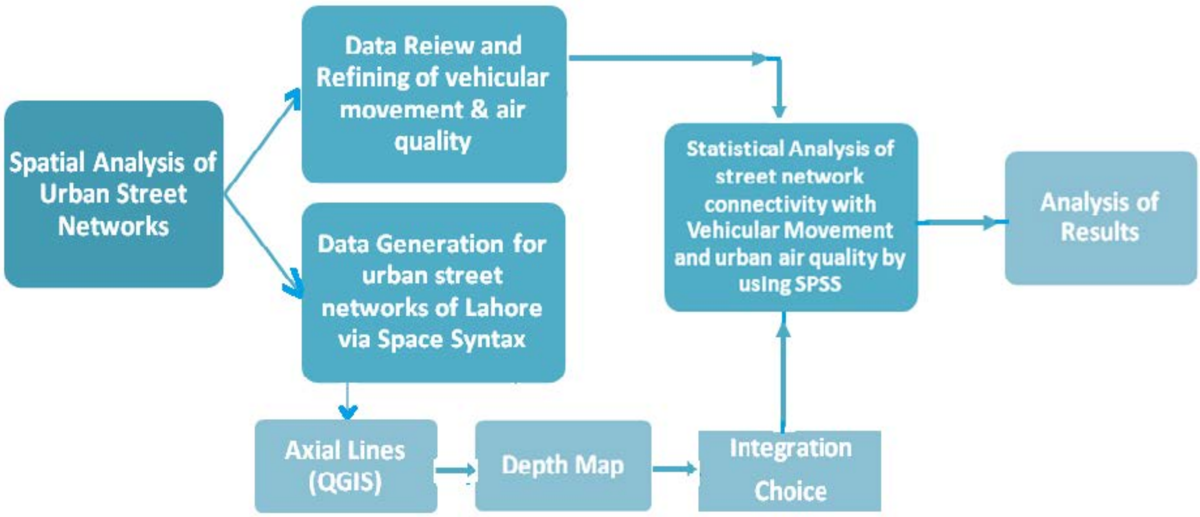

Figure 8: Data Analysis procedure

Source: Author, (2017)

3.6.1Data Review and Refining

This step involves critical review of the secondary data which is collected from the government EIA and TIA reports. This data has been collected by the different governmental departments for different projects having purposes to improve urban road infrastructure under different time span and scenarios, having same indicators used which are used in this research study. To make the symmetry of the collected data in order to use it in way that it can fulfil the research study requirement is carried out by following the step of data refining. The advantage of this step is you can exclude the extra data or the data which is old dated, not fulfilling the research study criteria or modify it according to your research study if necessary. For example: data code, measuring units, name can be changed according to the requirement of research study in a new way.

For this study, as already mentioned that number of vehicles and air quality data (PM10) is extracted from the reports so the name, measurements unit are not changed. Projection is applied on the data sets which were collected during year 2015-16, 2016-2017 by using the value provided by transportation department of the Lahore city, although it is stated that there is no major development occur after year 2015. To increase the validity of the data this projection has been done. This procedure makes data sets ready to compare with urban street connectivity indicators to perform statistical analysis.

3.6.2 Data Generation

This step link formulation of the primary data for urban street networks by using google open street map (secondary data source). First the boundary of the city is marked on google map and then by using open street map extension as a background layer in QGIS software, axial lines are drawn which is the representation of urban street networks. All the streets are marked as an axial lines either they are motorways, highways, primary, secondary or local roads because of the feature of the software which is not taking in account features of the urban street neither types nor characteristics. Straight lines are used to represent roundabouts because software is episodic by the presence of the roundabouts although they are serving as a traffic regulator to improve traffic flow. After formation of axial map, it is imported in depth map software to perform analysis for integration and choice which is done by software by itself in a quick and simple form. To create data on street networks from both map information is taken and tabulated to perform further statistical regression analysis by using SPSS software to answer the research questions.

3.6.3 Statistical Analysis

Statistical analysis is carried out to analyse cross-sectional data sets in the forms of simple and multiple regression by using SPSS software.

This analysis is performed in following steps: first the relationship of vehicular movement and urban street connectivity is found out by using multiple regression analysis method to answer research main research question as well as first sub-question one. This correlation let us to visualise either they have strong correlation or not and between Integration and choice which variable has greater influence on vehicular movement.

To answer research sub question two and second part of the main research question i.e. ‘impact of urban street connectivity on urban air quality’. Simple linear regression model is used in this research study. This will help the researcher to find out the relationship between urban air quality and urban street connectivity by taking in account vehicular movement in urban street networks.

- **Regression Analysis:**

Regression analysis is the statistical model to investigate the relationship between dependent variable and independent variables.

Regression model is defined by this equation:

Dependent Variable = Independent Variables + Random Error

In simple linear regression, there involvement of only one dependent variable (y) and one independent variable (x), which represent y in terms of x means change in amount of x will cause α_1 times change in amount of y. Equation below shows the simple linear regression model;

Equation 3: Simple linear regression model

$$y = \alpha_o + \alpha_1 x + \varepsilon$$

Source: (Yan and Su, 2009)

In above equation, y and x are dependent and independent variable, α_o is an intercept, "represent value taken on y when x is zero" (Menard, 2002, p.1), while α_1 is the slop (shows unit increase in x value changes the value of y), x is independent variable while ε is random error (capture the amount of variation not predicted by α_o and α_1). The correlation effect is measurement of connotation between two arbitrary variables. Second type of regression model is called multiple regression models having more than one independent variable as shown in equation below:

Equation 4: Multiple regression model

$$y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \ldots\ldots\ldots\ldots + \alpha_n x_n + \varepsilon$$

Source: (Yan and Su, 2009)

In this equation (2), $(\alpha_{1,}\alpha_{2,}\alpha_{3,}\alpha_{4.}\alpha_{n})$ are regression coefficients, $(x_{1,}x_2,\ x_{3,}x_4+\ldots\ldots\ldots\ldots+x_n)$ are independent variables while other factors are the same as described to illustrate equation 1. This type of analysis is more acquiescent to "ceteris paribus analysis" *(Wooldridge, 2015, p.68)* as it permits the control over other factors which might have effect on dependent variable. Whereas, due to presence of more than one independent variables through which variation in variable 'y' can be better explained is also advantage of multiple regression analysis.

For this research study, single and multiple regression models is used due to availability of one and more than one independent variable. Statistical computation will be carried out by using statistical analysis software that is SPSS. (Yan and Su, 2009)

3.7 Reliability and Validity

Research reliability is important research parameter to see that if the research will repeat in with same data sets under same circumstances it will be able to give the same results. This research study has two data sets, one data set collected from the secondary studies carried out by governmental departments but having same indicators and units. It shows that data is reliable as it is verified from the concerned department so reliability is adequate. As in the second data set, primary data is produced by drawing axial lines on google street map manually in QGIS software that would be the condition that data may loss its reliability but if the appropriate rules will follow to draw axial lines while doing such type of research again under same circumstance for same city then it will not loss the reliability. The version of data tool analysis is also an important parameter which contributes in reliability for again analysis, same version of data analysis tools should be used to maintain the reliability of the research.

While validity aims to represent how strongly the research study is fulfilling the criteria of internal and external validity. For this research study, internal validity reflected the data measurement and analysis methodology is fulfilling the requirements of internal validity. Space syntax which is one of its kinds used as an appropriate tool to draw axial lines and after that integration as well as choice value is calculated by using depth map software. This shows that used methodology enables to achieve the satisfactory results with negligible error. On the other hand, this study can be generalised for the same city having same street pattern and characteristics but cannot be generalised for the other cities who don't reflect similar characteristics, circumstances and pattern of streets. If there is a slight difference in results, it shows that there are some facts which are missed in research study, needs to be explored by doing further research in this field.

Chapter 4: Research Findings

This chapter is most important part of this research thesis to grasp the significant finding extracted from the research. It will be helpful to evaluate the appropriateness of the selected research model that is based on Multiple Regression and Simple Linear Regression Analysis to answers all research questions. This chapter is divided into two parts as listed below:

i. Data preparation and Description
ii. Inferential Analysis
   a. Research Model 1: Urban Street Connectivity and Vehicular Movement
   b. Research Model 2: Air Pollution with Urban Street Connectivity in terms of vehicular Movement

The first part has emphasised on the data preparation and description, as it has a significant influence on the results of the research. Under this part, different tests have been conducted by using SPSS software to make research transparent, valid and reliable. This step ultimately leads towards elimination of the biased research results. While second part of this chapter is formulated to carry out inferential analysis show different analysis between dependent and independent variables in order to find out the relationship among them to answer research questions.

Main Research Question:

To what extent does urban street networks connectivity have an impact on the vehicular and urban air quality, for city of Lahore?

Sub Questions:

i. Which urban street connectivity factor have significant influence on vehicular movement, specifically for Lahore City?
   - Integration (Mathematical_Closeness)
   - Choice (Mathematical_Betweenness)
ii. At what extent vehicular movement impact the urban air quality, for Lahore city?

Research Model 1:

This research model is developed to answer sub question i. and ii. stated above which will leads the researcher to analyse the overall influence extent of urban street connectivity on vehicular movement.

Equation 5: Multiple regression equation for research model 1

$$y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 + \varepsilon$$

Source: Author, (2017)

y = No. of Vehicles (Motorized)

x_1 = Integration (HH)

x_2 = Choice (CH_Nor)

Research Model 2:

This research model is developed to answer sub question iii. stated above which will leads the researcher to analyse the overall influence extent of urban street connectivity on urban air quality.

Equation 6: Simple linear regression equation for research model 2

$$y = \alpha_o + \alpha_1 x_1 + \varepsilon$$

Source: Author, (2017)

y = PM10

x_1 = No. of Vehicles (Motorized)

4.1 Data Preparation and Description

4.1.1 Description of Research Area

As shown in the map that Lahore is one of the biggest city of Pakistan having population of 10 million which is increasing day by day. In a result, the traffic flows also increasing every year with an annual growth of 3.108%[2]. From the report published by Bureau of Statistics Punjab, Government of the Punjab, it is stated that total 42876623 number of vehicles are registered by year 2015 in Lahore district and this number is keep increasing by every passing year. This vehicular movement is supported by road infrastructure having thousands of connecting roads with other cities (trunk roads), primary, secondary and tertiary (Local) roads network as shown in figure below.

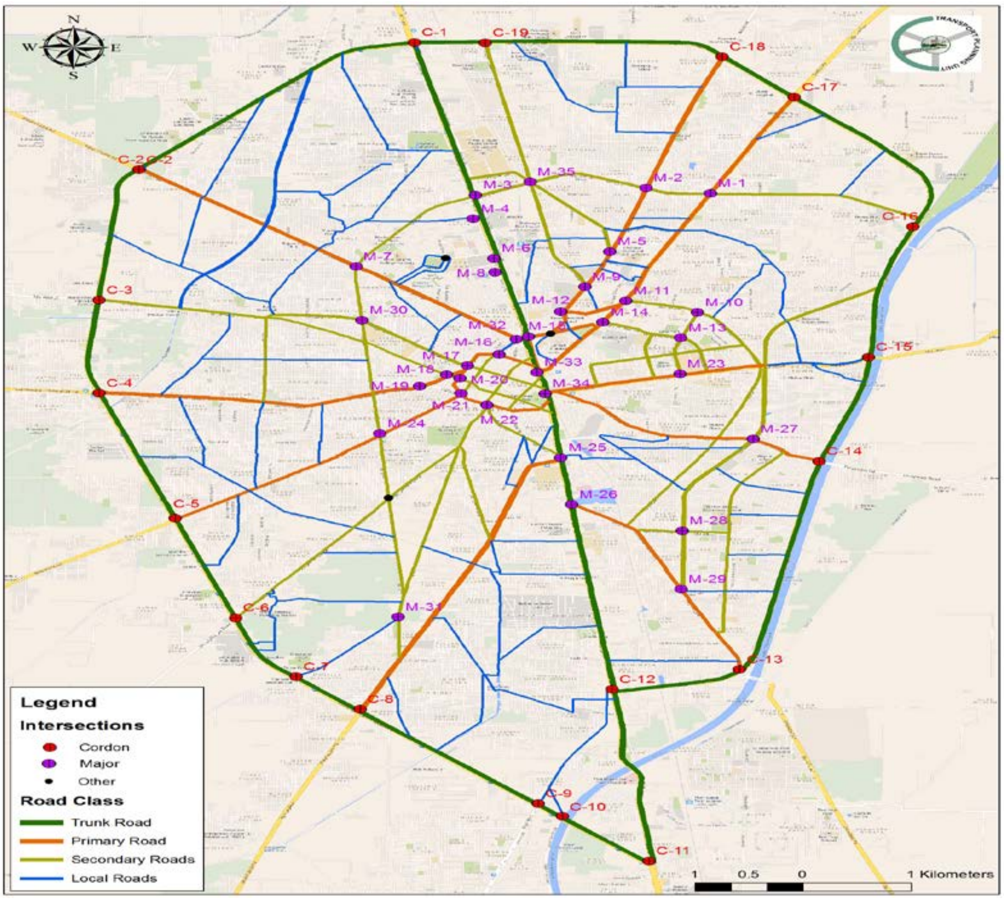

Figure 9: Lahore City Urban Street (Road) Infrastructure Map

Source: NESPAK, (2016)

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[2] Secondary data source (NESPAK)

[3] http://www.bos.gop.pk/publicationreports

4.1.2 Data Refining and Labelling:

To run the stated models for analysis, at this stage refining of the secondary data sets (both dependent and independent variables) has been carried out at utmost preference to avoid ambiguity in calculations for analysis.

i) Dependent Variables

For vehicular flow representation, vehicular count data has been collected for mixed type of urban street networks (primary, secondary, tertiary road) from different parts of the city to eliminate the segregated data representation. Therefore, this data represents well mix data sets. At the start the total vehicular count sample size only for motorized vehicles was 122. Afterwards data refining process has been carried out in which duplicate and unauthenticated values were removed. Hence, final sample of dependent variable (Vehicular Count) is comprised of 106 number of observation to run analysis with outliers and 101 is without outliers.

While for other dependent variable i.e. particulate matter 10 (PM10), the number of observation was 33 at start. This data represents the air quality in terms average concentration of PM10 at different intersections of the urban street networks (trunk, primary, secondary, tertiary road) as shown in figure below. After data refining the final data set consists of 30 observations which is not a very big data set due to unavailability of the updated and continuous monitoring of air quality data in city.

Figure 10: Sampling point for air quality (PM10) concentration measurement in Lahore city

Source: NESPAK, (2017)

Furthermore, air data quality requires to prepare the axial map. As it is highlighted by the data provision authorities (NESPAK) that air quality remains the almost same for the urban streets coming under the 2km radius which is considered as minimum radius in which air quality does not change significantly although under different circumstances this distance varies. Therefore, after plotted air quality (33 data points) on axial map in the form of red circular point as shown in fig.11. As average PM10 concentration is measured at intersection/junctions of urban street networks therefore, total number of vehicular count has been taken at respective road intersections/junctions to perform simple regression analysis.

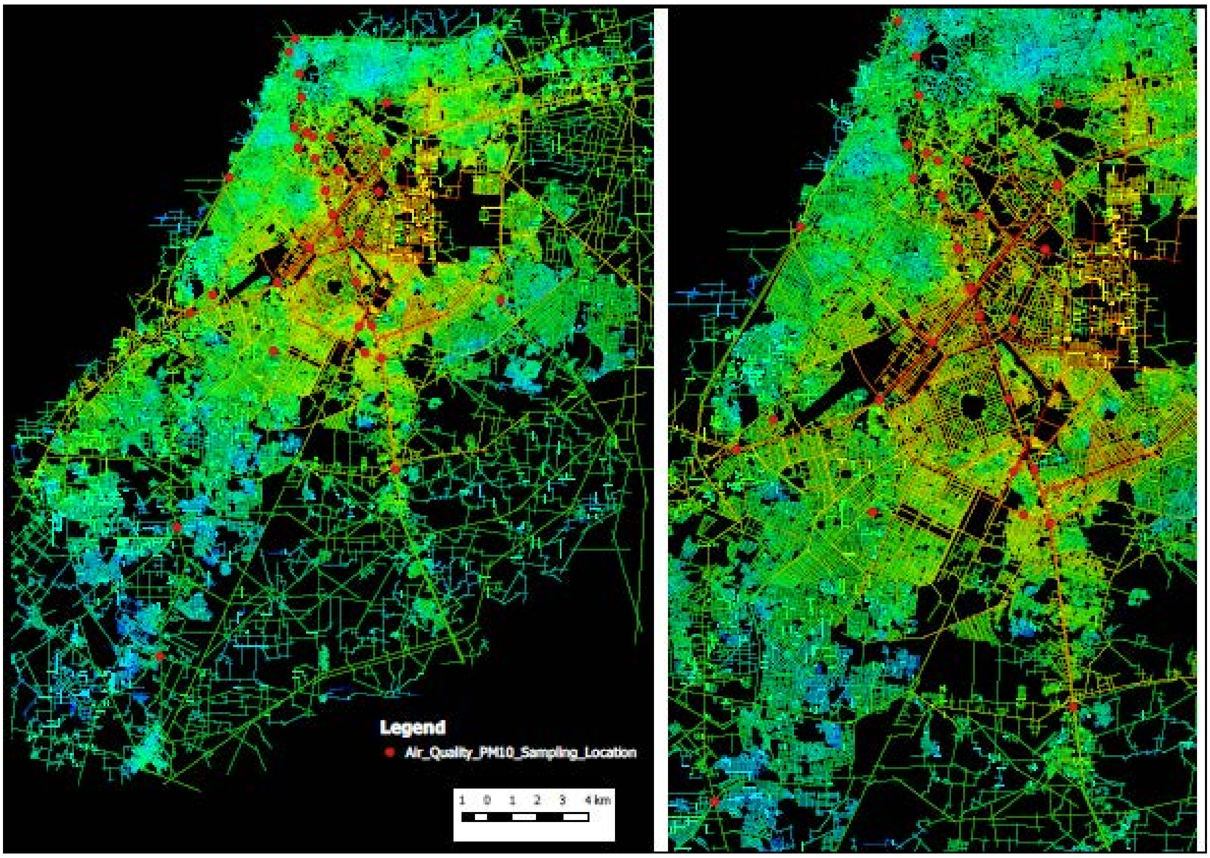


Figure 11: Axial map for air quality (PM10) concentration measurement points in Lahore City at different street intersections

Source: Author, (2017)

From the above graph, it is also clear that most of the data sets of air quality are mostly found very close to each other, taken along one long street but at different junctions (east-west direction) while few are in other parts of city. Although, points are not overlapping each other in real but quite close to each other. Because at some points PM10 concentration measured even less than radius of 2km due to uneven distribution of traffic flows at different urban street networks.

ii) Independent Variables

Integration and Choice

For research model 1, to represent urban street connectivity, integration and choice values have been taken in account. To get these independent variable indicators values, first step was to prepare the axial map using Google Street Map (GSM) as a base map. Hence, sixty thousand axial lines has been drawn to cover all primary, secondary, local as well as motorways and highways for the whole Lahore city. This research is focused on motorized vehicular movement therefore numbers of non-motorized vehicle like bicycles, donkey carts, etc are not taken in account and very narrow streets have not been considered which are only earmarked for pedestrian movement and motorized vehicular movement is not possible in these urban street networks.

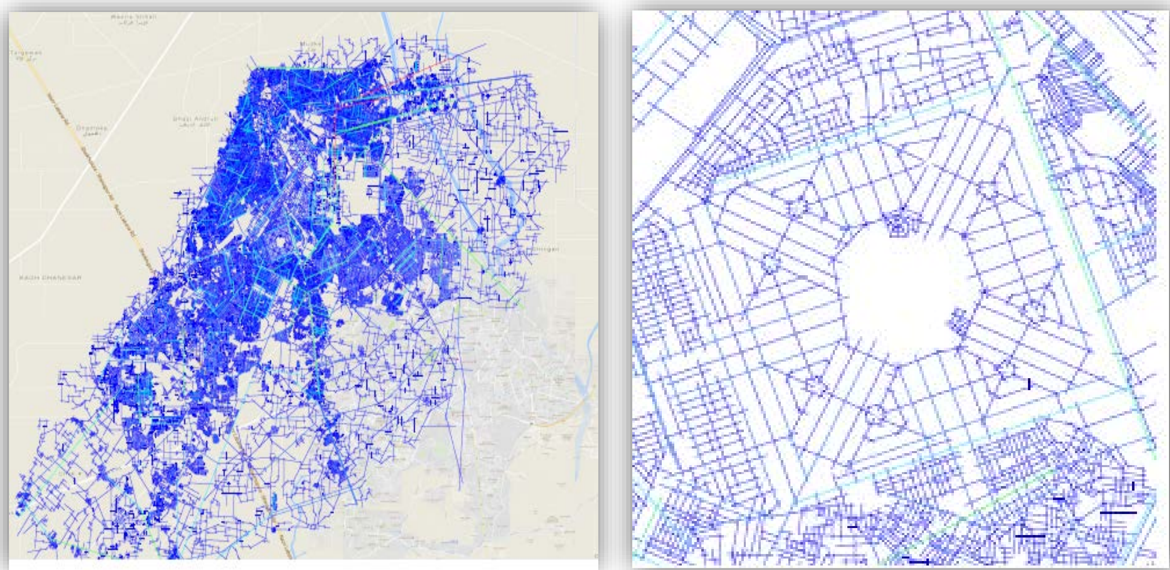


Figure 12: Representation of Lahore city axial map using GSM as base map

Source: Author, (2017)

However, by focusing the research scope connecting highways and motorways has also been considered along with primary, secondary, local networks while preparing city axial map. Furthermore, the edge effect[4] of axial map has also been considered during the axial mapping because for this analysis radius is equal to 'n' number in km (Global scale) and not limited to a certain value of radius (i.e. r=2, 3, 4, km) but if this effect has not been taken in account then axial lines at the boundary of the city will be considered segregated during analysis which will affect the results of analysis. Since, it has a strong influence over results of integration and choice values for vehicular movement research study in space syntax analysis. Therefore, this effect has been considered and rectified by drawing extra axial lines beyond the city boundary to get more appropriate and accurate space syntax analysis results for urban street connectivity.

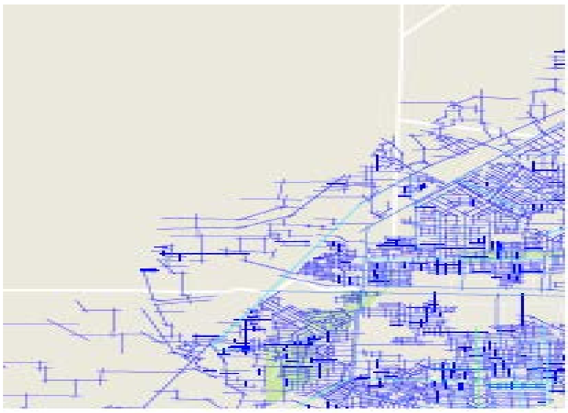


Figure 13: Removal of edge effect by drawing axial line beyond city boundary

Source: Author, (2017)

[4] Edge Effect: "Describes the fact that the edge of axial models appears disproportionately segregated due to the fact that streets on the edge of the map are not connected onwards" (UCL Space Syntax, 2017)

4.2 Urban Street Connectivity Analysis

After preparation of the axial map, connectivity analysis has been carried by considering the value of Integration (mathematical closeness) and Choice (mathematical betweenness) for the urban street networks of the Lahore city. Depthmap-Xnet 0.35 software version has been used along with QGIS to run this analysis and to get the figure of Integration and Choice as output of this connectivity analysis. The results of this analysis is given below in the form of integration and choice axial maps for further elaboration.

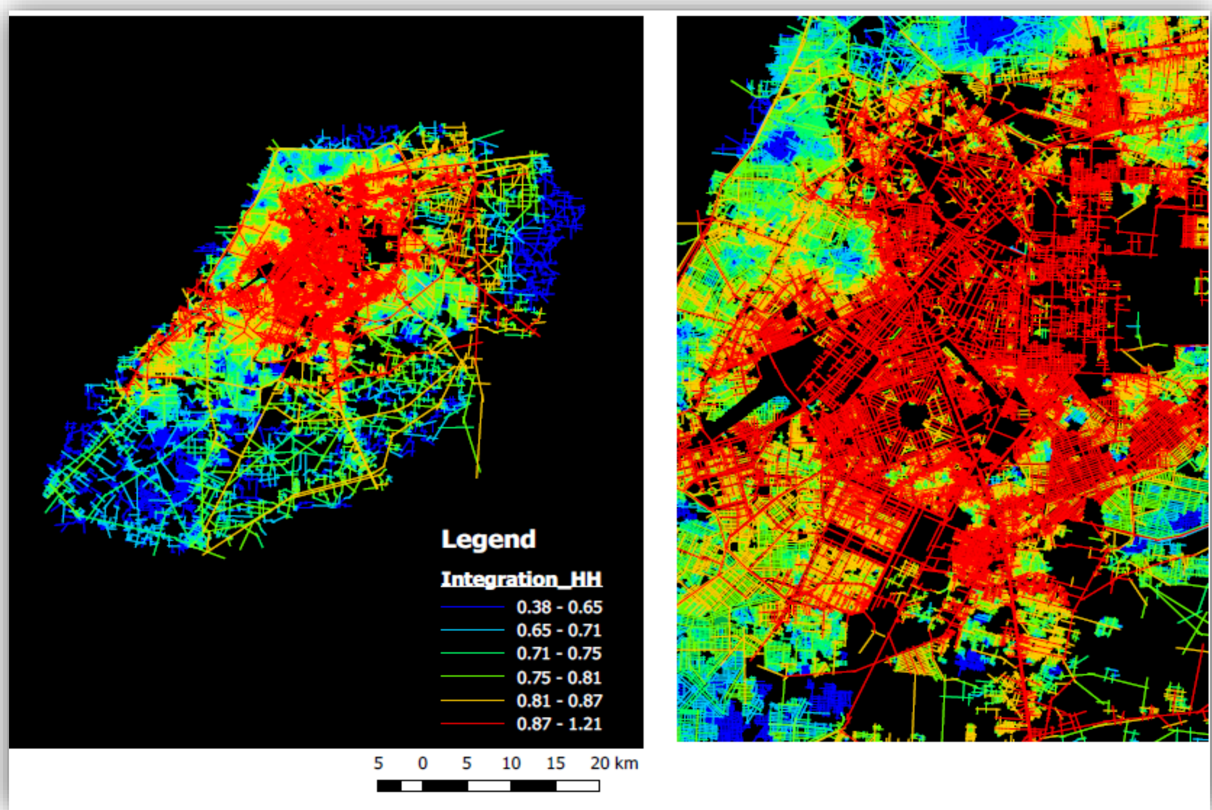


Figure 14: Axial integration (mathematical closeness) at 'n' topological steps for Lahore City

Source: Author, (2017)

Basically, axial lines are the linear representation of space and for this research they are used to represent urban street networks. Above integration map illustrates integrated or segregated spaces (urban streets) in the city of Lahore. More integrated places are easily accessible as compared to segregated places. As shown in legend that axial lines having higher values of integration falling between range of 0.87-1.21 are represented in Red color. Although, with the decrease of integration value from 1.21 (maximum integration value) to 0.38 (minimum integration value) the color scheme changes from red towards yellow, green and blue. Which is classical representation of axial integration map in general. It also illustrates that among sixty thousand axial lines some streets are completely isolated having minimum integration level 0.38.

Furthermore, the city centre (old and new) shows a higher level of integration as it is completely red in axial map and due to higher integration level, having mixed type of land use pattern as well as attractions like shopping malls, central station, offices, small and medium size industries in real. However, it is investigated that by moving from North to West towards the periphery of the city integration level is going to decrease. This decrease in integration level is somehow associated with the unplanned horizontal city expansion towards periphery of the city and most of the road development projects are under construction and consideration now a day at real ground to integrate these parts of the city. Therefore, it is expected to see greater vehicular movement in city centre as compared to the periphery of the city. Which is explained in next section by using regression under research model 1.

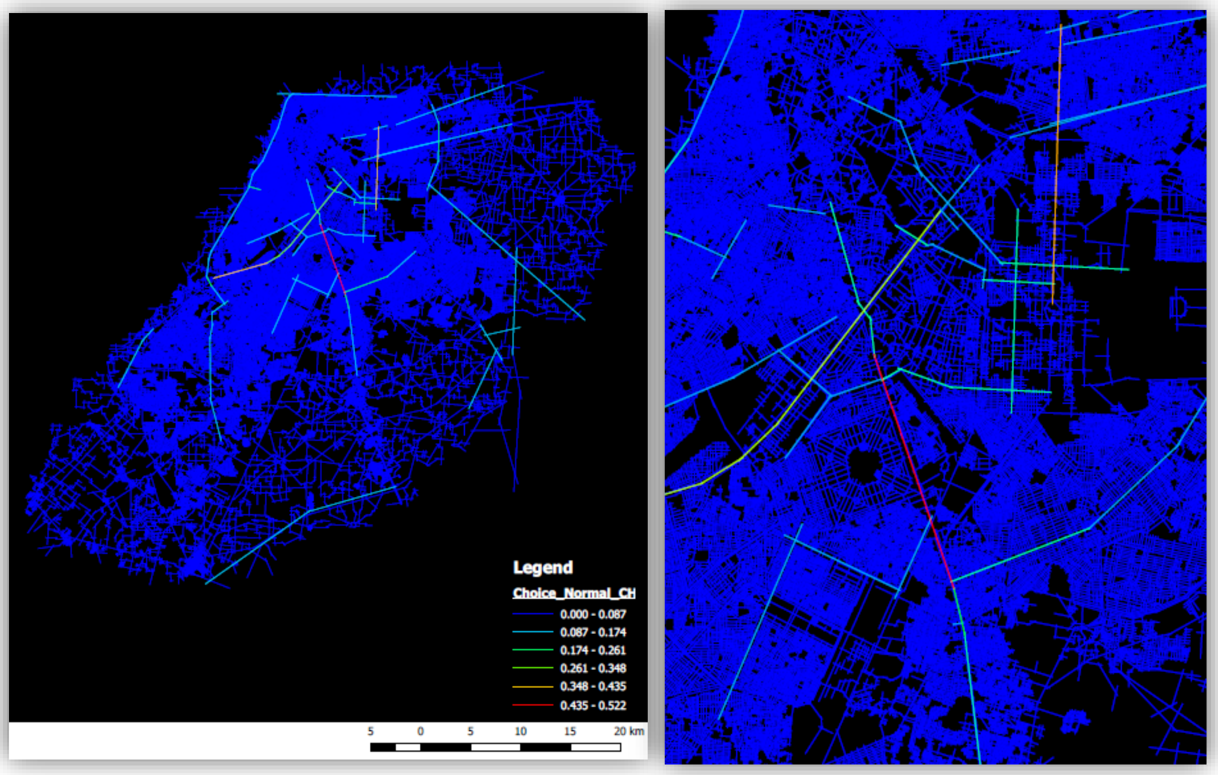


Figure 15: Axial Choice (mathematical betweenness) at 'n' steps for Lahore City

Source: Author, (2017)

Consider the above map which illustrates the choice (mathematical_betweenness) value of the urban street network indicates which street is most likely used to pass through while moving in a city. By doing analysis of axial choice map it has been analysed that there are very few streets in all over the city which are frequently used to pass through while moving in a city. Ferozpure road part from Gajju matta to Gulberge has the highest value of the Choice. But other factors may also impact the choice like number of attractions along the streets, ease to remember the path and less number of turns particularly in term of vehicular movement but these factors (like no. of attractions, psychological effect, travel time, congestion etc) are not taken in account in SS during analysis due to limitation of software. From the graph, it is cleared that most frequently used part of the urban street is the straight one having few number of turns. The highest choice value of axial lines (represent urban street networks) is falling in a range of 0.423 to 0.522 which is represented by red axial line. While moving from highest to lower value (0.000) of choice follows the color pattern red to blue. Therefore, in above Lahore city map most of the lines are blue which indicates that there are very few streets in the Lahore city which are frequently used while moving through the city. It is important to describe her that for analyses normalized value of choice is considered which is from 0-1. Although, the concept of choice remains the same.

4.3 Data Checking for Research Model Validation

4.3.1 Correlation Test

It measures the strength of the linear relationship between two variables in descriptive form. Correlation among variables is represented by taking in account the value of pearson correlation. It range is between -1.00 to +1.00. Negative and positive sign represent strong positive and negative relationship. If the value of Pearson correlation is closer to +1 it shows a strong positive linear correlation among variables and if it is closer to -1 then it represents a strong negative linear correlation, while when around 0 no correlation. To run multiple regression analysis, this test is good predictor to determine the strength of linear relationship between independent variables. If there is a high correlation exists between independent variables then it is not appropriate to run a multiple regression analysis.

i. Research Model 1

Scattered plot graph is considered an appropriate to visualize eventual relationship and from figure below, no linear relationship is found between integration_mathematical _closeness and Choice(Nor)_mathematical_betweenness.

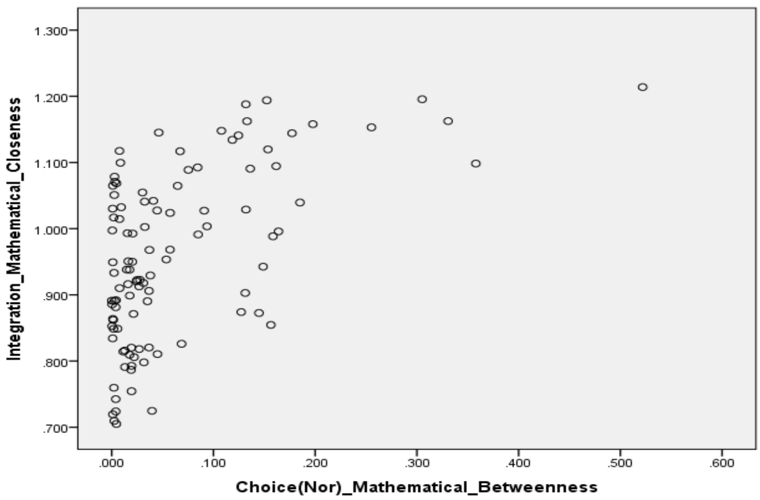


Figure 16: Scatter plot graph for research model 1

Source: Author, (2017)

Collinearity test is carried out to confirm that selected independent variables have collinearity issue or not and they are suitable to perform multiple regression analysis.

Table 2: Descriptive Statistics: Collinearity test_ Research Model 1

Source: Author, (2017)

Coefficients[a]			
Model		**Collinearity Statistics**	
		Tolerance	**VIF**
1	Integration_Mathematical_Closeness	.695	1.439
	Choice(Nor)_Mathematical_Betweenness	.695	1.439
a. Dependent Variable: No.of_Motorized_Vehicles			

To check the collinearity the value of VIF is considered, VIF is called variance inflation factor. If the value of VIF is greater than 10 it means that there is occurrence of collinearity issue among variables and they cannot be computed for multiple regression analysis together but if the value is less than 10 then it means that there is no collinearity issue among variables and they are suitable to perform multiple regression analysis. Consider the statistics of VIF from table above, it is visible that there is no collinearity issue occurs between selected variables i.e. integration _mathematical_closeness) and choice(Nor)_mathematical_betweenness. Hence, it is concluded that these selected variables are fit to conduct multiple regression analysis.

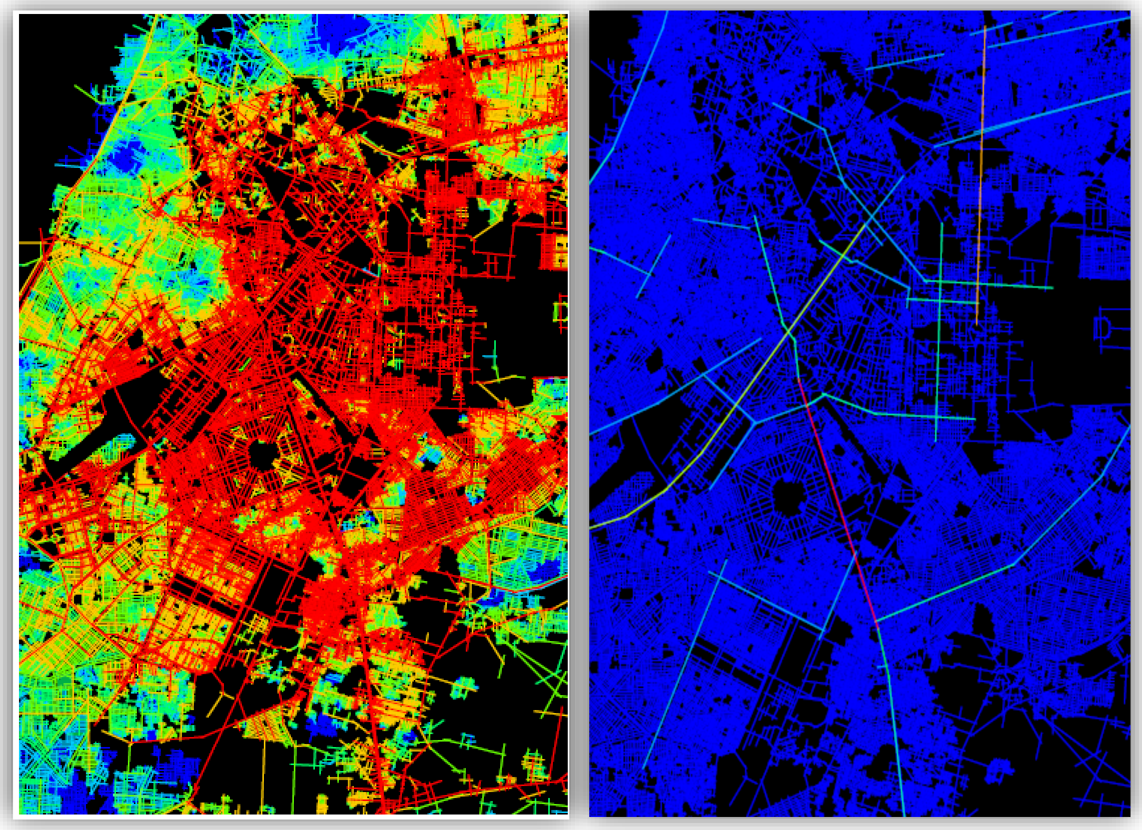


Figure 17: Visual representation of Integration and Choice through axial map

Source: (Author, 2017)

Consider the above axial map for integration and choice as well as results extracted from collinearity test between integration and choice. From statistics, scatter plot and axial map, it is examined that all results validate the finding of not significant relationship between them. From above map, it is identified that at some points integration and choice relate with each other but not everywhere in general. From the literatures referred in chapter 2 of this research, also evident that it is not important the most integrated route is always the most preferable route and take greater number of through movement. As choice, not only determinant of through movement but also depend on the various other factor like travel time, length of route etc which affects the flows of vehicular movement. While doing space syntax analysis through axial lines, these factors cannot be taken in account due to limitation of software.

ii. Research Model 2

It is assumed that higher vehicular movement contribute towards air quality deterioration if the traffic flows are not uniformly distributed and cities are not properly planned along with other factors stated as a control variable for this part of research. From the research model 1(reference: 4.3.2), it is verified that integration and choice accelerate the vehicular movement hence these two independent variables for this research model 2 are considered as an explanatory variable for greater vehicular movement. Therefore, for this research model 2, relationship is determined between vehicular movement and air quality in terms of PM10.

Table 3: Descriptive Statistics: Independent Variable_ Research Model 2

Source: Author, (2017)

Correlations			
		Air_Quality PM10	**Motorized_Vehicular_Count**
PM10	Pearson Correlation	1.000	.306
	Sig. (1-tailed)	.	.042
	N	33	33

From the above tabulated statistics, it is cleared that both variables have weak positive linear relationship mean with the increase of motorized vehicles in urban streets, air quality is going to degrade as PM10 concentration is increasing. Although, Pearson correlation value=0.306 shows that strength of the linear relationship is weak. Sig. value for this relationship shows that there is almost 96% probability to trust on this relationship means any changes in number of vehicles in streets will induces the change in concentration of particulate matter.

4.3.2 Linearity Test:

It shows that the relationship between the dependent and independent variables should be the linear one. It should be remembered that this test is particularly focused on the relationship between dependent and independent variables not among two independent variables. Because to run multiple regression there shouldn't be the strong relationship among independent variables. Output of the results has been presented in the form of scattered plot graph. If the plots are scattered it means there is no relationship among variables. If, they have some pattern, it means there is some relationship. Positive relationship shows that the increase in independent variable results an increase in dependent variable while negative relationship shows vice versa.

i. Research Model 1

For research model 1 validation, this test has been performed between the dependent variable (motorized vehicular count) and two independent variables (Integration_Mathematical_closeness, Choice (Nor)_Mathematical_Betweenness). The graphical output is shown in figure 18.

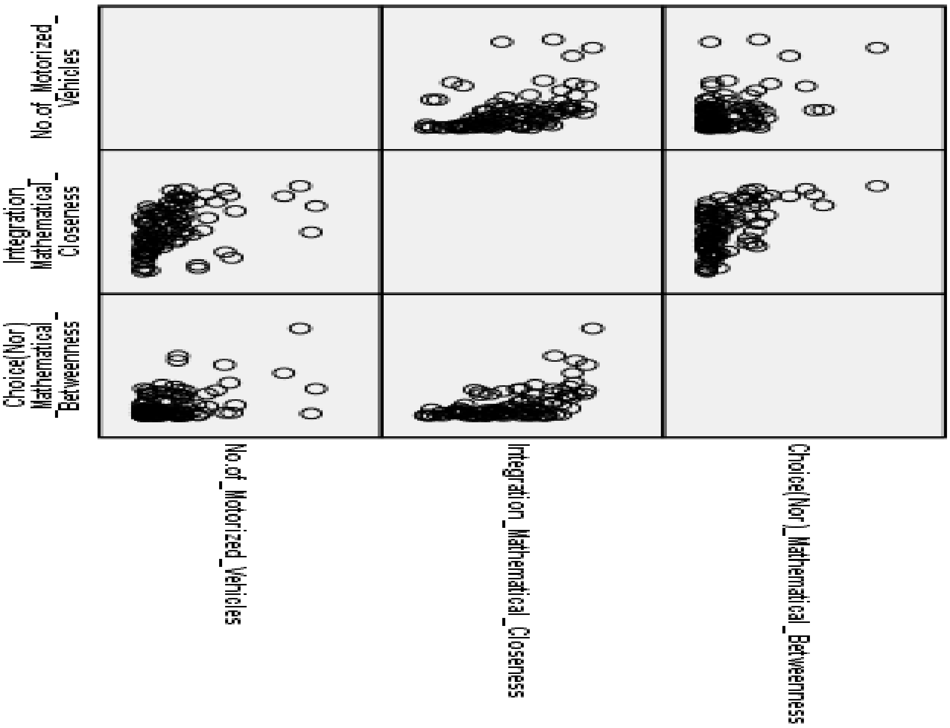


Figure 18: Scatter plot graph for research model 1

(Source: Author, 2017)

It is analysed that there is a positive linear relationship among dependent variable and independent variables of the research model 1. It illustrates that with the increase of integration and choice_Nor, vehicular traffic volume will also be going to increase. However, most of points condensed at one location but trend is clearly visible from graphical inspection between these variables.

i. Research Model 2

Same test has been performed for research model 2, data set is very small for this research model only comprised of 33 observation and outliers is also present but from the graphical output it is verified that there is a linear relationship between dependent and independent variable as represented in graph below:

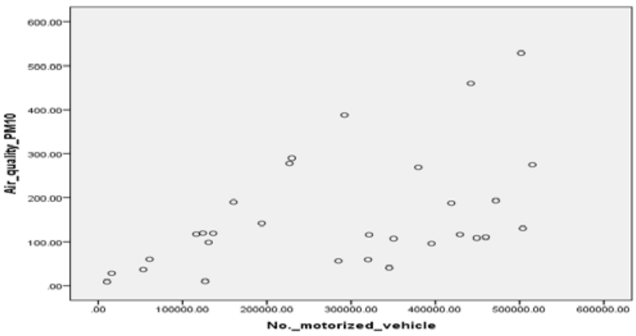


Figure 19: Linearity test for research model 2

Source: Author, (2017)

4.3.3 Homoscedasticity Test

The requirement for this test is that variance of the predicted values should be constant. However, if there is any trend appear in scattered plots graph it depicts that variance of residual is not constant. The visual output also shown in histogram which is also a virtuous visual representation that variance of residual is normally distributed or not.

i. Research Model 1

For the residual error normal distribution verification of the research model 1, this test has been performed which gives the satisfactory results as shown in descriptive table as well as in Histogram and Scatter plot form.

Table 4: Presentation of residual statistics of normality test for research model 1

Source: Author, (2017)

Residuals Statistics[a]					
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**N**
Predicted Value	3.9823	5.3891	4.6428	.34162	106
Residual	-1.49329	1.24378	.00000	.50458	106
Std. Predicted Value	-1.933	2.185	.000	1.000	106
Std. Residual	-2.931	2.441	.000	.990	106
a. Dependent Variable: No.of_motorized_Vehicle					

Considering the scattered plot of this research model as presented in figure below that the variance of the residual is constant mean with the increase of standardized predicted value, there is no change in residual variance apart from some outliers. Whereas, it is also visible that all the points are scatted having no regular pattern. Although, there is dense points are available at specific location which are very few and negligible.

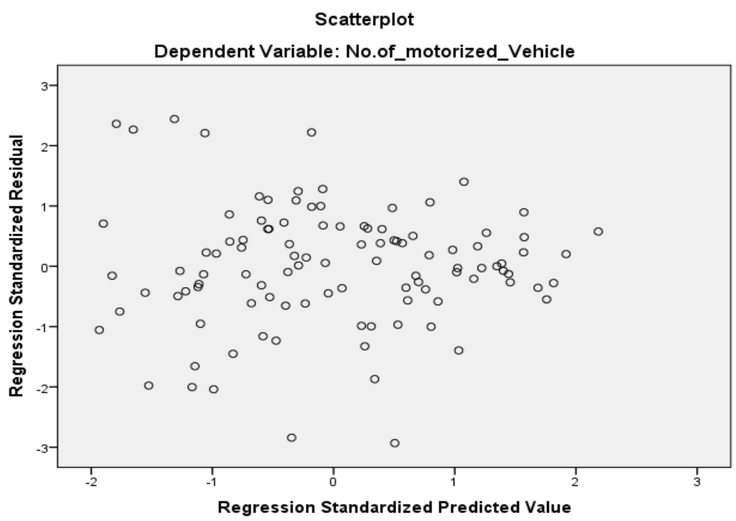


Figure 20: Presentation of homoscedasticity test in form of scattered plot

Source: Author, (2017)

In a similar way, through analysis of the histogram graph it is studied that the bell shape pattern of the histogram curve describes that the residual error is normally distributed around zero. Histogram graph is presented in figure below.

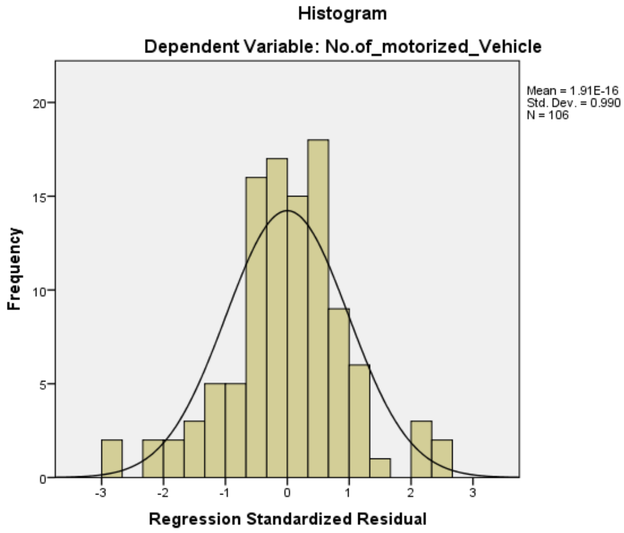


Figure 21: Presentation of homoscedasticity test output in form of histogram, research model-1

Source: Author, (2017)

ii. Research Model 2

To run the simple linear regression, same test has been carried out for this research model 2, and output in the form of scatter plot graph, histogram has considered to analyse. For this part of the research the data set is comprised of only 33 observations which are very small for regression analysis but acceptable to perform. Therefore, results might not highly significant but fulfilling the assumption apart from outliers as shown in scattered graph plot in figure 22.

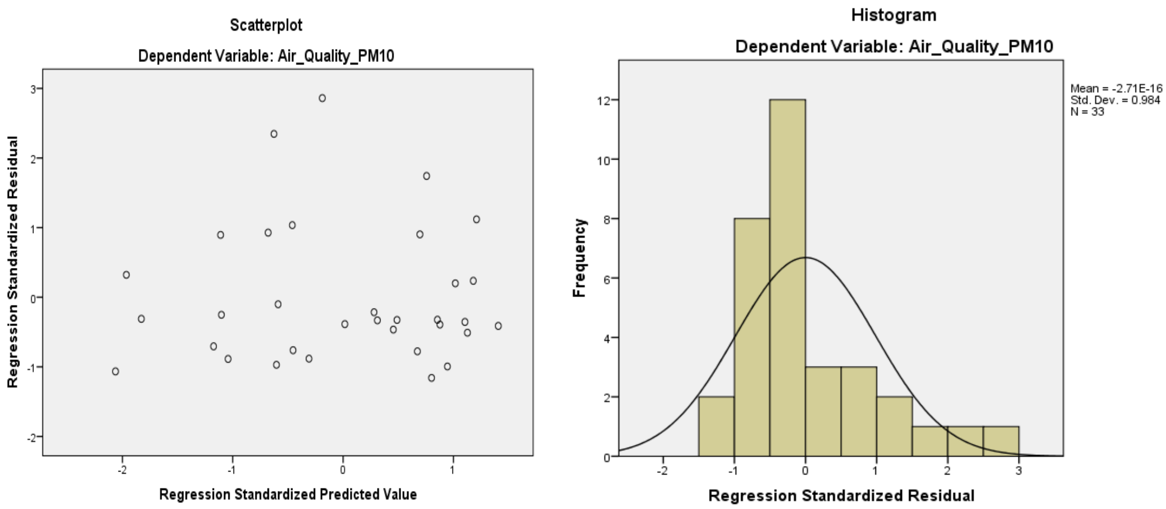


Figure 22: Presentation of homoscedasticity test output in form of scattered plot and histogram, research model-2

Source: Author, (2017)

Above figure 22, depicts that the residual error variance is constant and have not appropriate normal distribution of the residual errors. However, it shows presence of some outliers as well which should be removed before performing regression analysis. To highlight the impact of outliers in analysis it is decided to perform the simple regression analysis in both ways, first with outliers and second is without outliers which gives more transparency in results of the research analysis.

4.3.4 Normality Test

This test defines that data is normally distributed or not. If the data is not normally distributed then transformation of the data set is required into another form by taking log of it. The results of this result has been presented in descriptive as well as histogram and Q_Q plot. It is required to check the data to assess whether dependent variable and independent variable are normally distributed or not by performing following tests listed below. However, if dependent variable is not normally distributed but residual variance is constant, then analysis can still be performed (Habeck, Brickman, et al., 2014).

1. Shapiro-wilk Test: it is one of test among other normality tests (i.e. Kolmogorov-Smirnov, Cramer-von Mises, etc). It is carried out to represent the normal distribution of variables. In this test, the null hypothesis is data is normally distributed. if sig. value is below 0.05 then reject null hypothesis which stated that variables are not normally distributed.
2. Kolmogrorov-Smirnov Test: This test is also used to check the variables are normally distributed or not. "It is an empirical distribution function in which the theoretical cumulative distribution is contrasted with the EDF of the data. It is sensitive to extreme values. It has also been reported that K-S test has low power so it shouldn't be considered as a good determinant for test of normality as it is best determined by considering Shapiro-wilk test" (Ghasemi and Zahediasl, 2012, p.487). Hence, for this research study result of Shapiro-wilk test has been considered to check the normal distribution of the variables.
3. Histogram, Normal Q_Q plot is used to check whether dependent variable and independent variables are skewed or not.

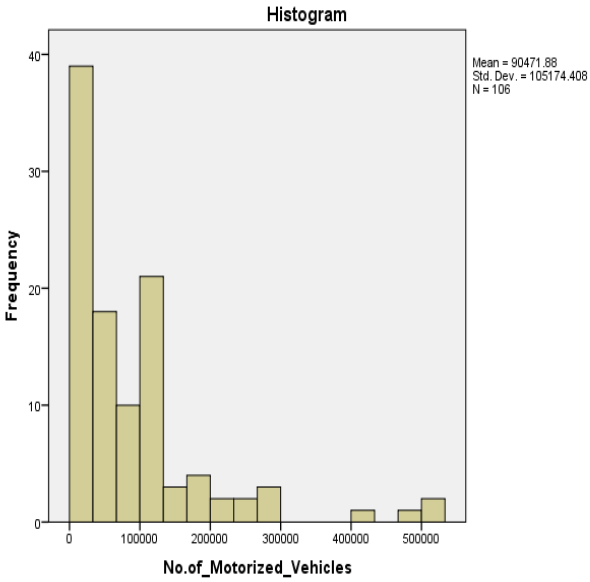
i. Research Model 1

For this research model, consider the statistics of shapiro-wilk test from the above tabulation which shows that dependent variable and one of the independent variable (Choice_Mathematical_Betweenness) is skewed having sig. value 0.00 which is less than 0.05. This skewness trend of data has also been analysed from the histogram graph which shows that for both variables data is not normally distributed. While on the other hand, value of independent variable (Integration_Mathematical_Closeness) have a sig. value 0.07 which is greater than 0.05 presents that data is normally distributed. It is also verified by analysing histogram graph and Normal Q-Q plots. Histogram gives the visual representation of the data normality. While normal Q-Q plots are used to compare quantiles of the empirical data set with the theoretical ideal normal distribution of data shown in form of straight line. Therefore, from both graphs, presence of outliers has also been observed as they are deviated from the normal trend which should be removed from the data sets to take appropriate results from multiple regression analysis.

Table 5: Descriptive statistics of normality test for research model 1

(Source: Author, (2017)

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
No.of_Motorized_Vehicles	.198	106	.000	.746	106	.000
Mathematical_Closeness	.052	106	.200*	.978	106	.070
Mathematical_Betweenness	.236	106	.000	.704	106	.000
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						



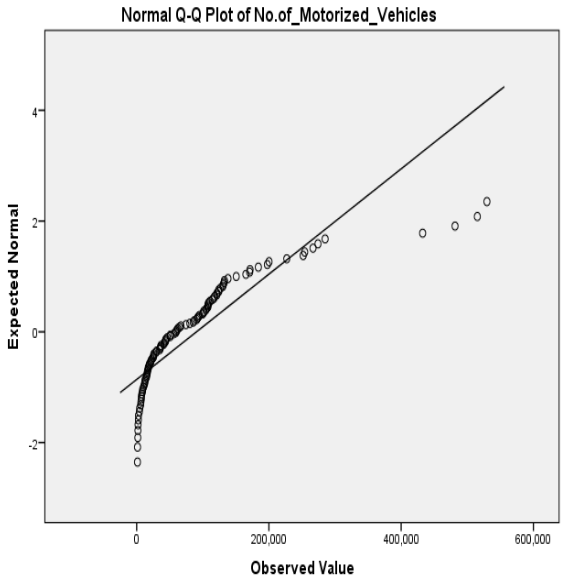


Figure 23: Representation of normality test for dependent variable (No. of Motorized vehicles) for research model 1

Source: Author, (2017)

From the above stated graphs (histogram, Normal Q-Q plot) it is concluded that independent variable is not normally distributed. In histogram graph and Q-Q plot outliers are present in range between 400,000-500,000. Therefore, this analysis not sufficiently support the normal distribution of the data sets of independent variables (No. of motorized vehicles).

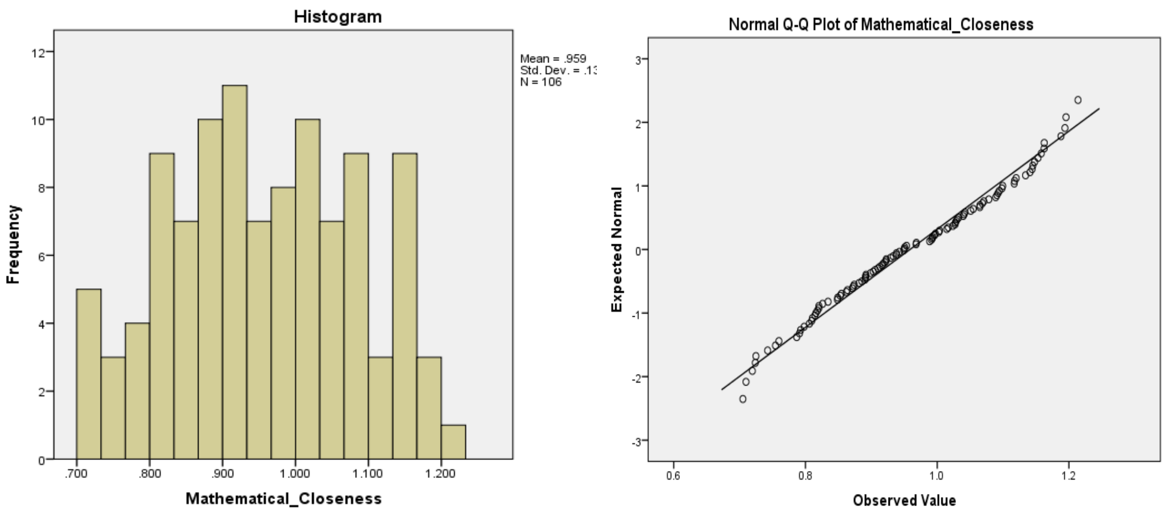


Figure 24: Representation of normality test for independent variable Integration_Mathematical _Closeness for research model 1

Source: Author, (2017)

From the graphical analysis presented (fig.24) in the form of histogram and Normal Q-Q plot, it is examined that independent variable (Integration_Mathematical_Closness) shows the normal distribution of the data set. In histogram graph and Q-Q plot, it is assessed that there is not so many significant outliers. Hence, normality analysis of this particular independent variable fulfilling the criteria and support the research model 1.

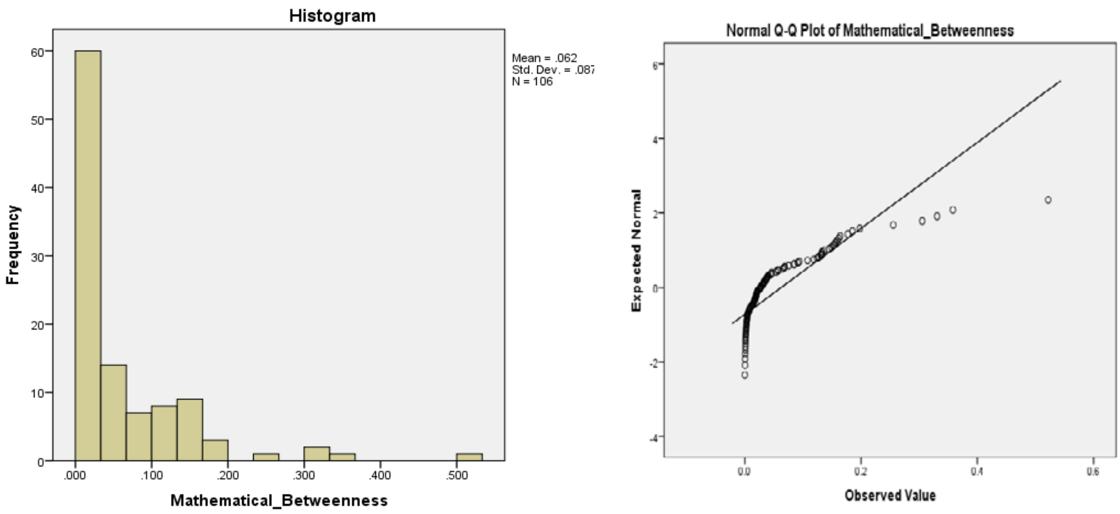


Figure 25: Representation of normality test for independent variable (Choice(Nor)_Mathematical_Betweenness) for research model 1

(Source: Author, 2017)

From the graphical analysis presented (fig.25) in the form of histogram and Normal Q-Q plot, it is examined that independent variable (Choice(Nor)_Mathematical _Betweeness) illustrates that normal distribution of the data set does not exists. From this graphical analysis, it is assessed that there are significant outliers is present, falling between range 3.00-4.00. Hence, normality analysis of this particular independent variable is not able to fulfil the normality criteria and not sufficiently support the research model 1.

Finally, from the above statistical description and graphical analysis of both dependent and independent data sets, it is concluded that selected variable for this research model are not sufficiently capable to fulfil this criterion although regression analysis can be performed.

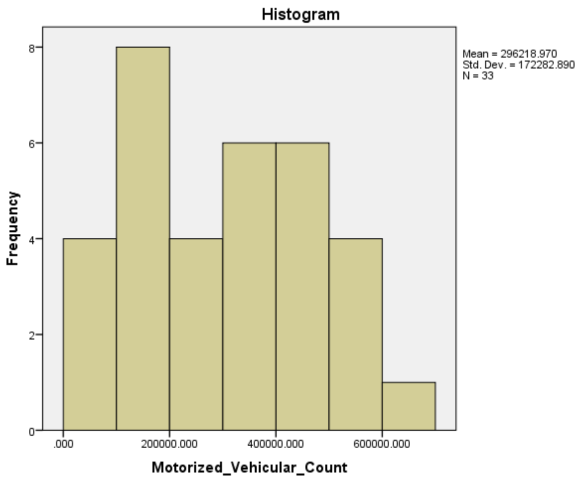
i. **Research Model 2**

From the below tabulation, focus the value of Shapiro-Wilk test for dependent (PM10 indicate air quality) and independent variable (Motorized_vehicular_count). The Sig. value for independent variables = 0.198 illustrates that variable is normally distributed as sig. value is greater than 0.05. But from fig. 24 it is analysed that although the data distribution is normal but not so well. For the verification of these descriptive statistics Histogram and Q-Q plot has been plotted which also helpful to assess the presence of outliers in data set and to show that our dependent variable is following the normal distribution. Few points that are at upwards in little away from bottom right not follows the line while rest of the points following the trend line.

Table 6: Descriptive statistics of normality test for research model 2

Source: Author, (2017)

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Motorized_Vehicular_Count	.126	33	.200	.956	33	.198
PM10	.222	33	.000	.864	33	.001
a. Lilliefors Significance Correction						



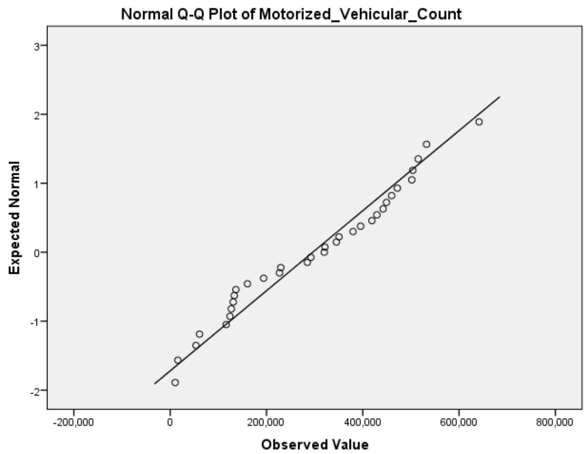


Figure 26: Representation of normality test for independent variable (Motorized_Vehicular_Count) for research model 2

Source: Author, (2017)

Consider the statics from table 6 for PM10, it also shows the same result as predicted from fig. 27 by histogram and Q-Q plot, sig. value is less than 0.05. Hence null hypothesis (data is normally distributed) is rejected. It is clearly visible that our dependent variable is not following the normal distribution as well as shows the presence of outliers in the data set. This test indicates that dependent variables is not capable to fulfil this assumption although simple linear regression analysis will be performed as per reference given above already.

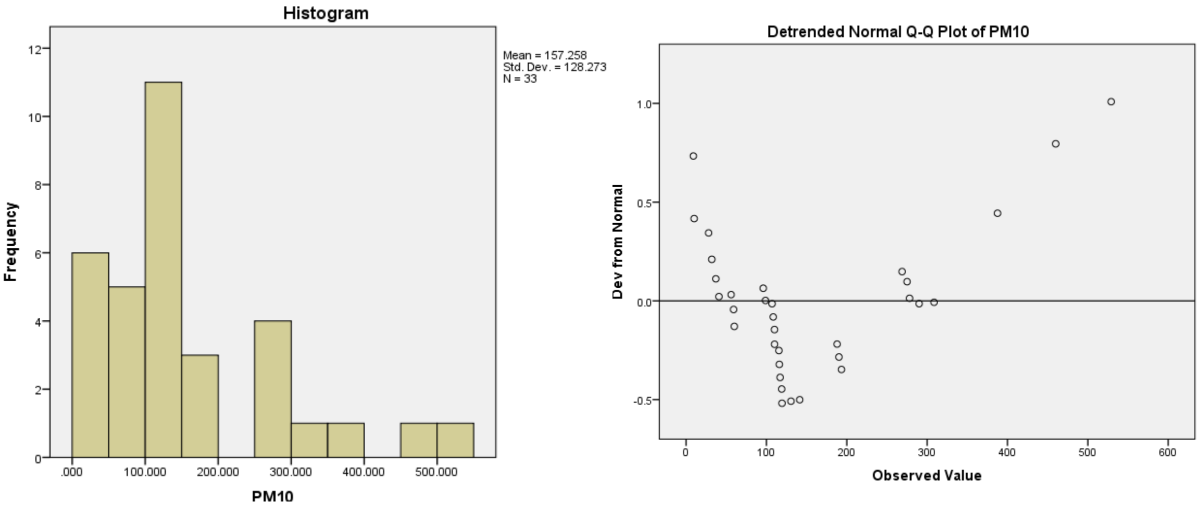


Figure 27: Representation of normality test for dependent variable (PM10) for research model 2

Source: Author, (2017)

4.4 Inferential Analysis

From all the above conducted test for the verification of selected variables and data sets either they have sufficient capacity to support research model 1 and research model 2. It is examined that all the test supports the regression model for carrying out analysis expect Normality test. However, from referred literature in normality test section, it is substantiated that by ignoring this test results regression analysis could be performed as both research models are strongly fulfilling rest of the assumption of regression analysis.

To make research more transparent regression analysis has been performed two ways for both research models are as follows:

i. Multiple Regression Analysis with outliers: Research Model 1
ii. Multiple Regression Analysis without outliers: Research Model 1
iii. Simple Linear Regression Analysis with outliers: Research Model 2
iv. Simple Linear Regression Analysis without outliers: Research Model 2

This method will help to examine the impact of outliers that how much they significantly affect the results and reliability of the model. However, the results of simple linear and multiple regression without outliers has considered as result for both models to explain the impact of urban street connectivity on vehicular movement and urban air pollution including sub-questions.

4.4.1 Multiple Regression Analysis with and without outliers: Research Model 1

First the multiple regression has been carried out to observe at what extend the urban street connectivity influence the vehicular movement. This research model is appropriate to explain this impact as well as to evaluate the impact of outliers on research.

Table 7: Descriptive statistics of multiple regression model summery for research model 1 with outliers

Source: Author, (2017)

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.495[a]	.245	.230	92271.272
a. Predictors: (Constant), Choice(Nor)_Mathematical_Betweenness, Integration_Mathematical_Closeness				

Table 8: Descriptive of multiple regression model summery for research model 1 without outliers

Source: Author, (2017)

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.693[a]	.480	.469	59557.60885
a. Predictors: (Constant), Choice(Nor)_Mathematical_Betweenness, Integration_Mathematical_Closeness				

Model summary of the multiple regression analysis by both methods (with and without outliers) has been presented by table 7 and table 8. From these two tables, consider the value of adjust R square which is accounted for to explain the variance of dependent variable due to independent variables or predictor variables. For research model 1 with outliers, its value is .230 ≈ 0.23. It demonstrates that 23% of the variance of vehicular movement has described by the independent variables i.e. Integration_Mathematical_Closeness and Choice(Nor)_Mathematical_ Betweenness. While descriptive statistics of adjust R square is 0.467 ≈ 0.47 for the same research model 1 but without outliers shows that almost 47% variance of motorized vehicular movement by choice (Nor)_mathematical_ betweenness and integration_mathematical_Closeness. It should be memorized here that due to unavailability of data for controlled variable, they are not being computed in this research analysis. If it is performed by computation of controlled variables then results will be more better because from results it is visible that except integration and choice(Nor), other factors also have influence vehicular movement.

By comparing values of adjusted R square with and without outliers, significant change in results of adjusted R square has been observed. Which describes that some data points are not following the data trend and may affect the normal distribution of the variables as well as results of the analysis of the research model. Therefore, assumption to remove outliers from the data sets should be mandatory to perform regression analysis.

Coefficient table of multiple regression analysis has considered as a most important table because it specified the one to one relationship of independent variables with dependent variable as tabulated below:

Table 9: Descriptive of multiple regression coefficients of research model 1 with outliers

Source: Author, (2017)

Coefficients[a]									
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-144360.408	76379.381		-1.890	.062	-295840.896	7120.079
	Integration_Mathematical_Closeness	222215.384	83321.047	.274	2.667	.009	56967.738	387463.029
	Choice(Nor)_Mathematical_Betweenness	349289.881	124625.834	.288	2.803	.006	102123.933	596455.829

a. Dependent Variable: No.of_Motorized_Vehicles

Consider the statistics of sig. values which is also called probability vale or P-value from the above tabulation 8 to explain how significantly each independent variable impact individually the motorized vehicular movement. By considering sig. value of integration_Mathematical_Closeness value = 0.009 and for Choice(Nor)_Mathematical_Betweenness =0.006 illustrates that this relationship can be trusted significantly around 99%. It represent that variables are statistically significant and change in value of dependent variable (vehicular movement) is significantly associated with change in independent variables (Integration_Mathematical_closeness) .

By considering the B coefficient value as tabulated above, it illustrates that 0.01 increase in value of Integration_Mathematical_Closeness of a street, induces an increase of approximately two thousand two hundred twenty-two (2,222) number of motorized vehicles in streets. While 0.01 increase in value of Choice(Nor)_Mathematical_Betweenness of a street, results in increase of almost three thousand five hundred ninty-three (3,493) number of motorized vehicles in streets. To illustrate which independent variable has greater impact on vehicular movement consider the value of “Standardized Coefficients Beta” highlighted in above tabulation, it is examined that the choice(Nor) has an overall slightly greater impact on vehicular movement as compared to integration value of urban street network. Which support the concept build on the base of literature review that Choice is considered as a better predictor of vehicular flow in streets because vehicular movement depends not only on the integration of the network but illustrates that for street which is likely to pass through while moving in a city automatically receive a greater number of vehicular movement as compared to integrated street.

Table 10: Descriptive of multiple regression coefficients of research model 1 without outliers

Source: Author, (2017)

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-165335.311	53171.994		-3.109	.002	-270853.403	-59817.220
	Mathematical_Closeness	229329.864	57886.148	.364	3.962	.000	114456.687	344203.041
	Mathematical_Betweenness	348049.682	85489.118	.374	4.071	.000	178399.310	517700.053

a. Dependent Variable: No.of_Vehicles

Consider the statistics of sig. and beta (B) values stated in above table 10, for research model 1 without outliers. In this case the sig. value for both independent variables is very significant mean this relationship can be highly trusted approximately 99.9 % it means that for this research model our independent variable have a significant relationship with dependent variable. By considering the B coefficient value of the same research model without outliers, it illustrates that 0.01 increase in value of Integration_Mathematical_Closeness results in increase of approximately 2,293 number of motorized vehicles in streets. While value of 0.01 increase in Choice(Nor)_Mathematical_Betweenness brings an increase of around 3,481 number of motorized vehicles in urban streets. To illustrate which independent variable has greater impact on vehicular movement consider the value of "Standardized Coefficients Beta" highlighted in above tabulation, it is investigated that the choice(Nor) has an overall slightly greater impact on vehicular movement as compared to integration value.

4.4.2 Summary of Research Model 1

By conducting analysis in presence and absence of outliers to explain the impact of urban street connectivity on vehicular movement (motorized). It illustrates that few number of outliers were present because by removing them the sample size is reduced to 101 from 106 which shows drastic change in a in analysis result. Therefore, the model without outliers has been considered as an appropriate model to explain the impact of urban street connectivity on vehicular movement based on the regression assumption that data should be free from significant outliers.

Results illustrates that overall explained variance is 47% in a vehicular movement is due to Integration_mathematical_closeness and Choice(Nor)_mathematical_betweenness of streets. Which is good relationship and result could be even better if it is performed by computing controlled variables data i.e. land-use, tip-destination time, vehicular speed, street width, size of vehicle and rest of the factors enlisted under control variable heading. Which depicts that vehicular movement is influenced by these stated variables as well. However, due to unavailability of controlled variable data they are not computed while performing analysis.

Although through coefficients statistics, it has been verified that Choice(Nor)_Mathematical_Betweenness has a slightly greater impact on vehicular movement (motorized) as compared to Integration_Mathematical_Closeness. Which shows real condition somehow as while driving motorized vehicle people preferred to pass through the street areas which are more centrally connected, short (in terms of number of steps) while travelling in city that's the reason of contributing towards higher vehicular flows due to preferred choice of the people. So, with increase of choice value number of vehicles also increased. Sig. value (P-value) showed around 99% probability to trust on the relationship between dependent and independent variables mean variables integration and Choice(Nor) have a capability to bring change in number of vehicles in street networks.

4.4.3 Simple Linear Regression Analysis with and without outliers: Research Model 2

This research model has formulated to examined the impact of urban street connectivity on air pollution in addition to answer the sub-question i.e. what's the relationship between vehicular movement and urban air quality.

Before going to the simple regression analysis, remember the result of research model 1. From research model 1, it is concluded that vehicular movement and urban street connectivity (integration, choice) has direct good relationship. By keeping in view this relationship, for this regression model 2, vehicular movement is considered as independent variable and PM10 as a dependent variable to answer both research questions through simple linear regression analysis.

Consider the adjusted R square value for this research model 2 tabulated below which is .155 ≈ .16 with outliers and .201 ≈ .20 without outliers. These values illustrate the variance in PM10 which is indicator of air quality is only 16% (with outliers) and 20% (without outliers) is accountable due to vehicular movement. Which is a determinant of very weak impact of vehicular movement indirectly referring to urban street connectivity on urban air quality (PM10). In this research model, the impact of outliers on the variance is around 4%. It should be noticed here as explained in above section that if this analysis will be performed by computation of control variables then results will be better and this relationship can be explained appropriately.

Table 11: Descriptive statistics of simple linear regression model summery for research model 2 (Vehicular_count and PM10) with outliers

Source: Author, (2017)

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.429[a]	.184	.155	87.633748
a. Predictors: (Constant), No.Motorized_vehicle/100				
b. Dependent Variable: Air_quality_PM10				

Table 12: Descriptive statistics of simple linear regression model summery for research model 2 (Vehicular_count and PM10) with outliers

Source: Author, (2017)

Model Summary[b]				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.478[a]	.229	.201	115.64856
a. Predictors: (Constant), No.Motorized_vehicle/100				
b. Dependent Variable: Air_quality_PM10				

Consider the coefficient table 13 and 14 for this research model 2 with and without outliers, it shows that the sig. value for both analysis with outliers and without outliers is less than 0.05.it means that change in number of vehicles has strength to induce changes in concentration of PM10. Therefore, relationship is trustable almost 82% in case of with outliers but around 99% in case of without outliers. Keeping in view B value from coefficient table 13 and 14, it is determined that in case of analysis with outliers: increase of more 10,000 cars induces approximately 3 more particulate matter (PM10) while B statistics from table 13 (research model 2 without outliers) indicates that per same number of cars increases the PM 10 quantity approximately to 4. It also explained the impact of outliers and importance why removal of outliers is necessary to run regression analysis because it has influence on the results of the research model. Therefore, Model without outlier is considered as a final model to elaborate the influence of vehicular movement on urban air quality which is indirect determinant of urban street connectivity condition.

Table 13: Descriptive of multiple regression coefficients of research model 2 (Vehicular_count and PM10) with outliers

Source: Author, (2017)

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	58.827	32.867		1.790	.084	-8.498	126.152
	No_Motorized_vehicle/100	.026	.010	.429	2.516	.018	.005	.046
a. Dependent Variable: PM10								

Table 14: Descriptive of multiple regression coefficients of research model 2 (Vehicular_count and PM10) without outliers

Source: Author, (2017)

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	48.716	43.374		1.123	.271	-40.131	137.564
	No.Motorized_vehicle/100	.039	.013	.478	2.883	.007	.011	.066
a. Dependent Variable: Air_quality_PM10								

4.4.4 Summary of Research Model 2

This model is formulated to visualize the relationship between urban air quality and street connectivity in terms of vehicular movements as vehicular movement is shaped by many factors, among them urban street connectivity is one of them. Simple linear regression has been carried out by taking vehicular movement as an independent variable and PM10 (indicator of urban air quality) as a dependent variable. This analysis is performed by comparing PM10 concentration in different streets within a city. Total sample size for this analysis was 33 with outliers which is reduced to 30 by removing outliers. But to visualize the impact of outliers, analysis has taken place with and without outliers.

From the analysis, obtained value of adjusted R square = .20 illustrates that only 20% variance in PM10 is due to vehicular movement and rest of the 80% impact on the relationship due to other factors which shows a weak relationship and impact of vehicular movement on urban air quality. Therefore, it is illustrated that vehicular movement only is not a strong predictor of change in urban air quality alone. Although, it is also determined that results will be improved if analysis will be performed by computing controlled variables because air quality is taking a strong impact of other variables i.e. land use, type and size of vehicles, travel time, congestion, seasonal atmospheric variation, vehicular speed. But due to unavailability of data on control variables they were not taken in account while performing analysis. For this part, unavailability of data on control variables is the biggest limitation which affects the results of research model 2 to properly explain examined the impact of urban street connectivity on urban air quality.

Here from result it is analysed that with the increase of number of vehicles, air quality is going to affect negatively mean with increase of vehicle due to higher urban street connectivity, air pollution (PM10 concentration) also going to increase. In (Pereira, Holanda, Frederico Rosa Borges de, et al., 2011), (Alba and Beimborn, 2005a, p.3), the analysis was carried out at city level among different cities, not in comparison of different streets of a same city. But for this research, analysis is carried out among different streets air quality of a same city. (Apte, Messier, et al., 2017) in Oakland, USA, by comparing different streets of a same city, show that more integrated street has greater number of vehicles which deteriorate the urban air quality due to greater quantity of exhaust gases and particulate matters by keeping all other conditions constant as shown in Map below.

Figure 28: Comparison of air quality among different streets within a same city Oakland, USA.

Source: (Apte, Messier, et al., 2017)

Chapter 5: Conclusions and recommendations

This chapter provides a brief overview of the research study purpose and how this research fits in to answer the research questions. The conclusion is drawn on the bases of research results and relevance of this study is given. At end some recommendations has been given which open doors for other researchers to perform further research in stated areas.

5.1 Research Purpose

The basic purpose of this research is twofold first to explore the spatial configuration potential of urban street networks connectivity in terms of accessibility (integration, choice) for vehicular traffic flows. While the other one, is to examine the impact of urban street connectivity through vehicular movement on urban air quality.

Based on literature review and theories (refer: chapter 2) conceptual framework has developed which helped the researcher to determine these above stated relationships and the extent of urban street connectivity impact vehicular movement and urban air quality. This study goals are achieved by taken in account space syntax (a space accessibility analysis technique) in addition with regression model as an appropriate methodology. According to Paul, Hillier and Hanson, space syntax has an ability to determine the traffic volumes without taking cost, land use pattern and other factors in account (which is limitation of the space syntax software). Although, the unavailability of the data enlisted under heading of control variables (ref. chapter 3) is considered the overall research study limitation. However, the scope of the research study is limited at only one city which in one of biggest city of Pakistan “Lahore” having a population of more than 10 million approximately. While with passage of time, population is keep growing which builds burden on environmental resources and raises the issues of urban management i.e., less accessibility due poor urban street connectivity which increases the number of private transportation in city and influence the urban air quality.

5.2 Research Results Echo

From this inclusive research study, it is analysed that integration (mathematical closeness) and choice_Nor (mathematical betweenness) are overall good predictors of the urban street connectivity to determine vehicular movement. However, in transportation engineering models to predict traffic flows, combination of integration, choice along with other parameters/indicators taken in account simultaneously which is considered as base to run multiple regression analysis instead of individual simple linear regression analysis for research model 1 because space syntax software doesn’t have ability to take other features in account during analysis. Due to this limitation, it is in critics by authors (Ratti, (2004); Paul, (2012); and many others) that vehicular movement cannot be explained significantly by considered or using only space syntax.

For second research model, along vehicular movement there are several other parameters (i.e. metrological effect, type and size of vehicles, land use patterns, and road width and traffic lights, etc) effecting the urban air quality but due to unavailability of data they are not taken in account in analysis. Results of this model, also showed that vehicular movement alone is not sufficient indicator to determine the influence of urban street connectivity on urban air quality and reason is further described in detail in this chapter after determining these relationships. These two independent relationships formation to answer the two sub questions is an important move to answer the main question that analyse inclusive influence of urban street connectivity through echo of results obtained by these relationships.

5.2.1 Determination of significant urban street connectivity factor influencing vehicular movement

Sub-Question 1: Which urban street connectivity factor have significant influence on vehicular movement, specifically for Lahore City?

- Integration (Mathematical_Closeness)
- Choice (Mathematical_Betweenness)

In space syntax, both types of human movement either by foot or through vehicles are related with urban street configuration. These movements are limited by the route (choice) and route integration value of the urban street networks. For ‘through movement’ urban street configuration impact is more obvious because it impacts on the traveller how they select their way in addition to the other factors which influence the choice i.e. shortest, non-congested, integrated having minimum travel time between origin destination point or to all other destinations and many more. Higher the choice value means higher the traffic volume in that street. Although, on the other side higher the integration means higher the ‘to movement’ having higher accessibility. Therefore, integration and choice are considered as important factors to determine the urban street connectivity influence to shape vehicular flows in a city or in an area. Hiller and Iida (2005), also determined these two factors in a space syntax analysis to predict vehicular flows through axial map formation.

From the statistical analysis of the results-Research Model 1 (refer: table 10, standardized B coefficient value) it is concluded that choice_Nor (value = .374) has a slightly greater impact over vehicular movement as compared to integration (value = .364) for Lahore city. It illustrates that streets which are more likely to pass have a slightly greater influence to increase the number of vehicles in the streets because they are more likely to be visited while moving in a city. In addition, research study results also depict that relationship between dependent variable (vehicular movement) and independent variables (Integration (Mathematical_Closeness) as well as Choice_Nor (Mathematical_Betweeness)) is highly significant having value of sig.0.00 means change in independent variable will statistically significantly induce the change (whose practical significance, or magnitude, is given from B coefficient) in dependent variable.

By visualizing the trend on the secondary collected data (no. of cars) against integration and choice_Nor values as shown in table 15 below (few example) reflects the same conclusion. Consider the street named “Doctorhospital_Jinnah” has higher integration as compared to street “ThokarNiazbaig_doctorhospital’ but receiving less traffic flows. Although it is integrated but not preferable to travel all time while moving in a city. Choice_Nor value for street “Doctorhospital_Jinnah” is lower as compared to street “ThokarNiazbaig_doctorhospital’ and have less vehicular flows.

Though, it is interesting to see from the secondary data (no. of cars) in same street with name “Walton_Kalmachowk” have highest integration and choice value. Which is also supported by the literature that most integrated street compliments the through movement of the vehicle but it is not obvious in all cases because choice is depend on many other factors like travel time, speed of vehicle and rest of the factors enlisted in chapter 3 under heading of control variables.

Table 15: Presentation of secondary data set

Source: Author, (2017)

Name of Street	Choice_Nor	Integration	Cars
Walton_Kalmachowk	0.521955	1.21386	481470
ThokarNiazbaig_DoctorHospital	0.357972	1.098326	111024
Doctorhospital_Jinnah	0.33073	1.162533	109000

5.2.2 Relationship Between Urban Air Quality and Vehicular Movement

<u>Sub-Question 2: At what extent vehicular movement impact the urban air quality, for Lahore city?</u>

In space syntax literatures, most of the authors i.e. (Paul, 2012; Hillier and Hanson, 2009; Hiller, 2009; Hillier, Penn, et al., 1993 and many more) determined that urban street connectivity which has a influence over vehicular movements in urban streets by considering topological aspects through axial lines analysis. It depends on the configuration and type of street like Neotraditional design has a more capability to regulate the traffic flows due to greater number of junctions/intersection (high integration) as compared to cul-de-sacs street design. Therefore, vehicular movement is fluctuating by taking direct impact urban street networks which ultimately going to impact the urban air quality. Srimuruganandam and Nagendra (2010) illustrated that vehicular movements in urban streets directly influence the urban air quality due to burning of fuel, road configuration, congestion, etc. The air pollution is going to decrease at city level if city is well planned and has overall high urban street connectivity mean less congestion (CA. Alba, 2003). It is also highlighted by author that air quality is also depend on other variables i.e. speed of the vehicle, congestion, trip origin destination travel time, land use, metrological variations and rest of the control factor mentioned in research model 2 (Wang, Zhang, et al., 2015). Therefore, they are included in this research under the limitation of the study as controlled variables but are not taken in account in performing analysis due to unavailability of the data on these control variables which will impact the results of the analysis. As the impact the impact of these control factors along with vehicular movement on urban air quality is investigated from authors i.e. (Srimuruganandam and Nagendra, 2010; (Wang, Zhang, et al., 2015), and many others) in their research studies..

Based on literature review conducted in chapter 2, research model 2 has been developed to visualize the strength of this relationship. From results, it is analysed that each 10,000 cars more induce 3.9 PM10 more in streets of Lahore city, this shows that with increase of vehicle numbers air pollution is increased.

5.2.3 Impact of Urban Street Connectivity on Vehicular Movement and Urban Air Quality

<u>Main Research Question: To what extent does urban street networks connectivity have an impact on the vehicular movement and urban air quality, for city of Lahore?</u>

From overall research study, it seems that urban street connectivity has a significant influence over vehicular movement which describes that approximately 48-50% of the variance in traffic flows is accountable by the urban street connectivity for the city of Lahore, Pakistan. This result compliment the theoretical concepts and importance of urban morphology is planning cities and determining human activities. According to Hiller urban morphology has greater impact in determining human living pattern which can be analysed by using space syntax tool. It’s application in determining traffic flow pattern is worthy as shown by statistical results through multiple regression model (Hillier, 2009). But due to limitation of the space syntax model there is a debate that choice taking an impact of other factors (as discussed in detail while answering sub question 1) but in space syntax while performing axial analysis these factors are not taken in account due to software limitation that's why somehow authors are not considering space syntax a good predictor of choice (Turner, 2007). Multiple regression analysis model is developed to perform this analysis so these factors can be taken in account to judge the overall impact of urban street connectivity on vehicular movement but as per data unavailability these factors are not computed while performing analysis. Which is limitation of this research study. Hence, it is evident from the results that there is an approximately 50-52% of the influence of other factors to shape vehicular movement flows. Furthermore, it is examined that there is slightly higher impact of 'through movement/mathematical betweenness/ choice' have a slightly higher tendency to increase the number of on vehicles in urban streets as compared to 'to movement/mathematical closeness/integration' as highlighted in literature review by Hillier and Iida (2005) and Turner (2007) that the most preferred street receiving higher vehicular number while moving in a city as they are likely to pass through while moving in a city.

From axial map analysis, it is analysed that in Lahore city, urban streets connectivity is higher for central urban street networks with reference to fig. 14 and 15, as the streets falling in this area have higher integration and choice values. While moving from north to south the urban street connectivity is decrease and most of the area have moderate integration but the few areas at periphery of the city are isolated. Therefore, central areas of Lahore city have higher vehicular movement as compared to areas outside the city centre or at periphery. But further research is required to understand that how vehicular movement is influenced by other social, morphological aspects for same city.

While second part of the research for Lahore city, illustrates that there is no direct impact of the urban street connectivity on urban air quality because air pollution is associated with vehicular movement and vehicular movement have direct influence on urban air quality which is supported by literature (Alba and Beimborn, 2005b). Therefore, only vehicular movement is taken in account as predictor of urban street connectivity in this case to carry out simple regression analysis. Results explained that only 20% variance is occurred in PM10 concentration due to vehicular movement which indirectly shows a very weak relationship between urban street connectivity (facilitator of vehicular movement in streets) and air quality. This justify the literature that other factors influenced the urban air quality along with vehicular movement due to contribution of other anthropogenic sources, land use pattern, vehicle fuel combustion type, metrological variation and many other (Ali, Shahzadi, et al., 2015). which are not taken in account due to unavailability of data. This model opens a thought to get in depth for determination of the strength of other environmental factors in relationship with morphological factors which are contributing to change the air quality in a city.

5.3 Recommendations

This research study is conducted for the Lahore city very first time to integrate the three major concepts urban street networks morphology, vehicular movement and environmental quality and visualize overall relationship as well extent of impact on one another in a light of available literature and studies conducted before in this field. In this study integration and choice (urban street connectivity parameters/factors) measures were calculated based on fewest turns (topological). After comparing vehicular movement pattern with the analysis numerical results, it examined that there is significant relationship has been described by using topological measurement between vehicular movement flows and urban street connectivity but according to Hiller and lida's empirical studies metric, geometric, and topological aspects were considered for this sort of analysis. Conclusion drawn based on Hiller and Iida's study is that vehicular movement relationship can also be explained describe by using geometric method and by metric analysis. This is also supported by turner's research (2007) based on his research finding. Therefore, it recommended to carry same research study under similar circumstances to find impact of urban street connectivity on vehicular movement and urban air quality by using geometric analysis to explore the difference in results among both type of analysis and discover which analysis best fits to describe the vehicular movement flow with urban street connectivity for Lahore city. In addition to determine, how and at what extent research will be able to support the Hiller and Iida's empirical studies concept/conclusion.

As well as it is also interesting to do the same research for same city under similar circumstances by collecting the data of control variables to analyses how significantly other variables have an influence on vehicular movement and on urban air quality along with urban street connectivity. This will be helpful to gives the appropriate picture of overall influence of controlled variables on relationship as well as more convincing results and conclusion. As from present research study result it is analysed that for research model 1 approximately vehicular movement taking and impact of other variables while research model 2 signifies that 80% of the rest of factors except vehicular movement (indirectly urban street connectivity) contribute to make change in urban air quality. These stated evidences open the research door in recommended perspective to explore integrated relationship between three pillars i.e. environment, social, morphological.

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Annex 1: List of Measure of Connectivity and Vehicular Movement for 106 Urban Streets-Research Model 1

Sr. No	Name of Street	Choice_Nor	Integration	Vehicular Count
1	Liaqatchowk_Gulshanravipark(Dubaichowk)	0.016041903	0.91610539	1194
2	Bhubatian_LDA_Avenue	0.002116188	0.75964898	1301
3	Thokar_LDA_AVENUE	0.022040974	0.80585414	1673
4	Jia Bagga-Kahna at Jia Bagga	0.068701863	0.82598966	1845
5	Raiwind-Kot Lukh Pat at Raiwind Railway Crossing	0.044653285	1.0274781	2099
6	ShukatKhanam_LDA avenue	0.01755143	0.80945337	2559
7	Raiwind_sundar@ijtama	0.004632478	0.70497239	2783
8	Schemore_Gulshanpark(Dubaichowk)	0.019124132	0.78666252	274155
9	Multanchungi_Gulshanpark(DubaiChowk)	0.000278372	0.85274208	4172
10	Raiwind-Sunder at Raiwind Bye Pass.	0.039586738	0.72475153	4544
11	Thokar_comset	0.012828799	0.81582105	6051
12	Thokar-Kahna	0.16397093	0.99587542	6398
13	Liaqatchowk_Gulshanravipark(Dubaichowk)	0.017696453	0.89883268	7124
14	Thokar_ShukatKhanam (SHK)	0.000372915	0.88575041	7125
15	Raiwind_Multan@sundarsharif	0.01952089	0.75442415	7742
16	Wapdatown_valencia@valenciagate	0.00116223	0.71937615	8689
17	Raiwind - Lulliani at Raiwind. Near Railway Crossing.	0.012995346	0.79091418	8955
18	Kahna_Raiwind	0.031691883	0.79802448	10341
19	Multanchungi_Sabzazar_Kharak	0.084987149	0.99124241	11363
20	Raiwind-Manga at Raiwind Bye Pass.	0.044994492	0.81048816	12162
21	Bhuptian Chowk-Molanwal at Bhuptian Chowk	0.021385876	0.87122619	12542
22	Enterance_Exit_NFC_Society_Wapdatown_Road	0.011382017	0.8142485	12962
23	Bhubatianchowk_ValenciaSociety	0.019481277	0.79266667	14811
24	MultanRoad_BhuptianChowk	0.007754031	0.91013581	14975
25	Lahore- Badian at Jambo Stop.	0.035146151	0.89037222	15921
26	Raiwind_Comsat_Bhubabtian_Chowk	0.027058979	0.81813878	16167
27	Enterance_Exit_EMESociety	0.015406589	0.99313658	16531
28	Lahore_Ring_Road@MuslimChowk_Qadirchowk	0.032562248	1.0025455	17454
29	Lahore - Wagha Near Gujran da Wahra	0.038011514	0.92929423	17721
30	Niazbeg - Raiwind	0.12735474	0.87397295	19011
31	Bhutta Chowk_Manawa	0.13614666	1.0906658	19275
32	ShuakatKhanam_Bhubatian	0.15646629	0.8545745	21296
33	Gulshanravi_Thokar_Niaz_baig	0.090900697	1.0271904	21400
34	Larri_adda_sabzimandi	0.002492519	0.70962822	22591
35	Gulshanravi_Samanabad	0.053661484	0.95348728	25104
36	Bahriatown_ThokarNIAZBaig	0.036691505	0.82033265	25104

37	Tolintonmarket_Jailroad	0.00302354	1.0707921	25542
38	Samanabad_Thokar_Niaz_Baig	0.00095188	0.83428383	26282
39	Raiwind_Thokar@OPF_housing_Society_Gate	0.13127202	0.90284121	29243
40	Lahore - Kahna at Gajju Matta.	0.057335496	0.96830773	30317
41	Gulshanravi_Chuburji	0.00153357	0.86204606	34819
42	Shaukatkhanam_raiwindroad@raiwind	0.027642434	0.92271245	35566
43	Schememor_Liaqatchowk_Sabzazar_Mainboulverd	0.005861408	0.84881598	36211
44	Thokar_multanchungi	0.040945031	1.0420043	36618
45	GCU_Istanbaul_Chowk	0.001109834	0.86371851	40747
46	Schememor_Kharak	0.031221557	0.91790742	41707
47	Niazbeg - Raiwind at Niazbeg	0.002257751	0.93323922	43581
48	Shadmanmosque_racecourse	0.002775542	1.0784098	43642
49	Raiwind_thokar@otherpatch	0.14887287	0.94258827	44482
50	Jailroad_Chinachowk	0.032376412	1.0408251	46371
51	Thokar-Bhubatian @LDA Avenue	0.02698227	0.91278738	50771
52	Zafferali_road	0.001107752	1.06486	50916
53	Jailroad_shadmanmarket	0.030320693	1.0547103	56183
54	Raiwind_Thokar@UniversityofLahore	0.002698967	0.89099568	59168
55	wapdatownroundabout_Ghazichowk	0.004265045	0.89193964	59693
56	SchemeMor_Wahdatroad_Dubai_Chowk	0.001911069	0.84857899	61240
57	LHR_ISB_M2motorway	0.18511291	1.039488	62323
58	Akbar_Ghazi_Chowk@Insafgeneral_Str	0.09366332	1.0034871	64534
59	Saggianroad_saggiantollplaza	0.14478537	0.87261152	66867
60	Schemmor_Thokar	0.036670633	0.9059878	74493
61	Kotlakhpat_hamdardchowk@shellpump	0.020546027	0.99263048	80392
62	Mainboulverd_Gulberg	0.007695916	1.1174304	85472
63	Chungi_Ammar_sadhu_Katcha_Jail_Road	0.084561735	1.0925421	87082
64	Mansoora_thokar@armydepot	0.016286682	0.9506864	90676
65	PU_Barkatmarket	0.13185869	1.1878855	92013
66	Canal_Shukatkhanam@shellpump	0.007667461	1.0145596	93264
67	Jinnahhospital_faisalTownroundabout	0.00860471	1.0995674	94928
68	Shukatkhanam_Shuqchowk	0.037081946	0.96786016	99525
69	Ghazi_Chowk_Ghazi_Road	0.17725769	1.1441832	101294
70	Edencenter_shadmanmosque_jailroad	0.004655219	1.0685433	101384
71	Qadafistadium_libertychowk	2.251E-05	0.89126891	104543
72	Chuburji_Thokar_Niaz_Baig	0.003907537	0.88139117	105636
73	Mughalpura_Harbanspura	0.13197102	1.0288355	107710
74	Zahorillahi_Libertychowk	0.000888301	1.0301981	107790
75	QartabaChowk_Gangaram_Hospital	0.009353465	1.0324261	107814
76	Doctorhospital_Jinnah	0.33072996	1.1625327	109000
77	ThokarNiazbaig_DoctorHospital	0.35797203	1.0983258	111024

78	LHR_Multan_Shahpura_Interchange	0.15857556	0.98851413	114232
79	Hussainchowk_libertychowk	0.000597132	0.99735999	116917
80	Faisaltown_university@barkatmarket	0.10788339	1.1478436	117765
81	Jailroad_Cantt	0.12454876	1.1408416	121169
82	Anarkali_GPO	0.017632814	0.93805754	121312
83	QartabaChowk_Service_Hospital	0.002036759	1.0168543	124095
84	Lower_mall_Crust Road	0.024300728	0.92034912	124133
85	PECORoad_ModelTown@Rajasahib	0.11860789	1.1341723	126843
86	Thokar_PU@JudicialColony	0.00111509	0.94927168	130385
87	Mallroad_Mughalpura	0.075326748	1.088814	130949
88	Kalmachowk_libertychowk	0.15246232	1.1939583	132301
89	Faisaltown_Barkatmarket	0.002559976	1.05086	132678
90	Walton_junction_walton_Road	0.046252687	1.1451859	138061
91	Kachehri_Istanbaul_Chowk	0.025023274	0.92251915	150515
92	JinnahHospital_Newcampus	0.067226075	1.1170232	165199
93	AzadiChowk_Ahmad_Ali_Road	0.003948929	0.74252087	170878
94	Larri_adda_ahmad_Ali_road	0.004000085	0.7238555	171401
95	MAO_College_DCourt	0.020357206	0.94996548	184024
96	Marian_Barkatmarket	0.13302089	1.1623801	197592
97	Chungi_Ammar_sadhu_Gajjumatta	0.057383932	1.0238166	200230
98	QartabaChowk_Shama	0.15357019	1.1198312	226947
99	Mallroad_Ferozpurcanal_road	0.30520284	1.1955674	251784
100	AzadiChowk_Bhatti_Chowk	0.019402882	0.82024741	254119
101	Racecourse_Canalcrossing	0.19772829	1.1579286	266678
102	QartabaChowk_Chuburji	0.064823866	1.0647086	284967
104	Ghazi_Chowk_Chungi_amarsadhu	0.25538975	1.1530863	432466
105	Walton_Kalmachowk	0.52195537	1.2138596	481470
106	Nabha_road_Istanbol_Chowk	0.014694276	0.93816048	515212
107	Kalma_Chowk_LinkRR	0.1617316	1.0944494	529694

Annex 2: List of Measure of PM10 and Vehicular Movement at 33 Urban Streets Junctions-Research Model 2

Sr. No	Name of Streets	Integration	Choice_Nor	Vehicular Count
1	Sundarroad_Raiwind	0.755	0.039	9.00
2	Phatak Stop	1.134	0.119	10.00
3	Baddianroad_near_Hera_village	0.948	0.031	28.00
4	Ferozpurroad_near_Chungi	1.153	0.256	32.00
5	Raiwindroad_near_Lake_City	0.89	0.002	37.00
6	Mazang	0.987	0.02	40.88
7	Jain Mander	0.9679	0.036	56.02
8	Near Allama Iqbal Medical College, Jinnah Hospital Underpass	1.117	0.067	59.10
9	Near_River_Ravi	0.87261152	0.144	60.00
10	Muslim Town Morr	1.184	0.202	193.35
11	Qadafi_Stadium	1.177	0.152	96.00
12	Zaman Park	1.08814	0.0753	98.80
13	Gajju Matta	1.03	0.057	107.00
14	Azadi_Chowk	0.786	0.004	108.42
15	Naseerabad	1.214	0.522	110.00
16	Qanchi	1.144	0.046	110.08
17	Shadman_intersection	1.069	0.005	115.50
18	Liberty roundabout	1.174	0.008	116.00
19	Main_Bazar_Ismail_Nagar	1.0925421	0.032	117.00
20	Fawara Chowk	1.141	0.125	118.95
21	Datta Darbar	0.882	0.06	119.36
22	Qartaba Chowk	1.065	0.065	130.46
23	MAO College	0.95	0.02	141.43
24	Canal View Housing Society, Near Meezan School	1.1625	0.33	187.90
25	Niazi Chowk	0.768	0.002	190.23
26	Charring Crossing	0.938	0.502	275.00
27	Ichra	1.12	0.154	278.08
28	Campus Bridge	1.1878855	0.132	308.57
29	UMT	0.967	0.037	290.00
30	Thokar Niaz Baig Chowk	1.128	0.378	387.56
31	UET_Gate_N0.3	0.945	0.1022	460.00
32	Ring Road	1.003	0.0325	529.00
33	Chuburji	0.881	0.004	268.81

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