Characterizing the Street Network of Adama City for Urban Vitality Using Space Syntax

Tizita Bogale Zewde

A Thesis Submitted to the Department of Architecture,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Urban Planning and Design

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

June, 2022

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APPROVAL OF BOARD OF EXAMINER

I, the advisor of the thesis entitled "**Characterizing the Street Network of Adama City for Urban Vitality Using Space Syntax**" and developed by **Tizita Bogale**; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Tizita Bogale** have read and evaluated the thesis entitled "**Characterizing the Street Network of Adama City for Urban Vitality Using Space Syntax** "and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in **Urban Planning and Design**.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head	Signature	Date
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School Dean	Signature	Date
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Office of Postgraduate Studies, Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled **"Characterizing the Street Network of Adama City for Urban Vitality Using Space Syntax"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

______________________	______________________	______________
Name of the student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Characterizing the Street Network of Adama City for Urban Vitality Using Space Syntax"** prepared under my guidance by **Tizita Bogale** submitted in partial fulfillment of the requirements for the degree of Master of Science in **Urban Planning and Design**. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

______________________	______________________	______________________
Major Advisor	Signature	Date

ACKNOWLEDGMENT

In the first place, I thank my Almighty God for giving me the strength from the beginning to the end of this research.

I would also like to express my very grate appreciation to my advisor, Asst. Prof. Tibebu Assefa (Ph.D.). This research would not have been possible without his support. His knowledge and attention to details has been an inspiration.

I am also grateful for my university, Adama Science and Technology University, for providing me with this opportunity to pursue my MSc, which I deeply appreciate. I would also like to express my gratitude for my lecturers Asst. Prof. Daniel Lirebo (Ph.D.), and Prof. Samson Kassahun for their help and support throughout my study.

I sincerely thank my whole family and friends. It would not have been possible to do any of this without their support and inspiration.

Finally, I want to express my gratitude to everyone who took part in this research because their efforts contributed to the success.

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LIST OF ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
Hr.	Hour
Min.	Minute
MS	Microsoft
OMS	Openstreetmap
RSDP	Road Sector Development Program
sDNA	Spatial Design Network Analysis
SS	Space Syntax

ABSTRACT

Street is the basic unit of urban space through which people experience a city. The street network is a generator of urban form; the best-connected street network tends to support specific forms of land-use with high population density. Adama city is expanding rapidly however; the existing road network is inadequate to serve the newly created districts which are creating segregated neighborhoods with a risk of security. The research aims to characterize the street network of Adama city and determine how it affects the city's vitality using space syntax, using a set of syntactic variables like integration, choice, connectivity, and control. Pedestrian movement survey was conducted in selected areas in order to measure how urban space networks and land-use of the area interact with pedestrian movement. DepthmapX was used to conduct the analysis. The results of the analysis show that Adama is highly integrated at the center, which indicates the core of the city is more vital and attracts people. 21.46 percent of the city's total street segments are integrated, while 11.5 percent are segregated. The streets with the highest choice-value highlight the roadways with the most mobility. The result of street connectivity shows streets in the center of the city have a comparatively large number of connections. Streets with high control value highlight a segment which highly controls access to adjacent space and attract pedestrians. Streets with high integration, choice, connectivity, and control values collectively present the vital streets of the city. They are concentrated at the center of the city and cover 21.54% of the total street segments. To increase the vitality of the city as a whole and to curb antisocial behavior urgent improvement is required in segregated areas. Prioritizing integrated roadways for improvement and proposing a diversified land use will also ensure the city's vitality.

Keywords: street network; urban vitality; integration; space syntax, pedestrian density.

CHAPTER ONE

INTRODUCTION

The street network configuration tends to guide the building density and land-use mix that influences how people use streets. The high number of people in the streets indicates a higher degree of vitality. Building density, diversity, and degree of street life are very strongly influenced by the street network configuration. Due to rapid population growth cities are expanding. The interconnectivity of the street network of the newly created areas with the existing main streets affects the vitality of the whole city. The motive for this research is the desire to contribute to sustainable city expansion and the desire to understand how the spatial configuration of the street network influences the flow of human movement and the existence of commercial land-use at certain location. This study characterizes the nature of the existing street network of Adama city to determine how it affects urban vitality by using space syntax analysis.

This chapter describes the background of the study, statement of the problem, objectives, research questions, scope, significance, and limitation of the study.

1.1. Background of the Study

The world is rapidly urbanizing, particularly in developing countries (Cobbinah, 2015). In 2050, two-thirds of the world's population will live in cities. This fast urbanization has been accompanied with a rise in urban people and the extension of urban built-up land. Newly-developed urban areas have lower infrastructure, access to employment opportunities, and availability of everyday goods and services than existing urban areas; as a result, new residents of cities tend to be gathered at nearby existing urban districts. This leads to issues such as low population densities, low levels of commercial activity, criminality, and anti-social behavior, all of which are related significantly with low urban vitality in newly created neighborhoods (Zhou et al., 2015).

Urban vitality is a key indicator of a city's attractiveness and competitiveness, as well as its ability to sustain urban expansion and quality of life. Compact urban development, inventive urban expansion, and people-oriented urbanization all require an understanding of urban vitality. The degree of human activity in different parts of the city and at different times is reflected in urban vitality (Li and Liu, 2016). Compact, well-organized functional areas can produce enough interactions and activities to keep areas lively (Yue& Zhu, 2019).

Previous studies have shown that street configurations, which are a generator of urban form, have a considerable impact on physical activity in streets and then urban vitality (Yue, 2019; Cooper et al., 2014). Street networks are critical to city planning because they are a complicated result of city development that determines future urban development patterns (Al-hinkawi et al., 2021). They act as a city's skeleton, revealing where the city's most important components are located. People's movements are mostly restricted when they travel from one location to another via streets (Yue & Zhu, 2019). Low vital districts are intensified by street segregation and limited accessibility (Li and Liu, 2016).

The street network, size of the city, and population distribution reflect the level of connectivity. Ethiopia, which covers an area of around 1.1 million square kilometers, has a very low degree of connectivity, with only 30 000 kilometers of roads, with the majority part of them existing in the federal network. Approximately 30% of rural regions are already connected by all-weather roads, and many of these are in poor condition (Yonas Minalu, 2014). Adama is the second-largest city in Ethiopia. The city has been spreading out, experiencing fast urbanization, accelerated population expansion, increased traffic congestion, and rapid and poor-quality sprawling over the past years, while the vitality of the city has commonly been underappreciated (Ahmed Buseri, 2016).

Cities can be classified according to their network’s structural characteristics. In other words, the street network of a city exhibits spatial signatures that can be quantified and operationalized to differentiate types of places (Boeing, 2019b). Researchers, planners, and community members can use network patterns to better understand local histories of urban design and morphology, for transportation planning, to evaluate existing street system patterns and configurations, and to explore new infrastructure proposals and alternatives by measuring these network patterns (Boeing, 2019a). To analyze the design-oriented elements of street networks that most influence street activities and then urban vitality, the relationship of street network configurations with movement patterns and land-use must be measured.

Space syntax is a set of theories that describe how urban space networks interact with the social and economic factors that they influence and shape in general (Van Nes & Yamu, 2018). The space syntax method is unique in that it connects specific components of the urban environment to socioeconomic characteristics like movement patterns and land usage (Dettlaff, n.d.). Space syntax analysis, which combines varying degrees of urban vibrancy, street activity, and the position of active land use such as stores and micro-economic businesses, depicts the built environment's 'hidden' spatial structure. Space syntax analysis is a widely used method for analyzing spatial relationships like modeling and predicting the effect of the street system on the socio-economic pattern, how to control traffic pollution, the processes of route selection, and analysis of anti-social activity (Hillier & TIM, 2010). It uses a series of syntactic variables like connectivity, control, choice, and integration to do a quantitative analysis of urban road networks (Van Nes & Yamu, 2021). From the perspective of street design network analysis, the street network configuration's connectivity, closeness, and betweenness affect urban vitality in an urban system (Fang et al., 2021).

1.2. Statement of the Problem

During the last few years’ cities transformed naturally and a sufficient number of badly functioning urban areas were built. Adama city is expanding rapidly due to population expansion. In the last 37 years, the expansion of built-up areas has climbed from 2% in 1973 to 10% in 2000, 23% in 2010, and is expected to rise to 60% in the next 30 years (2040); however, the road network is inadequate to serve the newly created districts(Bedasa Regassa, et al., 2020).

Urbanization and unplanned expansion are creating segregated neighborhoods with a risk of security. These newly formed expansions fail to consider the urban vitality and liveliness of the city, which are the basic principles for creating an active, safe, vibrant, and sustainable city. People in segregated neighborhoods travel a long distance to the center of the city for work, education, and shopping, which leads to high traffic congestion and travel costs. Due to the lack of an integrated road network, public transportation is not available in specific areas of the city. As a result, people are obligated to perform part of their journeys on foot and take the longest route to their destinations.

Low population densities, low levels of commercial activity, and risk of security indicate low urban vitality in newly created neighborhoods, which are mostly located around the outskirts of the city. These problems are mainly caused by; streets serving these neighborhoods are not connected with the main roads of the city. Unless these problems are solved, it is difficult to achieve sustainable city developments since the high travel demand to the center of the city is economically costly, environmentally polluting, and creating socially segregated neighborhoods around the outskirts of the city. Now is the best time to learn from these areas through identification and analysis of the special as well as social parameters and to apply this knowledge in urban planning practice. It is possible to show how the current unplanned city transformation is affecting the social-economic life of cities using the space syntax method.

There has been no research on the accessibility and vibrancy of Adama city's street network. Using space syntax analysis, this study aims to bridge the gap by demonstrating how providing a connected and integrated street network can assist cities' vibrancy and liveliness. Although it has been used by a few experts, space syntax analysis is not widely used in Ethiopia's planning process. Feven Mulushewa (2020) uses space syntax analysis to determine the level of integration of Addis Ababa's road system, locate the city's major roads, and investigate the city's highly segregated areas that require immediate development; however, the study fails to show how the street network configuration affected human movement at specific locations. By employing just integration measures, Khalil et al. (2016) use the space syntax technique to determine the source of jugol city isolation and limited accessibility to recoup lost vitality. This study examined the relationship between street network configuration, human movement, and land use by using all the major measures of space syntax. The measures used are integration, choice, connectivity, and control, which collectively indicate the degree of vitality of the city.

1.3. Objective of the Study

General objective:

To characterize the street network of Adama city and determine how it affects urban vitality using space syntax analysis.

Specific objectives:

1. To identify integrated roads of Adama city.
2. To measure the degree of choice of the streets.
3. To evaluate the level of connectivity of the streets.
4. To calculate the degree of control of the streets.

1.4. Research Questions

1. What are the integrated roads of Adama city?
2. Which are the most preferred streets of Adama city?
3. What is the level of connectivity of the streets?
4. To what extent streets control access to adjacent streets?

1.5. Significance of the Study

The study identified the integrated and segregated streets, the most preferred streets for mobility, and the level of connectivity and reachability of the streets within the Adama city structural boundary. This aids the city's road authority in reducing disconnections in segregated streets to increase people and commodities movement. In addition to that, the results of the measurement can also be used to improve the most integrated, reachable, and vital streets for comfort and ease of movement of pedestrians. The study helps in identifying the priority for the allocation of potential roads and land-use. This contributes to the degree of street vitality and liveliness of the city. The study is also beneficial for researchers to do similar types of research for other cities of Ethiopia to contribute to better accessibility and street vitality in the country. Generally, this study will contribute to understanding the relationship between spatial structure and human behavior.

1.6. Limitation of the Study

This study has some limitations with which the findings need to be interpreted accordingly. First, the research presented here was limited by the measures used; the effect of street width and adequate street infrastructure on urban vitality was not examined. However, the measures used to examine the degree of urban vitality help to conduct extensive spatial syntactic analysis to understand how the street arrangements impact the pedestrian volume of a certain location, which explains the urban vitality extensively. Secondly, space syntax analyzes natural roads as a straight line and calculates its integration without taking into consideration its function (two-way street, one-way street, pedestrian or motorway, etc.) and its density. This study is mainly based on how the interconnectivity of the street network system affects the density of pedestrian volume and the existence of diversified land-use at certain locations. The first step to conduct the analysis was to develop an axial map for Adama city, which is a clear single line map of the streets. The first challenge was creating a clear single line map of the total street system of the city. Although OpenStreetMap was a good source of road information, the downloaded shapefile needed lots of adjustments. Finally, the axial map of the city was developed with the help of Google Maps and GIS, though it takes more time. Despite these limitations and challenges, the study was done diligently.

1.7. Scope of the Study

This study was done within Adama city administrative boundaries and focused on the existing natural streets at all levels, from alleys in the residential area to the higher levels as boulevards of Adama. The study focuses only on the street network characterization of Adama city by using the main space syntax measures, namely integrity, connectivity, choice, and control measures, to determine the effect of the network on the city's vitality.

1.8. Definition of Key Terms

Urban vitality is the quality of spaces in cities that can attract heterogeneous peoples for different activities.

Space syntax encompasses a set of theories and techniques for the analysis of spatial configurations and is used to forecast the likely effects of architectural and urban space on users.

Axial lines are longer and uninterrupted lines and do not show any difference in syntactic value along their length.

An axial map depicts the least number of axial lines covering all convex spaces of a layout and their connections.

Segment lines represent the length of the line between any two intersections.

Axial analysis is a way of analyzing a spatial layout represented by an axial map.

Angular segment analysis is any analysis of is segment map including topological, angular, and angular metric analysis.

Segment map is constructed from the axial map. Axial lines are broken at intersects.

Depth between two spaces is defined as the least number of syntactic steps in a graph that are needed to reach one from the other.

To-movement is the movement to a space as a destination from all others. Integration is thought to be a predictor of to-movement.

Through-movement refers to movement that takes the shortest route from one place to the next in the layout. Choice is thought to be a predictor of through-movement.

1.9. Organization of the Research

There are six chapters in the thesis. Each chapter comprehensively examines the content and data of the study accordingly. The main chapters in the thesis are further demonstrated as follows.

Chapter One: Introduction describes the background of the study, statement of the problem, objectives, research questions, scope, significance, and limitation of the study.

Chapter Two: The Literature Review chapter focuses on the description of theoretical and empirical issues relevant to the study's conceptualization. The goal of this chapter is to describe the key research topics, such as the street network, urban vitality, space syntax analysis, and measures. It is composed of a variety of works of literature that provide a theoretical foundation for understanding the subject matter under study from multiple angles.

Chapter Three: The Materials and Methods chapter briefly summarizes the study's methods and techniques. The study area description, data sources, data collection, and data analysis methods, in particular.

Chapter Four: Result contains all the findings of the research from the quantities analysis gotten from street network analysis, correlation and multiple regression analysis between different variables, pedestrian movement observations and land-use.

Chapter Five: Discussion chapter briefly discusses and interprets the results of quantitative data findings and explain the significance of those results by comparing with previous researches.

Chapter six: Conclusion and recommendation is the last chapter of this research. This chapter drew conclusions based on the findings and discussions of different measurements. This chapter also recommended specific actions to be taken by stakeholders based on the findings of the research.

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CHAPTER TWO

LITERATURE REVIEW

This chapter focuses its attention on the description of the theoretical and empirical issues that have relevance in conceptualizing the study. This chapter aims to explain the main research concepts including street network, urban vitality, space syntax analysis and measures. It is composed of various literatures which gives a theoretical framework to understand the subject matter under study from different perspectives.

2.1. Theoretical Review

2.1.1. Street Network

Street is the basic unit of urban space through which people experience the city (Boeing, 2019a). Street is more than just a linear path; it can express civic society, a cultural interface, and urban life substance. As a result, the street has become a focal point for human activity. The basis of urban accessibility is the establishment of city street networks and the movement patterns of people and products (Al-hinkawi et al., 2021).

Whether planned or unplanned, orderly or disordered, street networks organize and constrain a city's traffic dynamics according to spatial logic (Boeing, 2019a). Streets are the determinants of urban growth. A good design will act as a catalyst, but a bad design will freeze city life. The urban street network must be recognized to improve the coherence between the urban and its street system (Al-hinkawi et al., 2021).

Human spatial dynamics and flows in a city are organized and structured by street networks. The study of street networks has become a vital link between graph theory and urban morphology and planning. Cities can be aggregated and categorized based on the structural properties of their networks or cities' circulation networks have spatial characteristics that may be quantified and operationalized to distinguish between different sorts of locales (Boeing, 2019b).

2.1.2. Urban Vitality

Urbanization processes share common characteristics, like rapid and poor-quality settlements, in which vitality has commonly been underappreciated (Ye et al., 2018). The lively urban environment benefits the economy and people's social and economic life by providing viable areas for sociability, relationships, and involvement in diverse activities (Chen et al., 2019). Although the importance of vitality has been recognized, and much research has been conducted on the subject, it is difficult to define urban vitality in a single definition. Researchers described urban vibrancy as the intensity of pedestrian activity on city streets, and well-organized dense functional spaces could generate adequate interactions and activities for creating vibrancy (Jacobs, 1961; Montgomery, 1998). Urban vitality has also been viewed as one of the most important factors in achieving a high quality of life in cities (Jin et al., 2017).

2.1.3. Urban Vitality and Street Network

Because of varying urban structures, different regions have varying levels of vitality. To better understand how the built environment affects human activity, it is crucial to investigate the relationship between urban form and urban vitality. A city's road network acts as the "skeleton" since it exposes where most of the important land uses are located, and people's movements are mostly confined as they transit from one location to another via streets (Yue, 2019).

Street centrality is a valid measurement of spatial accessibility and location advantage in a city (Rui and Ban, 2014). People living or working in the city can readily access a central area from various locales. In Baton Rouge, Louisiana, an experimental assessment of the relationships between street centrality and population (residential) and employment (business) densities indicated that they were substantially related in space (Wang et al., 2011). Many other studies have also confirmed the significant role of street centrality in facilitating urban vitality (He et al., 2019; Lin et al., 2018; Wang et al., 2014).

The diversity and intensity of activities, as well as the variety of comings and goings, social contacts, and transactions, are all influenced by the vitality potential of spaces emerging from topological, functional, and geometrical characteristics of the urban form (Montgomery, 1998).

2.1.4. How to Measure the Degree of Vitality of Streets?

To analyze the design-oriented elements of street networks that most influence street activities and then urban vitality, the relationship between street network configurations and pedestrian density must be measured. All street networks are composed of nodes and links. Nodes are intersections or connections between streets in street networks. As a specific type of spatial network, nodes have definite geographic locations, and links always have a physical shape (Cooper et al., 2014). From the perspective of sDNA, street network configuration's connectivity, closeness, betweenness, and control value affect urban vitality in an urban system (Fang et al., 2021).

2.1.5. Space Syntax Analysis

Space syntax, developed by Hillier and Hanson at the Unit for Architectural Studies, University College London, is a theory and method for analyzing spatial relationships using a variety of objective metrics (Hillier & Iida, 2005; Khalil et al., 2016). Space syntax measures how every street segment in a built environment relates to all other public spaces. Space syntax measures the to-movement potential, or closeness, of each street segment concerning all others. It also assesses the possibility for through-movement, or betweenness, of each street segment concerning the others. The street network’s to- and through-movement potentials represent various accessibility potentials (Van Nes & Yamu, 2021). Both types of relational patterns can be weighted by three different definitions of distance. The topological distance calculates the street network of the city as a system of the fewest-turn paths, whereas the metric distance measures the city's street and road network as a system of the shortest-length paths. The geometrical distance depicts the city's street and road network as a system of paths with the least amount of angle change. Each type of relationship can be calculated at different radii from each street segment by defining the radius as the shortest length, fewest turns, or least number of angle changes (Hillier & Iida, 2005).

As research has shown, there is a correlation between pedestrian and vehicular movement and the spatial configuration of the street network (Hillier et al., 1993, 2012). The purpose of the SS is to describe different aspects of relationships between the morphological structure of human-made environments and social structures and events (Dettlaff, n.d.).Understanding the interaction between humans and space is important because it allows you to forecast how spatial layout will affect users' experience. The city is defined as the physical layer's penetration into the social layer (Hillier & Vaughan, 2007). Applying space syntactic analysis as a method for sustainable development can help find a balance between the environmental, social, and economic components of a given place.

The methodology of space syntax has been applied extensively in a wide range of urban design and planning projects, from modest public spaces to large cities. A series of primary analyses in the space syntax approach guides the design process from the start by discovering the challenges and potentials identified by the spatial configuration analysis. These advantages and disadvantages are a direct reflection of the functioning of the urban system, allowing the design team to see them more clearly. The process of creating and assessing ideas can be repeated at various stages and scales until the best answer is found (Karimi, 2012).

The three basic elements of the space syntax approach are convex space, isovist field, and an axial line (Van Nes, 2011) as shown in Figure 1. Convex maps are used for analyzing buildings and the public spaces between a group of buildings in neighborhoods or smaller villages. The panoptical perspective a person has from a given place in an urban setting is represented by an isovist field. It is employed in the urban fabric for orientation and navigation. Axial lines are the most basic way of describing a city in space syntactic analysis. An axial line is defined as the longest line that can be drawn through a random point in the spatial configuration. It represents the way human beings move in lines through the urban street and road networks. The Depthmapx software can be used to perform axial line and all-points isovist analyses (Van Nes, 2011).

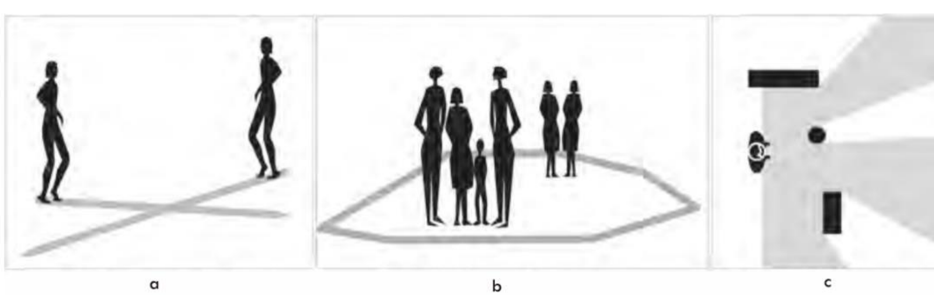


Figure 1: The basic elements of space syntax. The axial line for movement (a), the convex space for interaction (b), the isovist field for orientation(c).(source: Van Nes & Yamu, 2021).

Axial maps have inherent limitations, when computing spatial maps, however. The axial line is the smallest unit, and it ignores "segments," which are the smallest spatial units in a street network. Second, advanced angular studies are not possible with axial maps. A segment line is a derivation of axial lines that are generated by axial lines intersecting. Thus, as of recent, the axial maps are little or not at all used by space syntax researchers who have instead opted for segment maps (Shrestha, 2019). Recently, for analyzing large metropolitan areas, whole regions, or even whole countries, the road center line map is applied. The case-based routes are easy to aggregate from the road centerline when working on a metropolitan or regional scale. Sometimes a so called ‘hybrid model’, a combination of road centerlines and an axial map, is used (Van Nes & Yamu, 2021).

2.1.6. Space Syntax as Theory

Positivism and hermeneutics are two well-established but different study traditions. These two study traditions have an impact on our ability to understand and explain the relationship between the built environment and society. Space syntax research is interdisciplinary, and when it comes to studying urban artifacts, urban form, and urban space, these topics intersect the human, social, and natural sciences (Van Nes & Yamu, 2021).

The theory of the natural movement economic process is one of the descriptive theories on built environments that follow the positivistic research tradition. It states that the spatial configuration of the street and road network influences the flow of human movement and the location of shops in built environments. The greater the spatial integration of the street network, the significant the flow of human mobility and the more engaging the land along the street network becomes for economic purposes. The more people on the streets, the more shops tend to spring up along these routes, and the more shops there are, the more people are drawn to the area (Hillier et al, 1993). When the spatial layout of the street network is changed by physical interventions such as walls (Desyllas, 2000) or additional road or street links; this process changes (Van Nes, 2021).

2.1.7. Space Syntax Measures

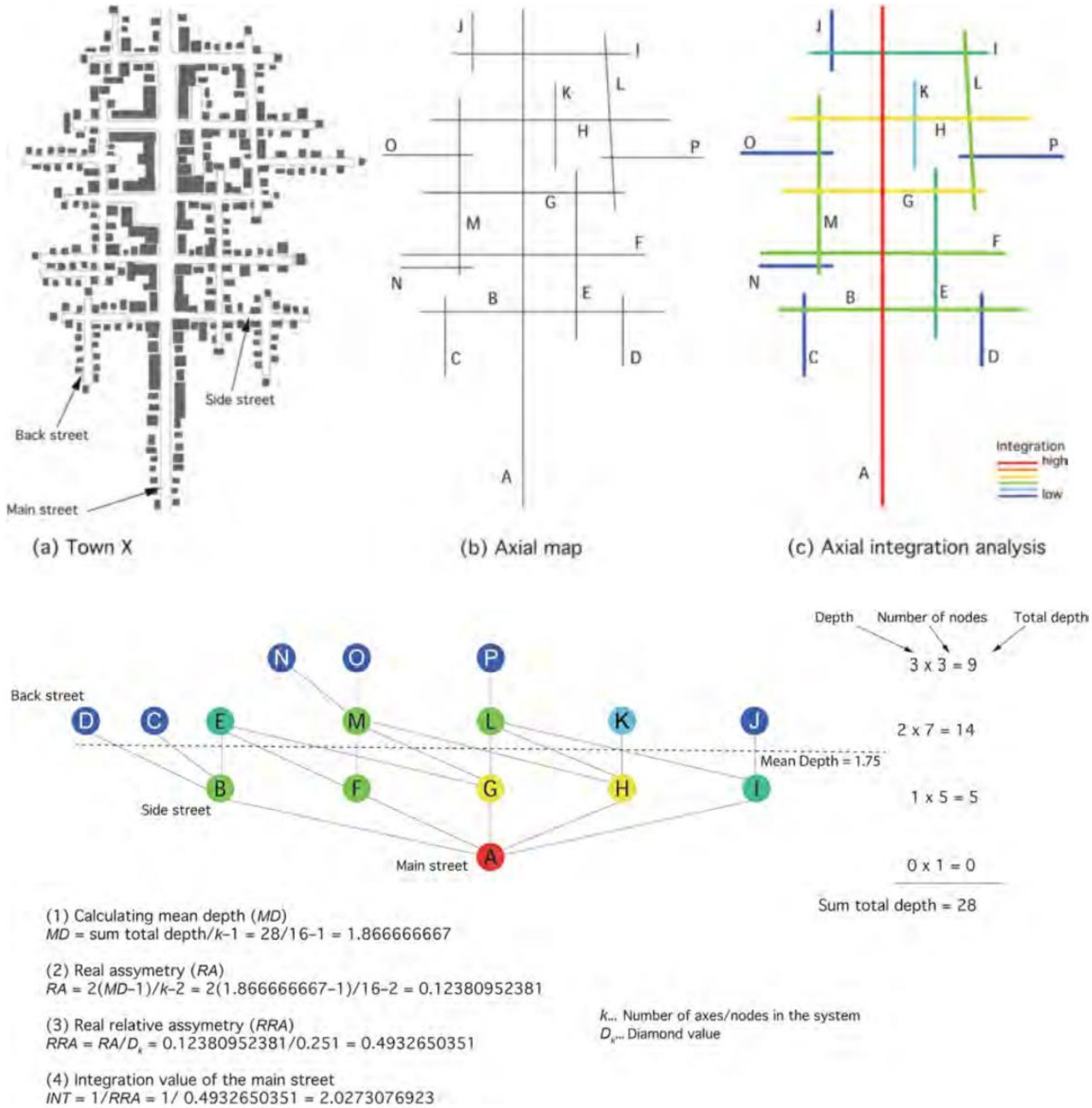
For the objective of describing social behavior, researchers in Space Syntax have created a variety of measurements (Al Sayed et al., 2014). The following are the most significant:

A. Integration

The most important measure is integration, which measures the to-movement potential or closeness of each street segment concerning all others. It represents the average topological distance in a network, or the number of directional changes from each line segment. Streets with fewer directional changes from all other streets are highly integrated in the system. Streets having many direction changes to reach all other sites in the urban system, on the other hand, tend to have poor global integration values. They are spatially segregated. The most integrated to the most segregated locations are ranked using integration. Integration is assumed to correlate with rates of social contact and retail activity, and it usually indicates how many people are expected to be in a space. The integration degree reflects the reachability and accessibility of street spaces (Van Nes & Yamu, 2021).

Figure 2 explains how integration is calculated using town x as an example. Each axial line denotes a public urban place that is connected to others. It is feasible to compute how each axial line in a particular system is connected to all other axial lines. In other words, the integration measure is used to calculate the topological depth of each axial line in relation to all other axial lines. The data are color-coded for the integration analysis (Figure 2(c)), with red axial lines representing the most integrated axis and dark blue axial lines representing the most segregated (Van Nes & Yamu, 2021). The justified graph (Figure 2(d)) depicts how the system can be viewed from the most integrated street.

Integration measure consists of local integration value and global integration value. Local integration exposes the relationship between one space and its adjacent spaces in the whole system. It reflects the topological proximity of a line to its neighboring axial lines (two turns away from a specific axial line) to all other lines in a network. The degree of integration between one space and others in a given scope is referred to as the global integration degree. It represents the average topological distance in a network, or the number of directional changes from each line segment. It also shows how streets relate to all other streets in a predefined special system (Zheng-yu & Quan, 2009; Li et al., 2016). The correlation between local and global integrations indicates what the synergy value is. A good link between global and local integration means that a busy local street will also be a busy global street (Dalton, 2011).



(d) Nodes of the justified graph and integration calclations.

Figure 2: Shows town X with its morphological footprint (a), its unprocessed axial map (b), and its axial integration analysis results (c), nodes of the justified graph (d). (source: Van Nes & Yamu, 2021).

These most integrated values (10%) are called integration core and can be distinguished on the map by a heavy red color. In good systems, the integration core relates to all other areas. This ensures you're never far from a high-integration line, no matter where you are in the system (Hillier et al., 1983).The most integrated lines in an urban plan are those lines that are most familiar to people and are frequently used for shopping (Van Nes & Yamu, 2021).

B. Choice

Choice or betweenness measures through-movement potential and how likely one is to pass through the segment on everyday trips or its potential as a route. It also measures how likely a street segment is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a fixed distance (radius) from each segment (Hillier et al., 1987). Choice measures movement flows through spaces. Spaces with high global choice are found on the shortest routes from all points of origin to all points of destination. A choice is a useful tool for predicting the possibility of pedestrian and vehicular traffic (Hillier et al., 2012).

When applying various metric radii for the angular choice analysis, the following results are obtained. For a small metric radius, the local main routes of the local centers of a city are highlighted. This applies, for example, to radii of 400, 800, or 1,200 m. The higher the applied metric radiuses, the more the main routes running through and between neighborhoods in a city are highlighted. In the radius n analyses, the highway network tends to get highlighted (Van Nes & Yamu, 2021).Correlating angular choice results with high and low metric radii indicate the degree of street life in built environments. When the correlation coefficient is high, the locally integrated main routes are also highly integrated on a city scale. Conversely, when the correlation coefficient is low, the locally integrated main routes are located far away from the main routes on a city scale (Van Nes & Yamu, 2021).

C. Connectivity

The number of immediate neighbors who are immediately connected to an area is measured by connectivity. The connectivity value of an axis refers to the number of axes linked to it; the higher value means the permeability of the axis is better (Zheng-yu & Quan, 2009). As a result, connectivity analysis is fairly straightforward. It's all about calculating how many links each street has to its neighbors. If the street spaces have a higher connectivity degree, it also has stronger reachability, and more relevance to surrounding spaces (Li et al., 2016).

D. Control

Control evaluates how tightly a space controls access to its immediate neighbors, taking into account the number of alternative connections available to each of them. The control value of an axial denotes the impact it makes on its connected axial lines; the higher value means the street is more important in the network (Zheng-yu & Quan, 2009). The control degree indicates how one space controls adjacent spaces. If the street spaces have a higher control degree, it also has higher reachability (Li et al., 2016).

As an example, Figure 3 shows how to determine control value using an axial line. Control is equal to the sum of the reciprocal of the connectivity of its neighbors. Each line has been decided to begin with a control value of 1. Each line will distribute its initial value of 1 to all intersecting lines evenly. Because line 1 crosses two other lines, it will divide its initial control value evenly across lines 2 and 6, giving each a value of 0.5. Line 3 will assign a value of 0.5 to line 2 and line 4 will assign a value of 0.333 to line 2. As a result, line 2's control value equals the total of 0.5, 0.5, and 0.333, yielding a control value of 1.333, which is higher than it was before. Other lines, such as line 6, which has a control value of 0.833, have control values lower than their initial ones (Hillier et al., 2012).

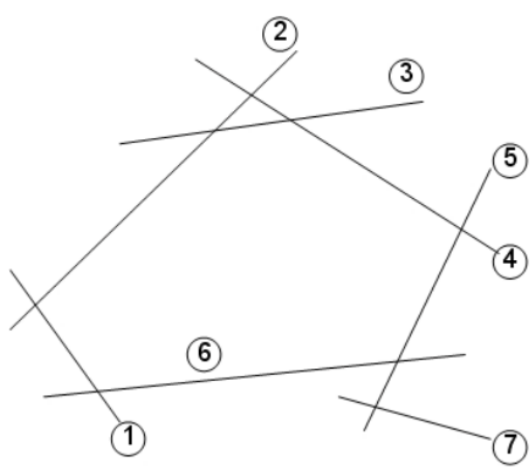


Figure 3: Axial lines demonstrating the control value. (Source: Hillier et al., 2012).

2.1.8. Space Syntax, Street Configuration, Land-Use, and Pedestrian Movement

The configuration of a network is considered the major generator of pedestrian movement in Space Syntax. According to the space syntax theory, the spatial distribution of pedestrian flows within a system is fundamentally morphological and topological, and is a functional effect of the configuration of the urban street. The volumes of pedestrians and space syntax indicators (Connectivity, Integration, Control, and Global Choice) were found to have a positive and large degree of association, with 'integration' having the strongest connection (Aziz, 2018).

Despite the fact that several researchers have attempted to investigate the relationship between urban morphological factors and pedestrian volume on city streets, the space syntax technique is unable to account for surrounding land use, which is a critical limitation when estimating or predicting pedestrian volume and walking activities (Lee at al., 2020). Combining GIS-to depict land-use with space syntax has great potential in investigating pedestrian walking activities. Non-residential land-use and pedestrian volume have a substantial relationship, according to the findings. For evaluating the relationship between pedestrian volume and non-residential land use, a 100-meter circular buffer from the pedestrian observation point is reasonable (Yun &Choi, 2013).

2.1.9. Space Syntax Observation

Space syntax observations are a collection of approaches for observing movement flows and patterns of space use in urban environments. There are several approaches to investigating social behavior (Al Sayed et al., 2014). A gate count will be used in this investigation in a few regions. This method has been used to demonstrate that highly integrated streets have high human mobility rates, but highly separated streets have a low number of people visiting them (Hillier et al. 1998; Hillier and Iida 2005). The counts of movement are usually helpful in understanding the relationship between spatial structure and human behavior (Grajewski, 2001).

The following requirements must be fulfilled to register pedestrian movement. The boundary of the area under observation must be marked on map. This should cover a range of well-used to moderately to poorly used spaces in and around the area of study. Select a reasonable number of gate positions (Van Nes & Yamu, 2021). According to Grajewski (2001), each area should have at least 25 gates, with the more the better. Select the gates based on the findings of space syntactic analysis. Observer should at least record 5 minutes in suburban regions or any place with little traffic, and 2.5 minutes on busy city routes. The rest of the time will be spent walking to the next gate.

This observation should be recorded again to represent weekdays and weekends. The date and weather conditions, including temperature, are especially critical to observe because they affect pedestrian flows. The recommendation is to pick a day with "average weather" for each case, which means you should check the weather prediction before starting the registrations. To maximize their vision field, observers should stand at the edge of each gate and count people who cross an imaginary line that connects two components of the architectural environment, such as columns and walls (Figure 4). A stopwatch will be used to count the minutes (Al Sayed et al., 2014).

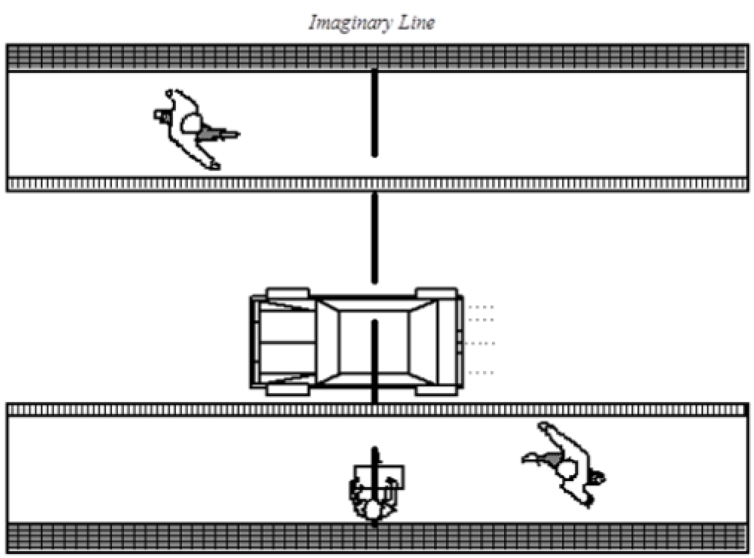


Figure 4: Position of observer to count pedestrian movement that crosses an imaginary line. (Source: Grajewski, 2001).

2.1.10. Pedestrian Level of Service

The street network serves as the urban space's spinal column and circulatory system, ensuring it's structural and vitality. Sidewalks, street furniture, and street lighting are all useful elements of the traffic design of pedestrian-friendly streets. Since the fundamental priority in environmental and urban design should be human convenience and amenity, pedestrian design guidelines should reflect the more generous space allocations (Devica, 2015).

Level of Service standards allow for a very close approximation when planning pedestrian zones that are safe, convenient, and useful in accordance with a design standard. The concept of Level of Service can also be used to design pedestrian environments (Banerjee et al., 2018). Pedestrian service criteria should be predicated on the option to choose a regular locomotion pace, as well as the flexibility to move at any speed. Pedestrian service criteria should be based on the ability to choose a normal movement speed, the ability to bypass slow moving pedestrians, and the relative ease of cross- and reverse-flow movements in congested areas (Devica, 2015).Figure 5 depicts the correlation between pedestrian flow volume and area relationships.

Level of Service		Flow Rate *(pedestrian/hour*
A		*0 -120*
B		*120-240*
C		*240-480*
D		*480-800*
E		*800-1200*
F		*>1200*

Figure 5: Pedestrians level of service. (Soure: Van Nes & Yamu, 2021; Devica (2015).

2.1.11. Software for Space Syntax Analysis

DepthmapX is a multi-platform open-source program that performs a series of spatial network analyses to better understand social dynamics in the built environment. It works at several scales, from single buildings to entire towns or states. The software's aim at each scale is to create a map of open space pieces, connect them via some relationship, and then analyze the resulting network using graph theory with variables that have social or economic importance (Space syntax network, n.d.).The general premise for DepthmapX came from two different lines of thought.

The first was isovist analysis (Benedikt, 1979), and the second was space syntax (Hillier and Hanson, 1984), both of which used the axial lines.

2.1.12. Drawbacks of Space Syntax

One of the inconsistencies with the Space Syntax technique is the exclusion of the city's third dimension, more specifically, the omission of building heights, densities, and other factors in the investigated locations. The fact that the impact of street patterns on mobility is conditional (in some places, there are more or fewer buildings, more or fewer destinations and origins of traffic) is overlooked. The axial map does not take into account the various land uses or building functions, which are important factors in traffic generation (Ratti, 2004).Although axial maps can infer main and secondary roads based on the lengths of axial lines, they have no direct bearing on road width. In other words, the pattern of axial maps may appear to suggest the existence of a road hierarchy when it does not. In the case of navigation and direction, the hierarchy of roadways cannot be overlooked (Hillier et al., 2012).

2.2. Empirical review

2.2.1. Best Practices of Urban Design by Using Space Syntax Analysis, City Of Jeddah.

The preliminary investigation began with the creation of a segment-angular analysis of Jeddah's complete metropolis. This model was integrated with population density, land use, vehicular traffic, and socioeconomic aspects to create composite urban models. The city's global results indicate major structural issues such as isolation of the historic core; lack of a proper City Centre; extreme shift of the city's center of urban form to the north; inefficient urban growth and sprawl; negative effect of undeveloped mega-scale sites in the heart of the city on their surroundings; and spatial segregation of unplanned settlements, which were quickly turning into urban slums (Karimi, 2012).

Strategic solutions for each of the highlighted challenges were produced through a series of analytical investigations. These solutions were put to the test, their influence was examined, and recommendations for improving the spatial system were made. On local and global dimensions, the spatial model measured the individual and aggregate impacts of all these urban shifts (Figure 6). When compared to the actual city and the proposed local plan previously adopted by the Municipality, the analysis found considerable improvements across the city (Karimi, 2012).Space syntactic methodology was used in the original study phase as well as the analytical evaluation phase in all of these projects (Karimi et al, 2007; Karimi & Parham, 2012).

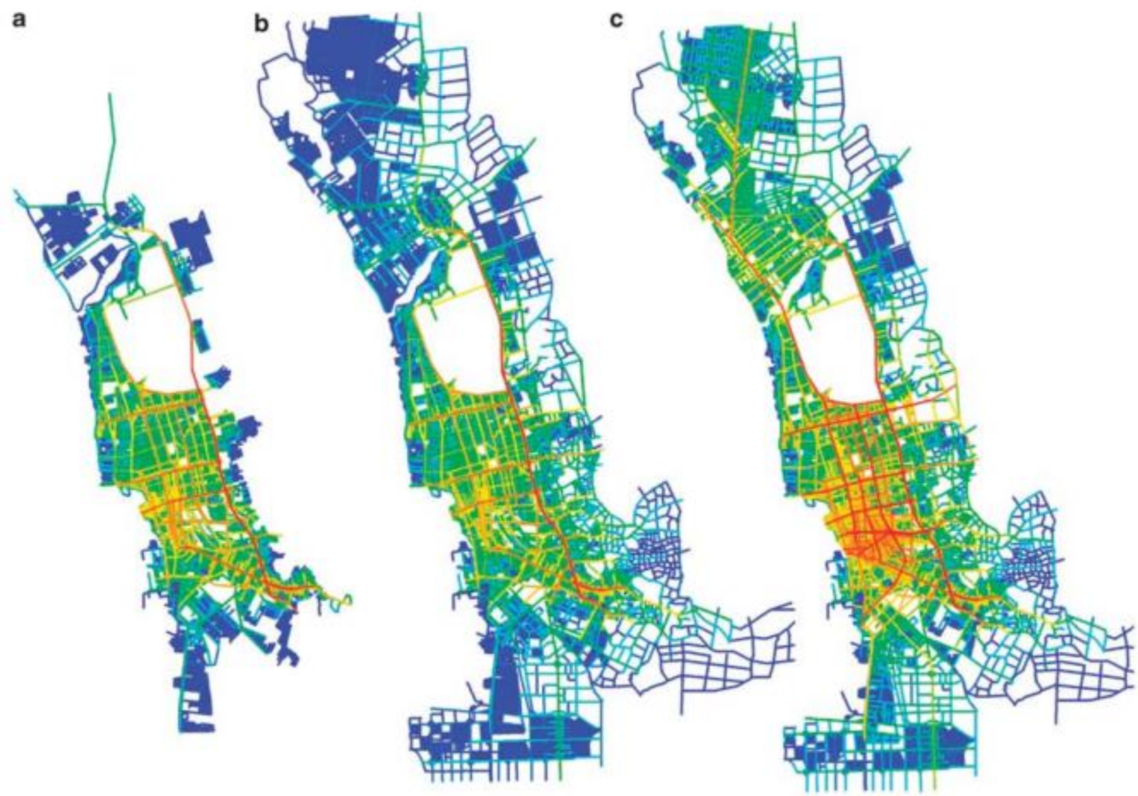


Figure 6: Space syntax models of the city of Jeddah, Saudi Arabia. The spatial structure of the city as exists now (a), is compared with what it would be like if the old Local Plan is implemented (b), and what it would become if all strategic transformation proposed by the Strategic Planning Framework are implemented(c).(Source: Karimi, 2012).

2.2.2. Space Syntax Practice in Ethiopia

Most city planners in developing nations, such as Ethiopia, do not have the resources to keep up with new planning theories, analysis methods, or planning strategies like space syntax (Berhanu, 1994). Although space syntactic analysis is not widely employed in Ethiopia's planning process, it has been used by a few scholars. For example, Feven Mulushewa (2020) utilizes space syntax analysis to identify the level of integration of Addis Ababa's road system, locate the city's key highways, and explore the city's highly segregated areas that demand urgent development.

Khalil et al. (2016) apply the space syntax method to determine the cause of jugol city isolation and limited accessibility in order to reclaim lost vitality. As the city suffers from poverty, congestion, environmental deterioration, isolation, and poor accessibility, Jugol's unique architectural identity and urban integrity are threatened. Such issues jeopardize the city's livability and render conservation efforts useless. The study proposed several options, compared them, and determined the best ones to improve the city's accessibility and connectivity with the rest of the city, thereby increasing its livability (Table 1 and Figure 7). The space syntax technique has been shown to be helpful in dealing with problems in historic areas at the street segment level, making it a useful tool for decision-making that will increase the success chances of future conservation efforts (Khalil et al., 2016).

Table 1. Integration values of the existing situation and the proposed alternatives.

	Existing	**1st option**	**2nd option**	**3rd option**	**4th option**
Mean integration of Jugol	0.54	0.56	0.59	0.6	0.6
Mean integration for new Harar	0.53	0.55	0.59	0.6	0.6
Mean integration of the core	0.78	0.75	0.82	0.82	0.81

Source: Khalil et al., 2016.

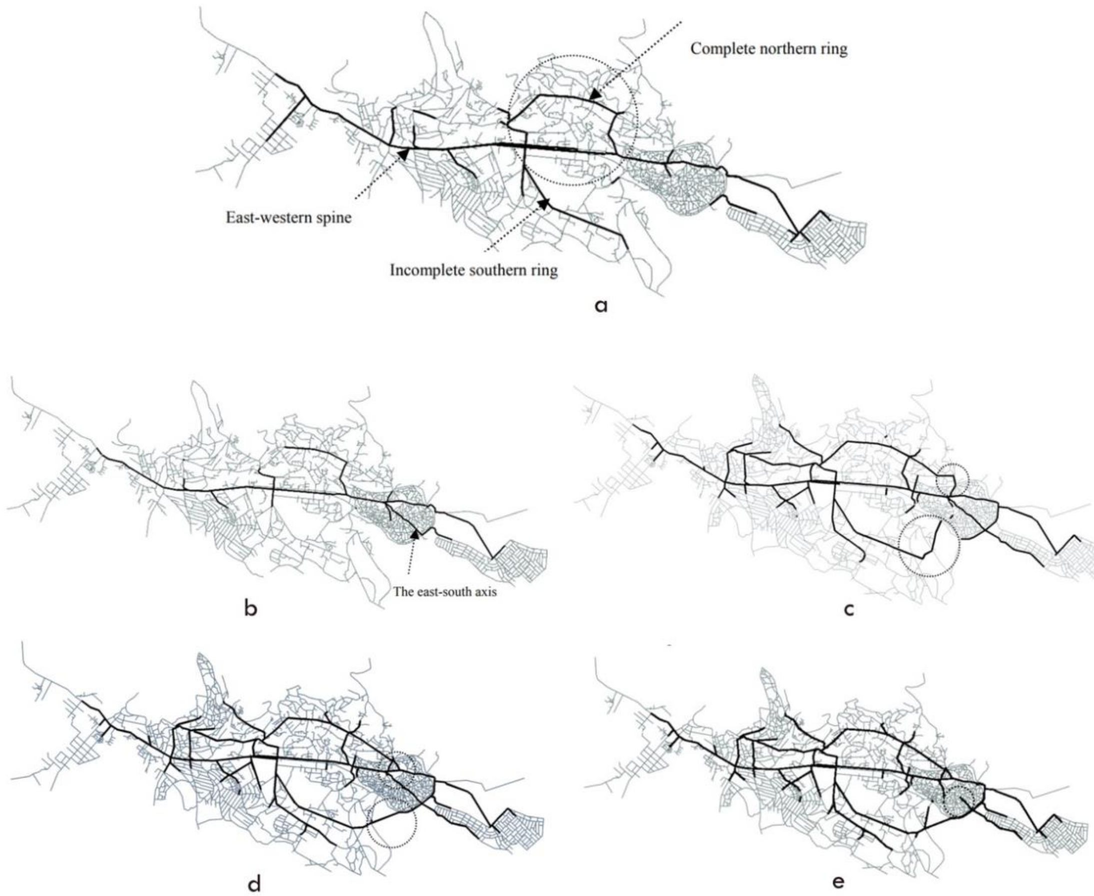


Figure 7: Segment map of the exiting situation showing that the east–west axis is the only link between the historic city and the extensions (a), Segment map of the 1st alternative (b), 2st alternative(c), 3rd alternative (d), and 4th alternative (e).(Source: Khalil et al., 2016).

2.3. Summary of Literature

Street is the basic unit of urban space through which people experience a city. To strengthen coherence between the urban and its street systems, the urban street network must be recognized. The street network, which serves as the skeleton of urban structure, regulates vitality levels. To better understand how the built environment affects human activities, it is crucial to investigate the relationship between street networks and urban vitality.

The hidden spatial structure of the built environment is depicted by space syntax analysis, which aggregates varying degrees of urban vitality, street activity, and the location of active land use such as stores and micro-economic firms. Integration, choice, connectivity, and control are some of the most important measurements produced by Space Syntax. The degree of street vitality is determined by the values of these measurements. DepthmapX is a space syntax program that analyzes social dynamics in the built environment through spatial network analysis. The space syntax observation method helps with movement counting and the study of the relationship between the spatial organization and human behavior.

2.4. Lessons Drawn from the Review and Research Gaps

The street configuration of a city affects human movement and the location of commercial land-use at a certain location which describes the vitality of a city. Although it is not widely used in city planning process in Ethiopia; space syntax describes different aspects of relationships between the morphological structure of human-made environments and social structures and events.

The Ethiopian government recognizes that the country's low road network coverage and poor conditions have impacted poverty reduction and economic growth. As a result, in 1997, the government launched the Road Sector Development Programme (RSDP), which aims to improve the country's road network and increase road density (United Nations Economic Commission for Africa, n.d.). Constructing new roads and increase road density, and improving existing roads will not be enough unless the streets are interconnected to have a good road system throughout the country.

There has been no research done on the integration, accessibility, and vibrancy of Adama's street network. This research will fill the gaps by showing how creating a connected and integrated street network will help to the vibrancy and liveliness of cities.

CHAPTER THREE

MATERIALS AND METHODS

The philosophy used in this research is positivism and hermeneutics. These two research traditions influence how we can gain explanations and understandings about the relation between the built environment and society. Space syntax research is interdisciplinary, and when dealing with research on urban space, these aspects lie in the overlap between the human, social, and natural sciences. The theory of the natural movement economic process is one of the descriptive theories on built environments that follow the positivistic research tradition. It states that the spatial configuration of the street network influences the flow of human movement and the location of shops in built environments. The greater the spatial integration of the street network, the greater the flow of human mobility and the more appealing the land along the street network becomes for economic purposes. In this research, the deductive research approach was used to explore the theory of the natural movement economic process and test if that theory is valid in Adama city's current natural street network.

This chapter briefly describes the methods and techniques used to conduct the study. Specifically, the study area description, data sources, data collection, and methods of data analysis.

3.1. Description of the Study Area

Adama, the largest city in Oromia National Regional State, is a rising secondary city with a population that is predicted to triple by 2040, from 253,000 to approximately 954,000 people. Adama lies 100 kilometers south of Addis Ababa, along the country's principal import and export corridor from the port of Djibouti. Adama is located 1600-1700 meters above sea level in the Rift Valley of warm climate, with latitudes ranging from 8.25^0 -8.37^0 N and longitudes ranging from 39.12^0 -39.22^0 E.

Adama city is expanding rapidly due to high population growth but the existing road network of the city fails to serve the newly created districts. Public transport is limited to certain parts of the city due to the unavailability of a road network. People are also obliged to take the longest route to their destination due to the lack of an integrated street network. Areas with highly segregated roads are facing socioeconomic challenges in the city. This calls for the development of effective street network planning within the city. The location map of the study area is shown in Figure 8.

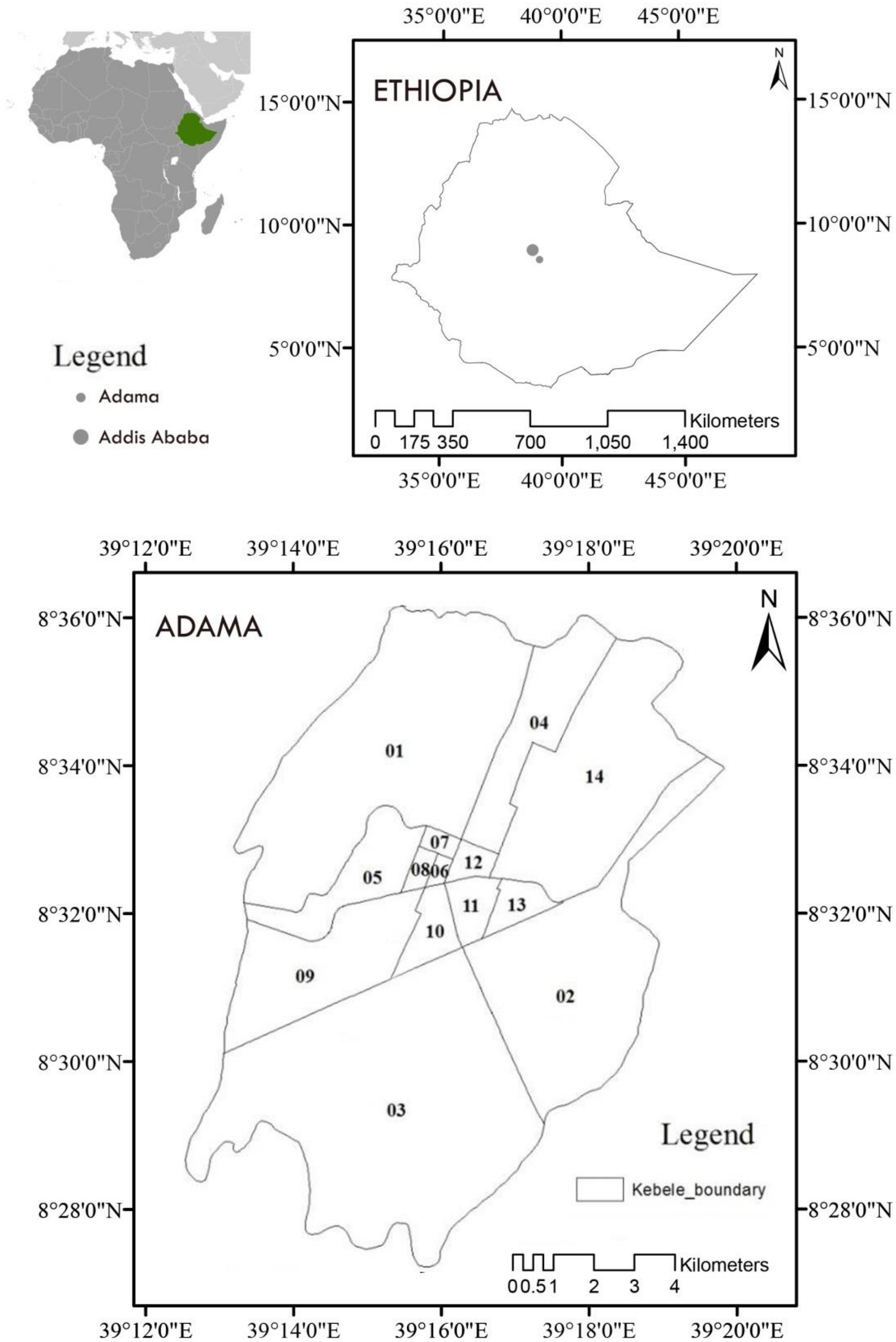


Figure 8: Location map of the Study area.

3.2. Data Sources

For this particular research primary and secondary data sources were used. Primary data sources include pedestrian and site observation, maps, and photographs. Land-use data were acquired from the 2017 Adama structural map. OpenStreetMap was used to generate an axial map of the city since it is one of the major sources of road information. Secondary data sources used were published and unpublished documents, journals, articles, satellite images. Human movement observation is used to collect observational data. Derived or assembled data was obtained from pre-existing data (like land-use and street network) from various data sources to come up with new data.

3.3. Data Collection

Quantitative data collection method was used based on mathematical calculations of different measures. First, it is critical to have reliable data representing a road network in order to analyze it. The analysis of the urban grid is based on the axial map. OpenStreetMap is used to generate axial maps of the city since it is one of the major sources of road information.

The axial map for Adama city was produced by using GIS from a single line road network representation downloaded from OSM (Figure 9). The axial map of Adama is composed of an amount of 10,048 axial lines. The railroad is not considered in the analysis because it has no connection to the city.

Space syntax measures the road as a graph rather than a map and calculates connectivity and control using an “axial map “for 10,048 axial lines. It also measures choice and integration using a “segment map” for 16,749 segment lines. DepthmapX software was used to analyze the street network integrity, intelligibility, connectivity, choice, control, and permeability.

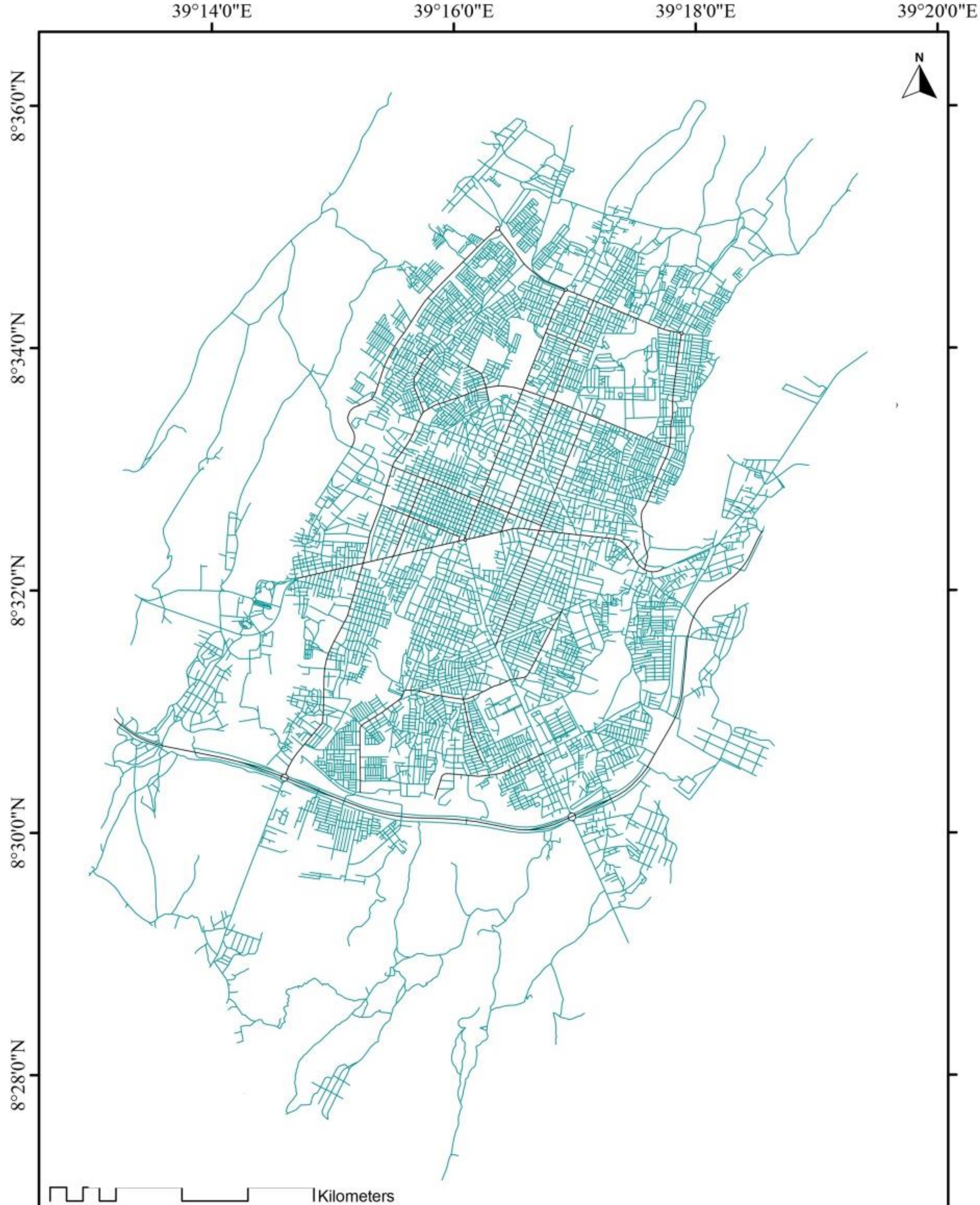


Figure 9: Axial map of Adama city.

3.3.1. Identifying Integrated Roads

The global and local integration value of each segment was generated by using angular segment analysis in DepthmapX. Mathematical Formulas used for Calculating Global Integration are explained below (Van Nes & Yamu, 2021).

Assuming the rout node is c.

The mean depth is the total depth multiplied by the number of axial lines or nodes in the system, and it indicates the average number of steps required to reach any of the system's axial lines

$$MD_C = \frac{1}{(k-1)} \sum_k d_{Ck} \tag{1}$$

Where k stands for the number of axial lines in the system, and d stands for the total depth. $\sum_k d_{Ck}$ stands for the total depth sum from the root node C to all other spaces.

In addition, the relative asymmetry (relative depth) was calculated. The mean depth provides the basis for the relative asymmetry, which provides a normalization of the mean depth measure between zero and one.

$$RA_c = \frac{1(MD_C - 1)}{(k-2)} \tag{2}$$

The effect of relative asymmetry is proportional to the system's size. As a result, genuine relative asymmetry gives a relativization that allows for depth comparisons between different sized spatial systems. "Real relative asymmetry is utilized to reduce the large effect that size can have on the level of relative asymmetry values in the real system," according to Hillier and Hanson (1984, p. 110). The formula used for calculating real relative asymmetry was:

$$RRA_C = \frac{RA_C}{D_n} \qquad D_n = \frac{2\{n[\log_2((n+2)/3)-1]+1\}}{(n-1)(n-2)} \tag{3}$$

$$n \text{ is the number of node}$$

where Dn stands for the diamond value that eliminates the effects that size can have on the relative asymmetry value.

The reciprocal of real relative asymmetry is integration. The following is how the integration value was calculated:

$$\text{integration} = \frac{1}{RRA_c} \tag{4}$$

The calculation behind the integration of an axial line is

$$l_i = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right) - 1\right) + 1\right)/(n-1)(n-2)}{2\left(\left(\frac{\sum_{j=1}^{n} d_{ij}}{n-1}\right) - 1\right)/(n-2)} \tag{5}$$

where n is the number of segments and dij is the shortest distance (least number of direction changes) between two segments i and j. The greater the number of steps (dij) between street axes is the lower the integration values become.

A. Pedestrian Movement Survey

Three different areas were selected which cover a range of well-used, moderately, and poorly integrated or used spaces in the study area as shown in figure 10. These areas were selected within a 500m radius since it is a walkable neighborhood distance with a range of community services. The observer can visit every street and alley within 500m radius to measure the characteristics of a neighborhood environment (Chiang et al., 2017). These zones also reflect a variety of land uses, including commercial, mixed-use, and residential. Land-use data were acquired from the 2017 Adama structural map. Area one represents the commercial core of the city and it is highly integrated. Area two was a mixed-use area which is located around Adama bus station or Menaheria, and a number of local shops and residential houses found in the area. Area three is a pure residential found on the outskirt of the city.

The method of gate count was used in each survey point and the number of pedestrians who passed through the gate was counted. Different criteria were set to collect an accurate pedestrian volume of selected areas according to the space syntax observation manual (Grajewski, 2001).

The survey was conducted from March 30, 2022, to April 2, 2022. Measurement points were selected strategically based on different global integration values and distribution of land uses across the city of Adama. The measurement was carried out in a total of 67 different points (gates); 30 gates in Area one, 24 gates in Area two, and 13 gates in Area three. Sidewalks on both sides of the street were measured at every location. The count took 5 minutes in suburban regions or any place with little traffic, and 2.5 minutes on busy city routes. Then, it is converted to pedestrian volume per hour. The measurement took place on a normal sunny day with average weather, three times a day from 8 am - 10 am (morning rush-hour), 12 noon - 2 pm (lunch-time peak), and 4 pm - 6 pm (evening rush-hour). This observation registration was conducted twice to come up with a pedestrian volume that represents weekdays and weekend days (Refer to Appendix 1, 2, 3&4). Table 2 shows the summery of methods used for gate count.

Table 2: Summary of the method for gate count.

	Area 1	**Area 2**	**Area 3**
Dominant land use	Commercial	Mixed	Pure residential
Number of gates	30	24	13
Count time(min.)	2.5	2.5	5

After selecting the observation points, real-life and detailed land-use distribution patterns adjacent to the observation points were observed on a street-by-street basis. The land-use data acquired from the 2017 Adama structural map was updated accordingly as shown in Figure 8 g, h, &i. Nonresidential land-use was measured in a 100-m circular buffer from each survey point to conduct a regression analysis between pedestrian volume (dependent variable) and independent variables (nonresidential land-use and global integration). The 100-m circular buffer is reasonable for examining the relationship between pedestrian volume and the adjacent built environment (Lee et al., 2020). Nonresidential land-use attracts high pedestrian volume to the area and was taken as the net density of the floor area within. Then, the integration value of each street segment was aggregated (Figure 10).

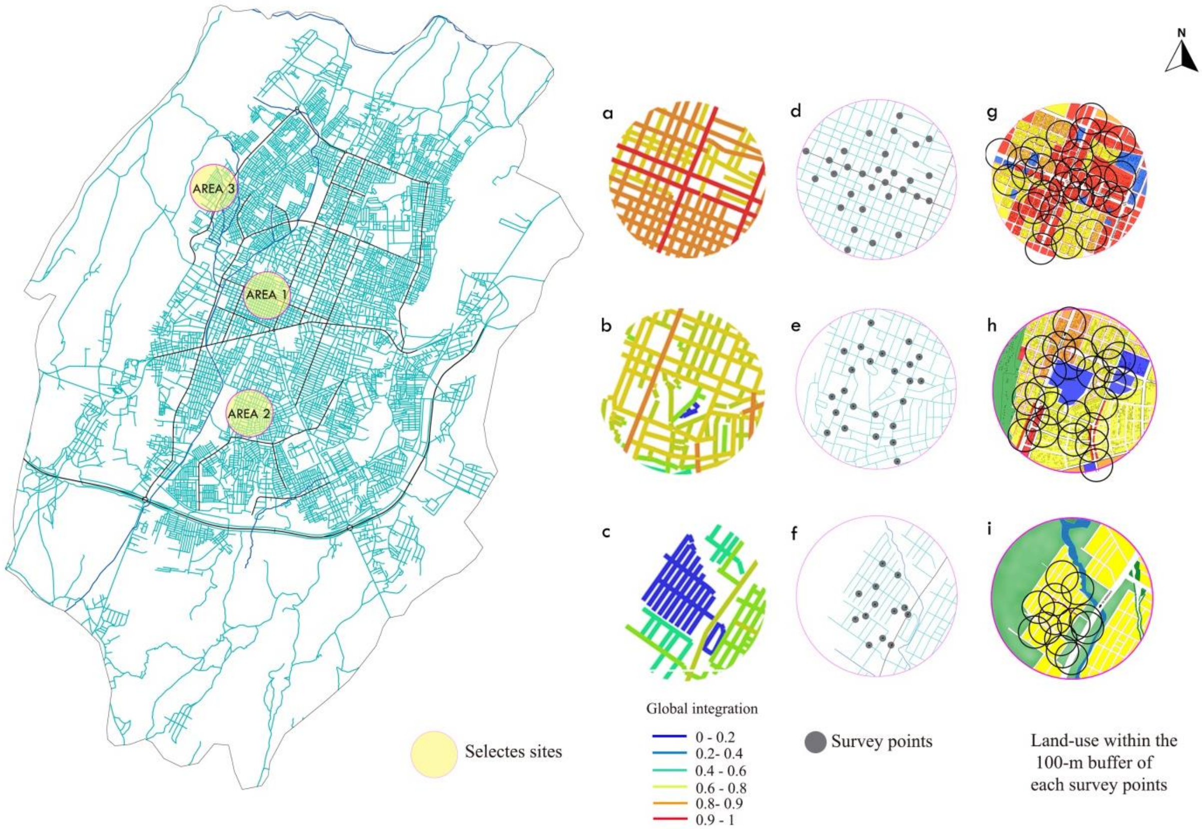


Figure 10: Areas for pedestrian count. Highly integrated area (a), moderately integrated area (b), segregated area(c), survey points for selected site (d, e, &f), and land-use within the 100-m buffer of each survey points (g, h, &i).

3.3.2. Degree of Choice

The small radius and large radius choice-value were generated by using angular segment analysis. The following formula was used to calculate choice (C) of a street axis (i) (Rashid, 2017):

$$C_i = \sum_J \sum_K g_{jk}^{(i)} \lg_{jk} \; (j<k) \tag{6}$$

where $g_{jk}^{(i)}$ is the number of shortest paths between segment j and k containing i, and g_{jk} is the number of all shortest paths between j and k.

3.3.3. Level of Connectivity

Street connectivity value for all axial lines was generated by using axial map analysis. Connectivity analysis is about counting the number of connections each street has to its adjacent streets (Van Nes & Yamu, 2021). The following formula was used to calculate the number of directly linked nodes (immediate neighbors) or connectivity:-

$$\ell_{ik} = \begin{cases} 1, & if\ i\ and\ k\ are\ connected \\ 0, & if\ i\ and\ k\ are\ disconnected \end{cases} \tag{7}$$

$$CN_i = \sum \ell_{ik}$$

3.3.4. Degree of control

Axial map analysis was used to generate the street control value. The impact of an axis on its related axes is represented by its control value; a greater value indicates that the axis is more important in the network (Zheng-yu & Quan, 2009). The sum of connectivity reciprocals of immediate neighbors is the control value and it was calculated:-

$$CR_i = \sum_K \frac{1}{CN_k}, \; k \in K \; if \; \ell_{ik} = 1 \tag{8}$$

3.4. Methods of Data Analysis

The gathered quantitative data was analyzed by a method of percentage, correlation and regression. The method of data analysis for all the specific objectives are describes below.

3.4.1. Identifying Integrated Roads

The generated data from the angular segment analysis of local and global integration was analyzed and simplified using MS Excel. The table displayed by Depthmapx showed all the local and global integration values for 16,749 segment lines and it was categorized in simple tables to clearly show the results. The results acquired ware weighted by using the natural break method according to Table 4.

Correlation analysis was conducted between global and local integration to measure the level of synergy. A strong correlation shows a high degree of synergy in the area and the area is easy to orient through and it is vital. Week correlation coefficient indicates the area is segregated in comparison with the rest of the city. A scatterplot was used to present the correlation between global and local integration of all axial lines of the city. Another correlation analysis was conducted between integration and pedestrian movement at selected gates to understand the relationship between street network and human behavior (movement) and to demonstrate how street network affects pedestrian volume in different land-use settings. The correlation value was analyzed according to Table 3 throughout the study.

A multivariate regression analysis was used to find significant links between street integration and land use and pedestrian volume in Adama's different land zones. To analyze the features of the land-use zones, four multivariate regression models were generated. The first step was to create a regression model for all survey points, regardless of their land-use zones. Then there were three more regression models, one for each of the land-use zones, because the link between pedestrian volume and street integrity in the commercial zone may differ from the relationship in the residential zone.

3.4.2. Degree of Choice

The generated data from the angular segment analysis of large radius and small radius choice was analyzed and simplified using MS Excel. The table displayed by depthmapx showed all the choice values for 16,749 segment lines then, categorized into a simple table. The choice values acquired were weighted by using the natural break method according to Table 4.

Correlation analysis was conducted between angular choices with high and low metric radius to measure the degree of street life. A strong correlation shows that locally integrated main routes are also highly integrated on a city scale. Week correlation indicates that locally integrated main routes are located far away from the main routes on a city scale. A scatterplot was used to present the correlation between these two space syntax measures.

3.4.3. Level of Connectivity

The generated data from the axial map analysis was analyzed and simplified using MS Excel. The table of the connectivity values for 10,048 axial lines displayed by Depthmapx was categorized into a simple table to clearly show the results. A highly connected street was identified and represented graphically by using adobe illustrator 2020.

Correlation analysis was conducted between segment length and connectivity since permeability is expressed by the correlation between the two variables and a scatterplot was used to present the correlation.

3.4.4. Degree of Control

The choice value of the axial map was analyzed by Depthmapx, and then categorized into a simple table using MS Excel. Street with high control values was identified and represented graphically by using adobe illustrator 2020.

All of the correlation values were interpreted by using Table 3. All the values of space syntax measures were weighted according to Table 4 throughout the study. Table 5 summarized the methods used to achieve the objectives

Table 3: The range for correlation coefficient r.

Correlation coefficient r	**Interpretation**
r < 0.3	No or very weak
0.3 < r < 0.5	Weak
0.5 < r < 0.7	Moderate
r > 0.7	Strong

Source: Moore et al., 2013.

Table 4: Weighting range of the spatial parameters from the space syntax.

Space syntax measures	High	Bb belongs to the highest one third according to the natural break method
	Medium	Bb belongs to the medium one third according to the natural break method
	Low	Bb belongs to the lowest one third according to the natural break method
	$B_b = \sum_{i=1}^{n} BtAR_{(x)i} \frac{L_i/D_i^{\alpha}}{\sum_{i=1}^{n} L_i/D_i^{\alpha}}$; Bb = the configuration values of each block, BtAR(x)i = the configuration values of surrounding streets, Li = the length of street central lines affecting the blocks, Di = the shortest Euclidian distance from the street central lines to the block's edge, a ¼ distance decay value**.**	

Source: Ye and van Nes 2016.

Table 5: Summary of methods.

Research questions	**Variables**	**Aim**	**Formula**	**Types of data**	**Source of data**	**Method of data collection**	**Software used**	**Data analysis**
What are the integrated roads of Adama city?	Local integration	To highlight local urban centers	$I_i = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right) - 1\right) + 1\right)/(n-1)(n-2)}{2\left(\left(\frac{\sum_{j=1}^{n} d_{ij}}{n-1}\right) - 1\right)/(n-2)}$ where n is the number of segments and dij is the shortest distance (least number of direction changes) between two segments i and j.	Quantitative data	Segment map of the city.	Street Analysis	GIs, Auto CAD, DepthmapX,	Angular segment analysis
	Global integration	To identify the location of main urban center.						
	Correlation between global & local integration.	To measure the level of synergy between local center and the city.	$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$	Quantitative data	Segment map of the city.	Street Analysis	DepthmapX,	Scatterplot / Correlation analysis
	Correlation between Global integration and pedestrian movement.	To understand the relationship between spatial structure and human behavior.	$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$	Observational Data and Quantitative data	Segment map of the city and pedestrian count.	Street Analysis, and Gate count observation	MS Excel 2010	Correlation analysis
	Regression analysis between pedestrian with land-use and integration.	To understand the effect of land use and integration on pedestrian volume.	$\boxed{Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i}$ Y : Dependent variable; β_0 : Intercept; β_i : Slope for X_i; X = Independent variable	Observational Dataand Quantitative data	Segment map of the city ,pedestrian count and land-use.	Street Analysis, Gate count observation and land-use data.	MS Excel 2010	Regression analysis

Research questions	Variables	Aim	Formula	Types of data	Source of data	Method of data collection	Software used	Data analysis
What is the level of connectivity of the streets?		To identify streets with high connections.	$\ell_{ik} = \begin{cases} 1, \; if \; i \; and \; k \; are \; connected \\ 0, \; if \; i \; and \; k \; are \; disconnected \end{cases}$ $CN_i = \sum \ell_{ik}$	Quantitat ive data	Axial map of the city.	Street Analysis	GIs, Auto CAD, DepthmapX,	Axial analyses
	Correlation between segment length and connectivity.	To measure the degree of permeability.	$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$	Quantitative data	Axial map of the city.	Street Analysis	DepthmapX,	Scatterplot / Correlation analysis
Which are the most preferred streets of Adama city?	Small metric radius analysis Metric radius=800m.	To identify local main routes of local city centers.	$C_i = \sum_J \sum_K g_{jk}^{(i)} \lg_{jk} \; (j<k)$ where $g_{jk}^{(i)}$ is the number of shortest paths between segment j and k containing i, and g_{jk} is the number of all shortest paths between j and k.	Quantitative data	Segment map of the city.	Street Analysis	GIs, Auto CAD, DepthmapX,	Angular segment analysis
	Large metric radius analysis. Metric radius=5000m.	To identify all main roads.						
	Correlation between small and large metric radius analysis.	To measure the degree of street life.	$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$	Quantitative data	Segment map of the city.	Street Analysis	DepthmapX,	Scatterplot /Correlatio n analysis
To what extent streets control access to adjacent streets?		To identify space that highly controls adjacent spaces.	$CR_i = \sum_K \frac{1}{CN_k}, \; k \in K \; if \; \ell_{ik} = 1$	Quantitative data	Axial map of the city,	Street Analysis	DepthmapX	Axial analyses

CHAPTER FOUR

RESULT

4.1. Identifying Integrated Roads

The degree of collection or separation between one space and the others is described by the integration value. The higher value of integration indicates better accessibility. There are two integration measures which are global and local integration.

4.1.1. Global Integration

The global integration value refers to the degree of integration between one street and others in the city. The set of most integrated streets is collectively known as the ‘integration core’. The integration core is shown in red and orange lines. The segregated streets or less accessible streets are indicated with light blue and dark blue and tend to cover the periphery of the city as shown in Figure 11 and Table 6. Table 6 briefly indicates the percentage of each category. The global integration degree of the street is higher in the central part and along the main streets of the city. The high value of integration is registered around the streets of “Sar-tera”. The main roads found in the area are Kechema Street, Adama-butta road, Elmo kilitun road and Leman Street. The global integration map of Adama city shows that the main city centers like Mebrat-hile, 04, and Posta-bet are located in highly integrated globally accessible areas. According to table 6, 21.46% of the total street segments have high integration, 67.0 % of the total street segments are moderately integrated and 11.5% of the total street segments are segregated.

4.1.2. Local Integration

Local integration means the degree of integration between one space and others in a certain scope, by computing a more immediate measure giving a value for integration among the spaces with a specific metric radius. The higher the value of the line, the higher the accessibility degree with adjacent spaces, and it could attract a large number of people. Figure 12 and Table 7 show that the local integration (Metric radius = 800m) highlights local urban centers. It indicates the degree of street local integration is relatively higher in the central area of the city (around Sar-tera), and it exposes that the accessibility degree of street spaces is higher in the central area. The local integration degree of the roads around Dire-Foka which is located behind the new Adama bus station (meneharia) is also high following the central part of the city.

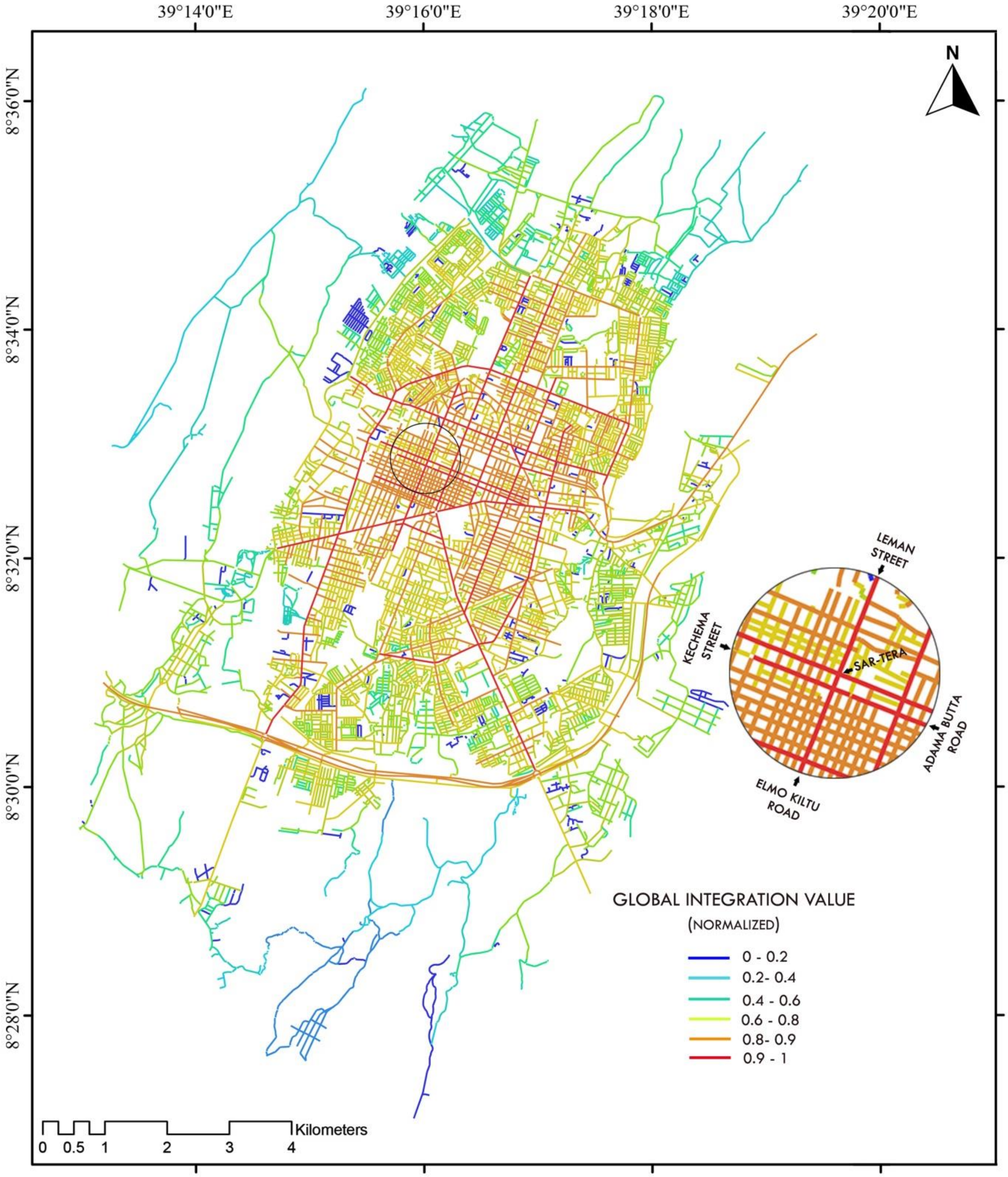


Figure 11: Global integration map of Adama city.

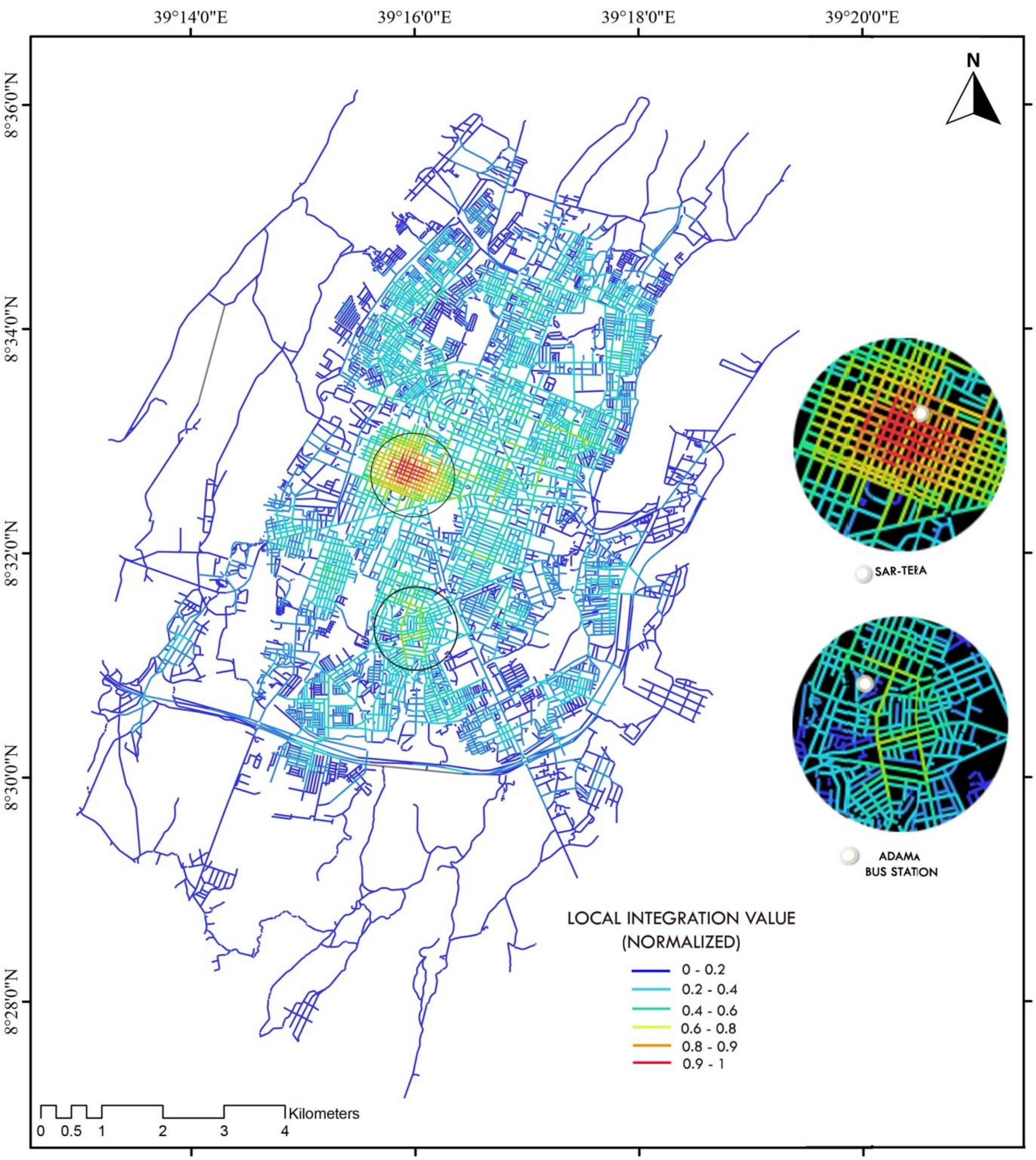


Figure 12: Local integration map of Adama city at metric radius of 800m.

Table 6: Global integration value of Adama city.

Integration value	Color code	Normalized value	Total length(m)	Percentage
2.59-502.00		0 - 0.2	68259.41	5.89
503.55-1008.53		0.2 - 0.4	64898.59	5.6
1008.81-1521.12		0.4 - 0.6	276977.92	23.9
1521.24-2036.31		0.6 - 0.8	499950.93	43.14
2036.31-2280.90		0.8 - 0.9	190523.72	16.44
2281.09-2541.53		0.9 – 1	58292.84	5.03
Total			1158903.42	100

Table 7: Local integration value of Adama city.

Integration value	Color code	Normalized value	Total length(m)	Percentage
2.59 - 67.98		0 - 0.2	774147.48	66.8
67.98 – 130.26		0.2 - 0.4	314062.83	27.1
130.26 – 192.85		0.4 - 0.6	48673.94	4.2
193.07 – 256.24		0.6 - 0.8	13906.84	1.2
257.43 – 286.80		0.8 - 0.9	4635.61	0.4
286.97 – 319.80		0.9 – 1	3476.71	0.3
Total			1158903.42	100

4.1.3. Synergy

The level of synergy of the areas is determined by the correlation between local and global integration. Where there is a strong correlation between local and global integration, the area is known to have a high degree of synergy between the local and the whole and it is easy to understand.

The strength of an association is often measured by the correlation coefficient r. The correlation existing between the metric depths R = 800 (local) and R = n (global) are verified, so as to better understand the value of the relationships between the part and the whole (Figure 13). The value R = 0.622 is indicative of the existence of moderate correlation between the configuration assumed by the urban grid at the local scale compared to that assumed at the scale of the entire city.

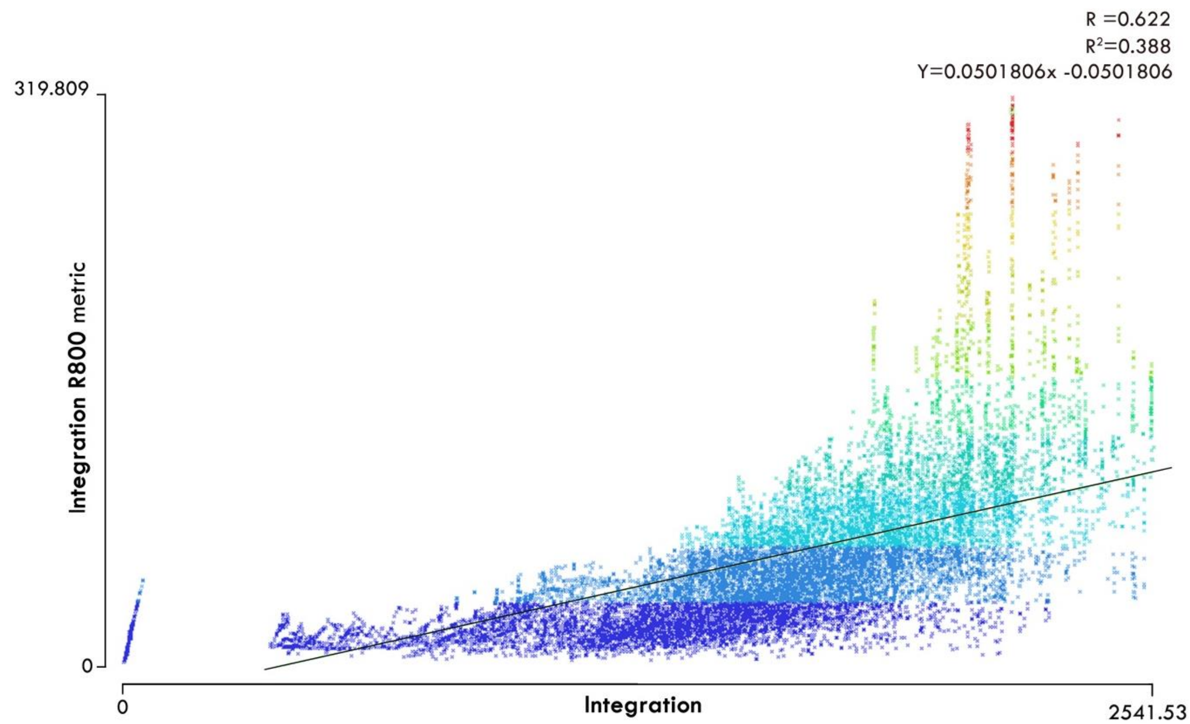


Figure 13: Correlation between local and global integration.

4.1.4. Pedestrian Volume

A. Site One

Thirty observation points were selected in this area. The area is found at the central part of the city and is largely occupied by the commercial and retail zones as shown in Figure 14 and 15. Several cafeterias and restaurants, hotels large vegetable markets, cereal markets, and Adama ginb gebeya, are situated within this zone. The area is dominated mainly by shopping streets.

The location of gates and the average pedestrian volumes per hour for all gates are presented in Figure 16 and 17 respectively (Refer appendix 1 for detail pedestrian volume). The highest pedestrian counts are observed on gate number 1,2,4,7,8,18,19,20,21,27,29,30, which is above 800 pedestrians per hour. These gates are found along commercial streets.

Figure 14: Pictures from site one. Shopping centers (a&c), vegetable market(b),kechema street(d),cereal market(e).

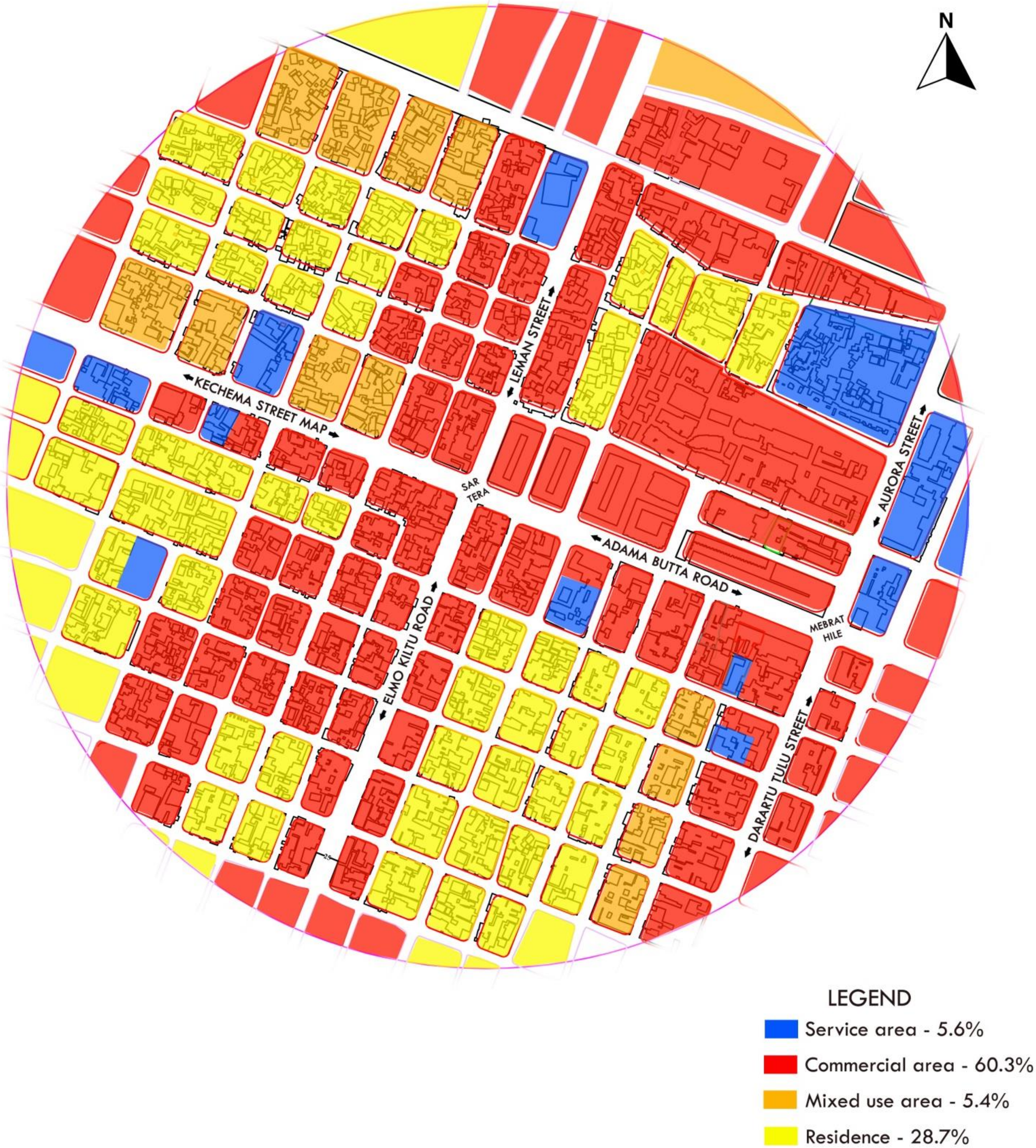


Figure 15: Land-use map of site one.

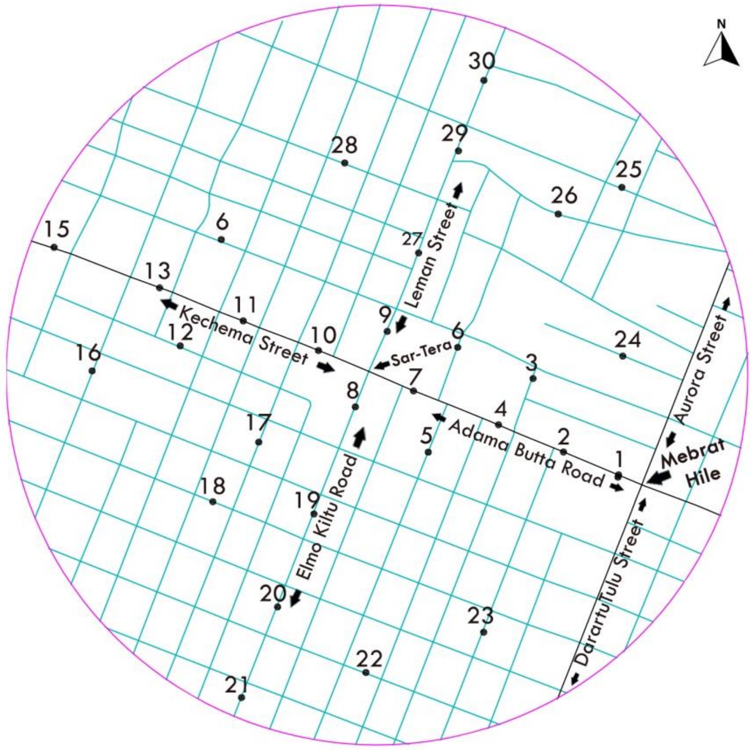


Figure 16: Pedestrian count gates for site one.

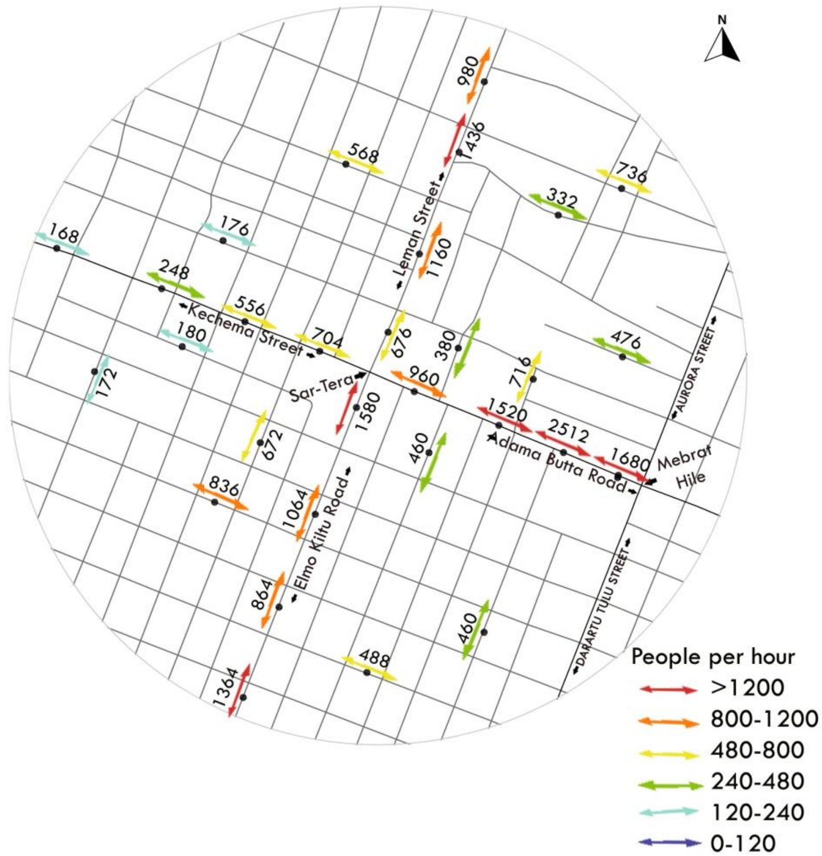


Figure 17: Average pedestrian volume per hr. at site one.

B. Site Two

Twenty-four observation points were selected in this area. The area is located along the main roads of Ababa Bikila Street and is occupied largely by Adama bus station (Menahria) and a small commercial corridor along the main road. As shown in Figure 18 and illustrated in Figure 19, the area is dominated mainly by residential land-use.

The location of gates and the average pedestrian volumes per hour for all gates are presented in Figure 20 and 21 respectively (Refer appendix 2 for detail pedestrian volume of the area). From the observation, it is very clear that the pedestrian flow along Ababa Bikila Street is slightly higher than other streets (Figure 20 and 21, Gate numbers 1, 2, 4, 5, 7, and 8). Ababa Bikila Street is found in front of the bus station and accommodates small commercial activities (Figure 19). In most cases, the numbers of pedestrians are very low on street in a residential area (Figure 20 and 21, Gate number 9, 10, 20, 21, 22, and 23).

Figure 18: Pictures from site two. Low pedestrian activity (a), medium pedestrian activity (b), narrow street which connects the neighborhood to the main road(c).

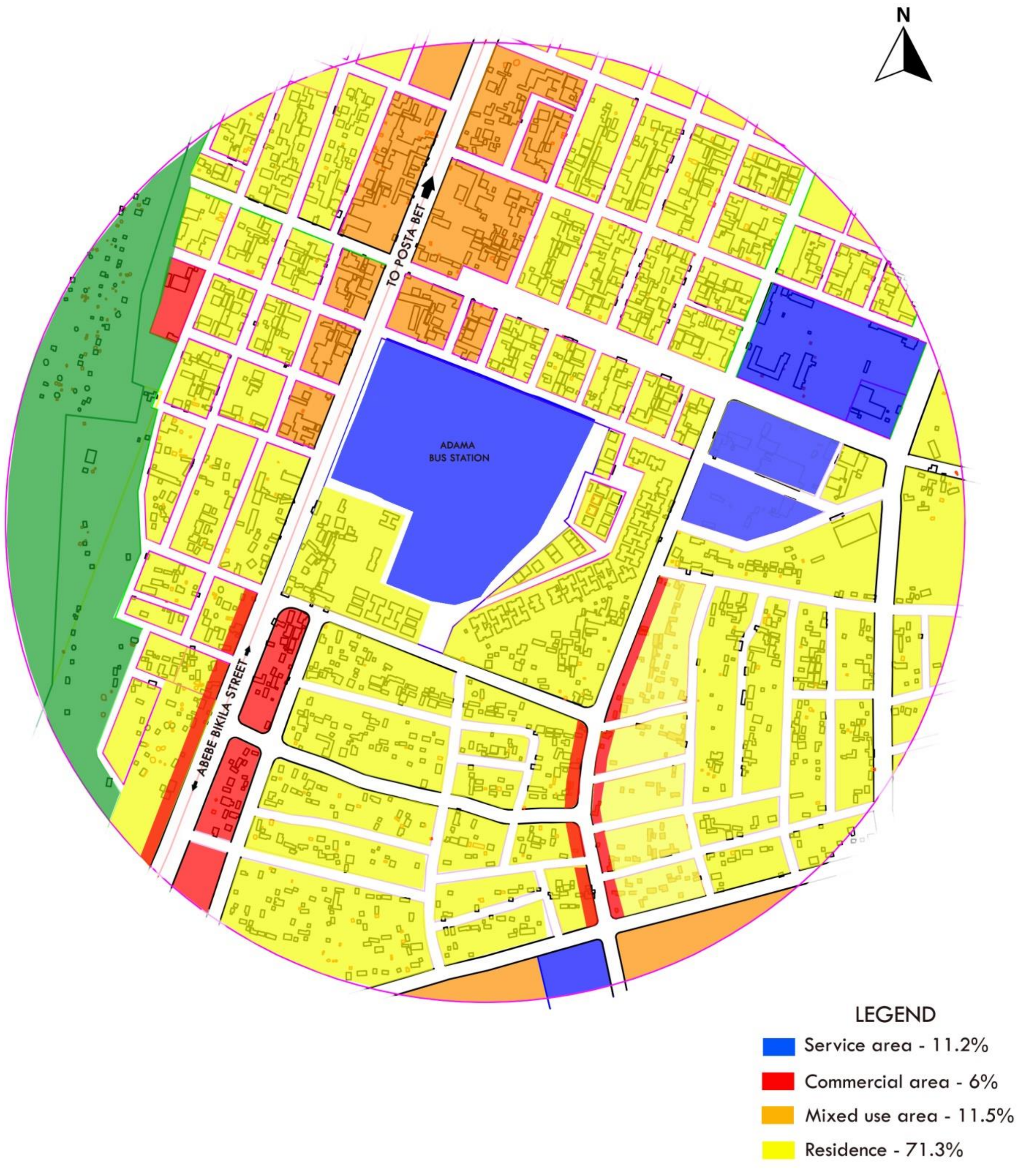


Figure 19: Land-use map of site two.

Figure 20: Pedestrian count gates for site two.

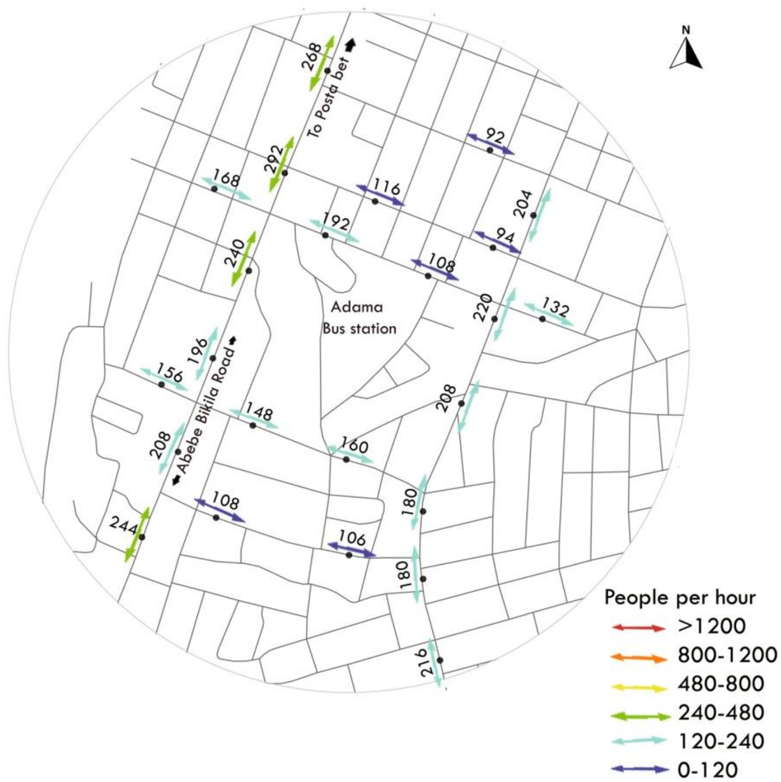


Figure 21: Average pedestrian count per hr. at site two.

C. Site Three

Thirteen observation points were selected in this area. The area is located on the outskirt of the city with pure residential functionality as shown in Figure 22 and 23. It is difficult to trace any trend in the variations of pedestrian counts in different time slots and days on residential streets except on weekdays, the morning pedestrian counts are lower than midday and afternoon (Refer appendix 3 for detail pedestrian volume information).

The location of gates and the average pedestrian volume per hour for all gates are presented in Figure 24 and 25 respectively. Figure 25 indicates that the lowest pedestrian counts were found on these residential streets.

Figure 22: Pictures from site three. Main road in front of the site (a), the only road connects the neighborhood to the main road (b), neighborhood streets(c &d).

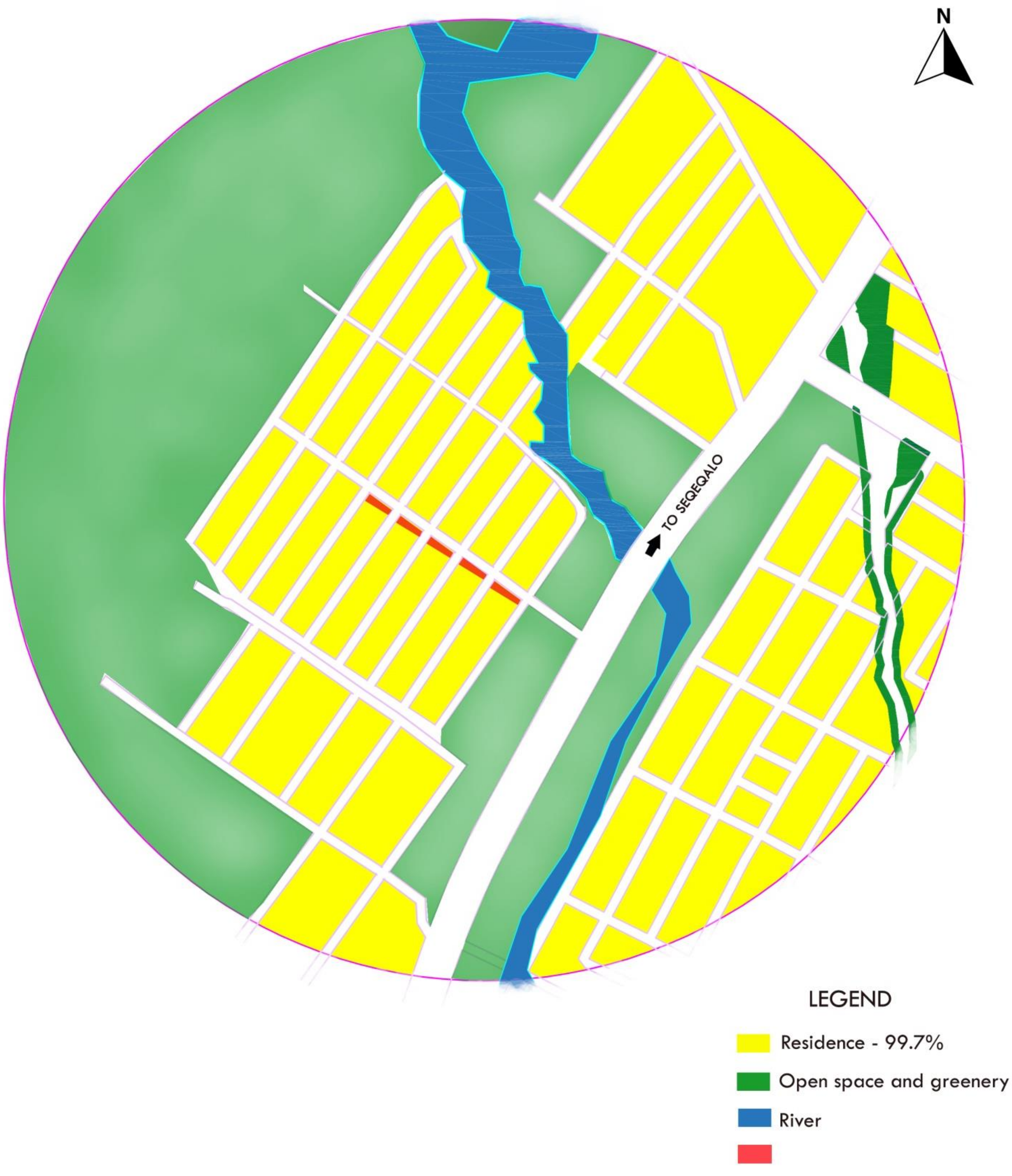


Figure 23: Land-use map of site three.

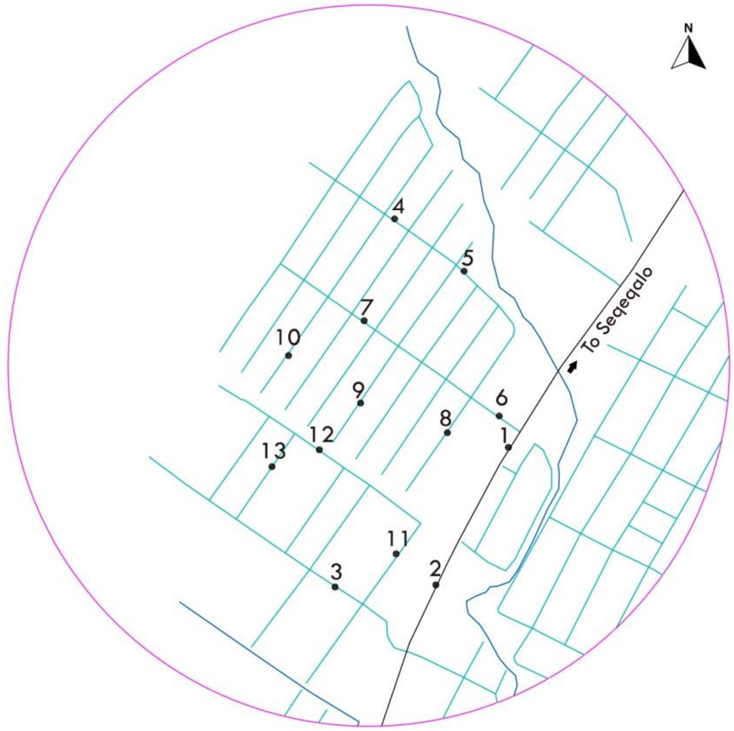


Figure 24: Pedestrian count gates for site three.

Figure 25: Average pedestrian count per hr. at site two.

4.1.5. Correlation between Pedestrian Counts and Global Integration

Correlation analyses were conducted to examine the associations between pedestrian counts with global integration values of the corresponding street segments. Since the original pedestrian count shows a significant skewness it is transformed into the logarithmic value of pedestrian volume. Table 8 shows a correlation analysis (R-value) between the average pedestrian volumes and integration for all three sites and there combination (total). The total correlation analysis is important in representing the association between pedestrian volume and integration for the whole Adama city.

Table 8: Correlation analysis between integration and average pedestrian volume.

Variable	**Pedestrian volume**			
	Total	Site 1	Site 2	Site 3
Global integration	0.64**	0.56*	0.75**	0.78*

Note: * $p < 0.01$; ** $p < 0.001$.

The integration values show a significant positive correlation with pedestrian volume in all cases as their p-value is less than 0.05. In site 2(mixed-use) and site 3(residential) the global integration and the pedestrian volume indicates strong association and site 1 and the total show a moderate association. The correlation data shown in table 8 examined the bivariate correlation between pedestrian volume and integration, ignoring the effects of land use on pedestrian movement.

4.1.6. Effect of Nonresidential Land-Use and Integration on Pedestrian Volume

Multivariate regression was used to analyze the effect of nonresidential land use and integration on pedestrian volume (Table 9). The dependent variable was the average pedestrian volume. The basic model was a multivariate regression model combining land-use and integration.

Table 9: Effect of nonresidential land-use and integration on pedestrian volume (Regression analysis).

	Site 1			**Site 2**			**Site 3**			**Total**		
	Coef.	t	p	Coef.	t	p	Coef.	t	p	Coef.	t	p
Integration	0.001	4.5	<0.01	0.001	5.2	<0.01	0.001	3.9	<0.01	0.002	4.5	<0.01
Non-residential land use	0.001	4.7	<0.01	0.008	2.5	0.02	0.006	0.7	0.511	0.002	7.6	<0.01
Observation	30			24			13			67		
R^2	0.621			0.664			0.63			0.667		

As shown in Table 9, both of the independent variables show statistically significant associations with the average pedestrian volume except in site 3(residential area) as there p-value is greater than 0.05. Site 3 is pure residential, the commercial activities are small shops owned by residents. Since there is very insignificant amount of nonresidential land-use the variable is insignificant.

According to the Table 9, 62.1%, 66.4%, and 66.7% of the variation in pedestrian volume is explained by the degree of existence of non-residential land-use with 100m2 radius buffers from the counting point and the integration value of the segment in site 1, 2 and total respectively.

4.2. Degree of Choice

Choice measures how likely one is to pass through the segment on everyday trips or its potential as a route. The Choice measure is divided into local choice and global choice according to the analysis radius. Since the main aim of this analysis is to identify all main roads or highly preferable streets for traffic flow, the global choice represents the radius of the 5000m car-based topological distance was selected as the evaluation index.

As shown in Figure 26, the highest choice value is presented with red and the lowest with blue. The street segments highlighted by red, orange and green are highly crossed or preferred roads within a 5000m radius.0.1% of the total street segment of the city have a high choice value (Table 10). The map highlighted the urban main (arterial) road system and the roads connecting the city with other towns like Adiss Ababa, Welenchete, and Melkasa.

4.2.1. Degree of Street Life

If the main routs of the city pass through local centers and neighborhoods, it helps in creating lively neighborhoods. The strong correlation between choice with a high metric radius and with a low metric radius indicates, the main routes are going through the neighborhood and are well connected to the local streets. Conversely, if there are weak correlations between these two variables, the main routes are placed outside the neighborhood and are poorly connected to the local streets.

To conduct the correlation analysis, 5000 metric radius choice value as shown in Figure 26 and Table 10 and 800 metric radius choice value of the city as shown in Figure 27 and Table 11 were aggregated. According to Figure 28, the correlation between choices with a high metric radius and low metric radius of Adama city indicates a week correlation which is 0.399.

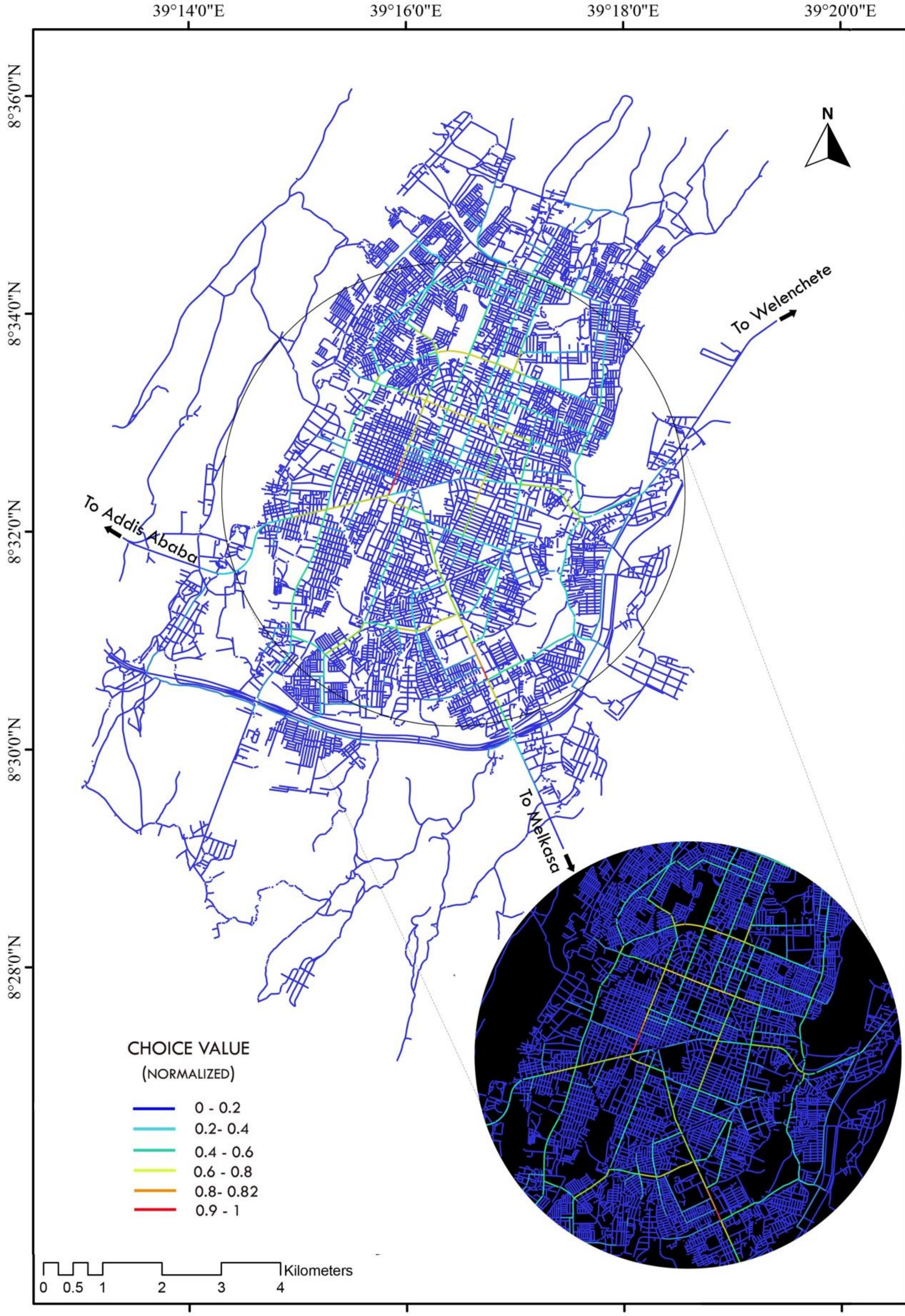


Figure 26: Choice map of Adama city at metric radius of 5000m.

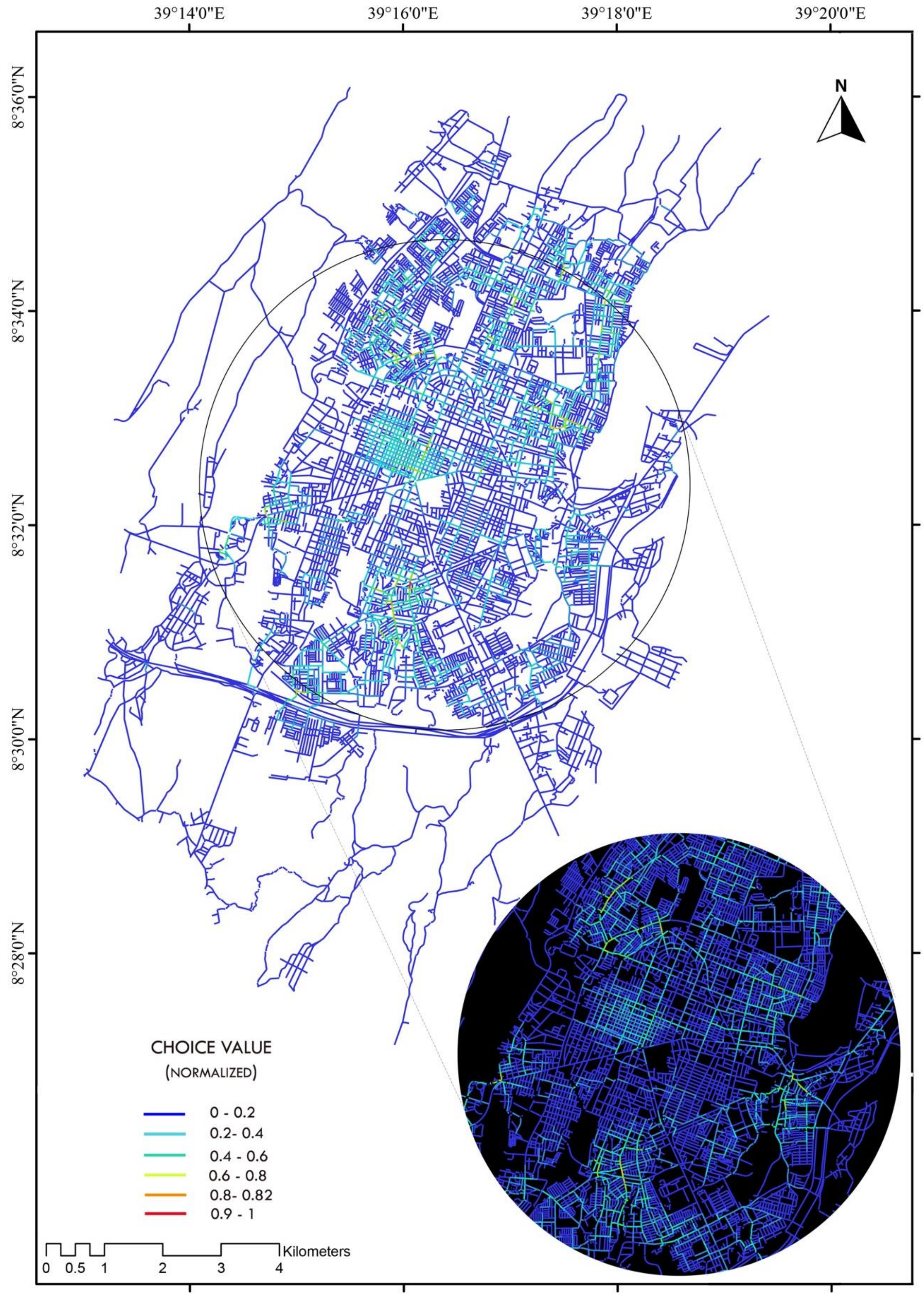


Figure 27: Choice map of Adama city at metric radius of 800m.

Table 10: Choice value at metric radius of 5000m.

Choice value	Color code	Normalized value	Total length(m)	Percentage
0 - 1067173		0-0.2	1090296.34	94.08
1068292 - 2141739		0.2-0.4	36621.35	3.16
2144334 - 3229501		0.4-0.6	19353.69	1.67
3229857 - 4289105		0.6-0.8	11473.14	0.99
4289515 - 4444167		0.8-0.82	579.45	0.05
5002103 - 5400374		0.9-1	579.45	0.05
Total			1158903.42	100

Table 11: Choice value at metric radius of 800m.

Choice value	Color code	Normalized value	Total length(m)	Percentage
0 - 2822		0-0.2	1036870.89	89.47
2823 - 5678		0.2-0.4	102910.62	8.88
5681 - 8569		0.4-0.6	16688.21	1.44
8664 - 11433		0.6-0.8	2259.86	0.195
11636 - 11723		0.8-0.82	11.59	0.001
13295 - 14325		0.9-1	162.25	0.014
Total			1158903.42	100

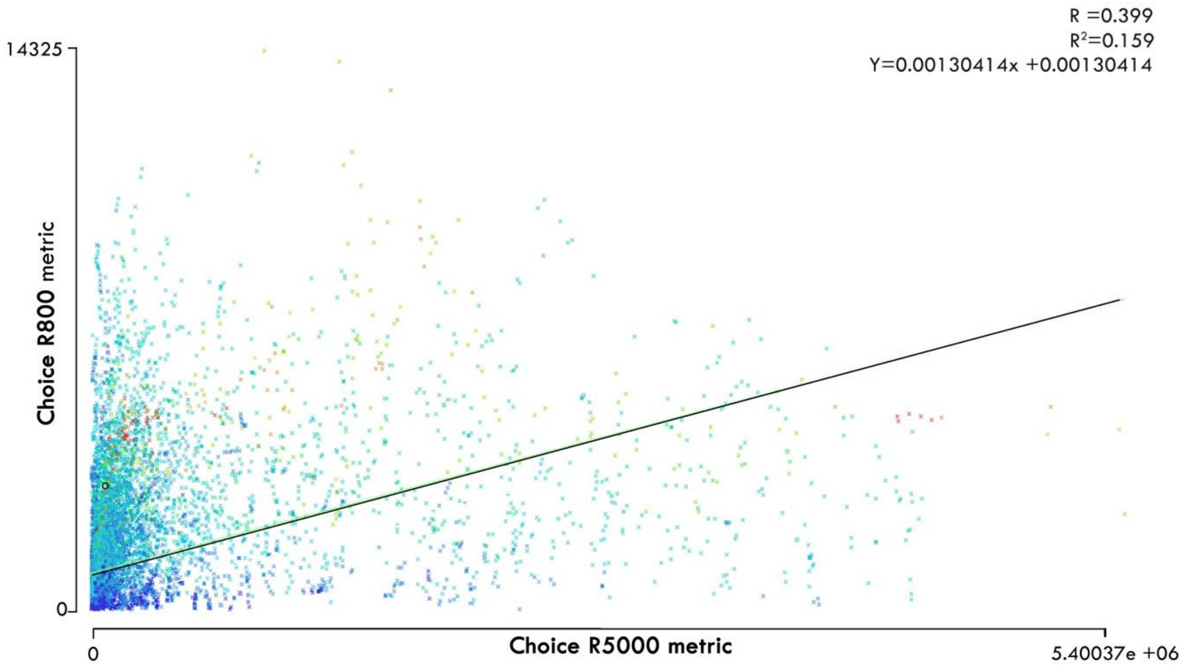


Figure 28: Correlation between choices with high metric radius and low metric radius.

4.3. Level of Connectivity

Connectivity measures how many links each street has to its neighbors. The street network of Adama is composed of 10,048 axial lines. The number of street connections changes between 1 and 27 meaning there are streets with one connection until the street with 27 connections.

The dark and light blue axial lines, corresponding to streets with fewer connections but they are the most dominant in the street connectivity map (Figure 29). According to Table 12, these streets are 88.88% of the total length. The normalized values assigned to the number of connections ranged from 0 (for dead-end streets with only one connection) to 1 (for streets with 27 connections). The streets with more connections are represented by red (Figure 29)and they mostly correspond to longer streets such as Onesomos Hesib Street, Haile Fida Street, Adama Butta Road Kechema Street, Sinke Street, And Aba Sena Road as shown in Figure 30. Most streets with a high number of connections are located in the central area (Sar-tera). This is directly linked with the grid urban structure which allows a high level of connectivity of streets.

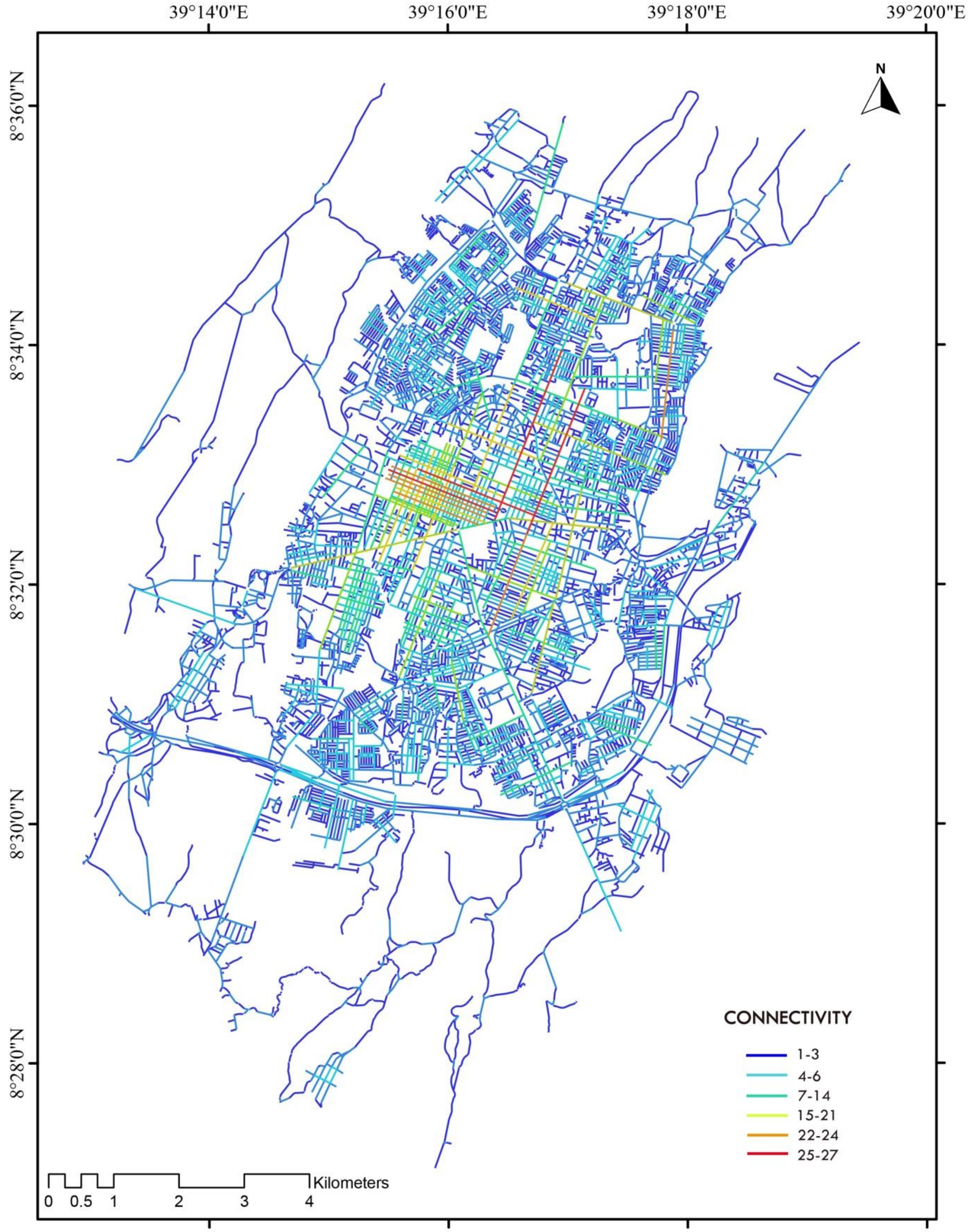


Figure 29: Connectivity map of Adama city.

Table 12: Street connectivity ranking.

No. of street connections	Color code	Normalized value	Total length(m)	Percentage
1-3		0-0.11	668107.82	57.65
4-6		0.12-0.22	269213.26	23.23
7-14		0.23-0.518	166650.31	14.38
15-21		0.519-0.778	37200.80	3.21
22-25		0.779-0.889	9271.23	0.8
25-27		0.89-1	8459.99	0.73
Total			1158903.42	100

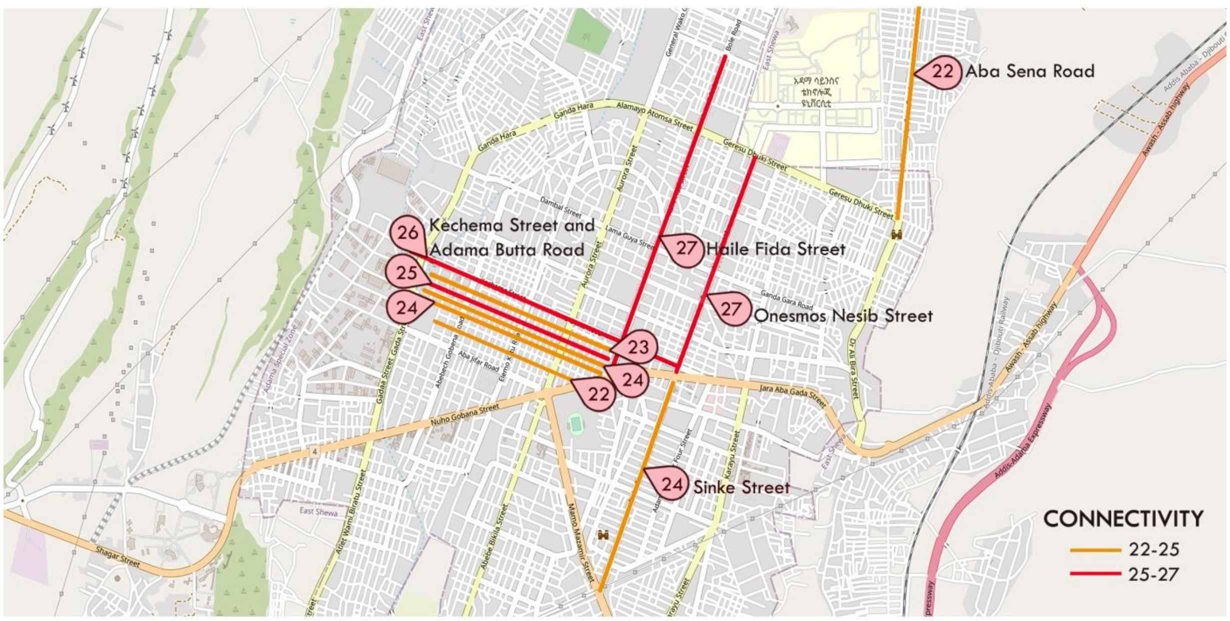


Figure 30: Streets with high level of connectivity.

4.3.1. Permeability

Permeability is expressed by the correlation between the connectivity and the axial line length. This measure permits to understand what degree the connectivity is more related to its length than to the actual porosity of a local area while revealing the potential diversity of paths inside the urban fabric and along the line. The R-value is high (R = 0.690), which means the street connectivity is strongly associated with the length of the street as indicated in Figure 31.

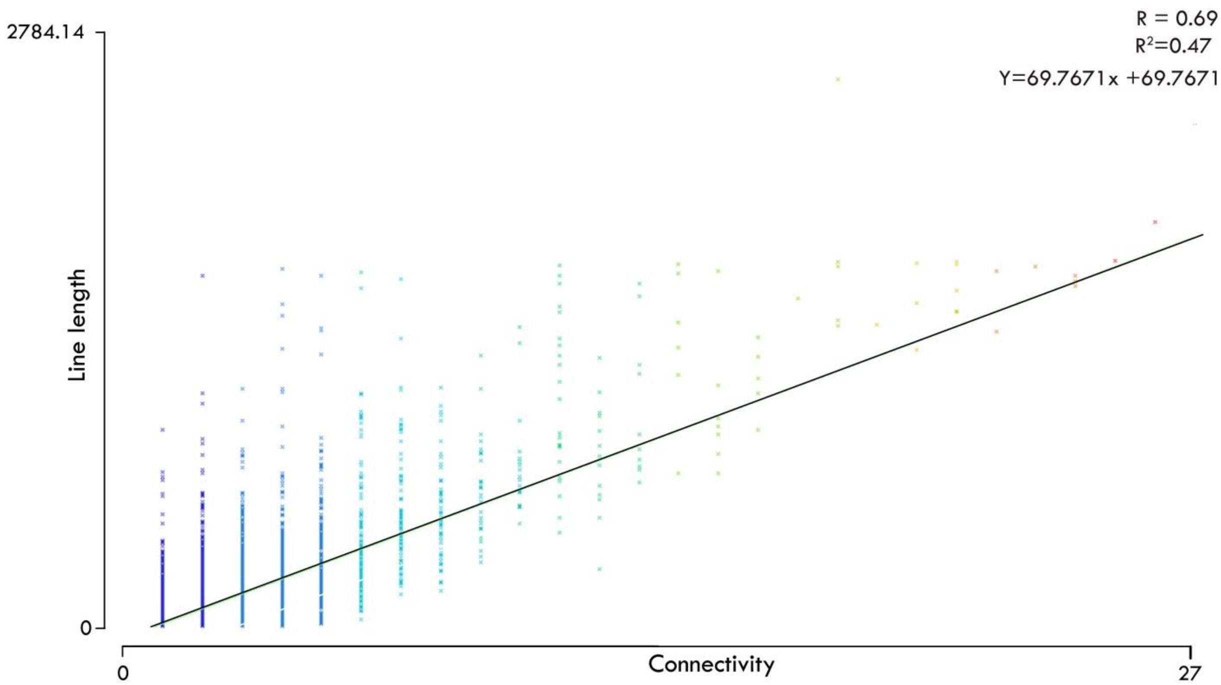


Figure 31: Correlation between connectivity and the axial line length.

4.4. Degree of Control

It reflects how one space controls adjacent space. The higher the value is the stronger the control of street space and the more important and highly reachable it is in the network. The control value of a street denotes the impact it makes on its connected streets and measures what degree of choice each space represents for its immediate neighbors as a space to move to.

As shown in Figure 32 and Table 13, from the total of streets, 0.104% of the street has high control value. These streets are highly important in the network and have high level of reachability. Among them, Sinke street has the highest control value which is 11.9(Figure 33).

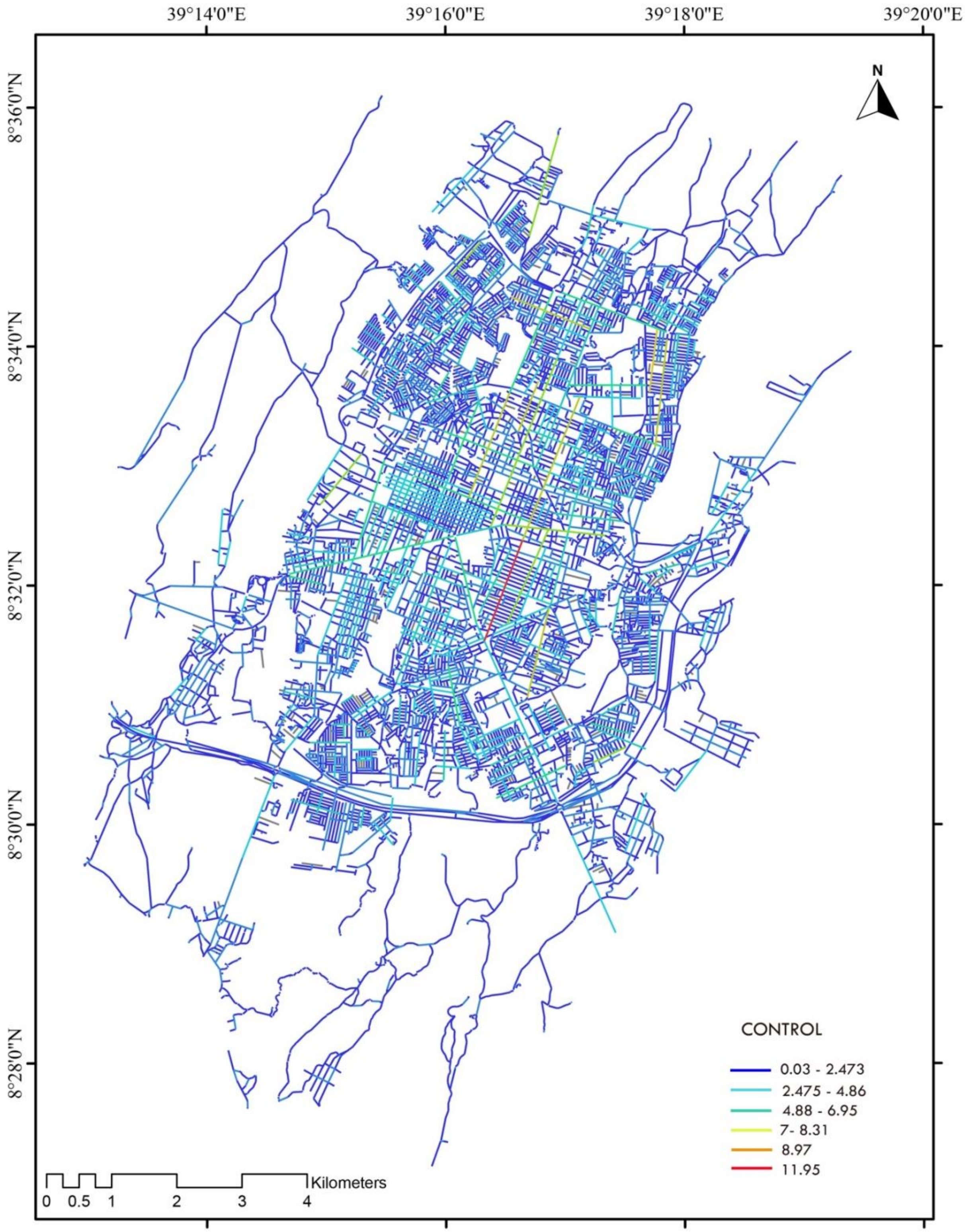


Figure 32: Control map of Adama.

Table 13: Control value of streets

Control value	Color code	Normalized value	Total length	Percentage
0.03 - 2.473		0 - 0.203	990289.52	85.45
2.475 - 4.86		0.204 - 0.405	130339.92	11.26
4.88 - 7		0.406 - 0.58	26316.82	2.27
7.5 - 8.31		0.62 - 0.69	9323.71	0.80
8.97		0.74	981.87	0.08
11.95		1	1651.57	0.14
Total			1158903.42	100

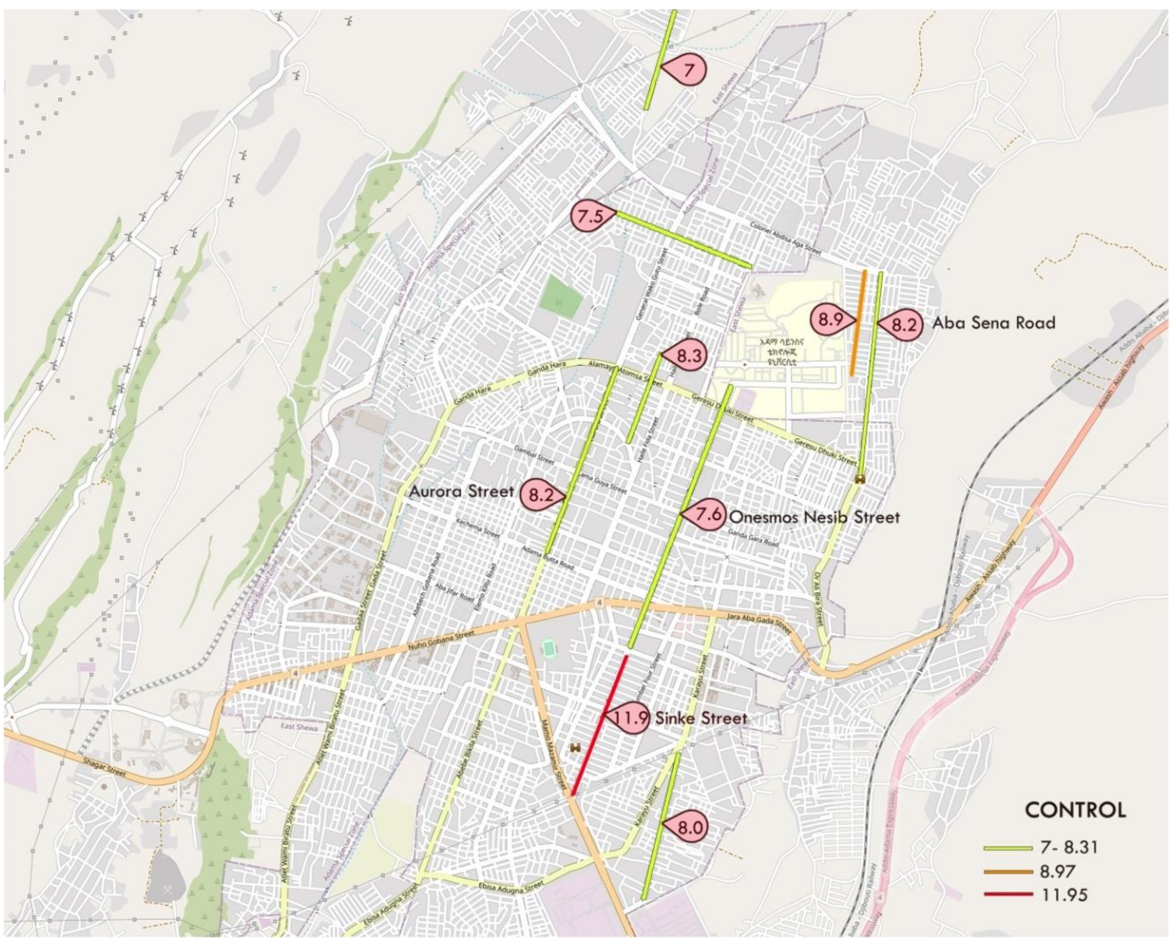


Figure 33: Streets with high control value.

4.5. Degree of Street Vitality

The four measures, namely integration, connectivity, choice (street preference), and control (reachability) collectively measure the degree of street vitality and street life. If a street segment has a high value in at list one of the four measures it is destined to have high vitality and street life because, this measures indicate the flow of pedestrians and the potential of diverse land use along the path. As Figure 34 indicates, 21.54% of the total street segments have high vitality and they are represented with black lines. The vital streets of the city are concentrated at the center of the city.

Figure 34: Degree of street vitality of Adama city.

4.6. Street Network Design to Increase Urban Vitality

By increasing the integrity and the connectivity of the segregated streets, the degree of street vitality of the city can be increased. Increasing the integrity of streets in the outskirt of the city will make the neighborhoods active, introduce diversified land use and attract people. Due to the existence of diversified land use, the residents will not travel a long distance to the center of the city. The existence of pedestrians and different activities in the area creates natural surveillance and the security problem of the area will be solved. Considering this, this research revised the existing street network of Adama to increase the degree of vitality of the total street system as indicated in Figure 35(h).

Figure 35(a) indicates the existing integration value of a neighborhood which is very low. There was only one street that connects the whole neighborhoods to the main road, especially in area with dark blue. This neighborhood is located on the outskirt of the city and is found to be very scary even during the daytime. Although, the main road in front of this neighborhood is new and well-constructed there is low activity and commercial land use due to fewer street connections. Increasing the connection of neighborhood streets above and below to the main road will increase the movement around this road which will attract the emergence of diversified land use so that the urban vitality in this outskirt area can be achieved. Figure 35(d) shows the integration value of the same area after new streets are introduced to increase the neighborhood connection to the main road. The newly added connection changes the integration value of the area from very low to medium integration. By applying a similar method to other segregated areas of the city, the total coverage of segregated streets reduced from 12% to 6% as indicated in Figure 36 and 37. This is achieved by increasing neighborhood connections to the main arterial road of the city.

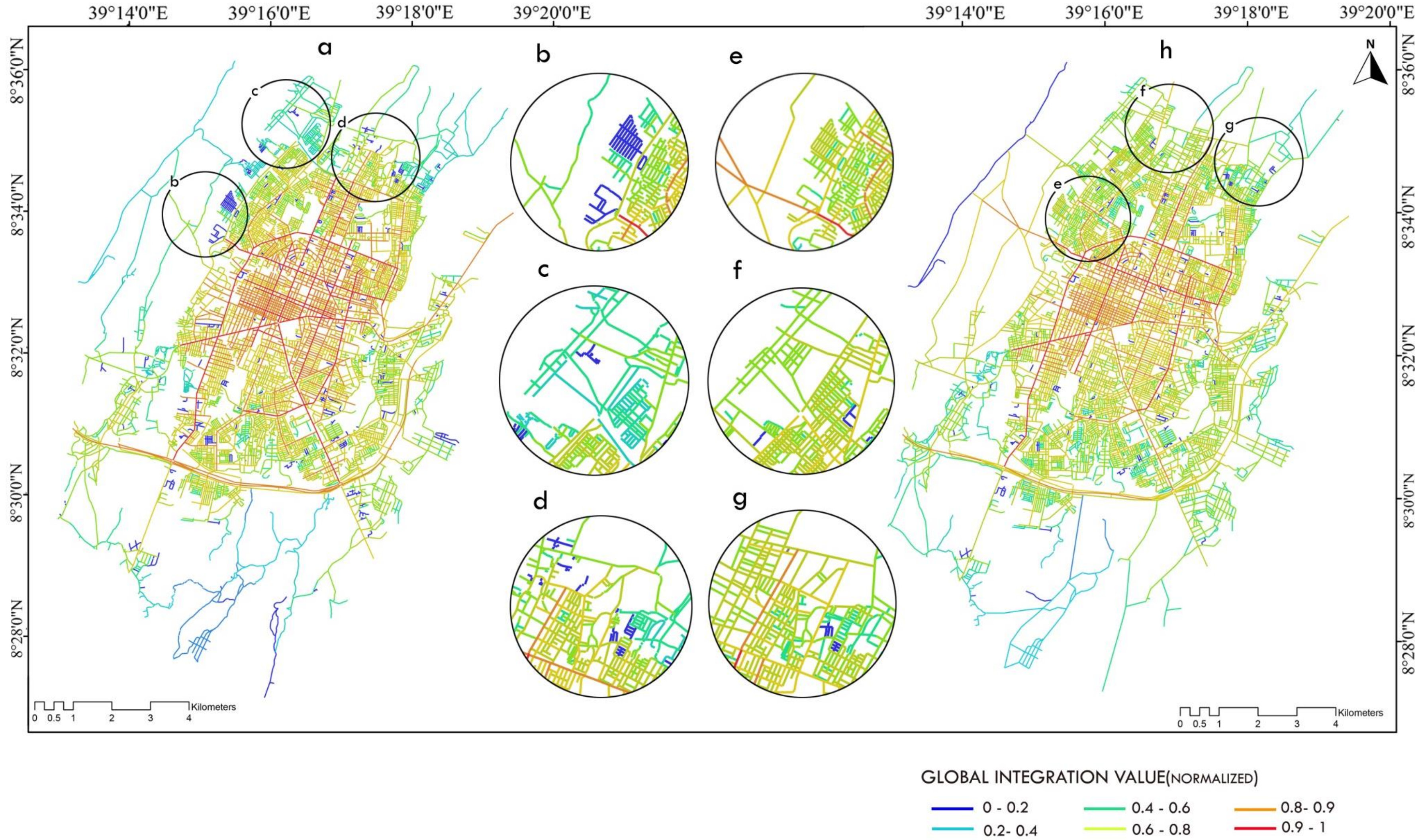


Figure 35: Recommended street network design to increase vitality.

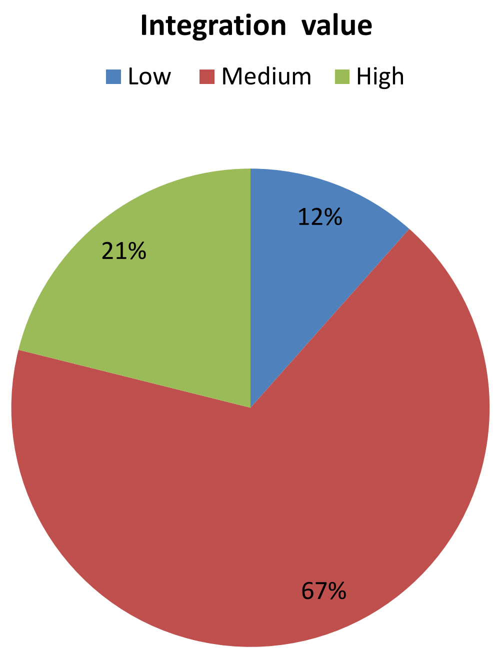


Figure 36: Existing degree of integration.

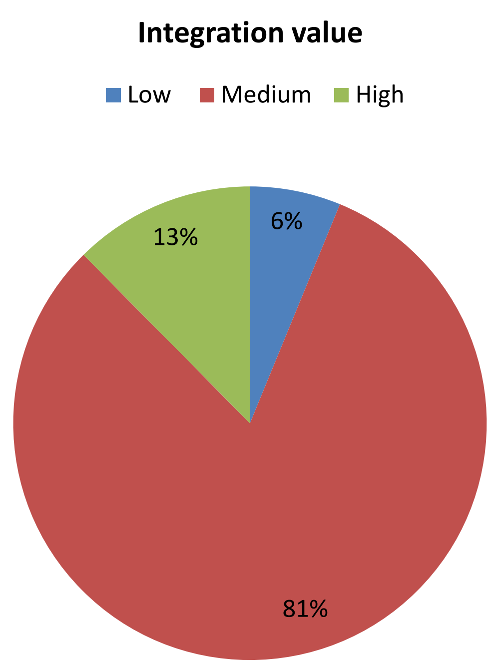


Figure 37: Recommended degree of integration.

CHAPTER FIVE

DISCUSSION

5.1. Identifying Integrated Roads

A global integration analysis determines how spatially integrated a street is with all other streets in a town or city. The higher the global integration values, the fewer change of direction to all other streets. Streets with numerous direction changes to all others, on the other hand, have low global integration scores. As a result, they are spatially isolated (van Nes, 2019).According to the result, streets are highly integrated at the center of the city and 21.46% of the total street segments of the city are integrated. The streets in the outskirt of the city are segregated and they cover 11.5% of the total street segments of the city. The identification of an integrated core shows the city's vibrant core, which attracts people, as well as the street networks that contribute the most to the city's street vitality pattern.

According to Space Syntax, the most dominant factor in pedestrian movements, as well as land-use patterns, is urban street configuration, and there is a correlation between the two(Aziz, 2018). In this study, the integration values of street segments ware compared to pedestrian movements and land-use patterns. The global integration variable exhibited a statistically significant relationship with average pedestrian volume. Pedestrian volumes are higher on highly integrated streets, while they are lower on segregated, less integrated streets.

Integration values are also related to land-use patterns. In most cases, retail and commercial developments were found in highly integrated streets, whereas residential developments were seen in less integrated streets. Pedestrian volume is not only affected by the integration of the street but also by the land use within a 100m radius of counting points (Lee et al., 2020).According to the results of this study, 62.1% - 66.7% of the variation in pedestrian volume is explained by the degree of existence of non-residential land-use with 100m2 radius buffers from the counting point and the integration value of the segment.

The commercial areas have a significant pedestrian volume. Devica (2015) claims that the level of service concept is a relevant guideline for pedestrian space design. Walking speed, pedestrian spacing, and conflict probabilities at varying traffic concentrations were used to determine breakpoints that indicate the various levels of service. However, certain streets in the city's well-integrated sections have a large volume of pedestrians going through but lack a walkway or the walkways are too narrow to support all of the foot traffic which is causing congestion and discomfort. As a result, it is critical to consider the pedestrian level of service idea while planning a street improvement projects.

The results also indicate the pedestrian volume in the mixed-use area is relatively higher than the pedestrian volume in residential areas but lower than that of commercial areas. Furthermore, it is observed that the peripherals are not integrated well; there is a high flow of movement from the peripherals to the core of the city because important roads engage more economic activity and attract people for interaction. Due to this the transportation system of the city is affected.

5.2. Degree of Choice

In addition to identifying the integrated core area of Adama, this study also identifies major important streets that help to activate all parts of the city. The higher the Choice value is the greater the probability of the space being crossed. The global choice index identifies the paths that benefit from the greatest preference for taking on traffic flows from one area of the city to another. They are therefore preferred axes for displacements, of entry or exit to/from an urban zone, or crossing. Regardless of the width of the road, streets with a high choice value will tend to attract more mobility than streets with a low choice value (Pappu, 2018).

Streets with a high level of choice indicate more movement would pass through the segment or highly preferable streets for traffic flow. In this study, streets with a high choice-value were found to be the main arterial roads of the city that connect the local areas, and the streets connecting the city with other towns like Adiss Ababa, Welenchete, and Melkasa. These streets have the potential to attract a high number of people. Since the quantity of visitors per street contributes to the degree of street vitality, identifying these streets helps in locating the vital streets.

The degree of street life which is indicated by the correlation between choice with a high metric radius and with a low metric radius is week(r=0.399). It indicates the main routes are placed outside the neighborhood and are poorly connected to the local streets. One of the main special principles for designing vital and safe public realm is the main routes of the city passing to the neighborhoods. It helps to create lively and economically vibrant neighborhoods (Van Nes & Yamu, 2021).

5.3. Level of Connectivity

Connectivity measures how well streets are linked with others and the density of intersections. Neighborhoods with high street connectivity tend to have streets with several short links, numerous intersections, and few dead ends, which facilitate physical activities such as walking and cycling (Hajrasouliha & Yin, 2015). According to the results, the streets with more connections correspond to longer streets such as Onesomos Hesib Street, Haile Fida Street, Adama Butta Road Kechema Street, Sinke Street, and Aba Sena Road (Figure 30). Streets with a high number of connections are located in the central area of the city. This is directly linked to the grid street structure.

The study shows the connectivity value and street length are highly correlated, which indicates the degree of permeability of the city. Permeability can account for a significant proportion of the variance in residents' social cohesion (Abdullah et al., 2015). Identifying these streets indicates the potential to develop the urban fabric along the line which also brings more vitality and life than it already has.

5.4. Degree of Control

The street's high value of control indicates the high level of reachability and importance of the street in the whole network. Of the total street segments, 0.104% of the streets have high control value. Among them, Sinke street has the highest control value which is 11.9 (Figure 33). Identifying the highly reachable and important street network of the city helped in locating the vital streets of the city.

5.5. Degree of Street Vitality

This research characterize the street network of Adama city using the above four measures to determine the degree of street vitality. Identifying streets which have high value in at list one of the four measures indicates streets with high levels of vitality. The cumulative from four measures indicates that 21.54% of the total street segments have high vitality. In another word, these streets have the potential of attracting a high rate of pedestrians along them which indicates the high potential for the existence of diversified land use.

Most of the highly connected, preferred and reachable streets are found in the integration core which indicates integration of the streets is the main factor in ensuring a high degree of vitality. By modifying the integration of segregated streets to the core of the city the degree of vitality can be increased. This is proven by increasing neighborhood connections to the main arterial road of the Adama by using Depthmapx. The total coverage of segregated streets reduced from 12% to 6%. In this study, the identification of vital streets of the city is mainly based on the four-space syntax measures and the effect of the quality of streets is not considered.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This study has explored the influence of street network layouts on urban vitality using space syntax for Adama, Ethiopia. The objectives of this study have been achieved. The fundamental relationship between pedestrian volume, street integration, and land use of the area was determined. The space syntax analysis tool was employed to measure street configurations, integration, connectivity, choice, and control and the following conclusions can be drawn.

Adama city is highly integrated at the center of the city. 21.46% of the total streets of the city are highly integrated. The integration core lies around the streets of “Sar-tera”.The main roads found in the area are Kechema Street, Adama butta road, Elmo kilitun road, and Leman street. The most segregated area of the city is found around the outskirt of the city. Integration values had a statistically significant association with the average pedestrian and land use of the area which indicates that highly integrated areas have high vitality.

The streets with high choice-value highlight the streets with high mobility and these are the main arterial roads of the city. The result of the street connectivity analysis also highlights the streets with high number of connections. Most of them are located at the central area of the city. Segments with a high level of reachability will have high vitality since they control the activity of the adjacent space and attract pedestrians.

To identify the most vital streets, which require combining the highest-ranking streets obtained from all four analyses, the output showed the vital street network of the city. From all this, the areas with the highest levels of urban vitality are clustered in the center of the city, whereas the outskirt areas are characterized by low urban vitality. The outskirt areas are characterized by low pedestrian volume, pure residential land and segregated streets, which was the main reason behind anti-social behavior and criminal activities. Identifying the vital streets of the city plays an important role in including different commercial land use along these roads. In addition, it is important to increase the connection of streets in segregated neighborhood to the main and integrated roads of the city, to achieve vitality in the area and in the city as whole which is important for achieving sustainable city development.

6.2. Recommendations

Based on the above conclusions and results of this paper the following recommendations are forwarded:

- Adama city's road authority should plan street improvement project. The most integrated roads attract high volume of pedestrian and commercial developments. The width and the infrastructures should correspond to the number of pedestrians passing through, since the quality of streets and public spaces increases the comfort of pedestrians and improves urban vitality. To accommodates all the pedestrian volume and reduce the congestion in these areas, improvements should be made according to pedestrian level of service.
- Adama city's road authority should also give attention to streets with high integration value for proposing land use around the area. Including the required amount of land use in integrated roads will attract more people and increase the vibrancy of the streets. Shops, retail, national and multinational enterprises, and open spaces can be located along highly integrated streets. Generally, the land use determination in the city must follow extensive analysis on street configuration.
- Urgent development is needed in highly segregated areas. Segregated areas are often affected by crime and experience social misuse because, highly segregated streets provoke anti-social behavior and criminal activities. To solve these problems and to improve the urban vitality of the following measures are recommended. First, it is important to increase the connection of streets in segregated neighborhood to integrated roads of the city by creating new linkages, which will improve the accessibility of the area. Then, diversified land use should be proposed. These interventions will increase the urban vitality in segregated areas and the whole city, which is important for achieving sustainable city development.

SPECIAL ACKNOWLEDGMENTS

This research thesis is funded by Adama Science and Technology University under the grant number; ASTU/SM-R/451/22.

Adama, Ethiopia.

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APPENDIX

Appendix 1: Pedestrian volume, integration value and land-use of site one.

- Weekday-March 31, 2022 Average whether -20^0 c.
- Weekend-April 2, 2022 Average whether -22^0 c.

Gate No.	Weekday			Weekend			Avg. Ped.	Log Ped.	Integration value	Land use (m^2)
	Morning	Mid-day	Afternoon	Morning	Mid-day	Afternoon				
G1	1320	1560	1608	1920	1560	1680	1608	3.21	2294.47	59,224.70
G2	2376	2592	2640	2208	2568	2688	2512	3.40	2294.47	55,527.71
G3	624	624	648	1128	576	696	716	2.85	2084.06	51,142.31
G4	1896	1248	1440	1728	1320	1488	1520	3.18	2294.47	47,970.59
G5	528	264	480	504	432	552	460	2.66	2080.85	24,054.11
G6	216	360	384	504	360	456	380	2.58	2015.77	44,159.74
G7	960	960	1008	792	960	1080	960	2.98	2294.37	48,644.33
G8	1296	1488	1560	1896	1560	1680	1580	3.20	2455.13	35,622.86
G9	888	528	720	528	648	744	676	2.83	2455.13	28,103.46
G10	816	528	720	792	672	696	704	2.85	2294.37	25,062.11
G11	552	480	600	408	576	720	556	2.75	2294.37	17189.649
G12	192	144	168	216	144	216	180	2.26	1855.33	9398.574
G13	312	192	240	192	192	360	248	2.39	2294.37	10058.2
G14	216	120	168	144	192	216	176	2.24	2298.74	7517.301
G15	168	120	192	120	168	240	168	2.22	2294.37	5355.364
G16	144	144	168	144	216	216	172	2.24	2090.36	9185.979
G17	720	648	672	648	624	720	672	2.83	2082.96	18294.416
G18	960	744	840	744	888	840	836	2.92	2194.4	18924.911
G19	792	1032	1200	960	1176	1224	1064	3.03	2455.13	14849.981
G20	696	888	936	792	888	984	864	2.94	2455.13	12,170.59
G21	1200	1392	1440	1344	1320	1488	1364	3.13	2455.13	12,009.20
G22	432	480	504	408	552	552	488	2.69	2193.09	0
G23	480	432	456	432	480	480	460	2.66	2076.96	11173.091
G24	360	480	552	384	480	600	476	2.68	2032.11	19700.293
G25	528	840	792	720	744	792	736	2.87	2190.5	19853.368
G26	240	384	360	288	336	384	332	2.52	2136.87	11857.32
G27	936	1200	1176	1320	1128	1200	1160	3.06	2455.13	16826.955
G28	480	576	624	504	576	648	568	2.75	2132.47	9471.575
G29	792	1680	1560	1464	1512	1608	1436	3.16	2455.06	19642.549
G30	480	1032	1200	792	1128	1248	980	2.99	2455.06	19900.63
Total	20280	21600	23448	22104	22416	24816	22444	80.87	67460.6	682891.85
Avg.	584	1096	1128	920	1072	1168	994.7	2.97	2347.53	16338.251

Appendix 2: Pedestrian volume, integration value and land-use of site two.

- Weekday-March 30, 2022 Average whether -20^0 c.
- Weekend-April 2, 2022 Average whether -22^0 c.

Gate no.	Weekday			Weekend			Avg. Ped.	Log Ped.	Integration	Land use (m^2)
	Morning	Mid-day	Afternoon	Morning	Mid-day	Afternoon				
G1	120	312	360	144	288	384	268	2.428135	2061.7	20780
G2	216	288	312	192	408	336	292	2.465383	2061.7	18151.42
G3	168	144	168	120	168	240	168	2.225309	1889.9	5697.381
G4	144	216	288	168	264	360	240	2.380211	2061.7	9718.676
G5	192	168	192	216	192	216	196	2.292256	2061.7	4117.79
G6	120	144	168	120	168	216	156	2.193125	1889.7	2986.348
G7	168	192	216	216	192	264	208	2.318063	2061.7	5068.105
G8	168	216	288	192	240	360	244	2.38739	2061.7	5955.846
G9	96	120	48	144	168	72	108	2.033424	1793	5403.829
G10	60	144	120	96	120	96	106	2.025306	1811.3	178.335
G11	168	144	168	144	168	288	180	2.255273	2068.2	3168.057
G12	120	240	288	120	312	216	216	2.334454	2092.5	8056.242
G13	192	144	168	168	144	264	180	2.255273	2068.2	2700.913
G14	96	120	240	120	120	264	160	2.20412	1883.7	1091.058
G15	216	120	96	168	144	144	148	2.170262	1883.6	5296.658
G16	216	192	192	216	216	216	208	2.318063	2008	1509.961
G17	96	144	120	120	144	168	132	2.120574	1889.9	14040.01
G18	72	240	288	120	288	312	220	2.342423	2008.2	9122.834
G19	120	216	264	96	192	336	204	2.30963	2008.2	14277.58
G20	72	96	60	96	144	96	94	1.973128	1955.9	5058.786
G21	96	120	96	72	120	144	108	2.033424	1889.9	7379.267
G22	48	120	96	72	96	120	92	1.963788	1886.8	0
G23	168	120	96	72	96	144	116	2.064458	1956.9	7715.812
G24	168	216	192	144	264	168	192	2.283301	1889.9	19569.55
Total	3300	4176	4524	3336	4656	5424	4236	53.37677	47244	177044.5
Avg.	137.5	174	188.5	139	194	226	177	2.224032	1968.5	7376.852

Appendix 3: Pedestrian volume, integration value and land-use of site three.

- Weekday-April 1, 2022 Average whether-20^0 c.
- Weekend-April 2, 2022 Average whether -22^0 c.

Gate no.	Weekday			Weekend			Avg. Ped.	Log Ped.	Integration	Land use (m^2)
	Morning	Mid-day	Afternoon	Morning	Mid-day	Afternoon				
G1	132	144	132	180	168	144	150	2.176091	1551.76	0
G2	168	192	168	216	180	168	182	2.260071	1572.27	0
G3	60	108	156	108	204	156	132	2.120574	1320.17	0
G4	60	96	144	96	156	132	114	2.056905	48.7022	0
G5	72	108	120	120	132	108	110	2.041393	48.5318	0
G6	60	96	132	108	144	156	116	2.064458	48.9312	293.454
G7	96	24	156	48	192	180	116	2.064458	48.9312	803.939
G8	48	60	96	84	108	96	82	1.913814	33.9861	534.945
G9	60	48	72	72	84	108	74	1.869232	33.0548	0
G10	60	108	96	108	84	96	92	1.963788	35.5692	0
G11	108	120	120	144	132	144	128	2.10721	1218.38	0
G12	60	96	144	120	180	132	122	2.08636	1130.75	0
G13	72	108	144	120	132	168	124	2.093422	1218.33	0
Total	1056	1308	1680	1524	1896	1788	1542	3.188084	8309.36	1632.34
Avg.	81.23	100.66	129.2	117.2	145.85	137.5	118.6	2.06	639.18	125.56

Appendix 4**:** Pedestrian movement survey.

- Location………………………………………
- Date…………………………………………..
- Weather……………………………………….

Gate	Time	Man	Women	Children	Elderly	Remark
G1						
G2						
G3						
G4						
G5						
G6						
G7						
G8						
G9						
G10						
G11						
G12						
G13						
G14						
G15						
G16						
G17						
G18						
G19						
G20						
G21						
G22						
G23						
G24						
G25						