DISSERTATION FOR THE DEGREE OF MASTER OF ENGINEERING

A STUDY ON SERVICE LOCATION MODELLING: ACCESSIBILITY, COVERAGE AND EXPANSION OF PARCEL PICKUP POINTS

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Abstract

A STUDY ON SERVICE LOCATION MODELLING: ACCESSIBILITY, COVERAGE AND EXPANSION OF PARCEL PICKUP POINTS

Last-mile delivery in the context of transportation and supply chain refers to the final stage of the product delivery process. The last mile is often the most challenging part of transporting packages to their final destinations. It is essential to have easily accessible infrastructure so that packages can be collected with less travel distances and transportation costs. Accessibility is an important aspect of transportation planning. It is used to measure the spatial separation of human activities such as commerce, employment and quality of life. Accessibility reflects the extent of interaction between an area's land use development and transportation system. The aim of the research is to evaluate accessibility using Geographic Information System (GIS)-based techniques, to measure coverage and associated potential market for existing pick-up points, and to suggest modifications to improve accessibility. Spatial analyses, which deal with service location modelling, are carried out using Flowmap software. The analyses include; proximity counts analysis, and catchment area analysis. Literature reviewed discusses the components of accessibility, indicators of accessibility, and GIS-based accessibility modelling. The common measurement of accessibility (gravity-based) used in trip distribution modelling is explained. Gauteng province is used as a study area. Various methods used to analyse the raw data to prepare it for use in modelling are discussed. The cumulative opportunity index, also known as the proximity count, which is an accessibility measure, is used to identify potential customers within a set distance. The user-defined distances in this case are 1610m (1-mile) and 3220m (2-miles). Without considering competition, a proximity count provides an indication of a potential market. Catchment area analyses were also performed. The technique searches within the set distance and allocates origins to the nearest destinations. Trend surface maps (suitability maps) were produced, and they showed the locations of potential populations that the parcel pickup points are not available. The maximum number of customers per site and the pickup points needed to cover an area were computed. In densely populated areas where Pargo service is already in high demand, growing the number of pickup facilities would improve accessibility. Future research directions suggested include analysis of the study areas based on land-use, assessing the accessibility of pickup facilities in densely populated areas and extending the scope beyond Gauteng province.

KEYWORDS
Accessibility, E-commerce, Flowmap, GIS, Last-mile delivery, Parcel pickup point, Spatial analysis

Contents

Plagiarism declaration i
Acknowledgements ii
Abstract iii
Table of contents v
List of figures vii
List of tables viii
Glossary viii
Acronyms and abbreviations x

1 Introduction **1**
1.1 Background and motivation 1
1.2 Problem statement 3
1.3 Research aim and objectives 4
1.4 Research questions 4
1.5 Research methods 5
1.6 Scope and limitations 5
1.7 Dissertation outline 6

2 Literature review **8**
2.1 Introduction 8
2.2 Accessibility measurement and components 8
2.3 Indicators of accessibility 9
2.4 Measurement of accessibility 11
2.5 Accessibility studies in South Africa 12
2.6 GIS-based accessibility modelling 13
2.7 Service location planning models 14
2.8 Last-mile delivery of goods 15
2.9 Accessibility and justice 16
2.10 Conclusion 17

3 Study area **19**
3.1 Research setting and participant 19
3.2 Demographics 20
3.3 Year 2021 Pargo pickup points 21
3.4 Income profile 22
3.5 Land-use planning 24

4 Methods **25**
- 4.1 Introduction . . . 25
- 4.2 Data collection . . . 26
  - 4.2.1 Road network . . . 26
  - 4.2.2 Transport analysis zones (TAZ) . . . 26
  - 4.2.3 Population . . . 27
  - 4.2.4 Parcel pickup points . . . 28
- 4.3 Data processing . . . 31
  - 4.3.1 Road network data processing . . . 31
  - 4.3.2 Population data processing . . . 31
  - 4.3.3 Pickup points data processing . . . 32
- 4.4 Accessibility evaluation . . . 32
  - 4.4.1 Analysis procedure . . . 33
  - 4.4.2 Proximity count analysis . . . 34
  - 4.4.3 Catchment area analysis . . . 35
  - 4.4.4 Service location planning . . . 35

5 Results and discussion **36**
- 5.1 Overview of findings . . . 36
- 5.2 Summary of key findings . . . 43
- 5.3 Expansion of logistics infrastructure . . . 60
- 5.4 Limitations and implications of findings . . . 67
- 5.5 Recommendations . . . 68

6 Conclusion **69**

Appendices **71**

A Python script to clean the road network **72**

B Python script to assign population to hexagons **73**

C Python script to calculate the number of points in a polygon **74**

D Python script to calculate the point of origin and assign population **75**

E Summary of output **76**

List of Figures

1.1	Research outline	7
2.1	Rings of opportunity	10
3.1	Study area	20
3.2	Year 2021 Pargo pickup points in Gauteng	22
4.1	Data cleaning procedure	25
4.2	Road network of Gauteng Province	27
4.3	Traffic zones of Gauteng Province	28
4.4	Population of Gauteng Province	29
4.5	Spatial distribution of raw data of the pickup points in 2021	30
4.6	Extract of the pickup points	30
4.7	Zone centroids/origin points	32
4.8	Analysis procedure	33
5.1	Suitable areas (unshaded) and no-go (shaded) areas for Westrand	37
5.2	Suitable areas (unshaded) and no-go (shaded) areas for Sedibeng	38
5.3	Suitable areas (unshaded) and no-go (shaded) areas for Ekurhuleni	38
5.4	Suitable areas (unshaded) and no-go (shaded) areas for Johannesburg	39
5.5	Suitable areas (unshaded) and no-go (shaded) areas for Tshwane	39
5.6	Existing pickup points and population distribution for Westrand	40
5.7	Existing pickup points and population distribution for Sedibeng	41
5.8	Existing pickup points and population distribution for Ekurhuleni	41
5.9	Existing pickup points and population distribution for Johannesburg	42
5.10	Existing pickup points and population distribution for Tshwane	42
5.11	Westrand proximity counts maps for 1 mile (1 610m)	44
5.12	Westrand proximity counts maps for 2 mile (3 220m)	45
5.13	Sedibeng proximity counts maps for 1 mile (1 610m)	47
5.14	Sedibeng proximity counts maps for 2 mile (3 220m)	49
5.15	Ekurhuleni proximity counts maps for 1 mile (1 610m)	51
5.16	Ekurhuleni proximity counts maps for 2 mile (3 220m)	52
5.17	Johannesburg proximity counts maps for 1 mile (1 610m)	54
5.18	Johannesburg proximity counts maps for 2 mile (3 220m)	55
5.19	Proximity count 1 for 1 mile (1 610m)	57
5.20	Proximity count 2 for 1 mile (1 610m)	58
5.21	Tshwane proximity counts maps for 2 mile (3 220m)	59

5.22 Photographs of typical Pargo parcel pickup points 61
5.23 Catchment area analysis - unsatisfied demand in Ekurhuleni 62
5.24 Catchment area analysis - unsatisfied demand in Johannesburg 63
5.25 Catchment area analysis - unsatisfied demand in Sedibeng 64
5.26 Catchment area analysis - unsatisfied demand in Tshwane 65
5.27 Catchment area analysis - unsatisfied demand in Westrand 66

A.1 Script to clean the road network 72

B.1 Script to assign population to hexagons 73

C.1 Script to calculate the number of points in polygons 74

D.1 Script to calculate point of origin and assign population 75

E.1 Summary of output 76

List of Tables

3.1 Average population and year 2021 Pargo sites per study area 19
3.2 Age distribution and population size. Source: (GHTS, 2020) 21
3.3 Population and created regular hexagons per study area 21
3.4 Source of household income, Gauteng province, 2016 23
3.5 General household income distribution, 2019 23

5.1 Summary of maps for suitable areas and no-go areas 37
5.2 Summary of maps for existing pickup points and population 40
5.3 Outline of maps for proximity counts 43
5.4 Westrand summary of analysis 46
5.5 Sedibeng summary of analysis 50
5.6 Ekurhuleni summary of analysis 53
5.7 Johannesburg summary of analysis 56
5.8 Tshwane summary of analysis 57
5.9 Summary of analysis for 1 mile radius 60
5.10 Summary of analysis for 2 mile radius 60
5.11 List of suburbs where there is potential for expansion 62

Glossary

access the ability to enter (ingress) and leave (egress) a parcel of land from an abutting roadway. 8, 11

accessibility a measure of the ease by which a given location can be reached from the numerous locations that comprise a region. iii, 8

activity node Places where public and private investment and activities tend to concentrate. A wide range of economic, social activities, and mixed use developments occur at these nodes. 70

e-commerce (or electronic commerce) is a business model that lets companies and individuals buy and sell things over the internet. iii, 1–3, 13, 15, 22, 23, 67

Flowmap A software tool used to carry out various geographical analyses of data. It is used to compute commuting and migration flows, interaction analyses such as accessibility analysis, network analysis and various gravity modelling. iii, 14

isochrone (iso = equal, chrone = time) a line drawn on a map connecting points at which something occurs or arrives at the same time. 10

last-mile delivery The final stage of goods delivery process involving the transportation of the shipment from a transportation hub to its ultimate destination.. iii

link A network component representing streets or road segments. 34

model A universal concept reducing a real system to the aspects relevant for understanding or solving a specific problem. 6, 10

network distance The length of the shortest path between two nodes along the road network. 34

node An element of a network representing intersections. 34

proximity analysis Proximity analysis is a type of spatial analysis in GIS that evaluates the relationships between geographic features based on their distance.. 34

trip The connection between two activities, composed of multiple legs. iii, 34

utility An economic concept representing satisfaction through goods consumption. 10–12

Acronyms and abbreviations

Abbreviations

CBD Central Business Districts

CSIR Council for Scientific and Industrial Research

CSV comma-separated values

GIS Geographic Information System

IDP Integrated Development Plan

ITP Integrated Transport Plan

NLTA National Land Transportation Act

NMT Non-Motorised Transport

O-D origin-destination

OSM OpenStreetMap

Stats SA Statistics South Africa

TAZ Transport analysis zone(s)

VGI Voluntary Geographic Information

Chapter 1

Introduction

1.1 Background and motivation

The term "last-mile delivery" refers to the concluding phase of the transportation and supply chain, covering the final step in the delivery process of a product. The final leg of package transportation, commonly referred to as the "last mile," is often recognised as the most challenging aspect of the process. In South Africa, the fulfilment of last-mile deliveries encompasses a variety of transport modes, comprising light delivery vehicles, passenger cars, and non-motorised transport. The emergence of e-commerce has witnessed significant advancements in last-mile delivery in recent years. Various methods, such as traditional postal operations, courier services, fixed parcel pickup points, and the utilisation of retail shops for parcel sending, collectively play a role in facilitating the final leg of parcel delivery. The cargo delivery business in Gauteng province of South Africa encompasses a fusion of conventional and contemporary approaches to the transportation of packages. The conventional approach is predominantly employed for the transportation of large and heavy commodities in large quantities across both short and long geographical spans. Modern techniques are predominantly employed for the conveyance of small, lightweight parcels, such as documents, or significant commodities necessitating prompt delivery to a different destinations. The distances travelled can vary in length and scope, encompassing both domestic and international destinations. The primary focus of this study is on the former where service location planning for parcel pickup points is evaluated. The case study focuses on Pargo, a courier company that specialises in the last-mile distribution of parcels. Pargo parcel pickup points are distributed throughout all the municipal areas of Gauteng province. Pargo is not the sole entity providing parcel pickup points in Gauteng; other service providers offering comparable services are also present within the province. The Pargo business model makes use of e-commerce. Customers shop online stores using the internet and select Pargo as their preferred courier method to deliver the ordered goods at checkout. Pargo has established parcel collection points throughout Gauteng province. Pickup locations include fuel stations, retail stores, and other convenient locations. Pargo parcel pickup points are small facilities that are ideal for handling light, small packages, documents, and important products that must be delivered to another address in a short time. Pargo will collect the parcel on the customer's behalf and notify the customer via text message and email when the parcel arrives at the Pargo point. The customer will then arrange for a convenient time to pick up the package. Cargo delivery in Gauteng is a hybrid of traditional and modern methods. Traditional methods are primarily used to transport large and heavy products in bulk over short and long distances. In addition to large and heavy goods, modern methods include small, light packages, documents, or goods that must be delivered to another location quickly. This study focuses on the latter, where e-commerce can be seen in e-hailing, food and non-food. It is difficult to determine whether the existing pickup locations are accessible and capable of meeting the demand. Pargo has strategically implemented a network of parcel collection points across the Gauteng province. The available pickup locations include fuel stations, retail stores, and various other convenient establishments.

The last-mile delivery of goods presents various challenges. The challenges under discussion primarily pertain to the difficulties encountered by the customer rather than those experienced by the logistics company. One of the primary obstacles arises from insufficient or substandard infrastructure in certain regions, attributable to the long-term effects of previous urban planning systems. In addition, the absence of innovation within postal operators has led to unreliable postal service, consequently prompting the development of alternative approaches to parcel collections. The emerging technologies which are currently undergoing development still require further improvement. Parcel delivery may experience delays as a result of road congestion during peak hours. One may experience significant waiting times when collecting a parcel, particularly when done during peak hours. The challenges at hand do not possess immediate solutions; however, it is widely acknowledged that the primary solution lies in the continued expansion of parcel pickup facilities over an extended period of time. This objective can be accomplished by augmenting the number of pickup locations. It is believed that increasing the number of pickup points improves accessibility directly. In addition, the road network could be improved to make the pickup points more accessible. Among other solutions is the general improvement of e-commerce. However, the enhancement of e-commerce is somewhat broad and has not been the focus of this study.

This study employs accessibility metrics to evaluate the coverage of Pargo parcel pickup locations. Pargo is a smart logistics company that deals with the last mile of parcel distribution. Pargo has strategically positioned parcel collection points throughout the Gauteng province. The evaluation of accessibility is a subject of significant interest as it provides insight into the level of interaction between Pargo parcel pickup points within a specific land-use development and the transportation network. Stover and Koepke (2002) outlines typical examples where accessibility measurement can be applied. They include evaluating alternative sites for the location of shopping centres, evaluating potential industrial sites, assessing the need for a new hospital, evaluating the need for a truck terminal, assessing the need for, or location of, public services such as fire station, police station, and solid waste collection point. This dissertation will discuss approaches to service location planning using GIS-based techniques. Accessibility evaluation at an aggregated level is applied. The motivation for conducting the research are (1) To practically apply accessibility measures in determining the current coverage of the pick-up points. (2) To determine the potential market for the pick-up points within an area (3) To propose intervention measures by determining the location for new pick-up points where services are inadequate.

1.2 Problem statement

The challenges of last-mile delivery of goods faced by those who rely on it include inadequate or substandard last-mile infrastructure. This means that the person travelling to collect a parcel may encounter traffic congestion while on the road. This is common in Gauteng, particularly during peak travel times. Upon arrival at the facility, parking spaces are scarce, especially during peak hours. In certain instances, the distance between the parked vehicle and the entrance of the facility is excessively long, making it impractical for individuals to cover the distance on foot. A similar phenomenon happens when individuals utilise public transportation. The spatial separation between a public transport terminal and the entrance of the facility is substantial. Upon gaining access to the facility, individuals may encounter considerable periods of waiting while collecting the shipment, particularly when undertaking this task during peak hours. The real accessibility issues that Gauteng residents face when it comes to last-mile deliveries and accessing their parcels is that the existing parcel pickup points are few and mostly concentrated in Central Business Districts (CBD)s and at isolated filling stations, with fewer in outlying and peri-urban areas. The above issues have a significant impact on the accessibility of last-mile deliveries as well as parcel accessibility.

Planning the optimal placement of facilities within a specific territory is essential for achieving equity. In the case of existing developments, a re-look is ideal for establishing coverage of facilities, and if minimum thresholds are not met, possible expansion is needed. Challenges to access e-commerce from a transportation perspective are twofold. Firstly, in outlying urban areas and rural setups, people travel long distances to get services. Long distances discourage last-mile delivery. Secondly, in an urban environment, access to services is most affected by congestion during peak hours. Parcel delivery is less efficient in higher population densities because each pickup point has a limited capacity. For example, if a person goes to a retail store to pick up a parcel and the time it takes to be served is long because there are other customers waiting to be served. Even if the pick-up location is close, the time spent collecting the parcel is as long as the pick-up facility is distant. The primary issue of concern regarding accessibility in this particular scenario pertains to the limited number of available parcel pickup locations, which fails to adequately align with the present demand.

Policies are available which outlines general guidelines on planning of neighbourhood amenities. As per legislative requirements, the National Land Transportation Act (NLTA), Act No.05 of 2009, states that planning authorities must prepare Integrated Transport Plan (ITP) [1]. Municipalities in Gauteng namely; Tshwane, Johannesburg, Ekurhuleni, Sedibeng and West Rand emphasise improving the transportation system and land use development in their policy papers. Better mobility and accessibility are two aspects of improved transportation systems that also increase social inclusion. Policy documents such as the

[1] An ITP is a statutory plan required by the NLTA to guide the transport development and operations in a municipality.

ITP and Integrated Development Plan (IDP) [2] mentions accessibility as a major policy direction. However, the degree of its application in planning is not consistent throughout the municipalities. The majority of existing urban infrastructure was built decades ago when most of today's policies did not exist. Is last-mile delivery supported in terms of land use and transportation changes? The extent of last-mile coverage and access to Pargo facilities within a mile radius is unknown. As a result, service location planning will be employed, which evaluates the population as well as the coverage of facilities within a mile. Improvements to accessibility are suggested in cases where it is lacking.

1.3 Research aim and objectives

This dissertation will discuss accessibility metrics to evaluate the coverage and expansion of Pargo parcel pickup locations in Gauteng province. It employs GIS-based techniques. Accessibility evaluation at an aggregated level is applied. The aim of the study is to conduct an investigation into service location modelling, with a specific focus on the aspects of accessibility, coverage, and expansion of parcel pickup points. The objectives of this study are:

(i) To apply GIS-based modelling techniques and other associated tools to evaluate accessibility.

(ii) To evaluate the coverage and associated potential market for existing pick-up points

(iii) To suggest modifications to the location and expansion of the pick-up points with the aim of improving accessibility.

(iv) To suggest interventions based on social inclusion and justice principles. The objectives of this study are:

Accessibility modelling using GIS techniques will be evaluated at an aggregated level. As summarised by Handy and Niemeier (1997), accessibility that facilitates better interaction in a community should have destinations that are closer to the origins, choices to get to destinations and choices on travel modes.

1.4 Research questions

Based on the background, problem statement, and research objectives described above, the overarching research questions that are of importance to this dissertation are:

(i) How can accessibility based on parcel delivery systems and service location be evaluated using GIS modelling techniques? To do this, one needs to know what kind of data is needed for the research area, how to process it, and how to use the right GIS tools to compute accessibility?

[2] An IDP is a plan that provide strategic direction and operational planning for a municipality for five years in terms of Chapter 5 of the Municipal Systems Act, 2000.

(ii) How can accessibility mapping in GIS be used as a tool to improve last-mile parcel delivery for Pargo pickup points?

(iii) How can accessibility be improved by modifying parcel pickup locations on the Pargo network? It is best to figure out how many potential customers are in each service area, and the distances between the pickup points. In what regions are services insufficiently accessible, and where is the demand unsatisfied?

By using intervention strategies like redistributing and expanding, accessibility of the pickup points can be improved. After implementation of intervention measures, the following follow-up questions are critical:

(i) After the interventions, has accessibility improved?

(ii) What conclusions can be drawn?

1.5 Research methods

In this part of the report, the specific methods used to collect the research data, the analysis that was done, and any assumptions that were made are laid out. The following data was gathered for this study: (1) the road network; (2) the transport analysis zones (Transport analysis zone(s) (TAZ)); (3) the population for each TAZ; (4) parcel pick-up points; and (5) provincial and municipal boundaries. The data was cleaned and geo-processed to make it usable for GIS analysis tools. In instances where the data proved to be incompatible, it was necessary to first convert the data into appropriate formats. The municipal boundaries were broken down into regular hexagonal cells with 1-mile (1 610m) long edges, and equivalent population data was assigned to each cell. The existing pick-up locations were combined with the regular hexagons and used in the analysis as partial solutions. Consideration was also given to *"no-go"* locations during the analysis. No-go locations are inaccessible locations that are characterised by physical constraints such as mountains, water bodies, environmental sensitive areas as well as other places that are unsuitable for human habitation. This category also encompasses areas that have not yet been developed. A user-defined distance, which in this case is 1-mile (1 610m), was set up. GIS tools that are capable of carrying out various geographical data analyses discussed. The analyses include catchment area analysis, a method that searches within the predetermined distance and distributes population to the closest locations, and proximity count, also known as the cumulative opportunity index. The cumulative opportunity measures the number or percentage of an area's inhabitants who can reach a specific fixed number of facilities in increasing time or distance (Voges and Naudé, 1983). The purpose of these analyses is to determine the potential customers per site and the number of pickup locations required to serve a given area. A comprehensive review of the specific methodologies is presented in the methods chapter of this report.

1.6 Scope and limitations

The approach to research employed in this study covers a theoretical foundation that encompasses the subjects of last-mile delivery and service location planning. The coverage and accessibility of the pickup points are assessed through the utilisation of GIS-based tools, employing a quantitative analysis of the available data. This paper presents a proposal for the expansion of pickup points, taking into consideration factors of accessibility and principles of justice. In summary, the scope covers service location modelling related analysis like:

1. Coverage model analysis - the model helps to establish how many of the existing facility locations meet a minimum level of service.
2. Proximity count analysis, also known as the cumulative opportunity index - is an accessibility measure that is used to identify under-served customers within a user-defined radius.
3. Expansion model analysis - the model helps to determine if there is a need for more pick-up points to serve an area.
4. Catchment area analysis - also known as analysis of service areas, helps to allocate origins to destinations.

The limitations of the study are:

(i) The emphasis is on last-mile delivery from business to customer perspective rather than business to business.

(ii) This study does not consider the quality of service at the facility where packages are collected.

(iii) The scope of this study is limited to the last mile delivery process from the Pargo pickup points to the customer. It excludes delivery of returned products.

1.7 Dissertation outline

The dissertation format in this study is sequential, firstly by presenting the literature of accessibility measures and their applicability in transportation planning. Various techniques to model accessibility are discussed together with research findings and an interpretation of results. The figure below shows a synopsis of the research outline, followed by a detailed description of each chapter.

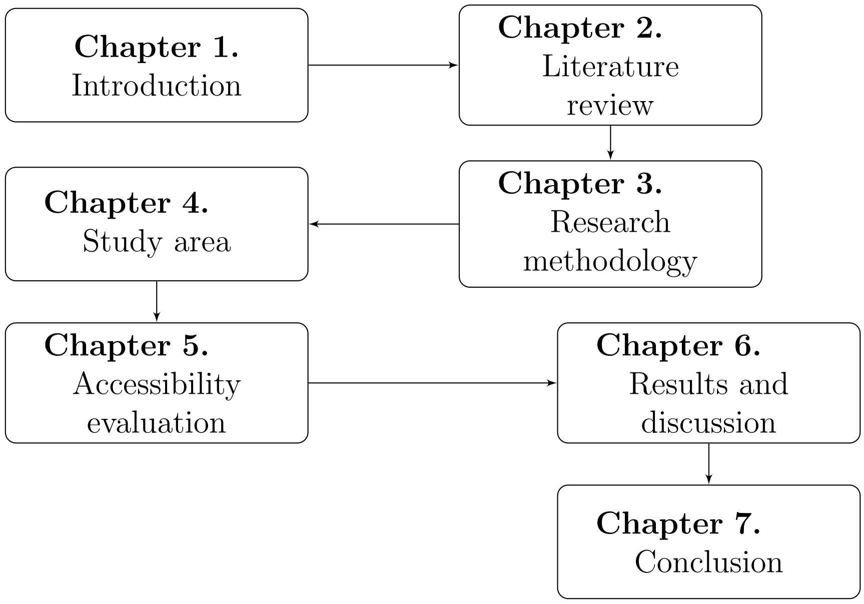


Figure 1.1: Research outline

In Chapter 1, the dissertation is introduced, and the background and purpose of the study are described. The difficulties with the accessibility of parcel pickup points are discussed in a problem statement. The broad research questions are presented after the research goals and objectives. Chapter 1 concludes with a discussion of the scope and various limitations. In Chapter 2, a more thorough review of the literature is done with a focus on the theoretical justifications for measuring accessibility. There is discussion of accessibility indicators, components, and modelling based on GIS techniques. The topic of last-mile delivery of goods is also covered, along with principles of justice. Chapter 3 provides an overview of the research methodology and discusses various accessibility metrics. The chapter ends with a summary of the data collected and a data processing procedure. Chapter 4 introduces the case study and delves into the available data. Various methods for analysing raw data to prepare it for use in modelling are discussed. The demographics of the study area, including its population, are also discussed in relation to existing Pargo pickup points. Lastly, land use is discussed as a transportation planning variable. Chapter 5 demonstrates how to model accessibility using GIS-based analysis techniques. The methods of analysis used in the study are explained in detail. In Chapter 6, an analysis of the simulation results is presented, followed by a summary of key findings. A detailed discussion of the findings is provided. The expansion of Pargo pickup points in areas where demand is high is presented. The limitations and implications are discussed, as well as recommendations. Chapter 7 concludes the dissertation and discusses potential future research directions.

Chapter 2

Literature review

2.1 Introduction

There have been numerous publications on the topics of location modelling, last-mile delivery, and parcel pickup points' accessibility. Although the literature encompasses a wide range of theories, this review will concentrate on relevant published research on accessibility, service location planning, last-mile delivery of goods, and access and justice principles. The identified sources will go into detail on accessibility measures, including their components, indicators, and the equations used to calculate accessibility. Previous South African studies on the subject are also discussed. The type of modelling, specifically GIS-based modelling, is briefly discussed. Service location planning, last-mile delivery, and the principle of justice are also discussed.

2.2 Accessibility measurement and components

The concept of accessibility is credited to Hansen (1959) and has been practically applied in the analysis of accessibility. In his research on the importance of accessibility on the pattern of urban development, he defined it as the potential of opportunities for interaction. Various definitions have been used to described the term "access or accessibility". Morris et al. (1979) defined accessibility as the ease with which activities may be reached from a given location using a particular transportation system. The normal activities that people require on a daily basis include employment, education, cultural, recreational among other things. To engineers and planners, accessibility is generally viewed as "how well public infrastructure components can be utilised". An example is the concept of universal access discussed by Stephanidis (2009). Another example is entrance for motorised vehicles and pedestrians into public amenities such as a shopping centres where an efficient flow is anticipated regardless of time of the day (Faura Pugés, 2012).

In this context, "*accessibility*" refers to the following definitions: (1) Availability and spatial pattern of facilities. (2) The ease with which people in an area can interact with facilities to get to services. (3) Transport related infrastructure available to people to enable them get to opportunities.

Accessibility is influenced by transport demand, mobility, transport options (modes), network integration, user information, affordability, land-use, transport network connectivity and transport management (Litman, 2017). Geographic factors such as natural barriers, terrain and climate also impact accessibility in rural areas. Geurs and Ritsema van Eck (2001) summarised accessibility into four components, namely:

1. Land-use
   - spatial distribution of supplied destinations and their characteristics
   - spatial distribution of demand for activities and their characteristics
2. Transport
   - the supply of infrastructure, its location and characteristics
   - the demand for passenger and freight travel
   - the characteristics of resulting infrastructure use
3. Temporal
   - time-based accessibility varies by mode and time of day.
   - availability of activities at different times of the days or week, seasons, years
   - the times in which individuals participate in certain activities vary
4. Individual
   - grouped according to different needs, abilities and opportunities

The accessibility framework is solidly established upon these components. This research focuses on the initial two elements, namely transportation and land use.

2.3 Indicators of accessibility

The broad application of accessibility indicators in transportation and land-use planning include the evaluation of transport and land-use systems, modelling travel choice situations and modelling urban development (Morris et al., 1979). The application of these indicators are equally applicable in both rural and urban contexts. Voges and Naudé (1983) presented an overview of the various indicators and then discussed the main justifications for using accessibility indicators. Among them are to gauge relative accessibility, forecast land use, and assess how well land-use transportation systems perform.

Accessibility measurement in land-use and transport planning is summarised by three indicators as discussed by Handy and Niemeier (1997); Ziemke et al. (2018); Geurs and Ritsema van Eck (2001); El-Geneidy and Levinson (2006). The indicators are:

1. Isochrone-based (or cumulative opportunities) measures
The isochronic or cumulative opportunity measure is one of the simplest class of measuring accessibility. This approach counts the number of potential opportunities that can be reached within a predetermined travel time or distance (El-Geneidy and Levinson, 2006); (Handy and Niemeier, 1997). This approach tends to be easier to apply and interpret by planners, policy makers and the public. The cumulative opportunities measure does not take into account the size of the facility (attractiveness) or the impedance of reaching it (cost). All facilities are weighted equally. An example is a count of the total number of schools in a given area that are within 500 meters distance or 10 minutes walking. It becomes tricky when a facility falls just outside the ring (e.g. 505 meters), the extra 5 meters mean that such a site is automatically not counted under 500 meters. A typical illustration of isochrone-based measure is shown in figure 2.1.

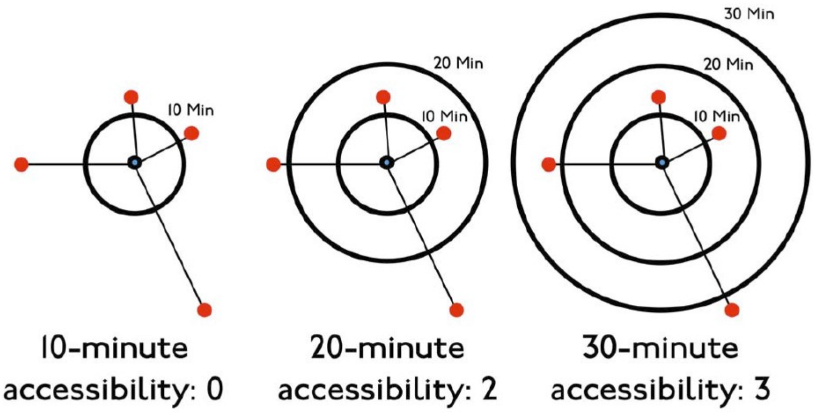


Figure 2.1: Rings of opportunity
Source: Levinson and Krizek (2017)

2. Gravity-based measures
The gravity measure was inherited from gravity-model for trip distribution in the four-step transport demand model. The measure is more complex and realistic as compared to the isochronic measure. This model takes into account travel distance (or cost) and the attractiveness of a location. The closer the opportunity from a point, the more it contributes to accessibility and the larger the opportunity, the more it contributes to accessibility. In the same manner, accessibility is expected to decline the farther the opportunities are from the origin point (El-Geneidy and Levinson, 2006). The impedance function may take many forms; however, the gravity-based measure is mostly used with a negative exponential function to calculate impedance. It is believed that the negative exponential is most closely tied to travel behaviour theory (Handy and Niemeier, 1997).

3. utility-based measures
This measure is regarded as the most complex and data-intensive. It is based on the random utility theory in economics, in which the probability of an individual making a particular choice depends on the utility of that choice relative to the utility of all

choices (Handy and Niemeier, 1997). In this approach, accessibility is measured at an individual level and computed based on the individual's characteristics, such as income group, age group etc. The main disadvantage of this approach is that it is difficult to interpret and to communicate the results as compared to other indicators.

The gravity-based measures have been used in transport planning including accessibility studies and the method has been refined over time. The gravity method measure will be used in this study. Additionally, the isochrone/cumulative measure is applied when summing the population of a given area. An aspect of distance is fully considered.

2.4 Measurement of accessibility

Access or accessibility measures are broadly defined in two types namely infrastructure-based measures and distance measures. Infrastructure-based measures focuses on travel speed or level of service provided by a transport system (Martens, 2012). Distance-based measures are related to the travel distance or travel time from origin to desired destination. A variety of accessibility measures have been developed, including cumulative opportunities measures, gravity-based measures, and utility-based measures. The gravity type of accessibility measurement is commonly used in trip distribution modelling. Below is the mathematical formulation:

$$A_i = \sum_j O_j f(C_{ij}) \tag{2.1}$$

where,

A_i = measure of accessibility in zone i,
j = all possible destinations,
O_j = Opportunities available at location j,
C_{ij} = Cost or distance between origin i and destination j
$f(C)$ = Impedance distance function, which decreases with increasing cost

In case of an exponential function, the above formula can be simplified to:

$$A_i = \sum_j O_j e^{-\beta C_{ij}} \tag{2.2}$$

where,

$-\beta$ = Distance decay parameter,
C_{ij} = Distance between origin i and destination j

In case of a power function, the formula can be simplified to:

$$A_i = \sum_j O_j e^{-\beta} \tag{2.3}$$

where,

$-\beta$ = Distance decay parameter,

2.5 Accessibility studies in South Africa

In South Africa, various accessibility studies have been conducted. Each study focused on a different theme, ranging from the location planning of public facilities such as health and education to economic development. Others dealt with accessibility indicators and accessibility measures. Accessibility to health care facilities is always a public health concern in South Africa. Tanser et al. (2006) conducted an assessment of the accessibility of community-based primary healthcare facilities in the Hlabisa district of KwaZulu-Natal. They developed a hybrid accessibility model that estimates the realistic average travel time to get to the nearest clinics. The results revealed the need to improve the accessibility of primary health care facilities in rural areas of developing countries. In a study to measure accessibility in rural areas of Eastern Cape Province and to analyse policies, Naude et al. (1999) applied GIS tools to determine accessibility to market centres. Isochrone-based indicators were used to analyse network-based travel times. The findings of the study concluded that a lack of accessibility is one of the major constraints of economic development in the Wild Coast region of South Africa. Voges and Naudé (1983) reviewed and evaluated various accessibility measures in order to propose methods for evaluating the planning of land-use transport systems as well as the spatial pattern of supply of community facilities and employment opportunities. The research looked into various metrics such as cumulative opportunity, network, gravity, utility, and time-space formulas. Each measure was discussed in detail, including its advantages and shortcomings. Voges and Naudé (1983) further discussed the cumulative accessibility measure, which measures the number or percentage of an area's inhabitants who can reach a specific fixed number or level of facilities within a set distance. This concept, which served as the foundation for the proximity count, is of special interest in this study.

Studies conducted by Cheruiyot and Harrison (2014) have examined accessibility in South Africa with a specific focus on its impact on economic development. Cheruiyot and Harrison (2014) modelled the relationship between economic growth and time-distance accessibility in four major metropolitan cities in South Africa. A simple gravity-based indicator was applied to determine travel times. Although their study could not conclude the view that high time-distance accessibility to major concentrations of economic activity is positively correlated with economic performance. The study showed positive relationships within sub-national economies. Case studies from the City of Tshwane are presented in a research by Venter and Cross (2014). A new mapping technique that is based on "access envelopes" is discussed. The method extends accessibility measures by factoring in public transport as well as policies related to the improvement of accessibility. Information such as the number of jobs, income, average walking time, and public transport travel costs is required as input. It is unlikely that such information is readily available. The authors assert that the "access-envelope method" offers improvements over existing accessibility measures. Aiv-

inhenyo (2019) conducted a study to develop context-sensitivity indicators of accessibility to evaluate land use and transport system in Cape Town. The research also evaluated equity in accessibility to basic opportunities and its effects on various urban population groups. The indicators presented in the study can be replicated in other developing cities with similar setup as Cape Town. The metropolitan areas of Gauteng province that are discussed in this report have similar conditions to the study conducted in Cape Town.
A study conducted in South Africa pertaining to the accessibility of last-mile deliveries has been undertaken by Weber and Badenhorst-Weiss (2018). Weber and Badenhorst-Weiss (2018) researched on the last-mile logistical challenges for grocery retailer shops in South Africa. The purpose of their research was to better understand the nature of last-mile logistical challenges hindering the efficiency of e-commerce for South African grocery retailers. Their investigation was qualitative in nature. The study, however, was not related to transportation planning, but it produced key findings that suggest that many of the last-mile challenges faced by grocery retailers stem from inefficient information (data) management along the supply chain. Another recent study that focused on last-mile delivery was carried out by Gundu (2020). Gundu (2020) developed an initiative with the goal of bridging digital divides between people living in different geographical areas. The study suggests using smart locker systems that are opened with pin codes. These lockers can be placed at secure locations in rural areas, such as hospitals or police stations, and used for parcel collection. The author argued that most rural areas are under-served by logistics service providers because they lack good roads and proper residential address systems. This argument is completely supported.

When the above studies are compared to what this research aims to achieve, it is clear that the concepts of GIS-based techniques to measure accessibility, last-mile delivery, parcel pickup points, and e-commerce have been studied in South Africa. Although the focus and depth of each study may not be directly related to the goals of this study, the major similarities in some of the studies are the use of GIS-based techniques to measure accessibility as researched by Naude et al. (1999), Tanser et al. (2006), Cheruiyot and Harrison (2014), and Aivinhenyo (2019). Similarly, Weber and Badenhorst-Weiss (2018)'s research lays a solid foundation for the use of e-commerce in last-mile deliveries. Finally, Gundu (2020)'s research claims that most rural areas are under-served by logistics service providers due to a lack of good roads and proper residential address systems, and it suggests using smart locker systems at strategic locations in rural areas. Conclusively, prior research carried out in South Africa align with the objectives of this investigation and establishes a solid basis upon which this study is built.

2.6 GIS-based accessibility modelling

GIS technology has evolved over time and has been applied in sectors like defence, mining, agriculture, navigation and telecommunications (Geertman, de Jong and Wessels, 2003). The technology has improved significantly and its use extended into modern day transportation planning and development. In transport planning, GIS helps planners to understand development patterns and relationships between land-use and transport systems. To the society at large its benefits include improved communication, better decision making and cost savings resulting in greater efficiency. Various planning support tools which focuses more on accessibility analysis have been developed to augment the normal GIS software. Among them is the Flowmap tool. Flowmap is a GIS-based planning support tool that provides more advanced analytical and modelling applications. The tool will be used to evaluate service coverage and the associated potential market for pick-up points and to propose modifications where appropriate.

2.7 Service location planning models

The field of location modelling has a rich historical background that can be traced back to the 16th century. During the beginning stages of development, the models primarily focused on the geometric properties pertaining to the spatial arrangement of points within the Euclidean plane (Eiselt, 1992). Today, facility location planning is used to solve the problem of deciding where to locate a specific public facility (such as a school or a clinic). A study conducted by Amer (2007) on health services planning for the City of Dar es Salam, Tanzania explored GIS methods to determined accessibility and service locations. The objectives of the study were to develop a spatial planning tool approach that contributes to equitable and efficient urban health care provision. A number of interrelated themes were investigated that include the development of a GIS-based planning approach that can identify spatial inequality and inefficiency. Although the themes focused on health services location in Dar es Salam, the outcomes of the study contributed to improving the citizens' quality of life. Analysis of health services locations were based on GIS data and patient household data survey. As one of the findings, the study pointed out that the success of spatial analytical tools relies on available data. Another GIS-based health related study conducted by Møller-Jensen and Kofie (2001) explored location modelling for health service planning in rural Ghana. Their research aims to look into issues concerning the use of location-allocation methods in health service planning for a specific area of rural Ghana. The main source of concern was data availability. This is common in South Africa, so many researchers interested in service location planning resort to using secondary data, which has its own set of challenges. Geertman, de Jong, Wessels and Bleeker (2003) researched on the efficient and effective use of different ambulance services in central Rotterdam, The Netherlands. In their paper, they presented an accessibility methodology in which GIS was used to calculate the origin locations that are within reach of each destination location. The proximity count concept is also discussed in detail in their paper. The proximity count gives an indication of the potential (job) market in a given location. It does not take into account any competition effects. It can be used to determine which sites reach above certain (minimum) threshold values (Geertman, de Jong, Wessels and Bleeker, 2003). The threshold values can be travel distance or travel time. The conclusion of the study was that some parts of the Rotterdam areas were over-served by existing ambulance services and some under-served.

A local study by Baloyi et al. (2017) for the City of Tshwane focusing on GIS-based analysis of ambulance response was conducted. The aim of the study was to improve placement of stations and allocation of ambulances per station to improve service delivery in the metropolitan City of Tshwane. Input information to the study included population, station locations, number of ambulance vehicles and emergency routes. The results showed that existing emergency services stations' locations were well distributed within the area; however, a spatial mismatch in vehicle allocation was reported. Yi (2004) conducted a study to evaluate the accessibility to public primary schools in the Yuhua district in Changsha, China. The study proposed patterns to improve the accessibility to public schools by selecting acceptable service centre locations. According to the study, accessibility analysis can provide a more accurate representation of the relationship between supply and demand than traditional methods. Lyons and Davidson (2016) examines transport planning and policy-making in the face of an uncertain future. Their paper draws attention to the *"Triple Access System"*, which consists of three components: spatial proximity, physical mobility, and digital connectivity. The system serves as a method for making adaptable and robust policy and investment decisions. With the progression of the digital era, one concept that has gained significant prominence is digital connectivity, which has greatly contributed to accessibility. Policy-making pathways (those that follow the rules and those that test the rules), if followed, will help transport planners and decision-makers.

The aforementioned discussion on service location planning theory establishes a robust framework upon which this study is founded. The service location planning models discussed in this research are based on GIS. The facilities in question refer to parcel pickup points that are strategically located throughout the Gauteng region. The main question to be addressed after the completion of service location planning is the determination of the number of distinct locations necessary to ensure accessibility for the Pargo pick-up point. The determination of the number of facilities is derived from the analysis results of proximity count and catchment area analysis. The required facilities are determined based on threshold distances of 1 mile (1,610 metres) and 2 miles (3,220 metres). The allocation of facilities is determined by the level of demand from Pargo customers within a specific geographical region. Despite the fact that the services discussed in the planning differ in nature, GIS techniques can produce easy-to-understand spatial maps. In summary, service location planning can also be used to solve a variety of urban transportation planning issues which are mentioned in the earlier chapters of this study.

2.8 Last-mile delivery of goods

When goods are delivered from a distribution centre to the end user's location, which is typically a home or business, this is referred to as the last mile of the supply chain. The last mile encompasses last mile logistics, last mile distribution, and last mile delivery (Liu and Hassini, 2023). The delivery component is the focus of this research. The last mile is typically the focus of urban goods transportation, primarily due to the effects of urbanisation and e-commerce. It has become important in the rise of e-commerce. Last-mile delivery vehicles frequently used include vans, trucks, and motorcycles. Other developed nations use bicycles and drones as transportation methods. The mode of transportation is determined by aspects such as package size, travel distance, level of urbanisation, and delivery time. For the last mile to be fully achieved, it thus requires a road network that supports local deliveries. According to Liu and Hassini (2023), in a study on the literature review of freight last-mile delivery, last-mile transportation is crucial for the entire supply chain and can make up as much as 75% of the total cost of transportation. Correia et al. (2023) summarised last mile challenges, which include transportation-related issues such as population number and dispersion, topography of the territory, and accessibility issues such as rural and mountainous areas. These challenges are closely connected to the Gauteng region. In some parts of Gauteng, last mile delivery is not fully supported due to poor or nonexistent infrastructure. Besides that, parcel delivery may experience delays as a result of road congestion during peak hours. One may experience significant waiting times when collecting a parcel, particularly during peak hours. Delivering goods often presents unique challenges like navigating through congested roads, limited parking areas in CBD, and restricted access to some premises. Pargo's use of permanent parcel pickup facilities inside stores has eliminated this. However, congestion-related challenges are considered temporary because, for fixed pickup points, a recipient can decide to collect the parcel during off-peak hours or a non-busy day. It is widely acknowledged that the primary solution lies in the continued expansion of parcel pickup facilities over an extended period of time. It is believed that increasing the number of pickup points improves accessibility directly. In built-up areas, where higher customer densities prevail, expanding the parcel pickup points results in a less expensive last mile delivery system (Harrington et al., 2016). In addition, the expansion of parcel pickup points in peri-urban and rural areas leads to a reduction in the travel distance required to reach these facilities.

South Africa has seen rapid growth in last-mile delivery of goods (Goga et al., 2019), (Barnard and Wesson, 2004), (Johnson and Iyamu, 2019), (Karine, 2021), particularly in traditional package delivery and food delivery. Customers can order food online and have it delivered from a restaurant, store, or independent food delivery service. In most cities where homes and restaurants are closer together, the delivery person may use bikes or motorised scooters instead of a car. Checkers 60, Mr Delivery and Uber are three examples of role players in the last-mile delivery of goods. Although their service differs from Pargo in that they do not have fixed parcel pickup points, these play an important role in the local distribution of consumer packaged goods. Their business models combine personal services with technology to meet the competitive opportunities of today's market (Smith, 2016). A case study by Kedia et al. (2020) sought to determine the optimal density and locations for establishing parcel collection and delivery points. Their findings reveal that parcel pickup locations in supermarkets and other retail establishments were more accessible and convenient than conventional post offices. Furthermore, customer-centric goals that ensure accessibility and last-mile delivery typically determine the strategic placement of supermarkets. The ecosystem of e-commerce has changed the way people shop, giving companies more ways to reach more customers.

2.9 Accessibility and justice

"Justice", in simpler terms, involves the concepts of fairness and reasonableness. Martens (2016) presented a comprehensive theory for transport planning based on the principle of justice. The research discusses a number of theories and practical insights related to transport justice and physical accessibility. The central claim of transport justice is that transport authorities sometimes discriminate against people based on their place of residence and that one's place of residence should not have an adverse impact on vital aspects of daily life or one's health (Soja, 2013). This is typical in urban areas where accessibility levels vary significantly between population groups, primarily as a result of income and place of residence. High-income areas have more parcel pickup locations, while low-income areas have few or none at all. Transportation plays a significant role in either fostering the development of socially equitable societies or exacerbating disparities within and between various geographical areas (Beyazit, 2011). Thus, in this instance, the principle of transport justice is invalidated. The topic of equity in transport planning strategies is also covered by O'Flaherty (2018). This entails distributing transport benefits equally. The concept disregards factors like income level, car ownership, age, disability, and people who reside in underdeveloped areas. In order to create a spatial planning tool approach that contributes to the equitable and effective delivery of urban health care, Amer (2007) conducted research on the topic of spatial justice in urban health services planning. The same justice principle applies regardless of the study's focus on equity in healthcare. Aivinhenyo (2019) affirmed the same approach, but with a stronger emphasis on context-sensitive accessibility indicators when assessing equity in access to fundamental opportunities. Since this research is concerned with evaluating pickup points and identifying potential accessibility intervention strategies to increase parcel pickup points, it is ideal to keep justice principles in mind. In order to conceptualise the notion of "urban transport justice," Gössling (2016) presented a research paper that defined three dimensions in which transport injustices become evident, one of which pertains to the distribution of space. The distribution of pickup locations has a significant impact on accessibility; therefore, increasing the number of pickup locations, irrespective of the area's socioeconomic standing, is one intervention strategy from the perspective of justice. Social inclusion and exclusion have a close relationship with justice (Martens, 2012; Gössling, 2016; Davis, 2023). In a recent study, Davis (2023) argued that the unequal transport systems of today are the result of past planning decisions, based on her experience from an American perspective. She encourages transport professionals to reflect on past injustices and elevate new inclusive practices. Davis (2023) advances innovative approaches and new ways of thinking to solve transportation planning issues, with the goal of connecting individuals to opportunities, employment, education, and other services that promote sustainability. For new technologies, such as parcel pickup point location, to be integrated into existing transportation systems, the transportation system and land-use must be in harmony so that the benefits mentioned above are realised.

2.10 Conclusion

The goal of this review was to gain an in-depth understanding of available literature on accessibility, service location planning, last-mile delivery, and transportation justice. The research reviewed clearly demonstrates that accessibility was established decades ago (Hansen, 1959) and has been successfully used in transportation planning. The cumulative opportunities method takes into account travel distance/time and opportunities, whereas the gravity model is built on the principle that accessibility decreases the further the opportunities are from a given origin point(Handy and Niemeier, 1997), (El-Geneidy and Levinson, 2006). It is also clear that various studies have been conducted in South Africa although the focus is not necessarily on parcel deliveries but is valid for modelling of location of pickup points. The use of GIS techniques (Naude et al., 1999), (Tanser et al., 2006), (Cheruiyot and Harrison, 2014), (Aivinhenyo, 2019), (Geertman, de Jong, Wessels and Bleeker, 2003), (Baloyi et al., 2017) are also widely used in the study of service location planning and last-mile delivery of goods with specific focus drawn in the use of Flowmap tool (Geertman, de Jong and Wessels, 2003), (De Jong and Van der Vaart, 2013). Other notable literature focusing on service location planning and last-mile delivery of goods has been explained using examples of companies that are leaders in last-mile delivery. The topic of equity in transport planning is critical and is discussed because today's unequal transport systems are the result of previous planning decisions, which require retrofitting to harmonise transport systems and land-use that promote equitable societies and reduce disparities within and between geographical areas. The literature review demonstrates that a thorough understanding of accessibility, service location planning, and last-mile deliveries, combined with the utilisation of conventional GIS techniques augmented by Flowmap tool, will facilitate the achievement of the study's objectives.

Chapter 3

Study area

3.1 Research setting and participant

Pargo was chosen for the research study in order to assess the accessibility of their package collection stations. As of year 2021, there are around 2500 pickup stations spread across the country. Even though there are other competitors in the field of smart logistics, the Pargo company has a great deal of room for expansion. Anyone with a business and appropriate premises can register to host a parcel pickup facility. It is unclear whether this is the sole method for establishing new pickup places. The research will determine the Pargo sites needed to cover each study area. The research will also determine if the pickup places are easily accessible. Pargo was also chosen due to the availability of their data for the pickup places. Gauteng province is ideal for research since it is the smallest in terms of geographical extent and the most populous in South Africa. According to the Gauteng Household Travel Survey figures of 2020, it has a total population of 13.4 million people which correspond to the rounded population used in this study shown in Table 3.1. According to 2021 figures, Pargo, on the other hand, had 557 pickup points in the same region. There is a spatial break in the continuity of the transportation network and land-use. Pickup locations are concentrated in urban areas, with fewer in rural areas and farming communities. Based on these features, it is therefore interesting to assess accessibility to determine whether there are any areas that are under or over-served. Intervention measures such as re-distribution and expansion is also of paramount importance.

Study area	**Average population**	**Existing pickup points**
Tshwane	2 900 000	161
Westrand	1 100 000	29
Sedibeng	1 200 000	41
Ekurhuleni	3 500 000	128
Johannesburg	4 500 000	198
Total	13 200 000	557

Table 3.1: Average population and year 2021 Pargo sites per study area

3.2 Demographics

Figure 3.1 below depicts the study area, which comprises five municipalities: West Rand, Sedibeng, Ekurhuleni, City of Tshwane, and City of Johannesburg. Gauteng province is South Africa's most populous and smallest in terms of land size. It has a population of 13.4 million people and an area of 18176 square kilometres (GHTS, 2020).

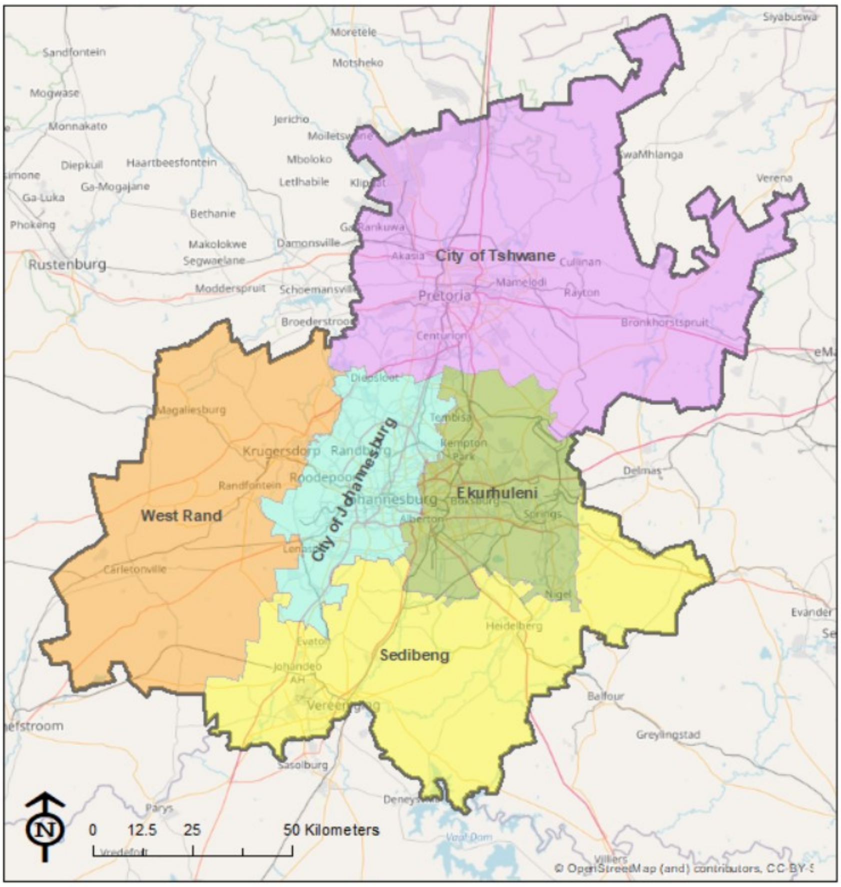


Figure 3.1: Study area

The table below shows the population distribution in Gauteng in 2019. The active age, 18 to 65, constitutes two thirds of the population. A significant number of people are concentrated in Johannesburg, Tshwane, and Ekurhuleni, which account for 37%, 24%, and 25% of the total population. The remaining 14% is shared between Sedibeng and West Rand. In general, the overall population has an impact on the demand for services.

Age group (years)	Population size	Percentage
0 - 6	1 686 273	12.6
7 - 17	2 163 619	16.1
18 - 25	1 850 949	13.8
26 - 65	7 025 341	52.4
65+	673 542	5.0
Total	13 399 724	100%

Table 3.2: Age distribution and population size. Source: (GHTS, 2020)

3.3 Year 2021 Pargo pickup points

The rounded population, total hexagons and year 2021 Pargo sites per each study area are presented in the table 3.3 and 3.2 below. The Gauteng Household Travel Survey figures of 2020 correspond to the rounded population used in this study. Comparing the population values to the total number of hexagons, Johannesburg and Ekurhuleni are densely populated, whereas, Westrand and Sedibeng are sparsely populated. Although Tshwane is evenly distributed in terms of its population and hexagons, it is also sparsely populated and predominately made up of agricultural areas. For the hexagons, polygonal tessellations were created with radius of 1610m, which represent 1 mile on physical ground. The total number of hexagons obtained varies depending on the total land area of each study area. The largest city in terms of land area is Tshwane, which has the most hexagons as can be seen in the table. In comparison to the other four areas, Johannesburg's land area is the smallest because it has the least hexagons. As of 2021, there are 557 Pargo sites throughout the province. The most pickup locations are in Johannesburg, followed by Tshwane and Ekurhuleni. The smallest number of Pargo sites exists in Westrand.

Study area	Average population	Total hexagons	Total Pargo	Population per Pargo site
Tshwane	2 900 000	5519	161	18 012
Westrand	1 100 000	3618	29	37 931
Sedibeng	1 200 000	3782	41	29 268
Ekurhuleni	3 500 000	1809	128	27 344
Johannesburg	4 500 000	1553	198	22 727
Total	13 200 000	16 281	557	

Table 3.3: Population and created regular hexagons per study area

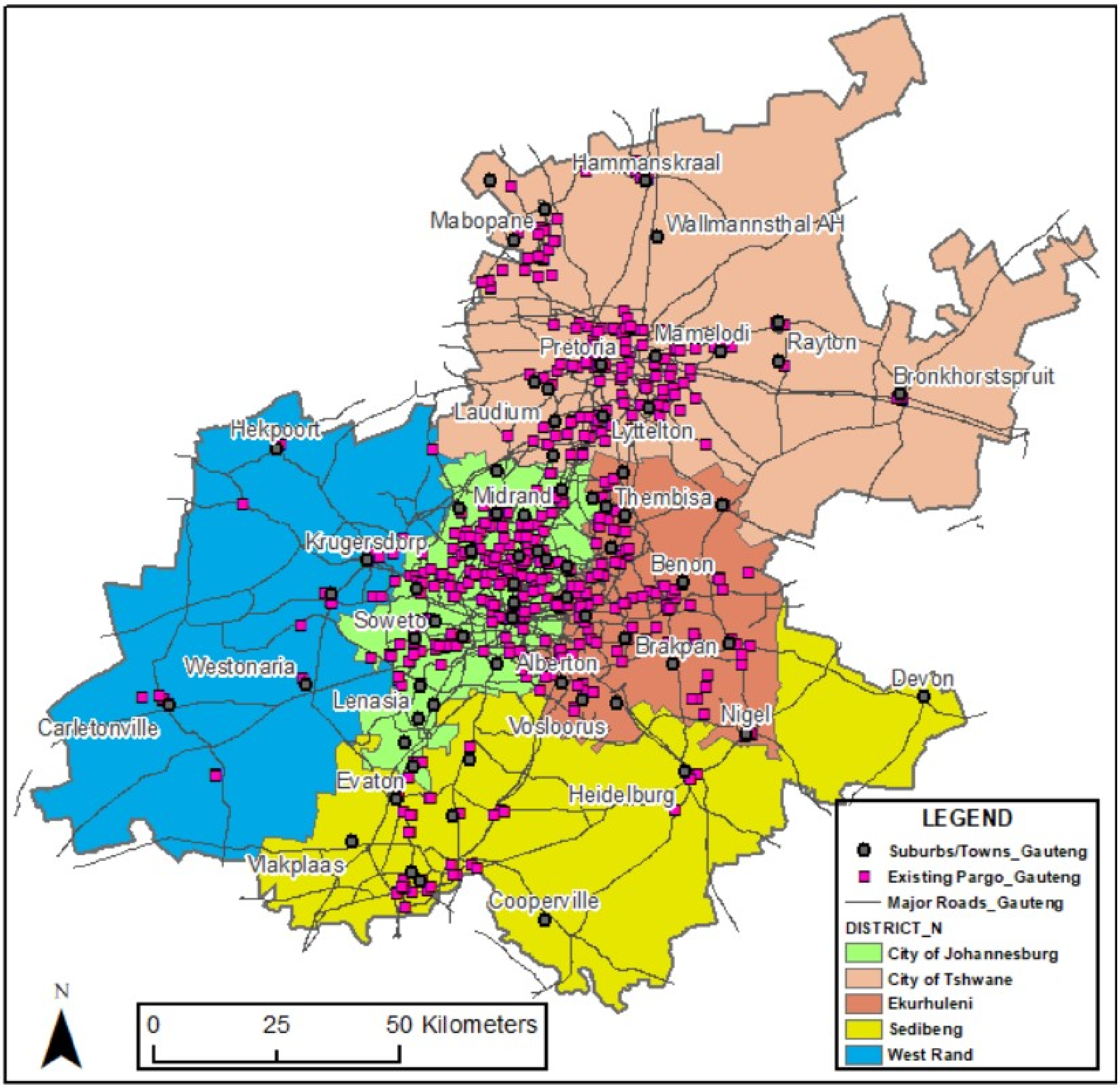


Figure 3.2: Year 2021 Pargo pickup points in Gauteng

3.4 Income profile

Gauteng is mostly a low to middle-income society, with the majority of the people falling into one of these two groups. A quarter of the population are classified as living in poverty. More than 75 percent of the inhabitants live in formal houses with access to water, sanitation, and electricity (Stats-SA, 2011). The table 3.4 depicts the percentage distribution of various income sources by households within the province. The income profile of residents plays a role in the use of e-commerce.

Source of household income	Gauteng Province
Salaries/wages/commission	77,6
Income from a business	10,8
Remittances/including child maintenance	8,6
Pensions	12,5
Grants	19,4
Sales of farming products and services	0,4
Income from UIF	1,0
Other income sources	6,0

Table 3.4: Source of household income, Gauteng province, 2016

As seen in the Table 3.5, earnings in the low income group vary from nothing to R3500, accounting for 38% of families. Lower-middle income spans from R3 500 to R16 000, accounting for 27.7% of the total. High income is defined as R30 001 or more (GHTS, 2020).

Income distribution	Number of households	% Households
Nothing	83 333	1.7%
R1 - R200	15 338	0.3%
R201 - R500	152 435	3.1%
R501 - R1 000	256 799	5.2%
R1 001 - R1 500	380 613	7.7%
R1 501 - R2 500	600 411	12.1%
R2 501 - R3 500	392 631	7.9%
R3 501 - R4 500	351 360	7.1%
R4 501 - R6 000	325 743	6.6%
R6 001 - R8 000	275 775	5.6%
R8 001 - R11 000	227 230	4.6%
R11 001 - R16 000	188 488	3.8%
R16 001 - R30 000	154 333	3.1%
R30 001 or More	74 004	1.5%
Don't know	299 494	6.0%
Refuse to answer	1 173 150	23.7%
Total	4 951 137	100.0%

Table 3.5: General household income distribution, 2019

The values presented in Table 3.5 give a picture of the citizens' living standards in comparison to persons who rely on grants and pensions. However, this could be subjective compared to the most recent unemployment statistics. The Pargo business model makes use of e-commerce, where customers shop online stores using the internet and select Pargo as their preferred courier method to deliver the ordered goods at checkout. A suggestion is that the income distribution of the population affects both the use of Pargo and e-commerce in general. The income distribution plays an important role in giving an indication of the living standards of people, which influences the number of patrons who uses Pargo service.

3.5 Land-use planning

Land-use is a transport planning variable which is essential in forecasting the amount of land parcels needed for transport development. The land parcel can be greenfield or brownfield. According to de Dios Ortúzar and Willumsen (2011) the interconnection between land use, transportation, and accessibility is almost universally acknowledged. The Gauteng province's land use includes a variety of residential, commercial, and industrial. Institutions such as education and health care, agriculture, recreation, mining, and transportation as well as utilities are also common. In terms of land use, residential and agricultural areas make up a larger percentage. Gauteng province is highly urbanised with a population density of 700 people per square kilometre (Stats-SA, 2011).

Transport network, or roads in particular constitutes a large amount of land. Roads are classified according to two main components namely land access and mobility. Roads that facilitate mobility takes large land parcel as compared to roads that facilitate land access. In South Africa there are three main classes of roads namely, arterials, collectors and locals. Arterials constitutes freeways, motorways and expressways. These facilitate fast-moving long distance traffic with no pedestrians and property frontage access. Neighbourhoods are connected by collector roads, which serve as a traffic collection and distribution point between local and arterial systems. Collectors carry medium distance traffic and are found mostly in areas commercial, industrial, shopping and mixed-use developments. In urban residential areas, collectors are most dominated by public transport. Local roads are the least class of roads and also called local access roads. They facilitate walking, cycling and they provide access to individual properties. Vehicle speeds are slow moving. In this study, land-use consideration in excludes arterial roads such as freeways and motorways. Collectors and local roads are taken into consideration since they facilitate access and not mobility. Any areas without some form of road connection is assumed as no-go area. The spatial configuration of land use will also have an impact on the expansion of the pickup points. Customers won't gain much from an increase in pickup locations if the existing land use is not taken into consideration. Currently, the pickup locations are mainly spread across built-up areas; for instance, two Pargo sites are situated within the same shopping mall, one in a retail store and the other in a petrol station. In that case customers have more options for collection, but if the last-mile delivery principle is used, there isn't much of a benefit. In this case, it would be preferable if the pickup locations were at least a mile apart.

Chapter 4

Methods

4.1 Introduction

This section describes the data requirements for the study and outlines the methodologies employed to achieve the research objectives. Data cleaning was carried out to fix geometric errors and inconsistencies. It also included checking the connectivity of line data and generating distance matrices. Refer to the Python script to clean the road network in Appendix A.1. Depending on the type of data, different data processing techniques were used. The Figure 4.1 below summarises the data cleaning process.

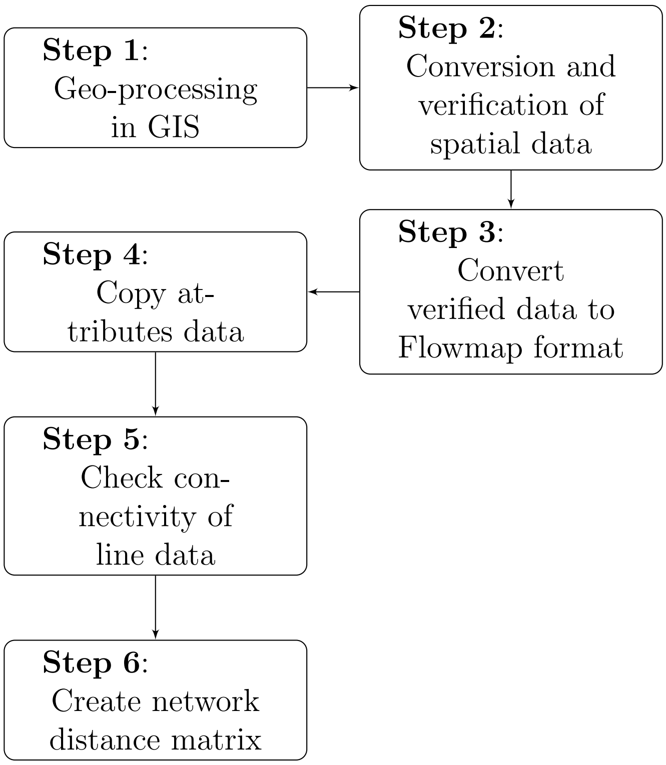


Figure 4.1: Data cleaning procedure

4.2 Data collection

This section gives an overview of the data collected and explains how it was obtained. The data gathered using the desktop study method is referred to as "secondary data" because it is existing data obtained from other sources. This also applies to data received from the logistics company, Pargo. Secondary data collected were processed before the researcher began to utilise it. The data collected is listed as follows:

- Road network
- Transport analysis zones (TAZ)
- Population per each TAZ
- Pargo pickup points
- Municipality and provincial boundaries

The researcher understands that research-related data must be correct, reliable, and truly representative of the original population. As a result, the data was subjected to crude checks and high-level verification before it was deemed usable. Best practises were followed during data processing to ensure sound decision-making. The subsections that follow go into great detail about how each type of data was gathered and handled.

4.2.1 Road network

Road network for the study area was obtained from available open source information known as Voluntary Geographic Information (VGI). In this case OpenStreetMap (OSM) which is rich in geographic data was used. The advantage of using an open source platform is that the data is free and there are no charges connected with acquiring it. In addition, it is updated information based on community input due to the millions of contributors from around the world. It takes less time to obtain and if one has the necessary skills it is straightforward to process. The data quality could, however, be inadequate and of poor quality to some extent. The road network comprise of approximately 8500 km of primary, secondary and tertiary roads. Local access roads were also considered as part of the road network as they also facilitate last-mile delivery of goods. Local access covers all roads that facilitate access to properties such as residential access links, access loops, cul-de-sacs, access ways, access courts and access strips. Given the study's degree of detail (resolution), the information contained in the road network is detailed enough to allow for the necessary analyses. The figure 4.2 below depicts the entire road network.

4.2.2 Transport analysis zones (TAZ)

The geographical region under consideration is already divided into homogeneous regions based on similarities in land-use and economic factors. Transport analysis zones (TAZs), simply referred to as zones, are considered to be various spatial units of the study area (Sarkar et al., 2017). These homogeneous units aid in the geographical measurement of

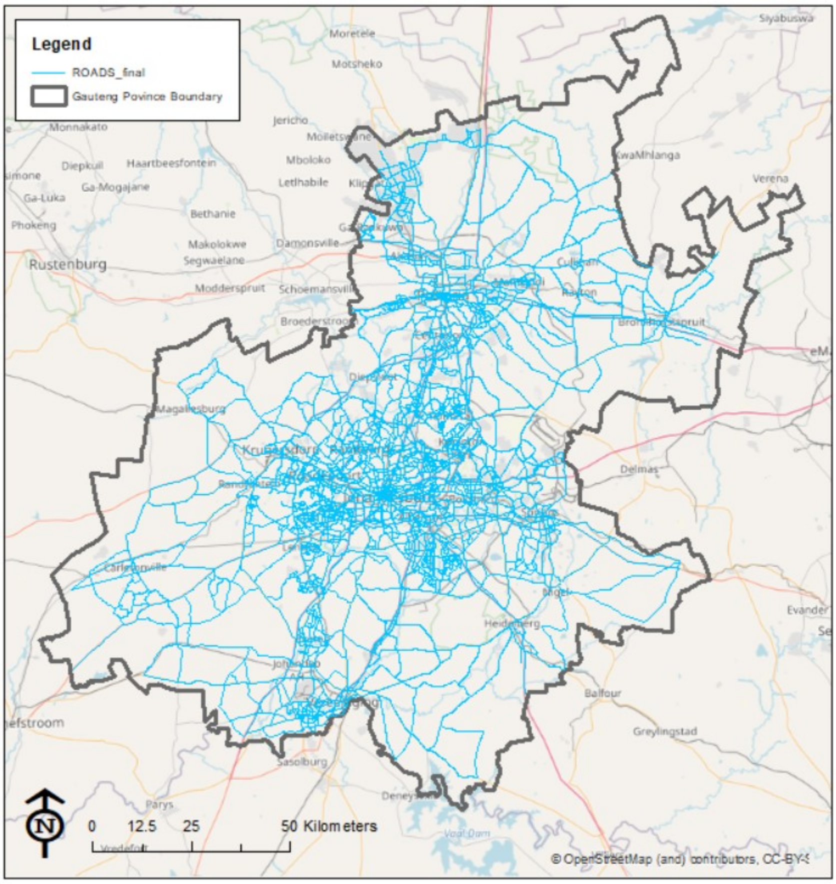


Figure 4.2: Road network of Gauteng Province

land-use and economic variables influencing travel patterns. The zones are used in transportation planning to establish the origins and destinations of trips. The TAZs information was obtained from the Council for Scientific and Industrial Research (CSIR). The study area has a total of 828 TAZ over an area of 18 176 square kilometres. The size of the TAZs vary in size, with different land uses such as residential of different income levels, commercial, industrial and agricultural.

The study area is characterised by smaller zones in congested areas and larger zones in un-congested areas. Mannering and Washburn (2013) points out that, the choice of the number of TAZs represents a trade-off between accuracy (smaller TAZs provide more detailed forecasts) and ease of implementation (larger TAZs require less data and are easier to incorporate in the overall model system). The zones are detailed enough for the intended study. Figure 4.3 below shows the TAZs in the study area.

4.2.3 Population

Population is simply defined as all of the people who live in a specific location. The population data was provided for each TAZ. The population information was obtained from the CSIR. Figure 4.4 below shows the population distribution of the study area. As shown

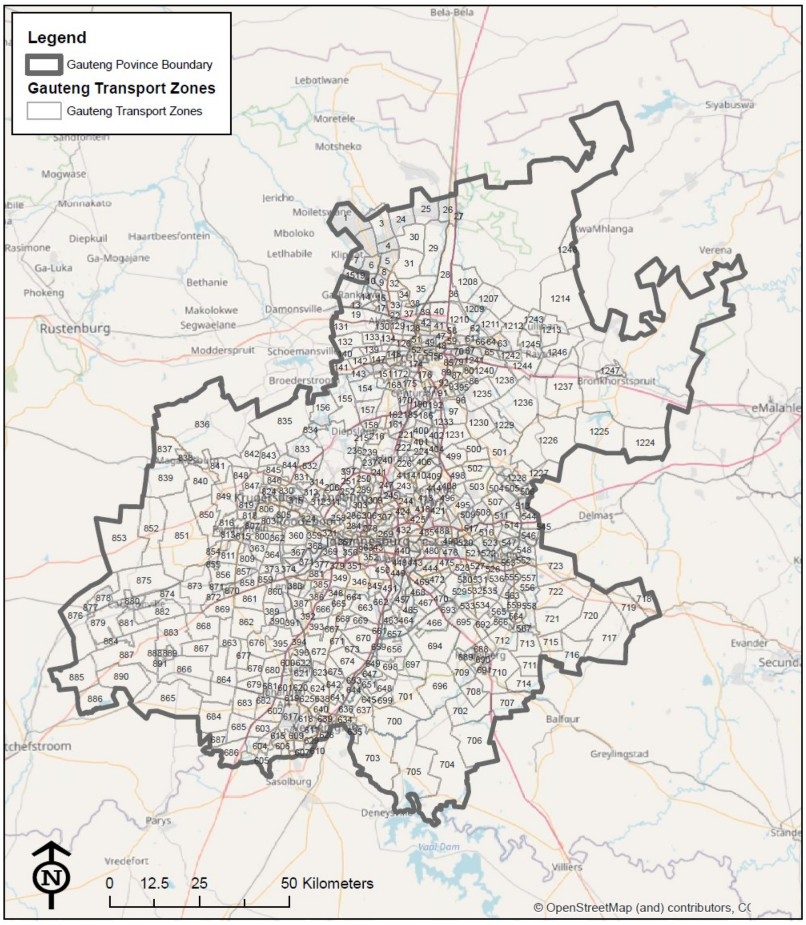


Figure 4.3: Traffic zones of Gauteng Province

on the map, the population density is highest in the CBDs and lowest in the outlying districts. Population density fluctuates dramatically depending on land use. High-income areas have low population densities, whereas low-income ones have high densities. The attractiveness of a location is determined by a wide range of elements. Residential area value is impacted by plot or home size, type, age, and quality of dwelling. The quality and closeness of schools, as well as the availability of recreational facilities, are all important considerations. Other factors that contribute include neighbourhood safety and proximity to industries for employment. The population information provided is sufficient for the proposed study.

4.2.4 Parcel pickup points

The data for pickup sites differs from the other data previously discussed in that it was obtained directly from the logistics company, Pargo. It is referred to as "primary data." The pickup points are also known as destinations or opportunities in accessibility terminology. The figure 4.5 below shows the raw data of the pickup points across the country.

Meyer et al. (2016) found that the attractiveness of a retail store is influenced by factors

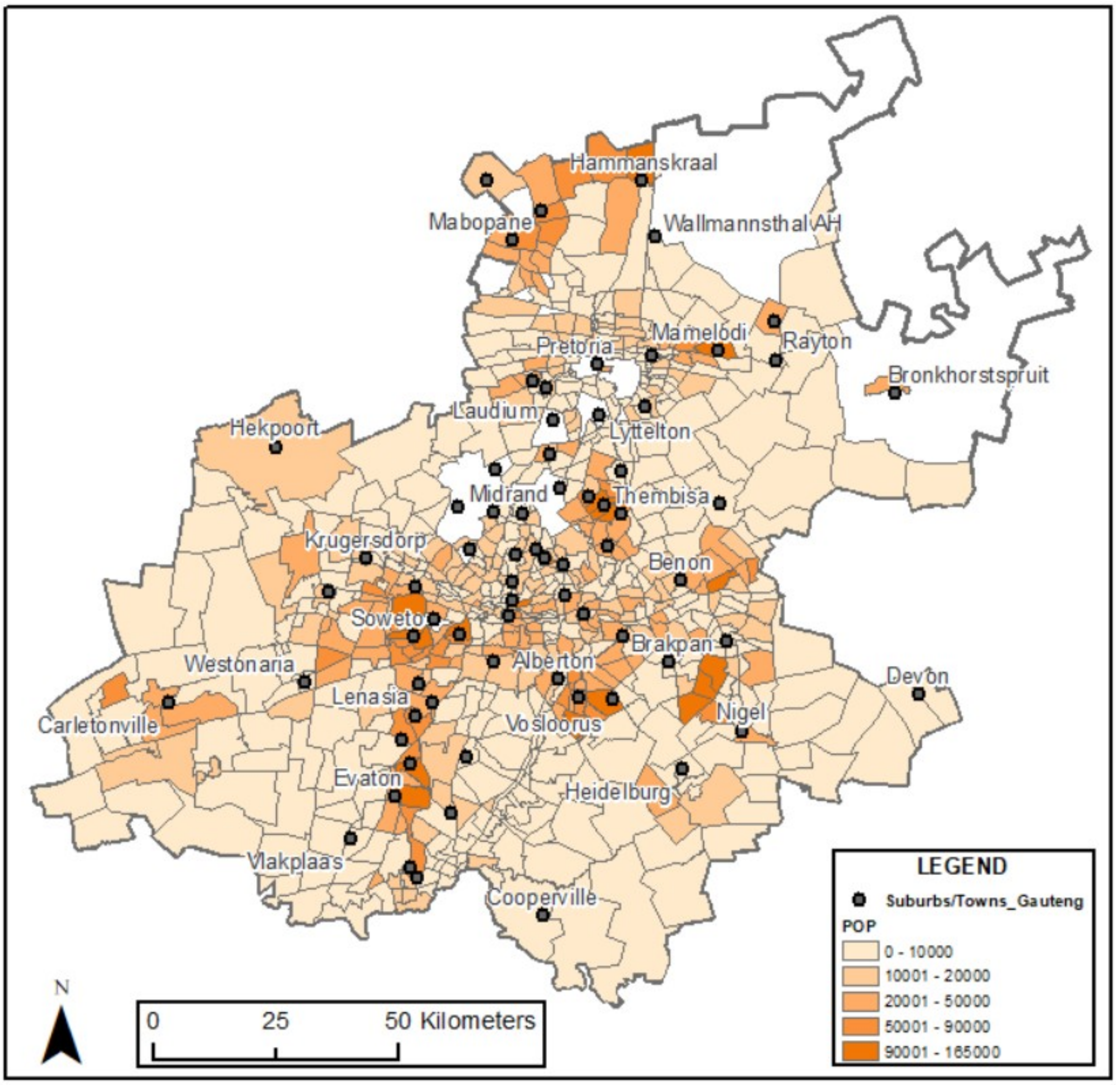


Figure 4.4: Population of Gauteng Province

such as (a) the availability of a suitable building for the store, (b) the location of the building relative to the street, (c) pedestrian flows and parking, (d) the building rent, (e) the expected market for the goods being sold at the location, and (f) the mix of retail stores currently located in the neighbourhood. It is firmly believed that the Pargo business model will draw customers into the retail establishment in the hopes that they will purchase items other than just parcel collection. Pargo facilities are hosted mainly by convenience stores, clothing stores, grocery/supermarket stores and filling stations. Pargo caters to both the high-income (individuals and businesses with formal addresses) and low-income (persons without a formal address) markets, where regular deliveries are impractical. The data provided by Pargo has all of the essential attributes, is comprehensive, and is sufficient for the planned study. The figure 4.5 below shows the spatial distribution of raw data of the pickup points.

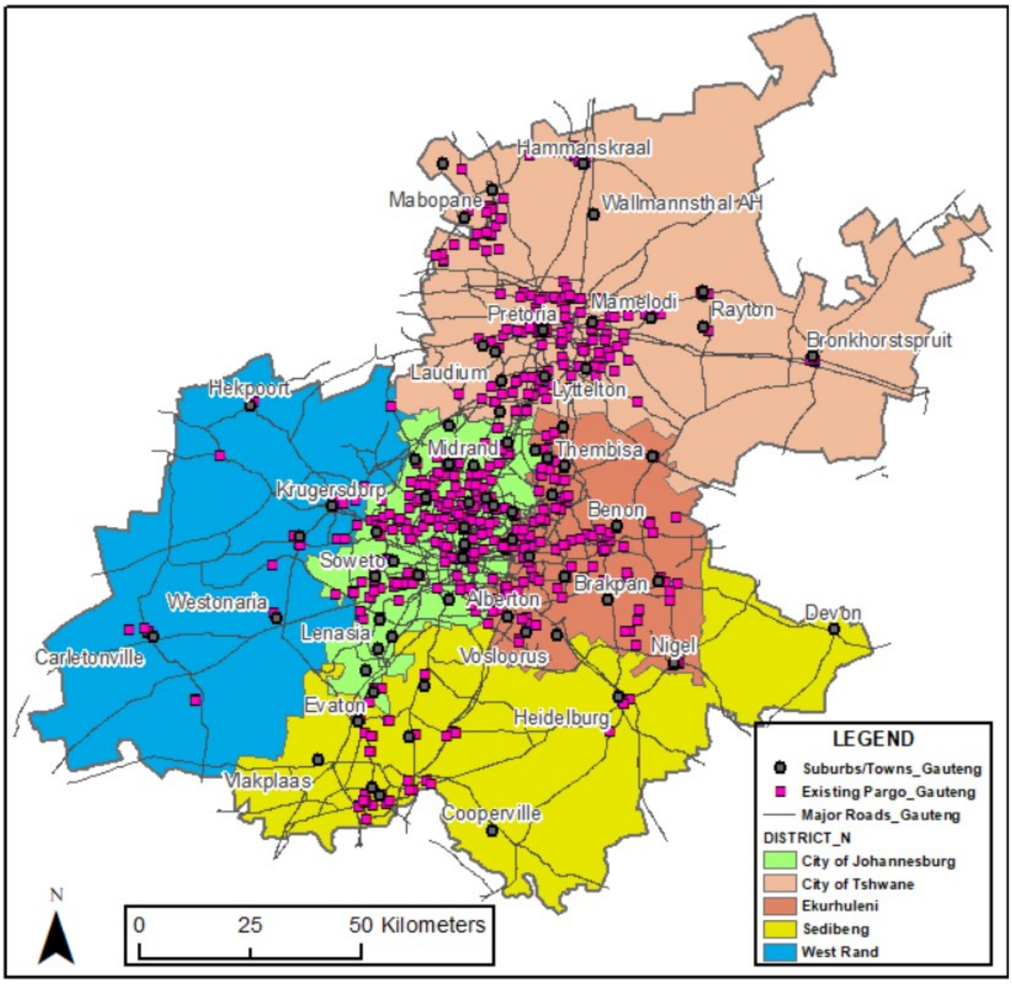


Figure 4.5: Spatial distribution of raw data of the pickup points in 2021

The main attributes of the data are the physical location, which is defined by the latitude and longitude, as well as the pickup point reference code. A zoom into the data, reveals that the majority of the existing parcel pickup points are located at fuel stations, convenience stores, clothing stores, grocery stores and supermarkets. The figure 4.6 below is a snippet of the raw data of the pickup points.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Latitude	Longitude	name	reference	country	province	suburb	city	postal_code	location_type	pup_xl	is_public	is_active
2	-26.1669201	27.9270415	Postlink Roodepoort	pup2006	ZA	Gauteng	Roodepoort	Johannesburg	1724	main	Yes	Yes	Yes
3	-29.889428	30.90414	Caltex - Queensmead Queensburgh	pup104	ZA	KwaZulu-Natal	Queensburgh	Durban	4093	main	No	Yes	Yes
4	-26.3560704	27.3980786	Beares Carltonville	pup4369	ZA	Gauteng	Carletonville	Carletonville	2499	main	No	Yes	Yes
5	-24.5557604	29.6460297	Global Fuel - Big Boy	pup4586	ZA	Limpopo	Masemola	Groblersdal	1060	regional	No	Yes	Yes
6	-23.8018051	30.1184103	Allesbeste Padstal	pup1145	ZA	Limpopo	Tzaneen	Tzaneen	850	regional	Yes	Yes	Yes
7	-34.44906	19.453388	Antjies Trading - Stanford	pup3825	ZA	Western Cape	Stanford	Stanford	7210	main	Yes	Yes	Yes
8	-26.1311505	28.1978475	Mabnet Services	pup4481	ZA	Gauteng	Croydon	KEMPTON PARK	1619	main	No	Yes	Yes
9	-32.9336263	27.7388707	Lue Apparel Shop	pup4924	ZA	Eastern Cape	Mdantsane	East London	5219	main	No	Yes	Yes
10	-34.211399	21.584814	Van Stadens Crafts - Albertinia	pup822	ZA	Western Cape	Albertinia	Albertinia	6695	regional	Yes	Yes	Yes
11	-26.246651	28.179044	Clicks - Lambton	pup691	ZA	Gauteng	Germiston	Johannesburg	1401	main	Yes	Yes	Yes
12	-26.1746102	27.9793845	Clicks - Sophia Town	pup4780	ZA	Gauteng	Sophiatown	Sophiatown	2092	main	No	Yes	Yes
13	-28.6705001	27.4113416	Engen - Marquard	pup3024	ZA	Free State	Marquard	Marquard	9610	regional	No	Yes	Yes
14	-27.6981555	31.0513792	Global Fuel - Kongolana	pup4219	ZA	KwaZulu-Natal	Louwsburg	Vryheid	3150	regional	No	Yes	Yes
15	-26.154214	28.417971	Best Home and Electric - Daveyton	pup1877	ZA	Gauteng	Benoni	Benoni	1500	main	No	Yes	Yes

Figure 4.6: Extract of the pickup points

4.3 Data processing

4.3.1 Road network data processing

The data set was in GIS shapefile format downloaded from OSM as geofarik. To facilitate last mile calculations, the road network was used as is from OSM. No filtering was done such as removing local streets and paths. The road network was geo-processed, and unnecessary features that hinders distance matrix creation were removed. The removal of duplicate geometry features, dangles, vertices, and zero-length lines are some of the common topology fixes for the road network. The connectivity of network line data was checked in Flowmap. Any connectivity problems were fixed in GIS software. A distance matrix was created in order to verify whether the network file is, in fact clean. If it is successfully created, it indicates that there are no topological errors in the file. The file needs more cleaning if a distance matrix creation is unsuccessful. The origins and destinations were kept the same with a road network set as the map file. A distance matrix provides a visual representation of the relative distances between origins and destinations.

4.3.2 Population data processing

The transport zones have the population information in them. Each zone was provided with population figures. The accuracy of the numbers were cross-checked against Statistics South Africa (Stats SA) data and verified to be reliable. The analysis for this study was hexagonal rather than zone-based. It was therefore necessary to first assign the population data such that corresponding values of population are assigned to each hexagon proportionally. This was achieved by creation of Python script that assigns the population to hexagons. The script is attached as Appendix B.1.

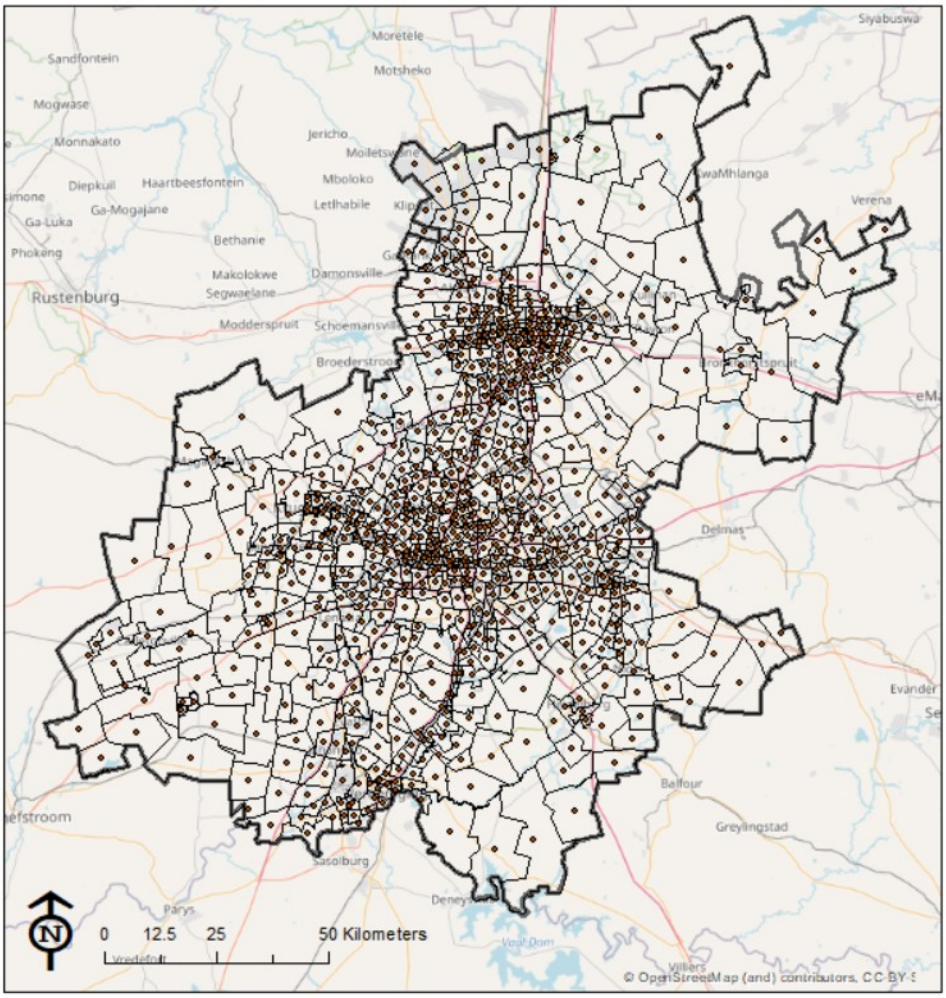


Figure 4.7: Zone centroids/origin points

4.3.3 Pickup points data processing

Attributes such as latitude, longitude, pickup point name and reference code, suburb, and city were included in the data for the pickup locations. The data was in comma-separated values (CSV) format and was easily processed in Excel. In the year 2021, the total number of Pargo points for Southern Africa was 1968. The data was then trimmed for the research region, leaving 557 parcel pickup points in total for the study area. The map and scale projection were also adjusted to match the rest of the shape files.

4.4 Accessibility evaluation

Accessibility indicators provide the most valuable and appropriate means of summarising a great deal of information on the location of households in relation to the distribution of urban activities and the transport system that connects them (Wachs and Koenig, 2021). The typical areas where accessibility evaluation can be applied is considered limitless (Stover and Koepke, 2002).

4.4.1 Analysis procedure

Available data to enable the analysis include road network extracted from OSM, population data in each transport zone and existing Pargo pickup points. Population data has been processed further into hexagon-shaped cells. The actual processing is discussed in Appendix B.1. The data processing methods applied are discussed in the earlier chapters of this research. The figure 4.8 below illustrates the analysis procedure undertaken.

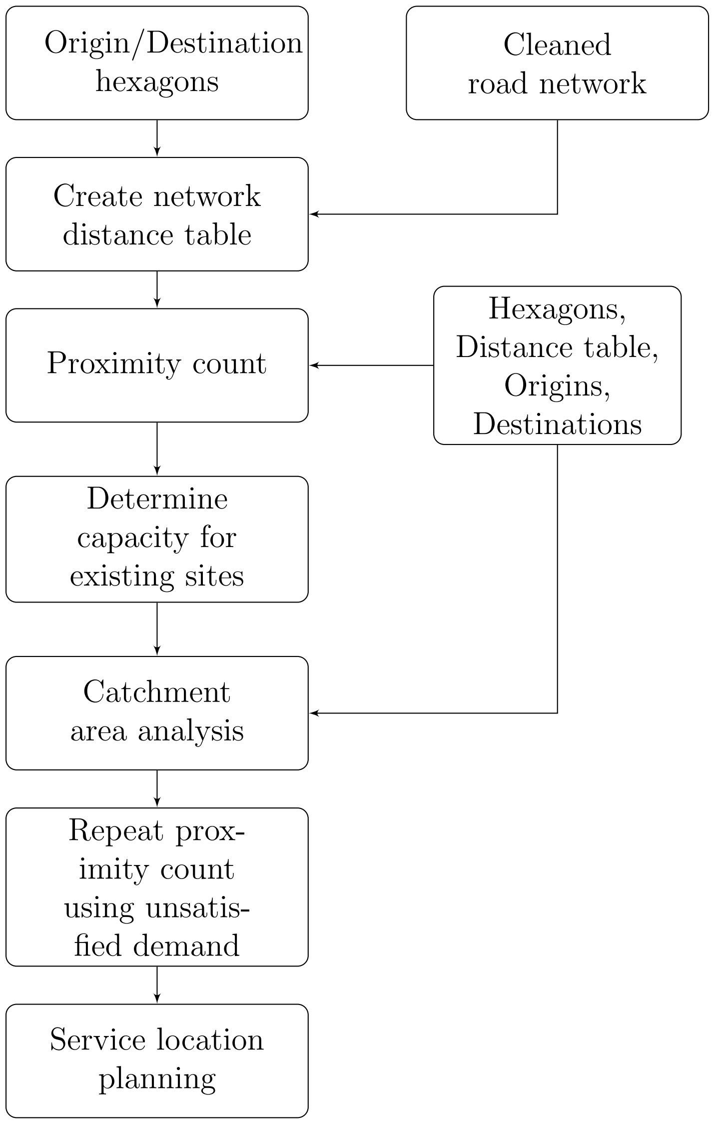


Figure 4.8: Analysis procedure

For the hexagons, polygonal tessellations were created with edge length of 1610m, which is equivalent to 1 mile on physical ground. Each hexagon was allocated a population value. In order to void deformed maps and wrong calculations of distances, the files were converted to Cartesian (planar) coordinates using the Lambert's Equivalent Azimuths Projection. This exercise was done for both the hexagon file and for the road network file.

No-go locations were considered in the analysis. No-go locations are inaccessible locations that are characterised by physical constraints such as mountains, water bodies, environmental sensitive areas as well as other places that are unsuitable for human habitation. These were factored in the analysis. All the current Pargo locations were included in the analysis and were treated as partial solutions. The average population summarised in table 3.3 was assigned to the partial solution areas per each region and the field was used to compute proximity counts and catchment area analysis.

Origin points were created and then verified such that each origin point is connected to a road link or node and at least in each hexagon except where the area is inaccessible. No origins were assigned to the primary roads, such as motorways, motorways, and trunk roads, since no trips should begin in these hexagons. The road network and the origin/destination file were combined to create a network distance matrix. As outlined in the analysis procedure in figure 4.8, the proximity count was performed using the hexagons, distance table, origins and destinations points as input. A catchment area analysis was then conducted. The distance used is 1 610 meters, and the analysis was repeated for a distance 3 220 metres. The proximity count computation was repeated using unsatisfied demand from the previous analysis as new input. The maximum distance remained the same.

4.4.2 Proximity count analysis

A proximity analysis proximity count is an accessibility measure representing the number of customers within a user-defined distance of each destination (De Jong and Van der Vaart, 2013). The proximity count, also known as the cumulative opportunity index, can be used to identify under-served populations. The technique is straight forward to compute and the amount of information produced when presented on a trend surface map is valuable in decision-making. By a maximum distance or by capacity, allocation for origins or population may be restricted. The user-defined distances in this case were taken as 1610m (1-mile) and 3220m (2-miles). A proximity count gives an indication of a potential market. Competition between the various destinations does not matter in a proximity count. De Jong and Van der Vaart (2013) describes two ways to calculate a proximity count:

- The number of origins within reach of certain destinations using a certain predetermined distance is counted.
- The number of destinations within reach of certain origins using a certain predetermined distance is counted.

The first way which aims to get the number of inhabitants within reach of a certain destination using a distance of 1610m was used. The count was repeated for a distance of 3220m. The results proximity counts are described in the next chapter.

The population or demand was broken down into symmetrical hexagons with a radius of one mile (1610 metres). The integration or summing of opportunities over space is what proximity counting entails. In general, all opportunities that are nearby or easier to access will be given more weight than those that are further away or more difficult to access.

4.4.3 Catchment area analysis

Analyses of catchment areas in Flowmap are comparable to GIS buffer analyses. The catchment area in this study is a geographic boundary that determines the buffer size, which is taken to be a one-mile radius. The technique searches within the set distance and allocates origins to the nearest destinations. An origin can be allocated only to one single destination. A destination can have a maximum capacity and destination can have a maximum reach (De Jong and Van der Vaart, 2013). The capacity adopted per study area varies and the maximum reach adopted is 1 610m and 3 220m. The catchment area analysis yielded four results namely; Sum of allocated demand, allocation centre label, allocation centre distance (catchment distance) and remaining (unsatisfied) demand. The first gives an indication of the amount of customers each destination can serve. The second gives an indication of destination to which origin was allocated. The third represent the distance between origin-destination (O-D). The remaining demand represent the unsatisfied population which is not covered within the defined distance. The values obtained from the catchment area analysis was used as input in the proximity count calculation.

4.4.4 Service location planning

Existing coverage of the Pargo pickup points was evaluated based on the total population for each study area. After subtracting the population served by existing Pargo pickup points, the potential population not captured is the remaining population that is likely to use the Pargo site if new facilities are implemented. The total potential customers within 1 mile and 2 mile distance for current Pargo sites was calculated, and the ratio of total customers to total population gave an indication of the required coverage. Coverage analysis answers the question of how many different locations are needed to meet a certain level of service. The expansion of Pargo pickup points was evaluated by first computing the number of top potential customers within 1 mile and 2 miles, followed by computing the number of potential customers not captured within the defined distance. The number of Pargo sites needed to cover a given area was calculated as the ratio of top potential customers within 1 mile to potential customers not captured. Expansion analysis answers the question of how many different locations are needed to meet a certain level of service.

Chapter 5

Results and discussion

In this section of the report, an accessibility results analysis is presented followed by a thorough discussion of the findings. Discussions include the interpretations of the key findings for each study area. The research questions posed in the introduction to this thesis are also attempted to be answered. A detailed discussion on the expansion of smart logistics infrastructure is also presented. There is also a thorough explanation of the development of smart logistics infrastructure. The suitability maps also show the areas where there is potential population that is not currently served by the service. The key findings' limitations and implications are also discussed. Finally, recommendations for further research are suggested.

5.1 Overview of findings

Potentially suitable areas and no-go zones are summarised in Table 5.1 and presented in Figure 5.1 to Figure 5.5. Potential suitable areas are inhabited areas that are not currently covered by the pickup points. The no-go areas are those that have not undergone any development, lack a road network, or have natural barriers. The locations of the current pickups are indicated by blue squares. For simplicity's sake, only the main routes of the road network are displayed; displaying all the road types would make the maps too crowded.

Figure name	Municipal area	Map description
Figure 5.1	Westrand	The ratio of suitable areas to no-go areas is almost equal
Figure 5.2	Sedibeng	Is dominated by by farms on the eastern side and residential suburbs on the western side
Figure 5.3	Ekurhuleni	More than 90% of the area is developed with a few pockets of land not developed
Figure 5.4	Johannesburg	More than 90% developed with only a few areas on the outer edges
Figure 5.5	Tshwane	70% of the area is developed with few areas on the outer edges that are classified as no-go areas

Table 5.1: Summary of maps for suitable areas and no-go areas

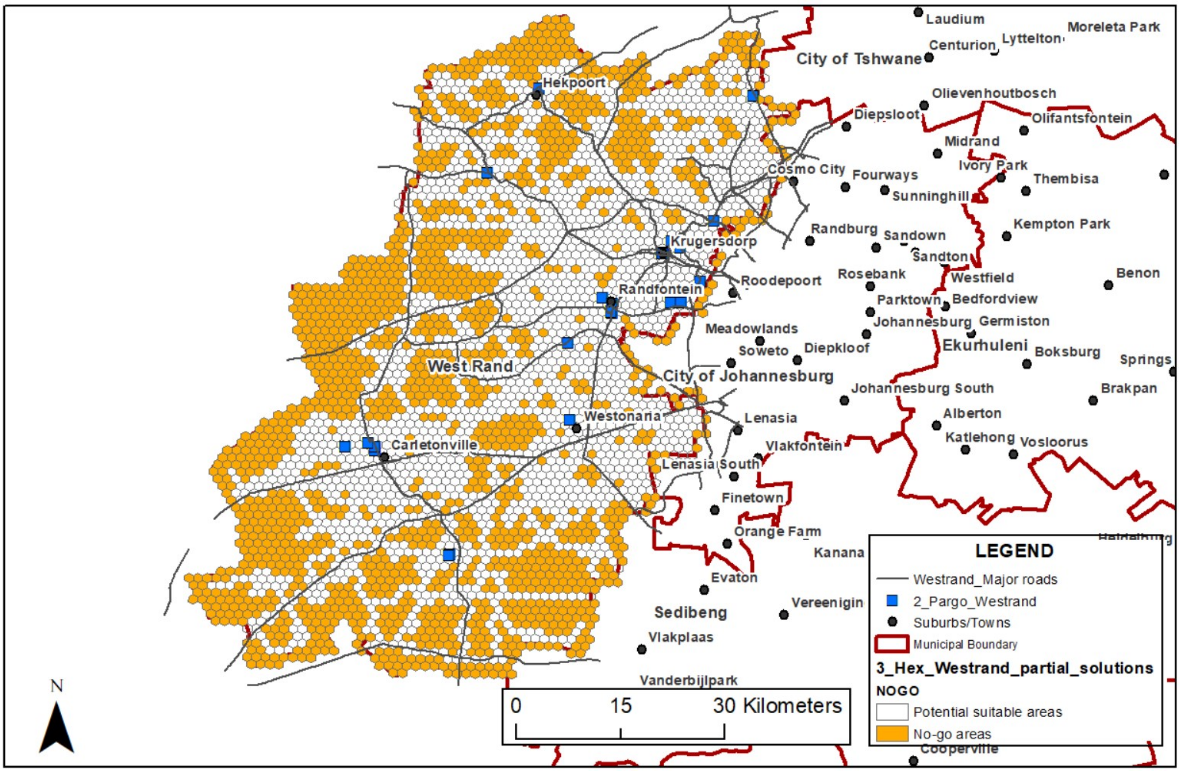


Figure 5.1: Suitable areas (unshaded) and no-go (shaded) areas for Westrand

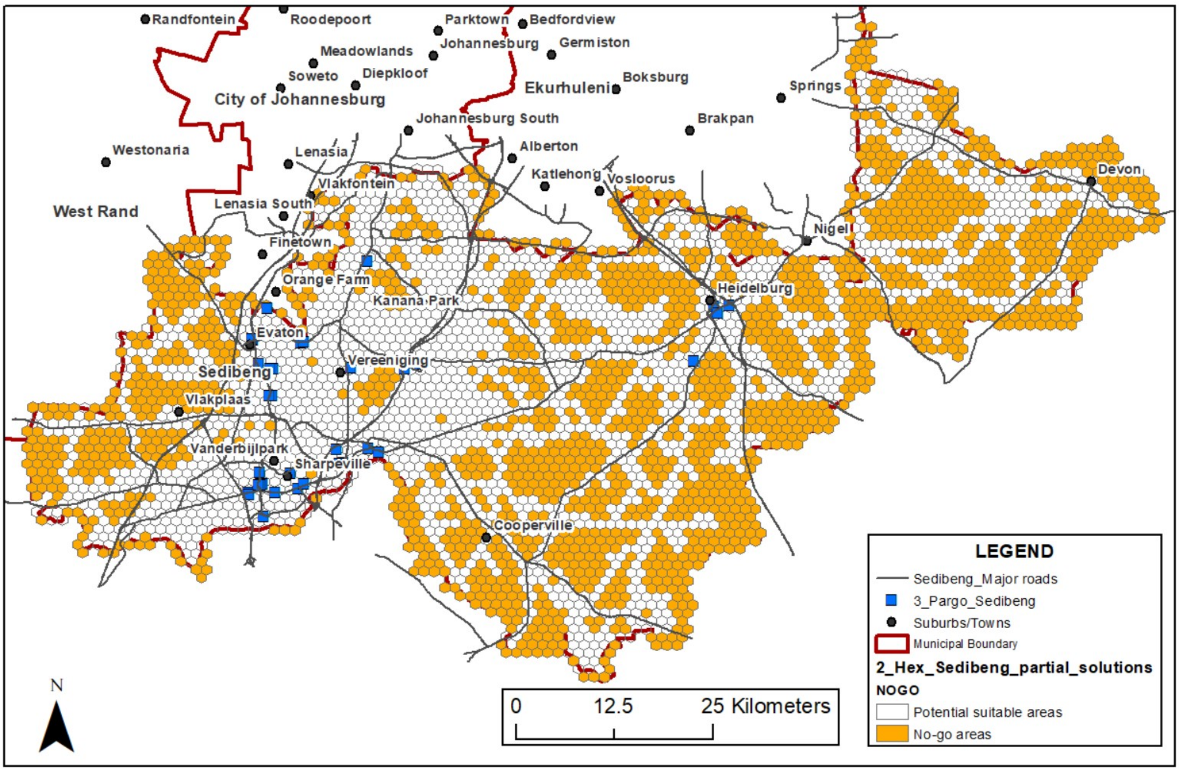


Figure 5.2: Suitable areas (unshaded) and no-go (shaded) areas for Sedibeng

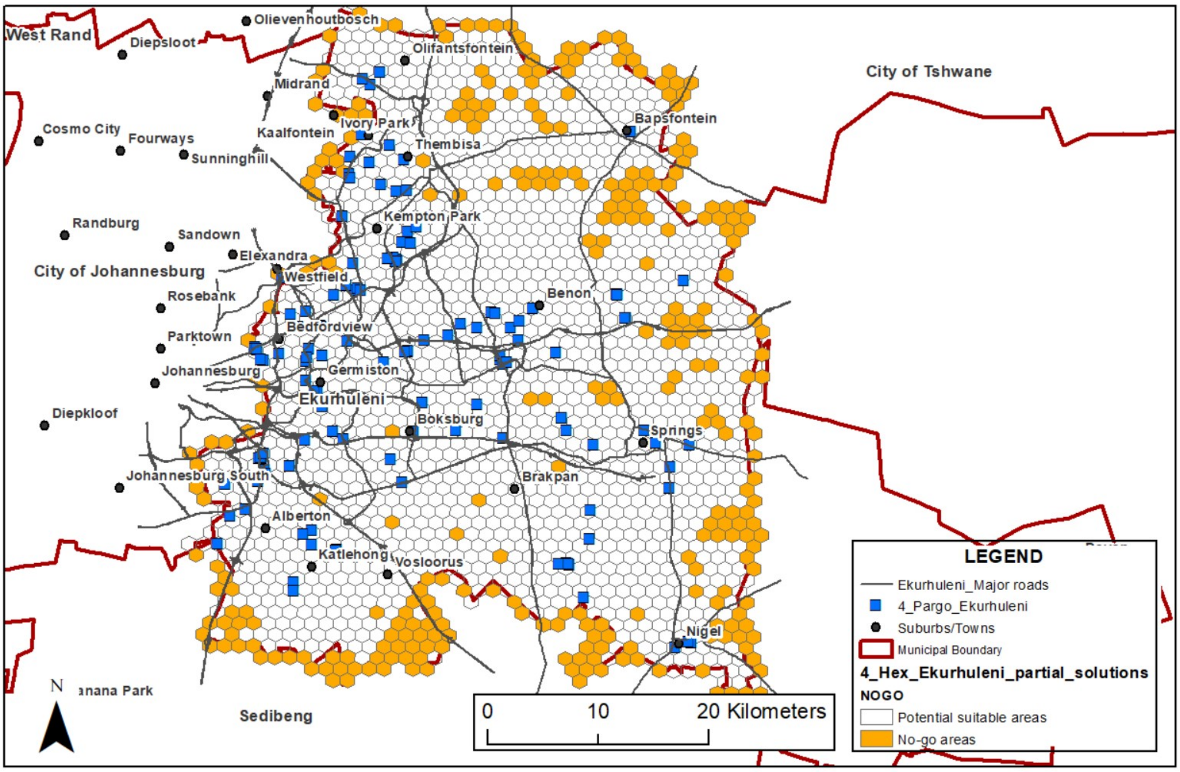


Figure 5.3: Suitable areas (unshaded) and no-go (shaded) areas for Ekurhuleni

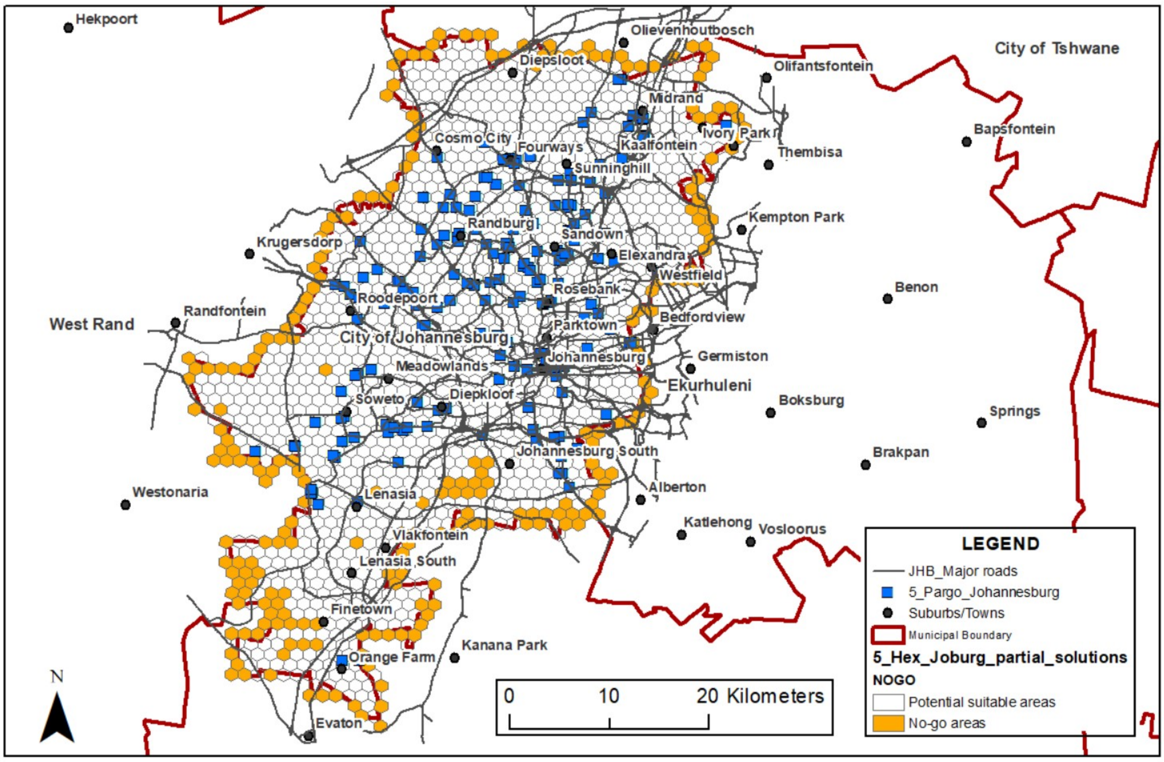


Figure 5.4: Suitable areas (unshaded) and no-go (shaded) areas for Johannesburg

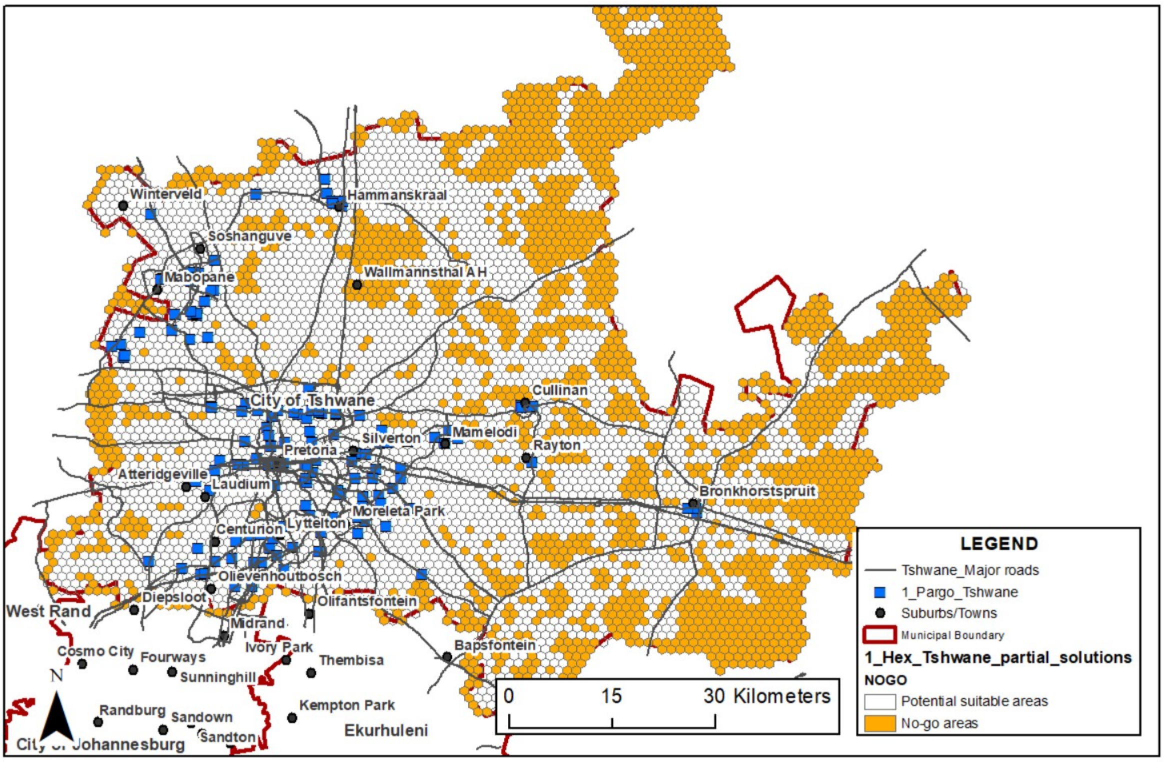


Figure 5.5: Suitable areas (unshaded) and no-go (shaded) areas for Tshwane

Figures 5.6 to 5.10 are maps that depicts population distribution as well as the current parcel pickup points in all the five study areas. A gradient map was generated, where hexagons with high population are represented by the colour red. The depicted road network represents the primary routes consisting of major roads, while smaller roads such as collector and local roads have been excluded to enhance the legibility of the maps. The following table provides a concise overview of the current pick-up points and hexagons, along with their corresponding assigned population.

Figure name	**Municipal area**	**Map description**
Figure 5.6	Westrand	Total existing Pargo sites are 29 for a population of 1 100 000. This gives population of 37 931 per Pargo site.
Figure 5.7	Sedibeng	Total existing Pargo sites are 41 for a population of 1 200 000. This gives population of 29 268 per Pargo site.
Figure 5.8	Ekurhuleni	Total existing Pargo sites are 128 for a population of 3 500 000. This gives population of 27 344 per Pargo site.
Figure 5.9	Johannesburg	Total existing Pargo sites are 198 for a population of 4 500 000. This gives population of 22 727 per Pargo site.
Figure 5.10	Tshwane	Total existing Pargo sites are 161 for a population of 2 900 000. This gives population of 18 012 per Pargo site.

Table 5.2: Summary of maps for existing pickup points and population

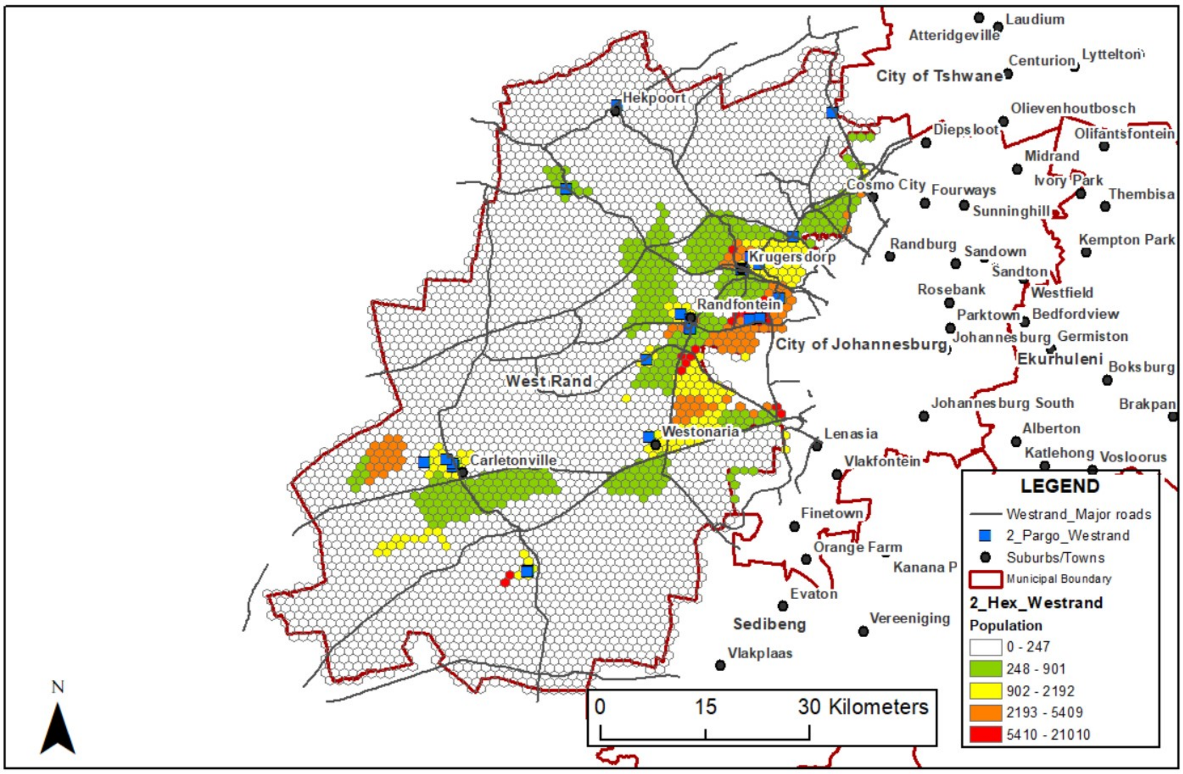


Figure 5.6: Existing pickup points and population distribution for Westrand

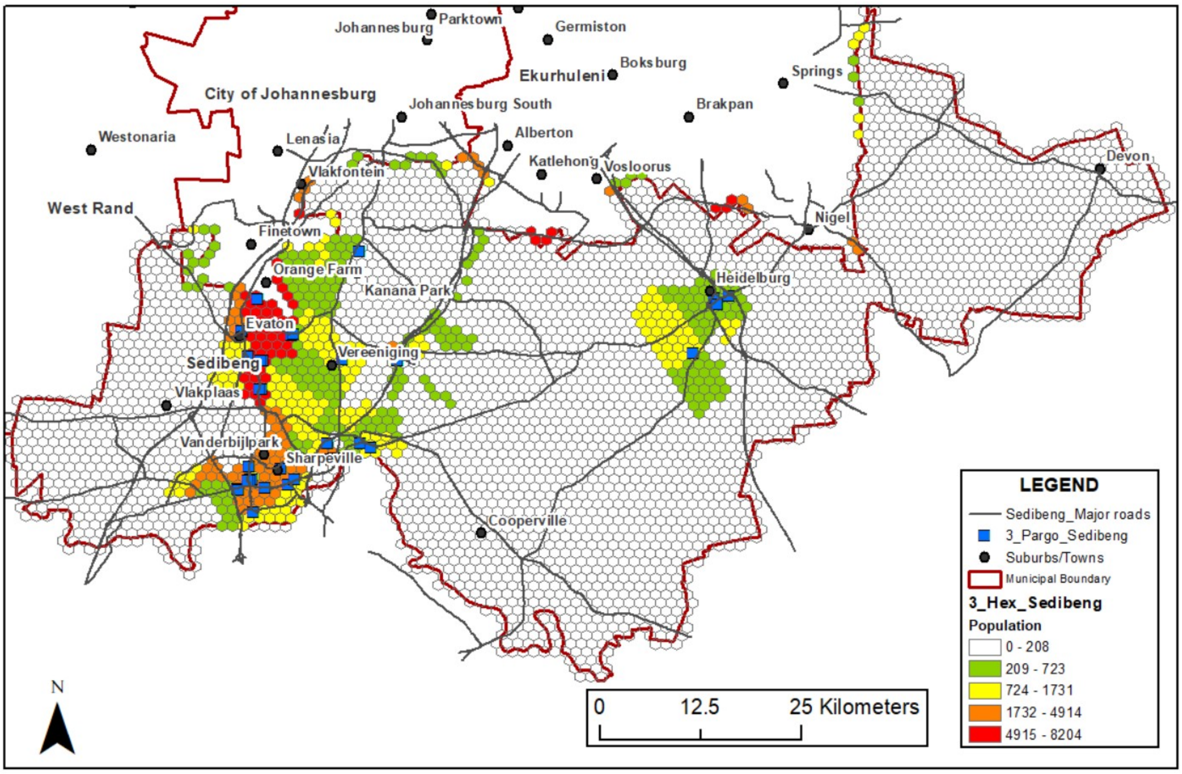


Figure 5.7: Existing pickup points and population distribution for Sedibeng

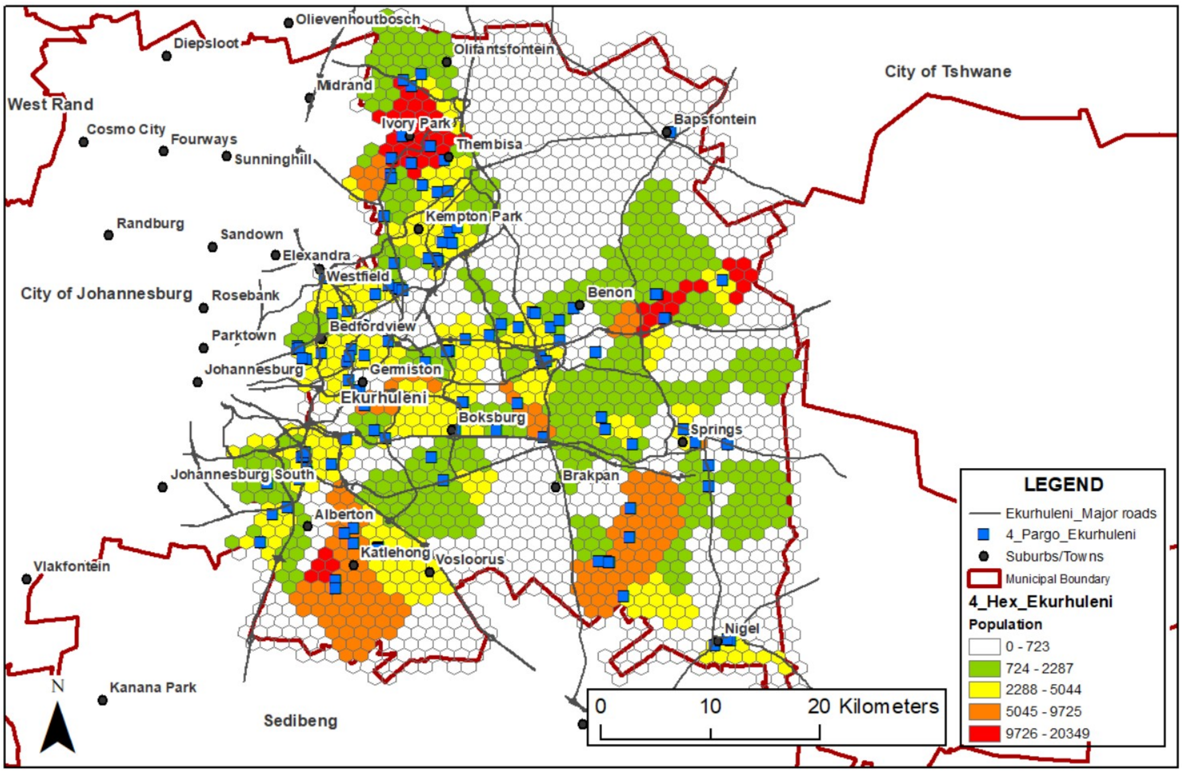


Figure 5.8: Existing pickup points and population distribution for Ekurhuleni

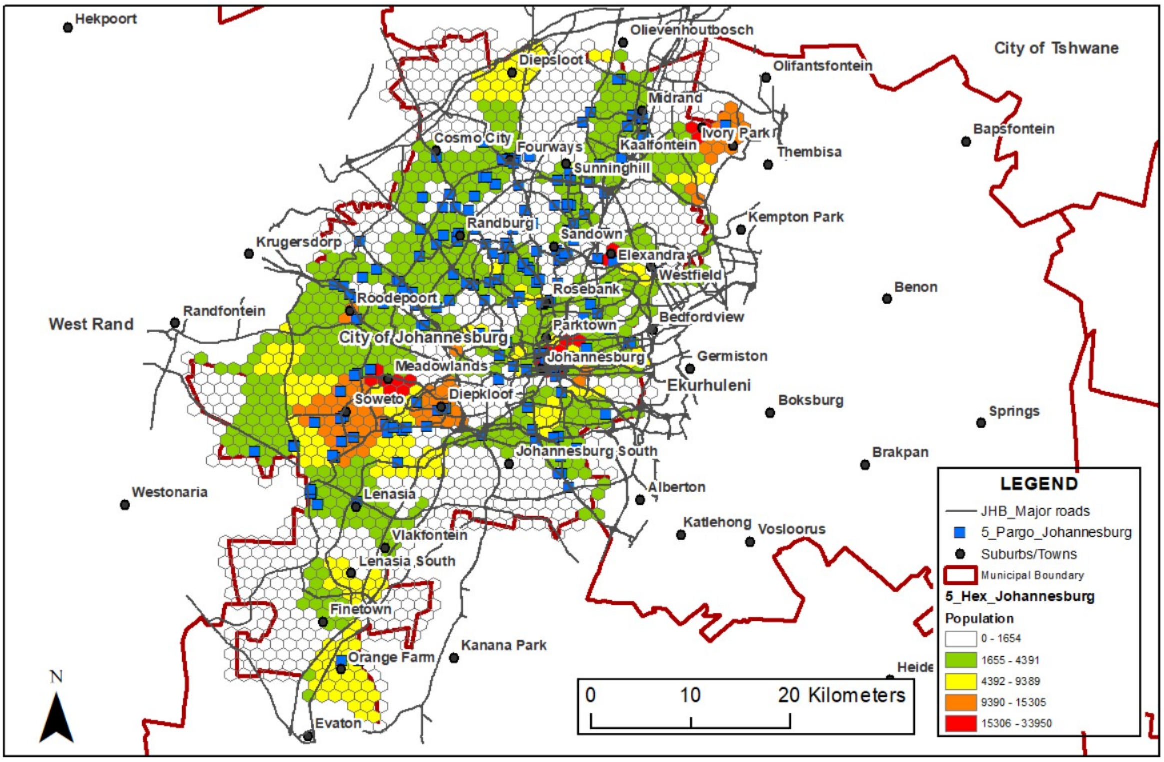


Figure 5.9: Existing pickup points and population distribution for Johannesburg

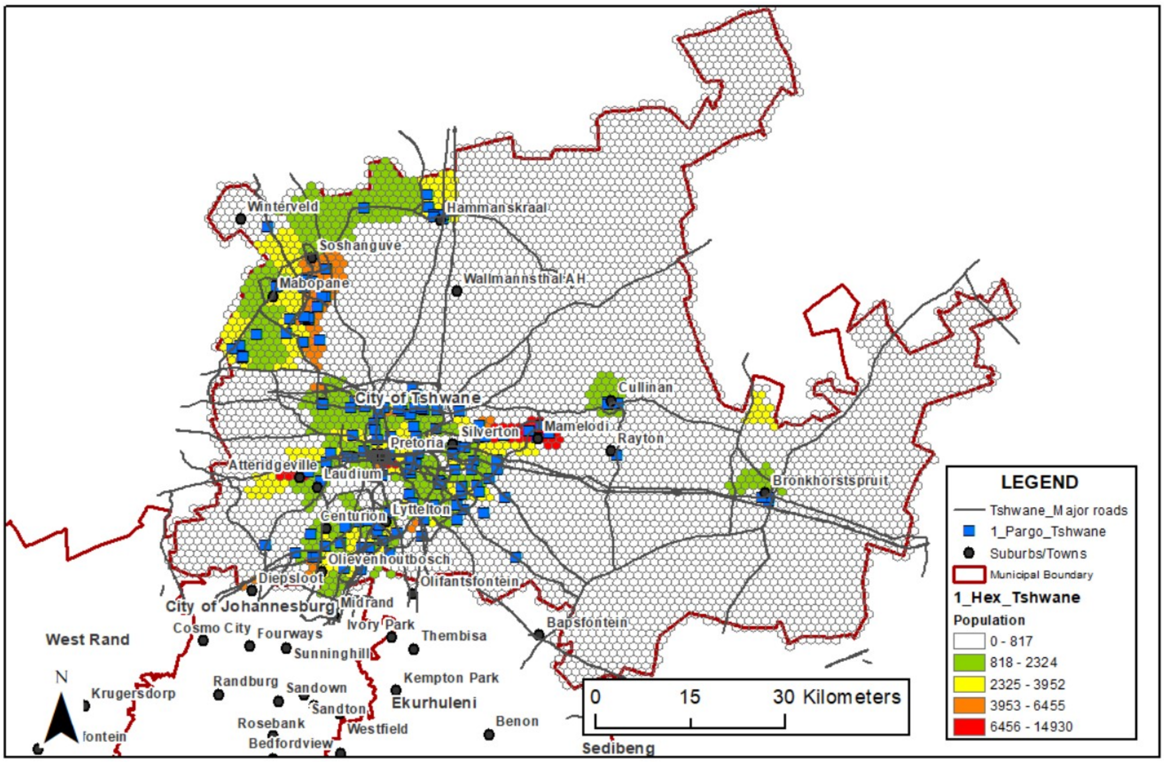


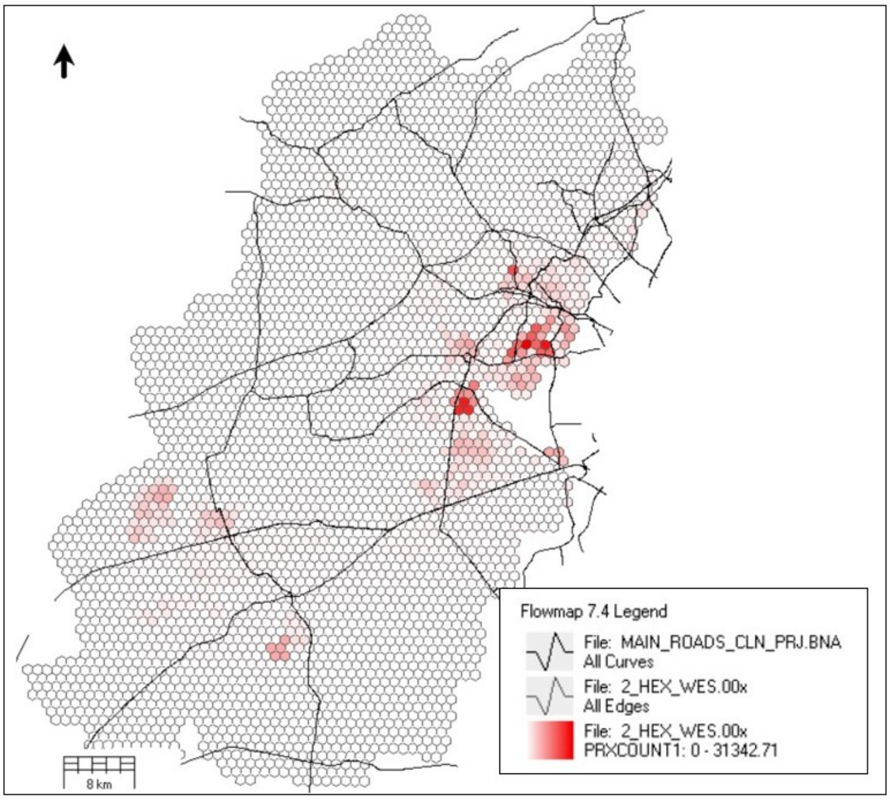
Figure 5.10: Existing pickup points and population distribution for Tshwane

5.2 Summary of key findings

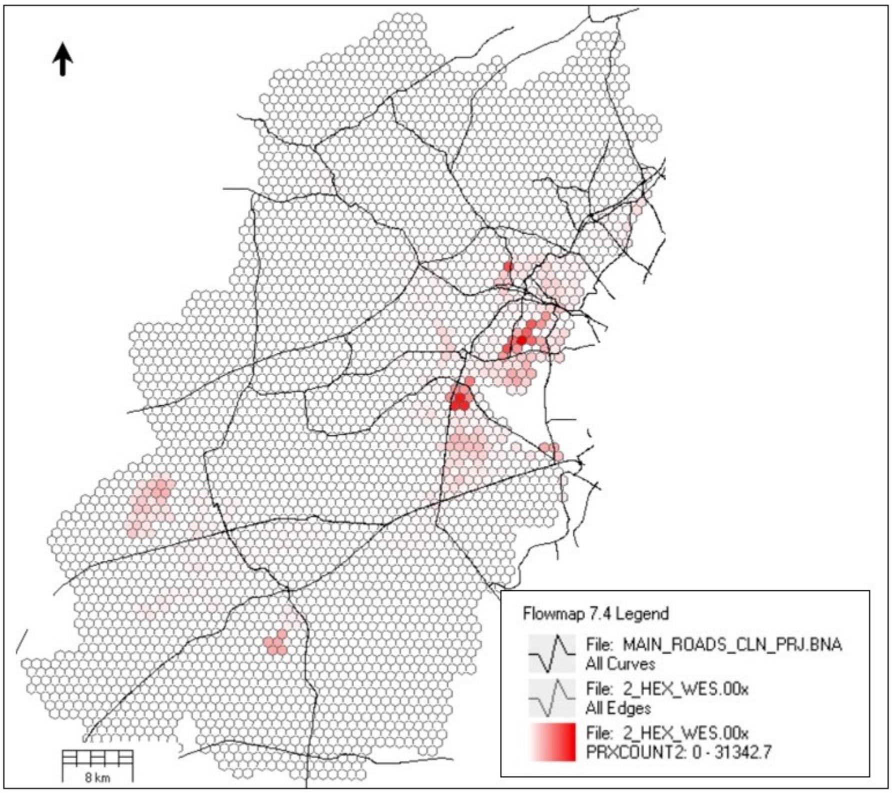
The analysis was carried out for both a radius of 1 mile and for 2 mile distance. The proximity calculation was carried out in two stages. The first proximity calculation was based on the total population enclosed in each hexagon. The total population was used as the weight variable per origin/destination. The same computation was repeated with varied distance of 1 mile and then for two miles. The figure 4.8 from previous chapter shows a flow chart that summarises the analysis steps. The proximity count analysis was repeated using results of catchment area analysis (also referred as proximity count 2 in the maps). In this case, a catchment area remain (unsatisfied demand) was used as the weight per origin/destination for the second proximity count. To summarise, the distinction between proximity count 1 and count 2 lies in the fact that proximity count 1 is derived from the population of the original hexagon, whereas proximity count 2 is derived from the population obtained through catchment area analysis. From the tables of result presented, the increase in the radii from 1 mile to 2 mile shows an increase in the coverage of potential customers. In towns and cities the number of customers is high as compared to rural areas. The maps presented in the next sections of this chapter shows the proximity counts for 1 mile and for 2 miles within each study area. The analysis results are presented in this sequence: Ekurhuleni, Johannesburg, Tshwane, Westrand and Sedibeng.

Figure name	**Municipal area**	**Map description**
Figure 5.11	Westrand	Proximity counts maps for 1 mile (1 610m)
Figure 5.12	Westrand	Proximity counts maps for 2 mile (3 220m)
Figure 5.13	Sedibeng	Proximity counts maps for 1 mile (1 610m)
Figure 5.14	Sedibeng	Proximity counts maps for 2 mile (3 220m)
Figure 5.15	Ekurhuleni	Proximity counts maps for 1 mile (1 610m)
Figure 5.16	Ekurhuleni	Proximity counts maps for 2 mile (3 220m)
Figure 5.17	Johannesburg	Proximity counts maps for 1 mile (1 610m)
Figure 5.18	Johannesburg	Proximity counts maps for 2 mile (3 220m)
Figure 5.19	Tshwane	Proximity counts 1 for 1 mile (1 610m)
Figure 5.20	Tshwane	Proximity counts 2 for 2 mile (3 220m)
Figure 5.11	Tshwane	Proximity counts maps for 2 mile (3 220m)

Table 5.3: Outline of maps for proximity counts

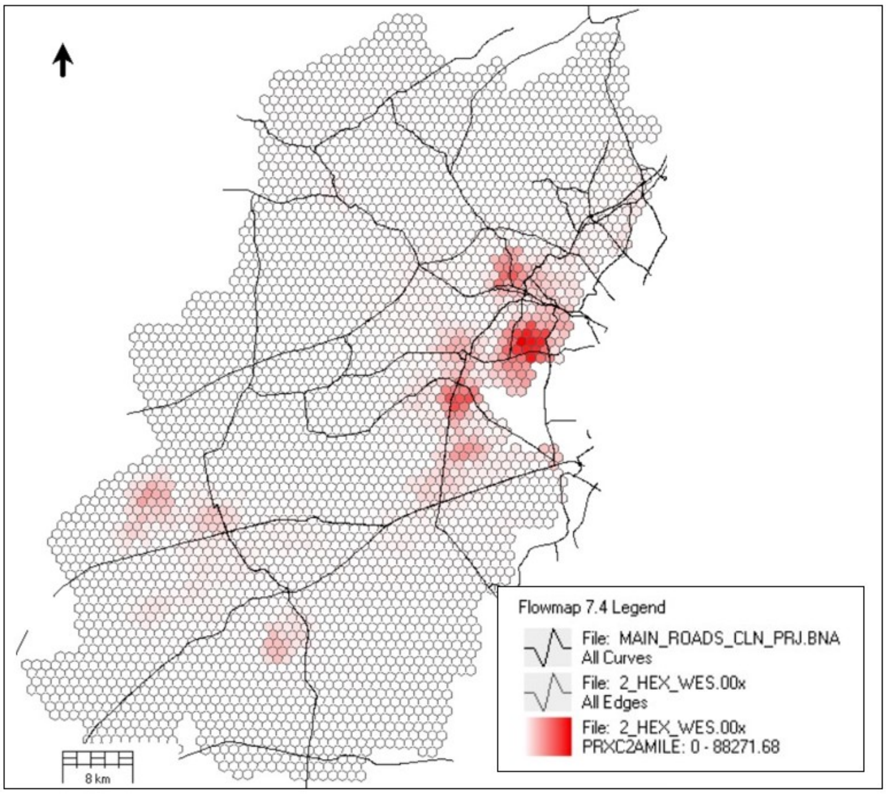


(a) Proximity count 1 for 1 mile (1 610m)

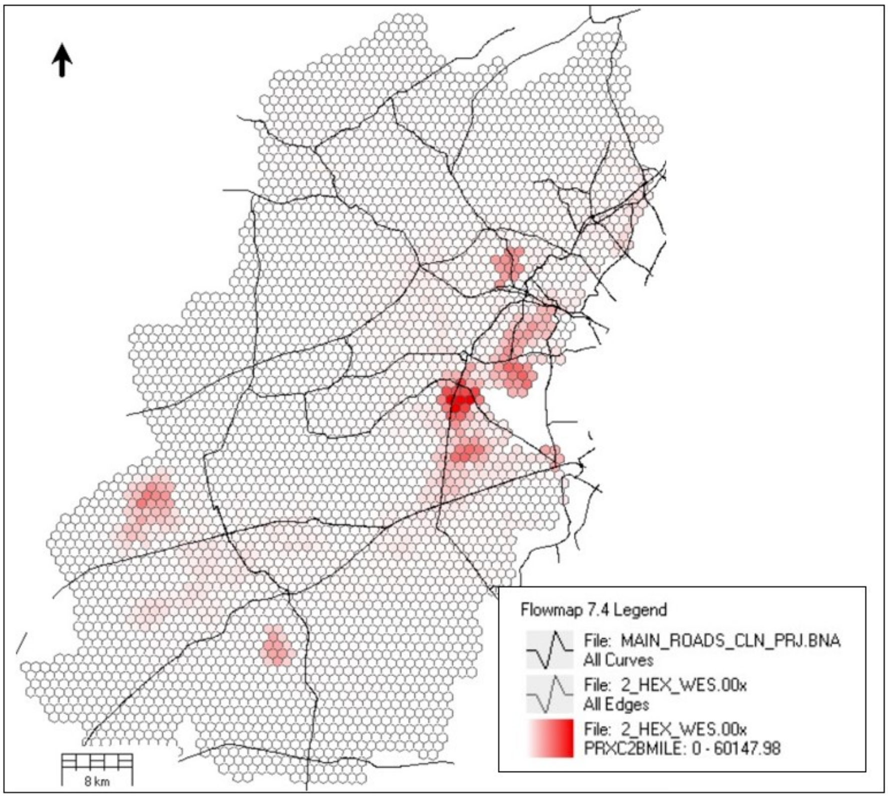


(b) Proximity count 2 for 1 mile (1 610m)

Figure 5.11: Westrand proximity counts maps for 1 mile (1 610m)



(a) Proximity count 1 for 2 mile (3 220m)



(b) Proximity count 2 for 2 mile (3 220m)

Figure 5.12: Westrand proximity counts maps for 2 mile (3 220m)

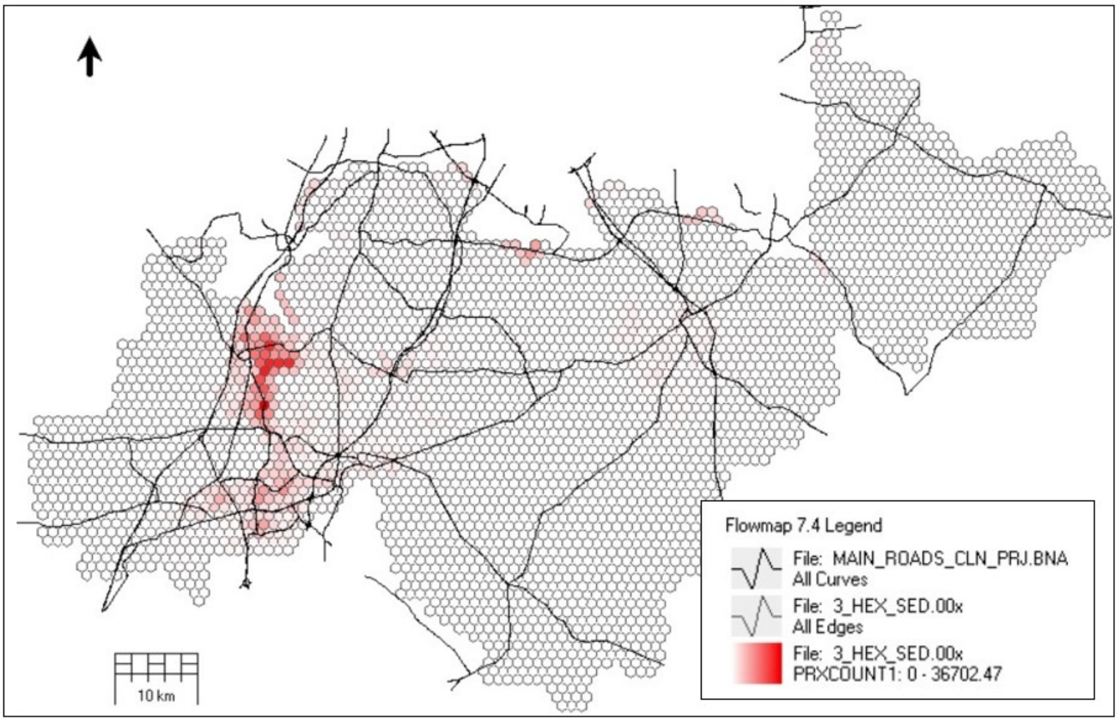
The key findings are summarised in table 5.4 below. The current hexagons containing Pargo sites are 23 in the Westrand study area, refer to figure 5.6. But in total there are 29 pickup points, meaning there are some hexagons with more than one Pargo point and these add up to 6. This makes a total 29 Pargo pickup points. The area has a total potential customers just above one million distributed over a total of 3 492 hexagons. The top potential customers recorded within 1 mile (1 610m) is 31 342 while for 2 miles (3 220) is 88 271. The total potential customers within 1 mile for current Pargo sites is 93 305 which increases to 274 594 for 2 miles. The ratio of total customers to total population is 9.02% for 1 mile and 26.54% for 2 miles. The lowest number of customers per Pargo site is 18.47 for 1 mile and 34.33 for 2 miles. The calculated maximum number of customers per Pargo site is 18 778 for 1 mile and 47158 for 2 miles. The potential customers not captured within 1 mile is 941 424 and the value decreases to 760 135 when the radius is increased to 2 mile. The total Pargo sites required to cover the area are 30 considering a 1 mile radius. From Figure 5.11a to Figure 5.12b, the hexagons shaded in red colour indicate areas with high population, while the unshaded regions is a combination of areas with low population, no-go areas or not yet developed areas.

Description	**1 mile (1 610m)**	**2 mile (3 220m)**
Current Pargo sites	29	29
Current Pargo sites in each hexagon	23	23
Total potential customers	1 034 724	1 034 724
Hexes to be captured by Pargo within 1mile	3 492	3 492
Top potential customers within x-mile	31 342	88 271
Pargo sites needed to cover whole area	33	12
Potential customers for current Pargo sites	93 305	274 594
Total customers / Total population (%)	9.02%	26.54%
Lowest no.of customers per Pargo site	18.47	34.33
Max no.of customers per Pargo site	18 778.67	47 158.47
Potential customers not captured	941 424	760 135.9
Hexes not captured	3 443	3 317
Pargo sites needed to cover area	30	9

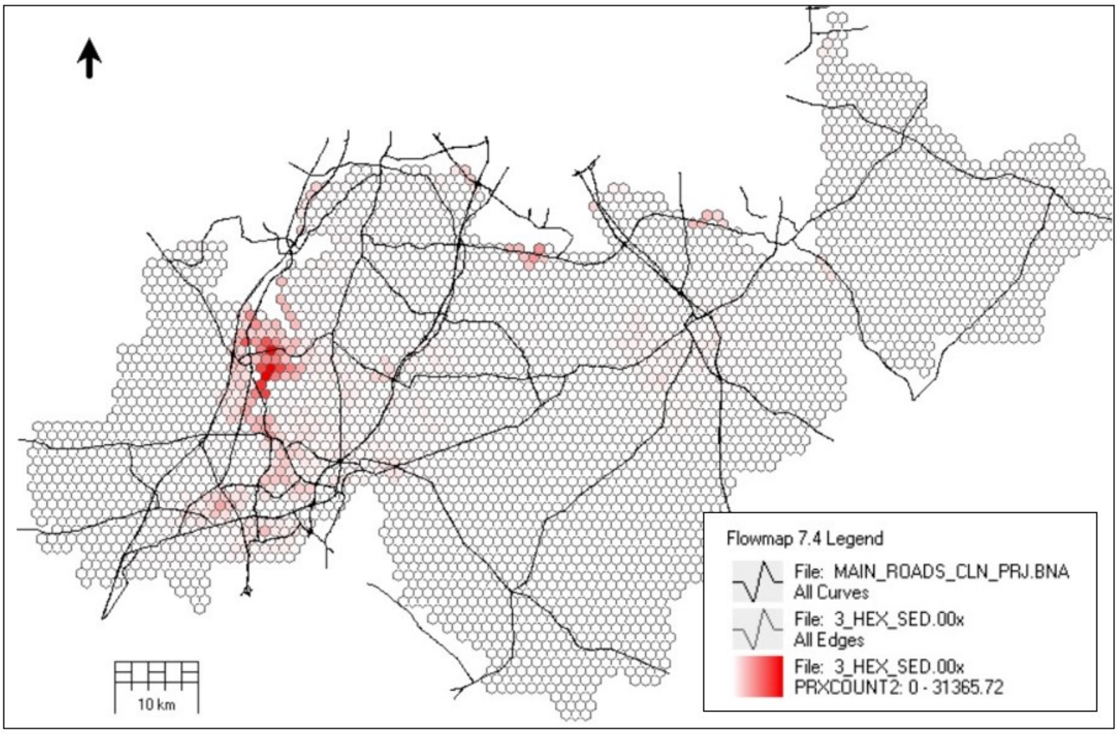
Table 5.4: Westrand summary of analysis

The key findings for Sedibeng area are summarised in table 5.5 below. There are currently 29 hexagons with Pargo sites. But in total, there are 41 pickup points, meaning there are some hexagons with more than one Pargo point and these add up to 12. The area has a total potential customers of 1 088 513 distributed over a total of 3 622 polygonal hexagons. The top potential customers recorded within 1 mile (1 610m) is 36 702 while for 2 miles (3 220m) is 125 861. The total potential customers within 1 mile for current Pargo sites is 174 630 which increases to 518 454 for 2 miles. The ratio of total customers to total population is 16.04% for 1 mile and 47.63% for 2 miles. The lowest number of customers per Pargo site is 13.44 for 1 mile and 52.25 for 2 miles. The calculated maximum number of customers per Pargo site is 36 702 for 1 mile and 70 949 for 2 miles. The potential customers not captured within 1 mile is 913 886 and the value decreases to 570 060 when the radius is increased to 2 mile. The total Pargo sites required to cover the area is 25 for

1 mile radius. The value decreases to 5 for 2 mile radius.



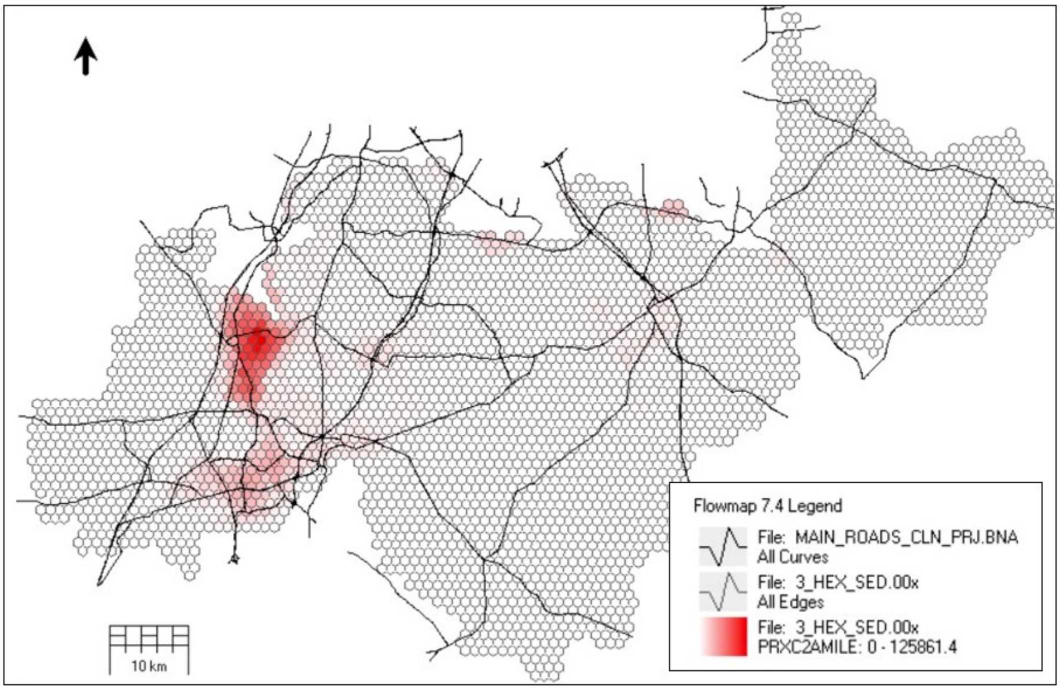
(a) Proximity count 1 for 1 mile (1 610m)



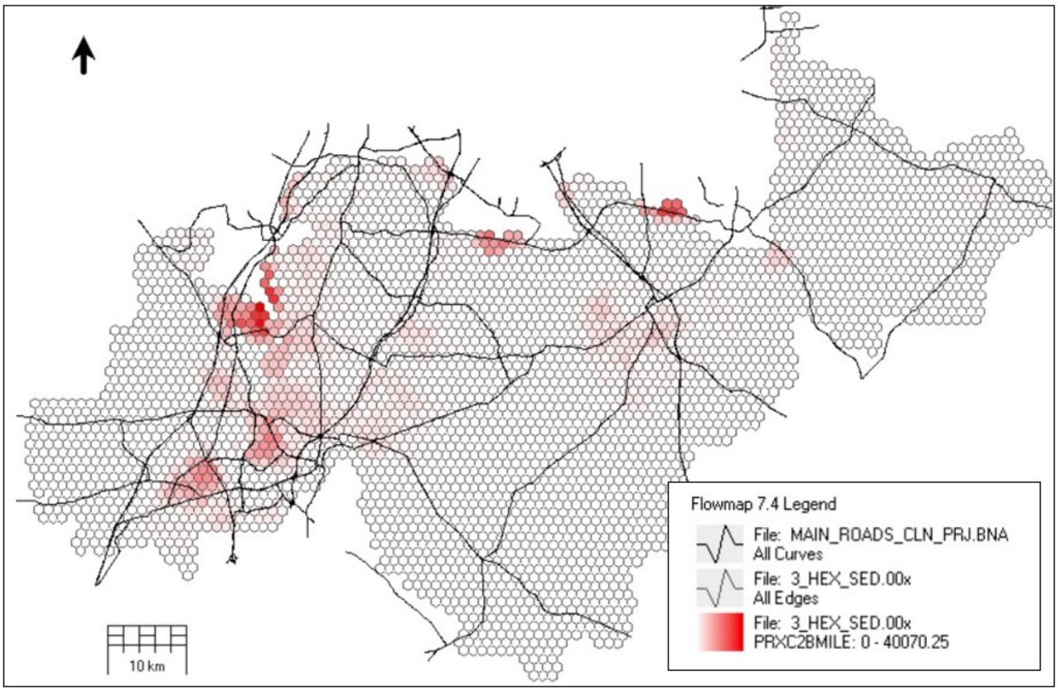
(b) Proximity count 2 for 1 mile (1 610m)

Figure 5.13: Sedibeng proximity counts maps for 1 mile (1 610m)

Figures 5.13a and 5.13b shows the proximity counts for a radius of 1 mile for Sedibeng study area. The hexagons shaded in red colour indicate areas with high population, while the unshaded regions is a combination of areas with low population, no-go areas or not yet developed areas.



(a) Proximity count 1 for 2 mile (3 220m)



(b) Proximity count 2 for 2 mile (3 220m)

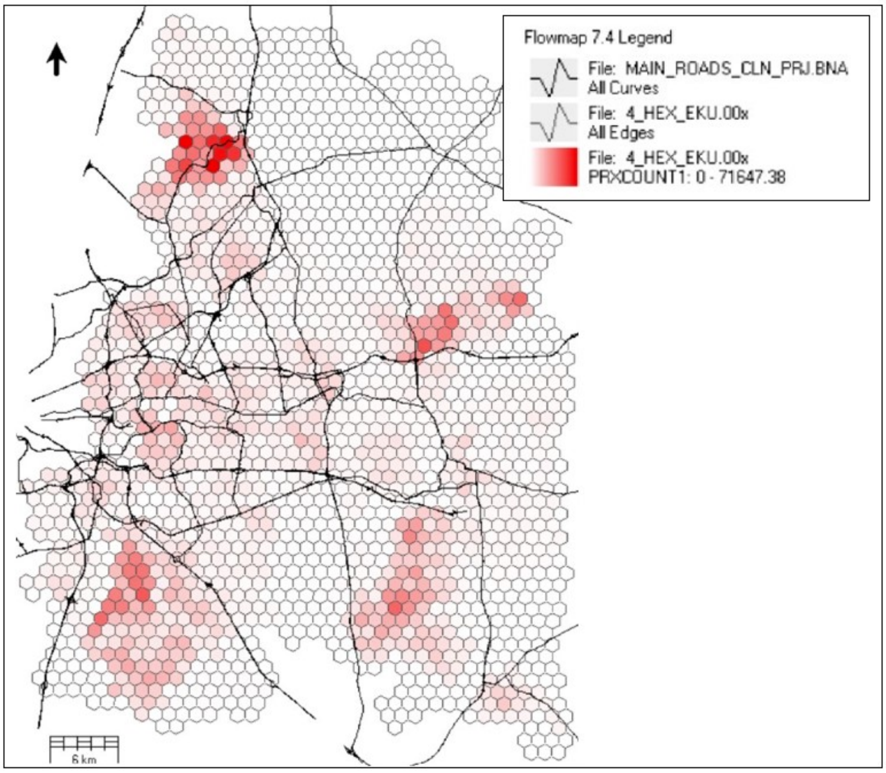
Figure 5.14: Sedibeng proximity counts maps for 2 mile (3 220m)

Figures 5.14a and 5.14b shows the proximity counts for a radius of 2 mile (3 220m) for Sedibeng study area. As indicated on the maps, the population coverage for 2 miles is higher that the previous maps which are for 1 mile. The hexagons shaded in red colour indicate areas with high population, while the unshaded regions is a combination of areas with low population, no-go areas or not yet developed areas. The areas shaded in red are the major towns which includes Vereeniging, Vanderbijl Park, Meyerton and Heidelberg. The townships in Sedibeng include Everton, Sebogeng, Sharpeville, Bophelong and Nigel. A greater percentage of the land-use in Sedibeng is zoned agricultural. Table 5.5 gives highlights of the findings for Sedibeng study area.

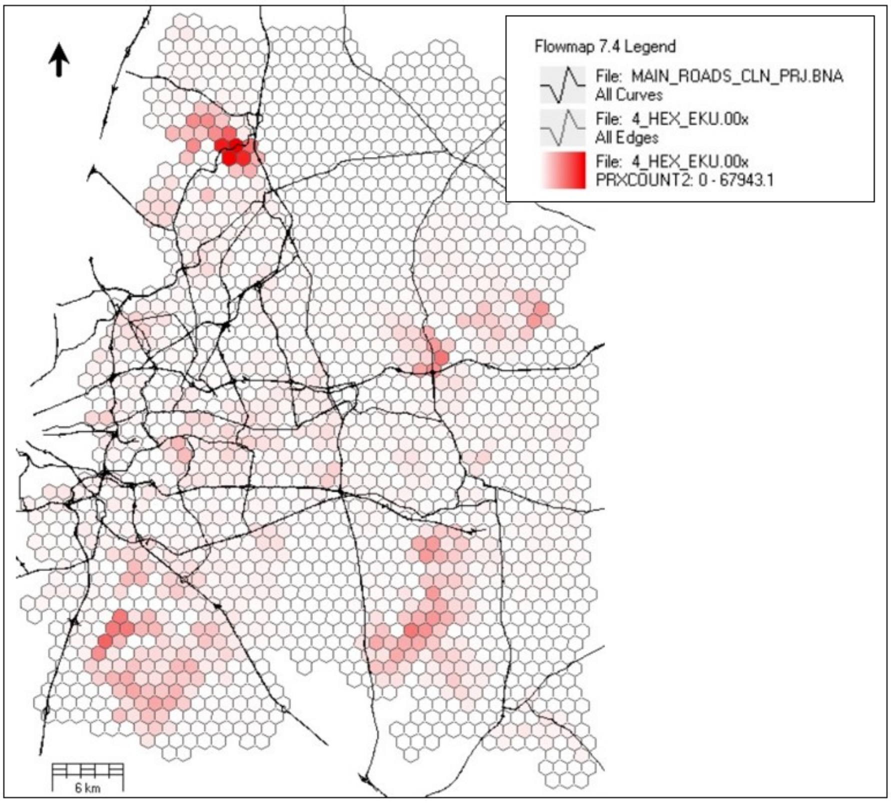
Description	**1 mile (1 610m)**	**2 mile (3 220m)**
Current Pargo sites	41	41
Current Pargo sites in each hexagon	29	29
Total potential customers	1 088 513	1 088 513
Hexes to be captured by Pargo within 1mile	3 622	3 622
Top potential customers within x-mile	36 702	36 702
Pargo sites needed to cover whole area	30	9
Potential customers for current Pargo sites	174 630	518 454
Total customers / Total population (%)	16.04%	47.63%
Lowest no.of customers per Pargo site	13.44	52.25
Max no.of customers per Pargo site	3 6702.47	70 949.96
Potential customers not captured	913 886.2	570 060.6
Hexes not captured	3 558	3 416
Pargo sites needed to cover area	25	5

Table 5.5: Sedibeng summary of analysis

In the Ekurhuleni study area, as presented in table 5.6, there are currently 102 hexagons with Pargo sites. But in total there are 128 pickup points, meaning there are some hexagons with more than one Pargo point and these add up to 26. The area has a total potential customers of 3 471 177 distributed over a total of 1 775 polygonal hexagons. The top potential customers recorded within 1 mile (1 610m) is 71 647 while for 2 miles (3 220m), is 243 481. The total potential customers within 1 mile for current Pargo sites is 830 153 which increases to 2 110 225 for 2 miles. The ratio of total customers to total population is 23.92% for 1 mile and 60.79% for 2 miles. The lowest number of customers per Pargo site is 8.24 for 1 mile and 49.45 for 2 miles. The calculated maximum number of customers per Pargo site is 71 647 for 1 mile and 142 198 for 2 miles. The potential customers not captured within 1 mile is 2 641 022 and the value decreases to 1 360 948 when the radius is increased to 2 mile. The total Pargo sites required to cover the area is 37 for 1 mile radius. The value decreases to 6 for 2 mile radius. Table 5.6 summarises the key findings for Ekurhuleni.

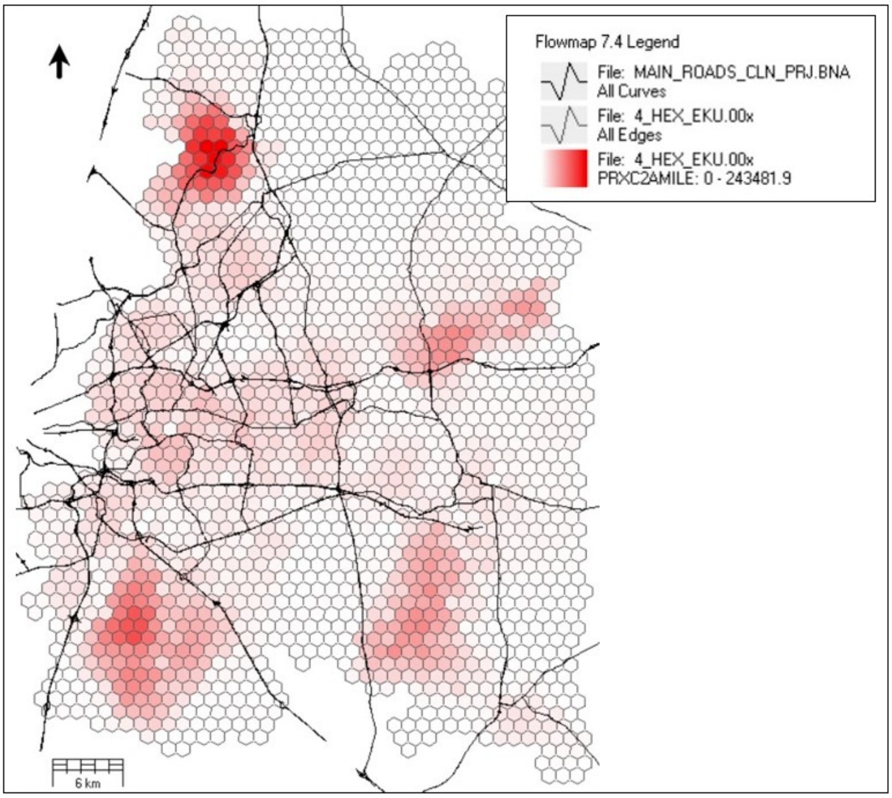


(a) Proximity count 1 for 1 mile (1 610m)

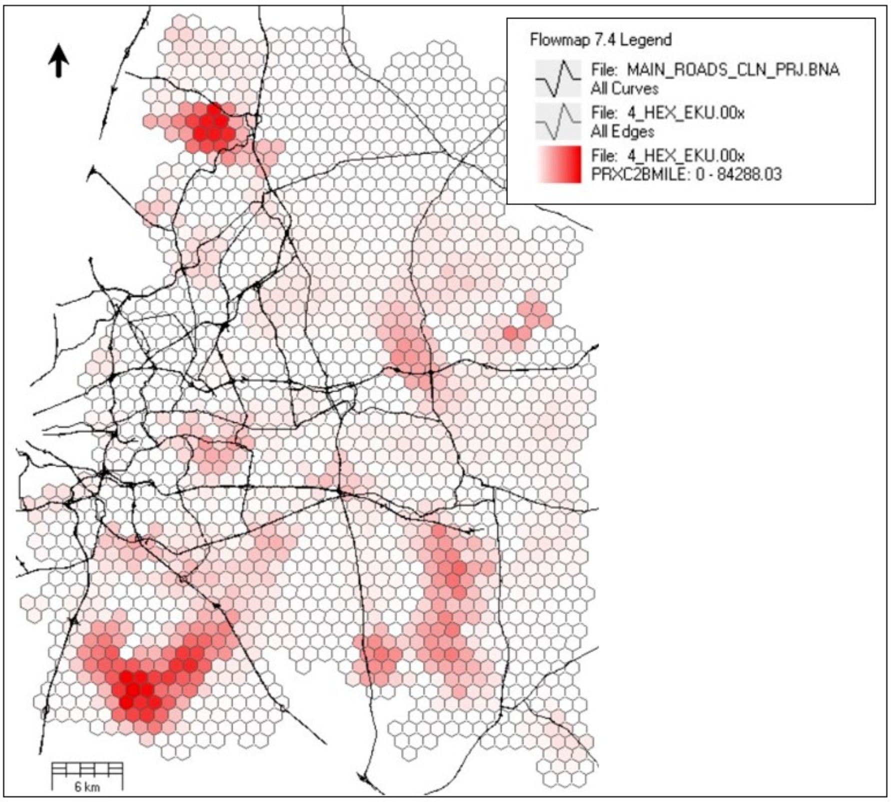


(b) Proximity count 2 for 1 mile (1 610m)

Figure 5.15: Ekurhuleni proximity counts maps for 1 mile (1 610m)



(a) Proximity count 1 for 2 mile (3 220m)



(b) Proximity count 2 for 2 mile (3 220m)

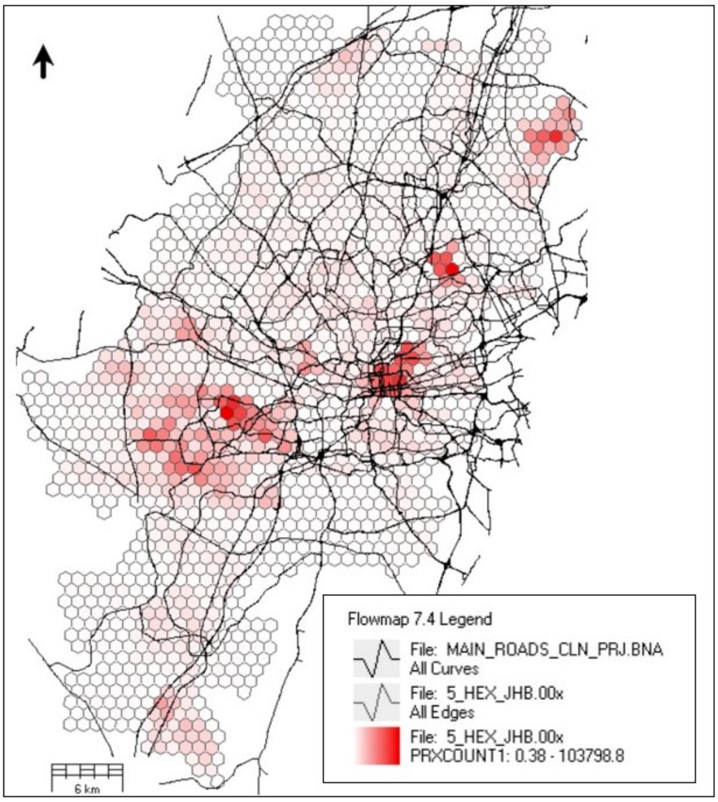
Figure 5.16: Ekurhuleni proximity counts maps for 2 mile (3 220m)

Description	1 mile (1 610m)	2 mile (3 220m)
Current Pargo sites	128	128
Current Pargo sites in each hexagon	102	102
Total potential customers	3 471 177	3 471 177
Hexes to be captured by Pargo within 1mile	1 775	1 775
Top potential customers within x-mile	71 647	71 647
Pargo sites needed to cover whole area	48	14
Potential customers for current Pargo sites	830 153	2 110 225
Total customers / Total population (%)	23.92%	60.79%
Lowest no.of customers per Pargo site	8.24	49.45
Max no.of customers per Pargo site	71 647.38	142 198.7
Potential customers not captured	2 641 022	1 360 948
Hexes not captured	1 565	1 158
Pargo sites needed to cover area	37	6

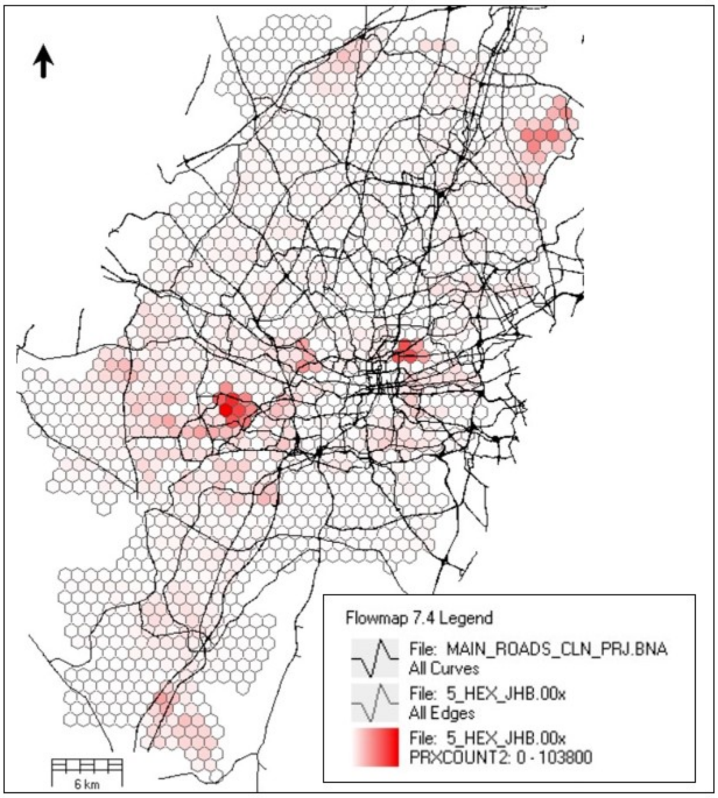
Table 5.6: Ekurhuleni summary of analysis

Figures 5.15a to 5.16b shows the proximity count maps for Ekurhuleni. The hexagons shaded in red colour indicate areas with high population, while the unshaded regions is a combination of areas with low population, no-go areas or not yet developed areas. The northern part of Ekurhuleni is Thembisa which is a highly populated township. To the south are the townships of Thokoza and Katlehong. These are also highly populated as shown on the maps.

In the Johannesburg study area, as summarised in table 5.7, there are currently 148 hexagons that contain Pargo sites. But in total there are 198 pickup points, meaning there are some hexagons with more than one Pargo point and these add up to 50. The area has a total potential customers of 4 446 470 distributed over a total of 1 554 polygonal hexagons. The top potential customers recorded within 1 mile (1610m) is 103 798 while for 2 miles (3 220m) is 241 069. The total potential customers within 1 mile for current Pargo sites is 1 243 873 which increases to 3 020 605 for 2 miles. The ratio of total customers to total population is 27.97% for 1 mile and 67.93% for 2 miles. The lowest number of customers per Pargo site is 3.00 for 1 mile and 88.50 for 2 miles. The calculated maximum number of customers per Pargo site is 97 856 for 1 mile and 154 491 for 2 miles. The potential customers not captured within 1 mile is 3 202 687 and the value decreases to 1 425 858 when the radius is increased to 2 mile. The total Pargo sites required to cover the area is 31 for 1 mile radius.

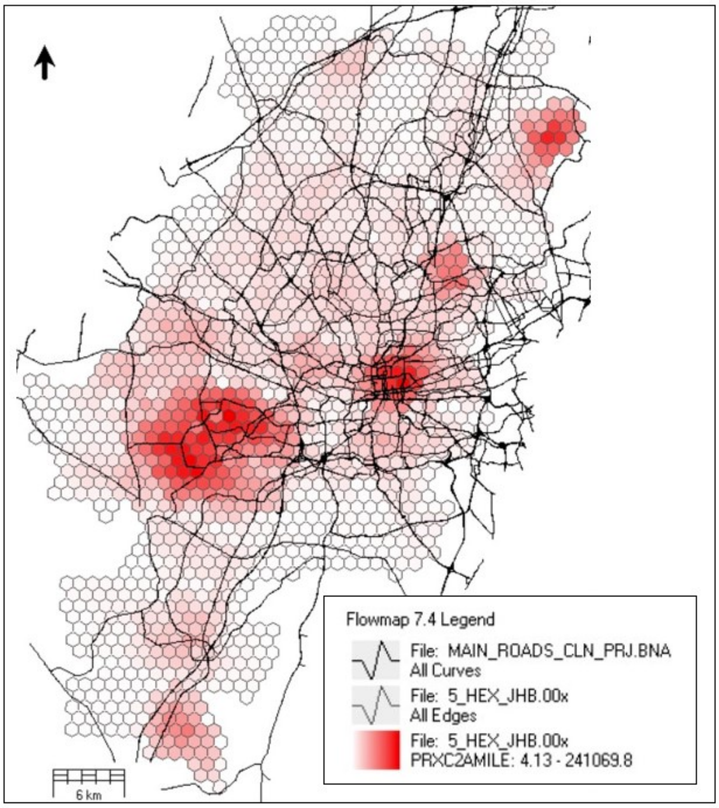


(a) Proximity count 1 for 1 mile (1 610m)

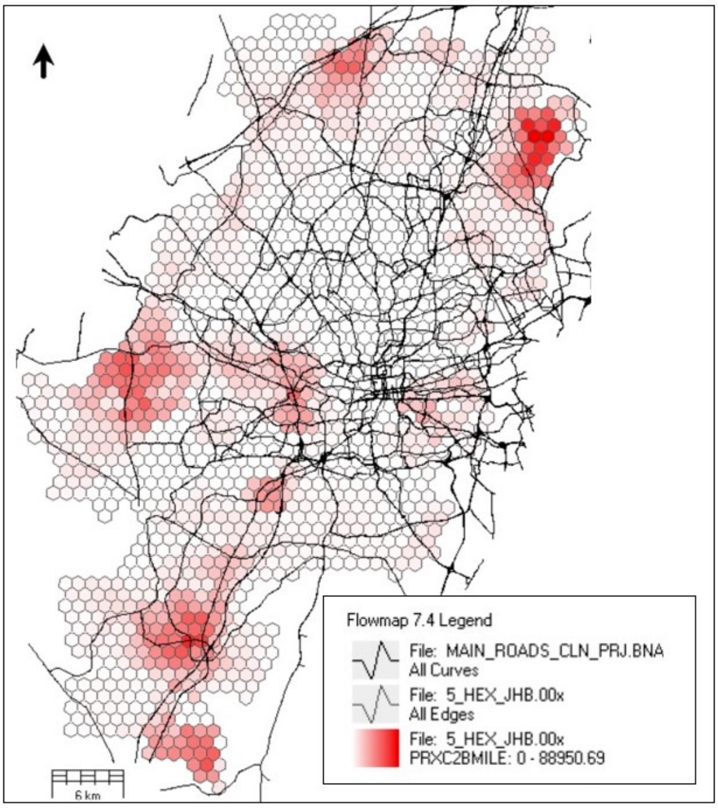


(b) Proximity count 2 for 1 mile (1 610m)

Figure 5.17: Johannesburg proximity counts maps for 1 mile (1 610m)



(a) Proximity count 1 for 2 mile (3 220m)



(b) Proximity count 2 for 2 mile (3 220m)

Figure 5.18: Johannesburg proximity counts maps for 2 mile (3 220m)

Description	1 mile (1 610m)	2 mile (3 220m)
Current Pargo sites	198	198
Current Pargo sites in each hexagon	148	148
Total potential customers	4 446 470	4 446 470
Hexes to be captured by Pargo within 1mile	1 554	1 554
Top potential customers within x-mile	103 798	241 069
Pargo sites needed to cover whole area	43	18
Potential customers current Pargo sites	1 243 873	3 020 605
Total customers / Total population (%)	27.97%	67.93%
Lowest no.of customers per Pargo site	3.00	888.50
Max no.of customers per Pargo site	97 856	154 491.90
Potential customers not captured	3 202 687	1 425 858
Hexes not captured	1 268	794
Pargo sites needed to cover area	31	6

Table 5.7: Johannesburg summary of analysis

Figures 5.17a to 5.18b shows the proximity count maps for Johannesburg. As shown on the maps, there are isolated pockets of hexagons shaded in red colour scattered across the metropolitan area. These indicate areas with high population. In general, Johannesburg has a larger population than the other study areas. Low-income neighbourhoods like Orange Farm township in Johannesburg's south are an indication of how populated the region is. The central part is Soweto and its surrounding areas, and to the north is Kalfontein and Ivory Park. These townships are highly populated as shown on the proximity count maps.

For Tshwane study area, as summarised in table 5.8, the current hexagons containing Pargo sites are 130. But in total there are 161 pickup points, meaning there are some hexagons with more than one Pargo point and these add up to 31. The area has a total potential customers of 2 865 638 distributed over a total of 5 230 polygonal hexagons. The top potential customers recorded within 1 mile (1 610m) is 48 171 while for 2 miles (3 220m) is 158 603. The total potential customers within 1 mile for current Pargo sites is 667 877 which increases to 1 722 001 for 2 miles. The ratio of total customers to total population is 23.31% for 1 mile and 60.09% for 2 miles. The lowest number of customers per Pargo site is 0.33 for 1 mile and 180.98 for 2 miles. The calculated maximum number of customers per Pargo site is 37 379 for 1 mile and 78 227 for 2 miles. The potential customers not captured within 1 mile is 2 198 015 and the value decreases to 1 143 658 when the radius is increased to 2 mile. The total Pargo sites required to cover the area is 46 for 1 mile radius. Table 5.8 summarises the key findings for City of Tshwane. Figures **??** to 5.21b shows the proximity count maps for Tshwane for a radius of 1-mile (1 610m) and for 2-mile (3 220m). As shown on the maps, there are isolated pockets of hexagons shaded in red colour mainly at the western side of the city. These indicate densely populated low-income suburbs. The low-income suburbs include Mamelodi to the east, Atteridgeville to the west and Soshanguve and Mabopane to the northern side of the city.

Description	1 mile (1 610m)	2 mile (3 220m)
Current Pargo sites	161	161
Current Pargo sites in each hexagon	130	130
Total potential customers	2 865 638	2 865 638
Hexes to be captured by Pargo within 1mile	5 230	5 230
Top potential customers within x-mile	48 171	158 603
Pargo sites needed to cover whole area	59	18
Potential customers for current Pargo sites	667 877	1 722 001
Total customers / Total population (%)	23.31%	60.09%
Lowest no.of customers per Pargo site	0.33	180.98
Max no.of customers per Pargo site	37 379.20	78 227.54
Potential customers not captured	2 198 015	1 143 658
Hexes not captured	4 977	4 481
Pargo sites needed to cover area	46	7

Table 5.8: Tshwane summary of analysis

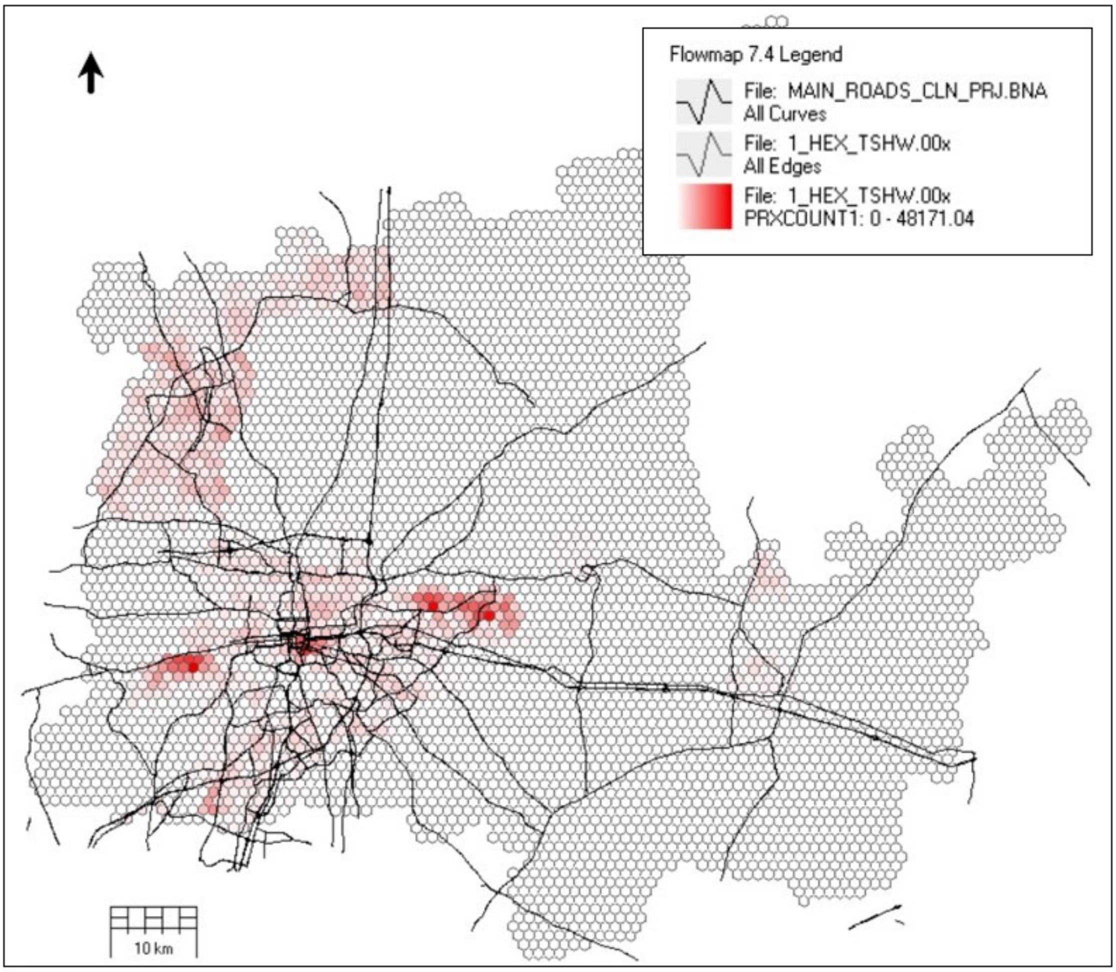


Figure 5.19: Proximity count 1 for 1 mile (1 610m)

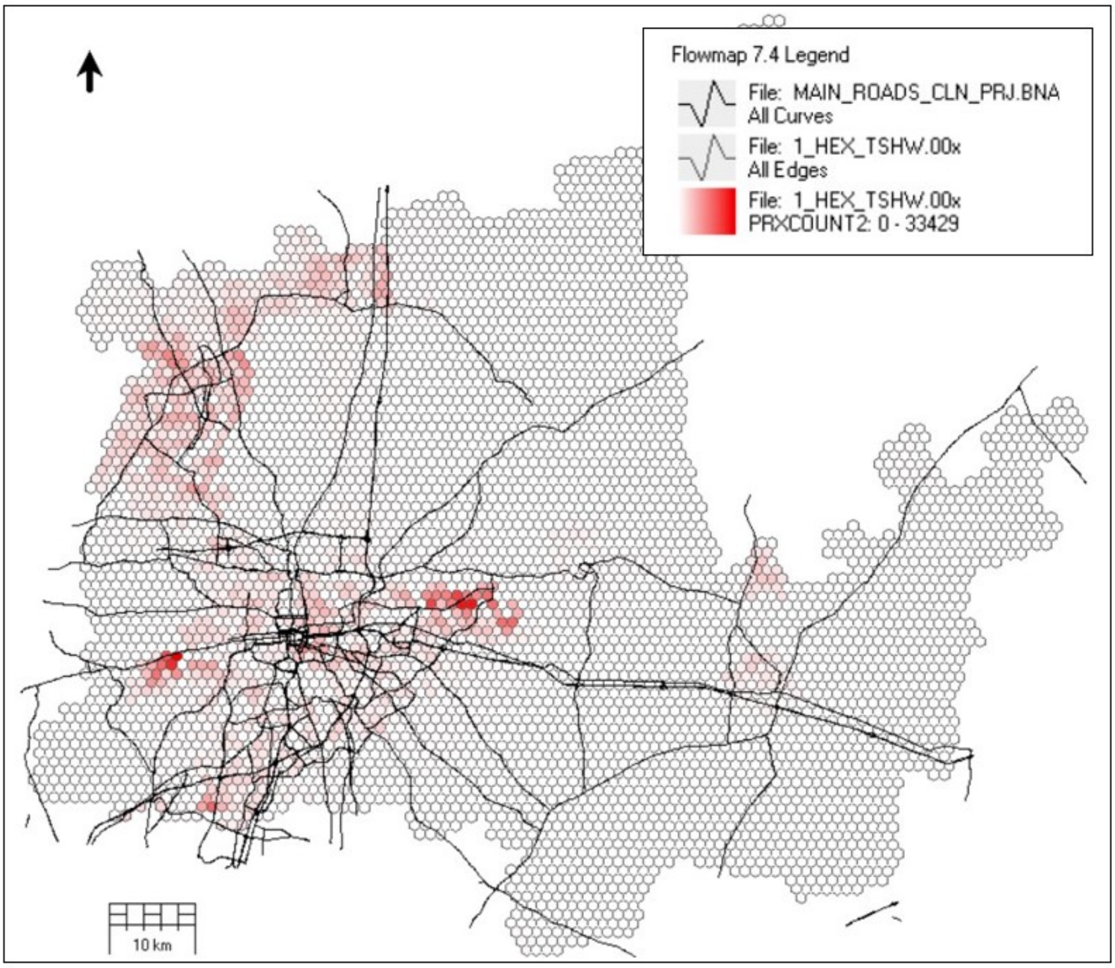
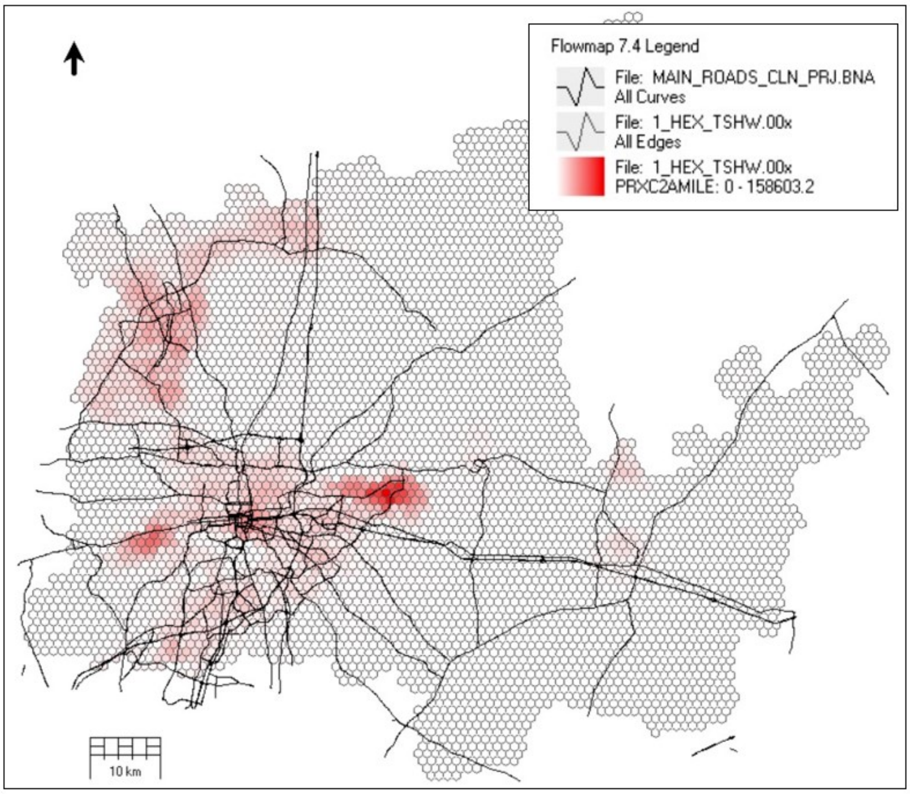
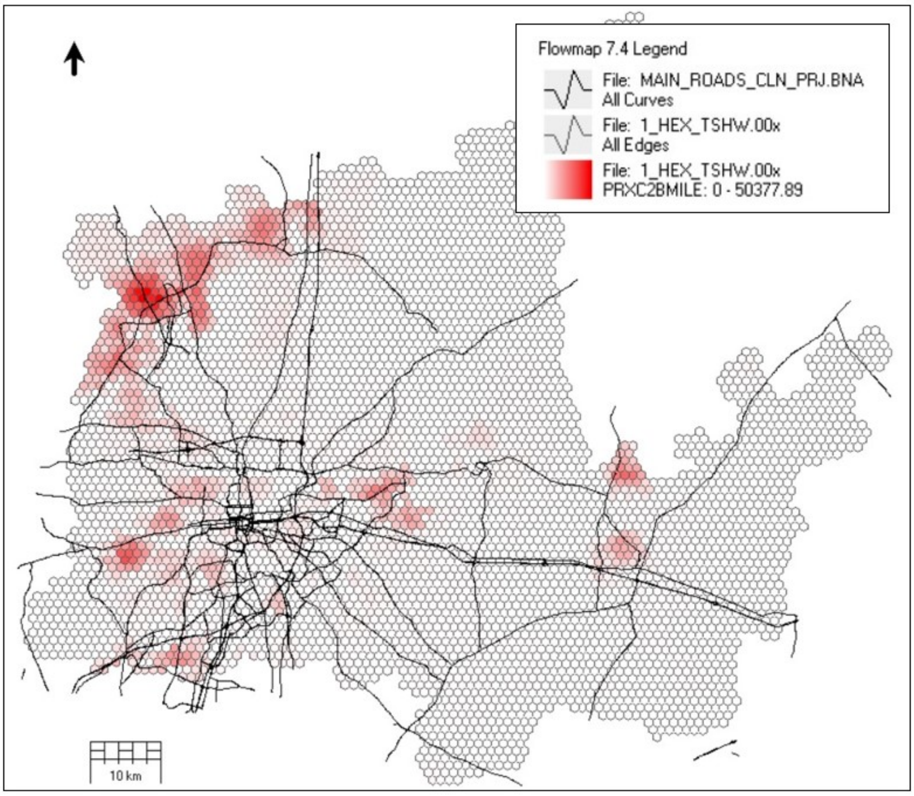


Figure 5.20: Proximity count 2 for 1 mile (1 610m)



(a) Proximity count 1 for 2 mile (3 220m)



(b) Proximity count 2 for 2 mile (3 220m)

Figure 5.21: Tshwane proximity counts maps for 2 mile (3 220m)

Study area	Potential customers within 1 mile	Pargo sites needed to cover whole area
Westrand	31 342	33
Sedibeng	36 702	30
Ekurhuleni	71 647	48
Johannesburg	103 798	43
Tshwane	48 171	59

Table 5.9: Summary of analysis for 1 mile radius

"Potential customers" are people who might be interested in using Pargo service and are not covered by the existing sites. The market for Pargo service depends on a number of things, including the availability of retail shops, fuel filling stations and many others. The potential customers within 1-mile distance varies per study area and the variance is mainly caused by the current population and existing pickup points. The potential customers increases greatly for a 2 mile radius.

Study area	Potential customers within 2 mile	Pargo sites needed to cover whole area
Westrand	88 271	12
Sedibeng	125 861	9
Ekurhuleni	243 481	14
Johannesburg	241 069	18
Tshwane	158 603	18

Table 5.10: Summary of analysis for 2 mile radius

5.3 Expansion of logistics infrastructure

The next issue that arises is what are the associated costs that are required to expand the pickup points infrastructure after the total number of Pargo sites required to cover each study area has been established. The logistics company has set the minimum requirements for becoming a pickup point operator. The requirements, among others, include an android device with a camera, and the device must be available during operating hours. It is also required that the business be operational for at least one year. Finally, there must be adequate space to accommodate the parcels. The logistics company is responsible for providing branding that identifies the business as a registered Pargo pickup point. According to Pargo, setting up a pickup point facility does not require any capital costs. Photographs showing typical pickup points are shown in figures 5.22a and 5.22b.

(a) Typical Pargo point inside a retail store, Clicks Atterbury, Pretoria

(b) Typical Pargo drive-through pickup point, V&A Waterfront, Cape Town

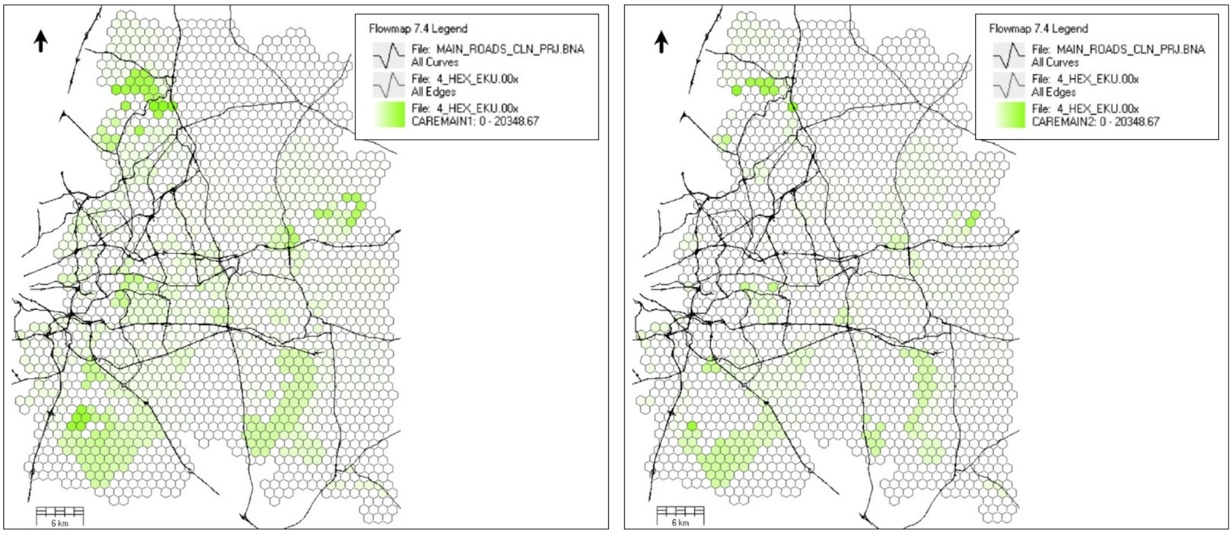
Figure 5.22: Photographs of typical Pargo parcel pickup points

Expanding pickup locations in rural areas is justified by the need to meet the basic needs of the local population, which encourages social and economic productivity. As long as there is a functional road network connecting rural communities to the closest urban centres, as well as a connection for electronic communication. Because there are no capital costs associated with opening a pickup point, any willing business owner can establish one. Rural households can experience slight social and economic change as a result of new Pargo infrastructure.

The outcomes of the catchment area analysis for both 1 mile and 2 mile distances are shown in Figures 5.23a and 5.23b. Each study area shows regions where a sizeable number of customers are not served. Green-shaded hexagons indicate populated areas where Pargo service is currently insufficient to meet demand. This means that the population demand is not being met by the current pickup points in these areas. The associated suburbs where there is deficiency and where the expansion of the Pargo service is highly required is presented in Table 5.11 below.

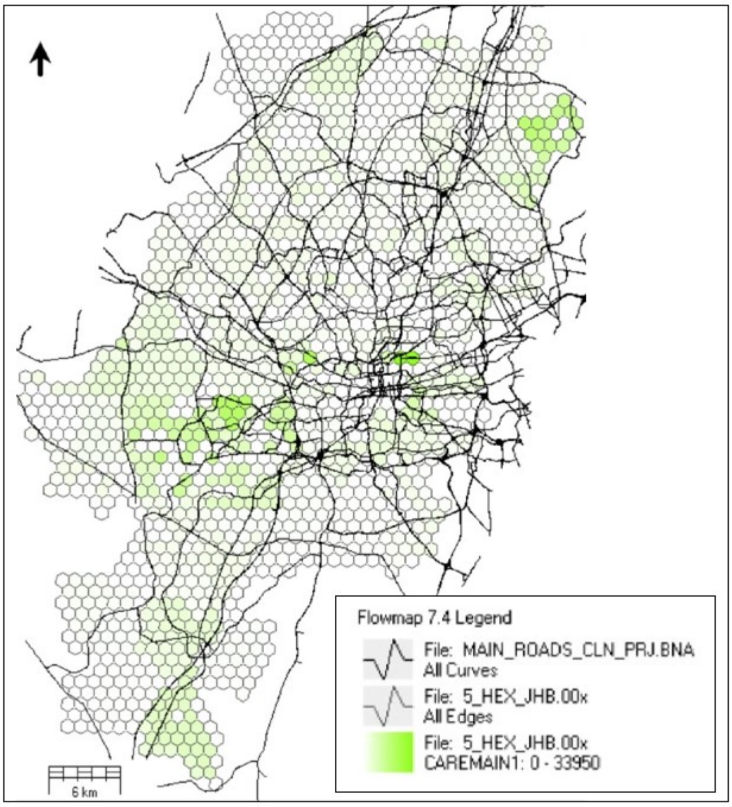
Study area	Suburbs
Tshwane	Mamelodi, Atteridgeville, Soshanguve, Mabopane
Johannesburg	Orange Farm, Ennerdale, Lanesia, Soweto, Kalfontein, Ivory Park
Ekurhuleni	Thembisa, Katlehong, Vosloorus, Daveyton, Kwa-Thema, Nigel
Westrand	Randfontein, Krugersdorp, Carletonville
Sedibeng	Vanderbijlpark, Sharpeville, Evaton, Sebokeng,

Table 5.11: List of suburbs where there is potential for expansion

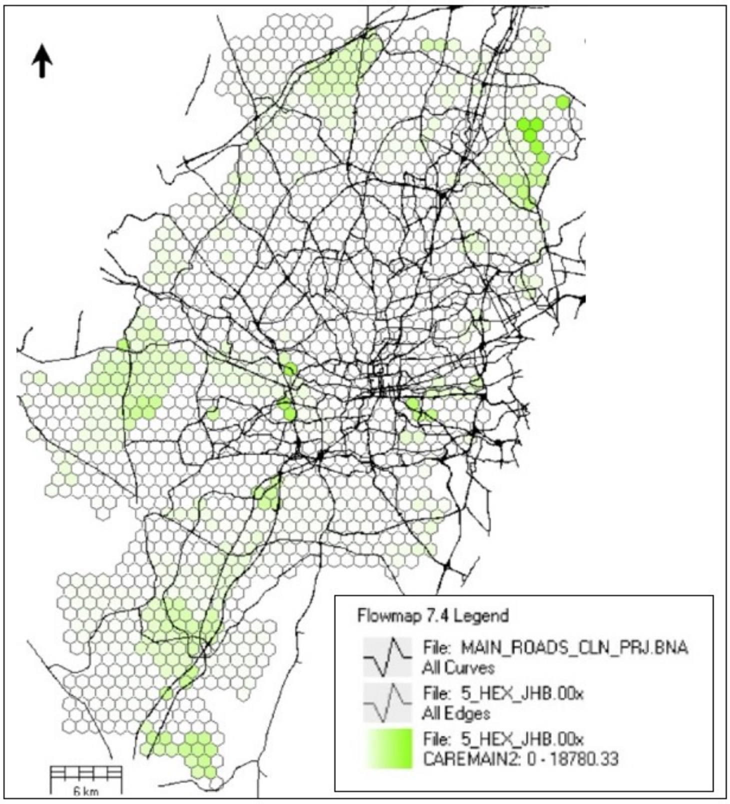


(a) Unsatisfied demand for 1 mile (b) Unsatisfied demand for 2 mile

Figure 5.23: Catchment area analysis - unsatisfied demand in Ekurhuleni

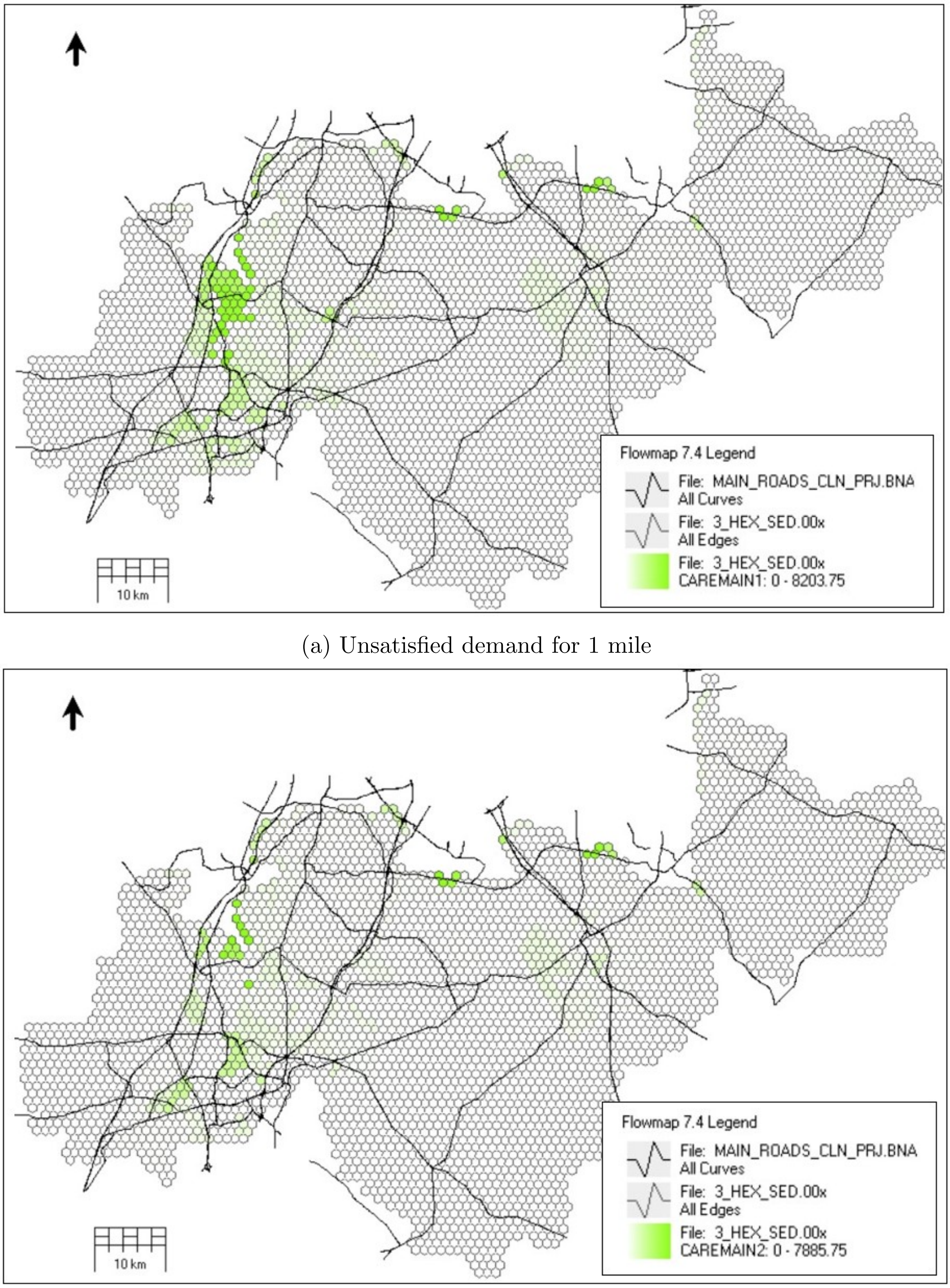


(a) Unsatisfied demand for 1 mile



(b) Unsatisfied demand for 2 mile

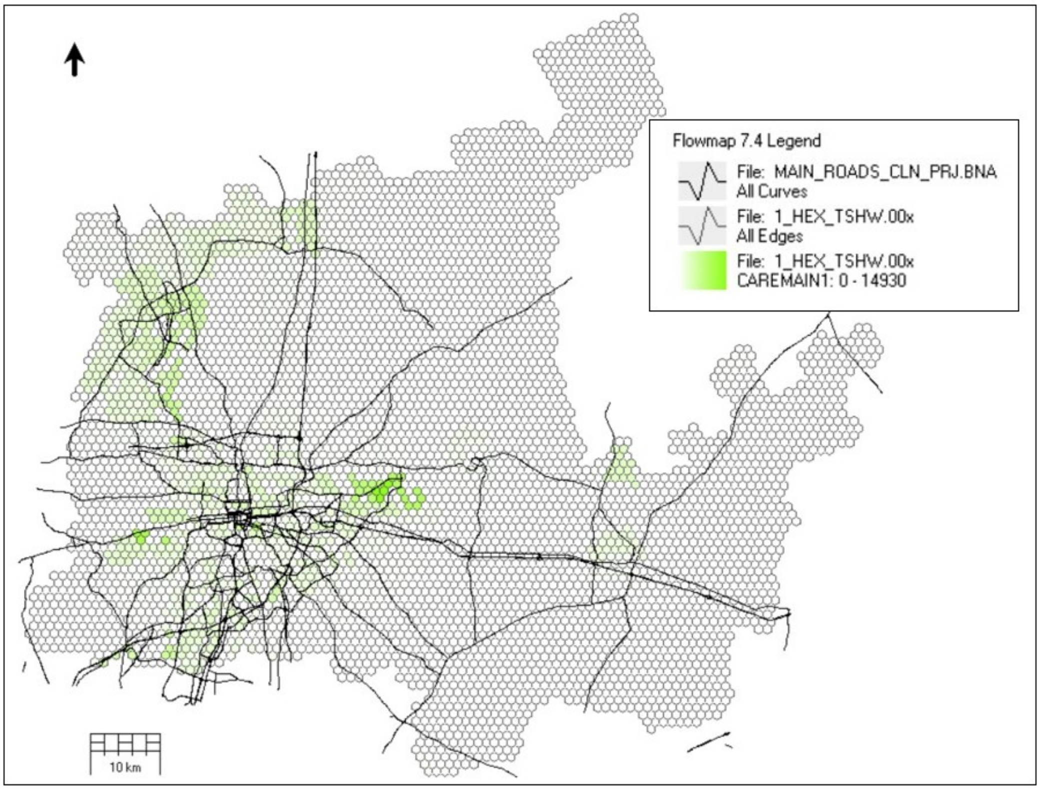
Figure 5.24: Catchment area analysis - unsatisfied demand in Johannesburg



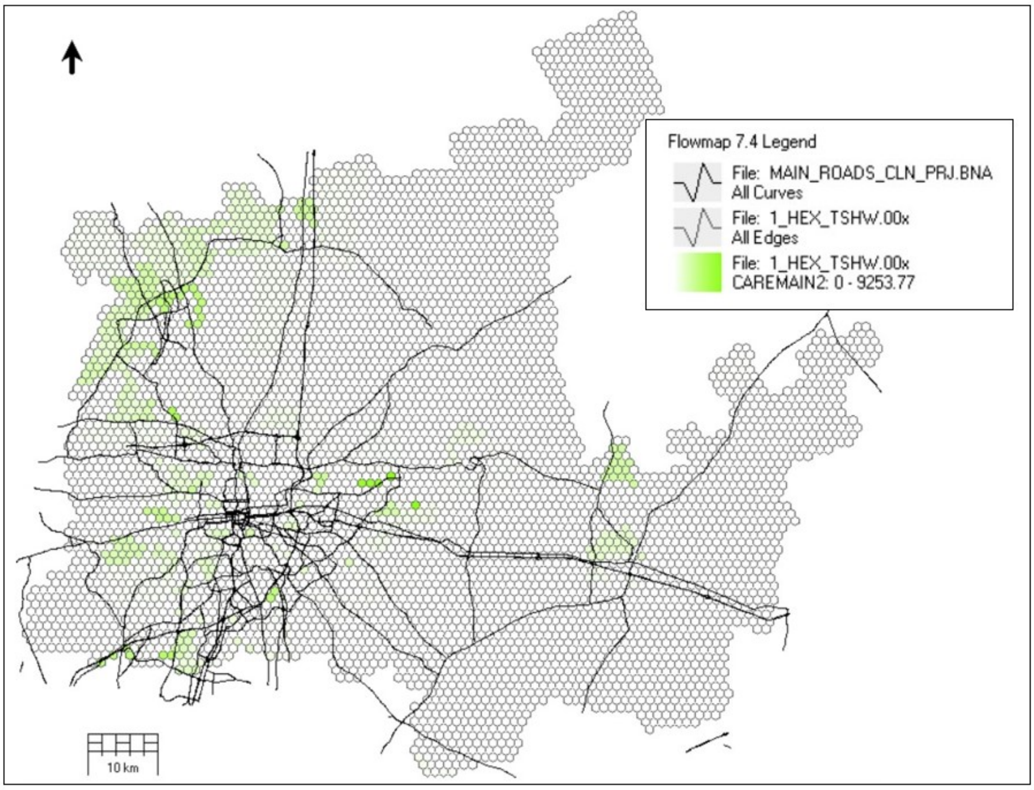
(a) Unsatisfied demand for 1 mile

(b) Unsatisfied demand for 2 mile

Figure 5.25: Catchment area analysis - unsatisfied demand in Sedibeng

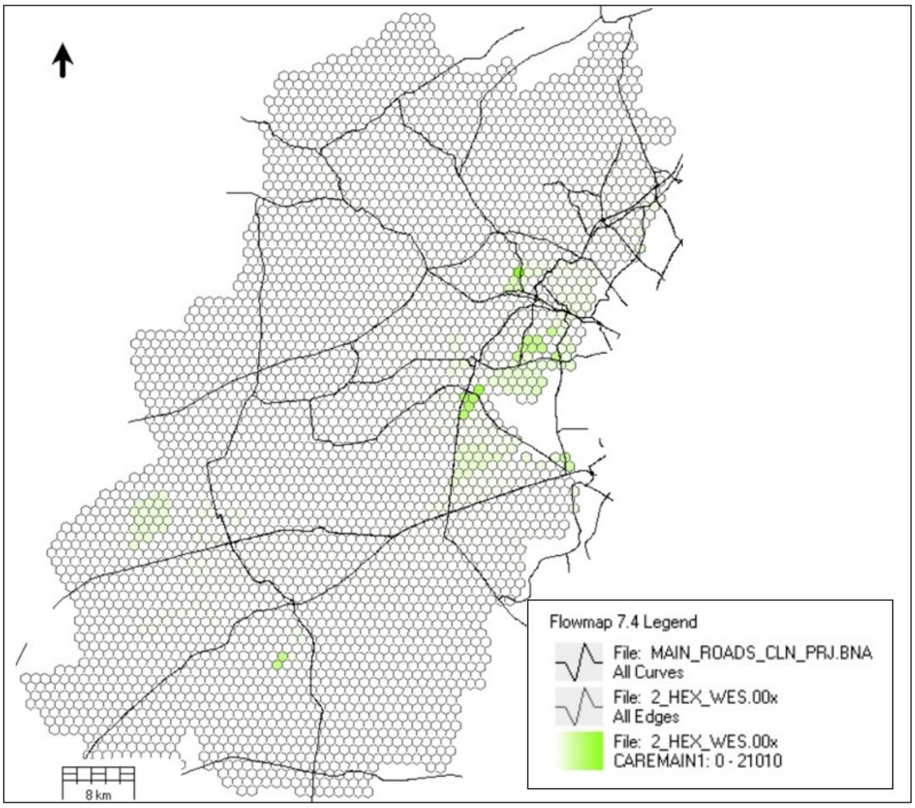


(a) Unsatisfied demand for 1 mile

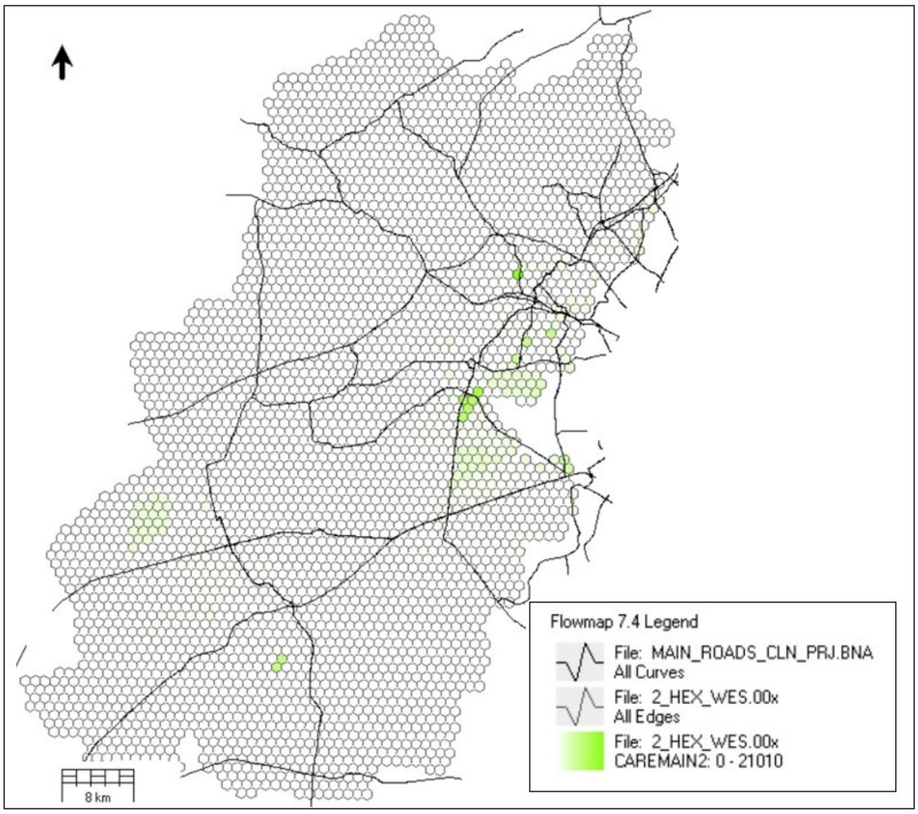


(b) Unsatisfied demand for 2 mile

Figure 5.26: Catchment area analysis - unsatisfied demand in Tshwane



(a) Unsatisfied demand for 1 mile



(b) Unsatisfied demand for 2 mile

Figure 5.27: Catchment area analysis - unsatisfied demand in Westrand

5.4 Limitations and implications of findings

a) Poor road infrastructure
This study suggests increasing the number of pickup points, but there are practical considerations that must be taken into account. An expansion of pickup locations is probable in low-income areas due to their large population and the relatively lower number of existing pickup points compared to high-income areas. Lack of road infrastructure does not necessarily mean the absence of accessible roads, but an area becomes less desirable for last mile distribution of goods if the road network has a higher proportion of unpaved roads. Locations that have low levels of accessibility tend to have higher costs for many goods (Rodrigue, 2020). This is common in rural areas. Low-income consumers also face security challenges, cargo theft, and crime challenges, as noted by Neto and Vieira (2023) in their research on consumer intention to use pickup point services for last-mile distribution in developing countries. This is analogous to South Africa. All of these factors have a negative impact on e-commerce logistics. Despite this, Pargo is not solely responsible for security risks; shop owners also bear a greater share of responsibility because they have complete control over the building structure.

b) Poor internet signal and penetration
A major factor in the development of e-commerce is the expansion of telecommunication. Telecommunication is one of the fastest growing economic sectors in South Africa, due to the rapid growth of mobile and broadband connectivity. Though most rural and remote areas are generally covered by network signal, the type of internet connection is characterised by weak signal strength, making it unsuitable for e-commerce operations. Therefore, before one can confidently discuss the full implementation of e-commerce that satisfy last-mile deliveries, it is necessary that improvements to internet connectivity and associated technologies be implemented first. In addition, one of South Africa's biggest problems is the high cost of mobile devices and internet connectivity. The province of Gauteng, though, might be above other provinces in terms of coverage. It is essential that the telecommunications sector develop in order to reach the millions of potential customers who are not in towns and cities.

c) Regulatory environment
Challenges to the parcel delivery system include rising demand, governmental regulations, congested traffic during peak hours, and environmental issues (Neto and Vieira, 2023). Additionally, the free movement of people, vehicles, and the distribution of e-commerce are all made more complex by the fast and disorderly population growth (Dablanc, 2007). Mobility and accessibility go hand in hand. Poor mobility often result in congestion. This scope does not include mobility that takes travel behaviour into account. The amount of time it takes a parcel to arrive at its destination, however, is influenced by the mobility of the vehicle. Government policies and urban development trends, are the driving forces behind these factors. Any logistics business has no control over these. This also implies that any advice given in this study has some limitations because of shifting demographics and governmental regulations.

5.5 Recommendations

The earlier sections of this chapter presented the total number of potential customers within a given distance for each municipal area. Pargo sites needed to cover each municipal area were also discussed in detail. The limitations and implications relating to e-commerce were also discussed. The number of new sites recommended per municipal area need to be weighed against the limitations and practical implications. The recommendations are listed as follows:

a) It is important to conduct a qualitative study to comprehend how customers behave and how they perceive and support last-mile delivery of their packages. It is believed that customer behaviours drive the introduction of new delivery services (Zenezini et al., 2018). A qualitative study will highlight customer preferences and experiences such as store opening and closing times, the Pargo collection point's accessibility, barriers to online purchases, and the length of time they had to wait in the queue with other regular customers in order to be served. This will benefit the business owner of the neighbourhood store as well as the Pargo business at large. It is not needed to reiterate the benefit of understanding customer behaviour for business owners.

b) The principle of justice and its application in transport planning as researched by Martens (2016) and Soja (2013) emphasises that one's place of residence shouldn't have an adverse impact on vital aspects of daily life or one's health. Establishing pick-up points in the current under-served areas, which are primarily low-income areas, is essential to ensuring that everyone has access to e-commerce delivery services. There is potential for complete coverage of the Pargo pickup locations to spread as long as there is supporting infrastructure, such as pre-existing small local businesses (shops or filling stations) to house the parcel pickup points, a road network, and at least minimal internet connectivity. The NPC (2012) identifies spatial justice and sustainability as key spatial development principles. Private companies are not incentivised to invest in densely populated areas, but doing so increases revenue and profitability.

c) It is suggested that the following investigations be conducted in the future: (1) Increase the allocation of origins or population's maximum distance to 3 miles (5 km). This will increase the population served. However, longer travel times to the pickup location as a result cause accessibility problems like not supporting Non-Motorised Transport (NMT). (2) An analysis of densely populated areas to determine whether a facility within one mile of the area does indeed meet capacity. This is typical in urban areas where blocks of flats under residential type 4 zoning, which allows for a density of up to 120 dwelling units per hectare. (3) For a specific municipality, divide the areas into rural and urban areas based on the type of land use. Then, assign each area a different capacity based on population. Due to the fact that rural areas are typically less densely populated than urban areas, and the maximum distance in rural areas is greater than in an urban one, the pickup points needed to cover the area are likely going to be in the same range. (4) Relocation of the current sites to have a more equitable spread. (5) Expanding the scope beyond Gauteng.

Chapter 6

Conclusion

This study provided information on the role that e-commerce can play in the last-mile delivery of parcels. Spatial analyses, which deal with the expansion of parcel pickup points to improve accessibility are applied. The analyses performed to expand current Pargo parcel pickup points in five Gauteng municipalities include proximity counts and catchment area analysis. The principle of justice was taken into consideration when planning transportation. This study was successful in both addressing the research questions and making other significant contributions. Based on the analysis, it is clear that extending the coverage of pickup points, as suggested in this study, will improve accessibility in low-income and densely populated areas. Below is a summary of each research question, along with an explanation of how it was accomplished and sections where it was addressed.

How can accessibility based on parcel delivery systems and service location be evaluated using GIS modelling techniques?

Spatial data for transport planning is not always available but the freely available data from OSM made it possible to carry out the analysis. Accessibility measures are traditionally known to be data-intensive. Throughout the case, it became clear that accessibility measures are useful in evaluating existing transport systems and land-use for a given area. It was not straight-forward to process the data at any stage. Data processing relied on software tools like Excel, Python, and GIS. These tools can perform the pre-processing, though in some cases, the data processing will demand above-average skill. The actual accessibility analysis was carried out using Flowmap. The tool has demonstrated its value in the analysis of geographic data. It is a very useful tool for strategic planning and decision-making for policy-making purposes. The actual evaluation entails data processing with the aforementioned tools, data conversion to appropriate formats, and feeding the data into Flowmap for further analysis. The existing parcel locations were incorporated and used as partial solutions in the analysis. In the evaluation, no-go locations were also taken into account. The proximity count and catchment area analysis were computed using 1 and 2-mile distances. The accessibility evaluation section in Chapter 4 of this report contains a detailed description of these analyses.

How can accessibility mapping in GIS be used as a tool to improve last-mile parcel delivery for Pargo pickup points?
The analysis conducted in this research demonstrated that the current Pargo sites adequately cover most built-up areas. The majority of areas, particularly at activity nodes and in CBDs, are adequately covered while the Pargo sites in outlying areas show potential for expansion. Taking hexagons with a radius of 1-mile (1 610m), some CBDs contain multiple pickup sites in the same hexagon meaning that last-mile is achieved. There are fewer pickup points in outlying regions, indicating potential for expansion of the service. GIS tools can perform a variety of geographical data analyses, including accessibility analysis. This was accomplished by first locating areas with existing pickup points. The next step was to specify a user-defined distance, in this case 1-mile (1 610m). Catchment area analysis, a method that searches within a predetermined distance and distributes population to the closest locations, and proximity count, also known as the cumulative opportunity index, were among the analyses performed. The goal of these analyses was to determine the number of pickup locations needed to serve a given area and the number of potential customers per site. The pickup locations necessary to completely cover areas where pickup points are not available were calculated taking potential customers into account, and the results are summarised in the previous chapter.

How can accessibility be improved by modifying parcel pickup locations on the Pargo network?
Greater accessibility to parcel pickup points opens up more economic opportunities for both individuals and businesses. Implementing the potential sites required increases the market area for Pargo. Additionally, accessibility promotes the effectiveness of a transportation system. There is a chance that installing Pargo pickup facilities in an existing retail establishment will draw in more customers because of the added convenience of parcel collection. The Pargo system has greater potential for expansion to ensure improved accessibility of the parcel pickup points. More pickup points reduce geographic distances by bringing opportunities closer to people. The previous chapter's Section 5.3 describes the expansion of the logistics infrastructure. In each study area where there is prospect of expansion, specific suburbs are listed. Future research directions include analysing land usage, assessing the accessibility of pickup facilities in densely populated areas, and extending the scope beyond Gauteng province.

Appendices

Appendix A

Python script to clean the road network

```python
import networkx as nx

# Load the road network graph from a file or source
G = nx.read_shp('roads.shp')

# Remove any nodes with degree 2
degree = dict(G.degree())
to_remove = [n for n in degree if degree[n] == 2]
G.remove_nodes_from(to_remove)

# Save the cleaned-up graph back to a file or use it for further analysis
nx.write_shp(G, 'cleaned_roads.shp')
# Load the road network graph from a file or source
G = nx.read_shp('roads.shp')

# Remove any connected components with fewer than 3 nodes
isolated = [c for c in nx.connected_components(G) if len(c) < 3]
G.remove_nodes_from(set.union(*isolated))

# Save the cleaned-up graph back to a file or use it for further analysis
nx.write_shp(G, 'cleaned_roads.shp')
```

Figure A.1: Script to clean the road network

Appendix B

Python script to assign population to hexagons

```python
import pandas as pd

# Load data
province_data = pd.read_csv("province_data.csv")
ward_data = pd.read_csv("ward_data.csv")

# Merge data
merged_data = pd.merge(ward_data, province_data, on="province")

# Group by ward and calculate population
ward_population = merged_data.groupby("ward")["population"].sum().reset_index()

# Output results
print(ward_population)
```

Figure B.1: Script to assign population to hexagons

Appendix C

Python script to calculate the number of points in a polygon

```
import geopandas as gpd
from shapely.geometry import Polygon

# Load the country polygon shapefile
country = gpd.read_file('path/to/country_shapefile.shp')

# Calculate the number of points in the country polygon
num_points = len(list(country.geometry[0].exterior.coords))

# Load the ward polygon shapefile
wards = gpd.read_file('path/to/wards_shapefile.shp')

# Calculate the number of points in each ward polygon
ward_points = []
for ward in wards.geometry:
    num_points = len(list(ward.exterior.coords))
    ward_points.append(num_points)

# Add a new column to the wards dataframe with the number of points
wards['num_points'] = ward_points

# Save the updated wards shapefile
wards.to_file('path/to/output_wards_shapefile.shp')
```

Figure C.1: Script to calculate the number of points in polygons

Appendix D

Python script to calculate the point of origin and assign population

```python
import geopandas as gpd
from shapely.geometry import Point

# Load the shapefile for the hexagons and the population data
hexagons = gpd.read_file('hexagons.shp')
population = gpd.read_file('population.shp')

# Make sure the two shapefiles have the same coordinate reference system (CRS)
population = population.to_crs(hexagons.crs)

# Calculate the centroid of each hexagon and create a new GeoDataFrame
centroids = hexagons.centroid
points_of_origin = gpd.GeoDataFrame({'geometry': centroids})

# Perform a spatial join to assign the population data to the hexagons
hexagons_with_pop = gpd.sjoin(hexagons, population, op='within')

# Aggregate the population data by hexagon
pop_by_hexagon = hexagons_with_pop.groupby('HEX_ID')['POPULATION'].sum()

# Assign the population value to the point of origin for each hexagon
for hex_id, pop in pop_by_hexagon.items():
    point = points_of_origin.loc[hex_id, 'geometry']
    points_of_origin.loc[hex_id, 'POPULATION'] = pop
    points_of_origin.loc[hex_id, 'POINT_OF_ORIGIN'] = Point(point.x, point.y)

# Save the points of origin to a new shapefile
points_of_origin.to_file('points_of_origin.shp')
```

Figure D.1: Script to calculate point of origin and assign population

Appendix E

Summary of output

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13	Col 14
Study area	Current Pargo sites	Current Pargo sites in each hexagon	Total potential customers	Hexagons to be captured by Pargo within 1-mile	Top Potential customers within x-mile	Pargo sites needed to cover whole area	Total potential customers within x-mile for current Pargo sites	% Total customers / Total population	Lowest no.of customers per Pargo site	Max no.of customers per Pargo site	Potential customers not captured	Hexagons not captured	Pargo sites needed to cover area
Westrand (1 Mile)	29	23	1,034,724	3,492	31,342	33	93,305	9.02%	18.47	18,778.67	941,424	3,443	30
Westrand (2 Mile)	29	23	1,034,724	3,492	88,271	12	274,594	26.54%	34.33	47,158.47	760,136	3,317	9
Sedibeng (1 Mile)	41	29	1,088,513	3,622	36,702	30	174,630	16.04%	13.44	36,702.47	913,886	3,558	25
Sedibeng (2 Mile)	41	29	1,088,513	3,622	125,861	9	518,454	47.63%	52.25	70,949.96	570,061	3,416	5
Ekurhuleni (1 Mile)	128	102	3,471,177	1,775	71,647	48	830,153	23.92%	8.24	71,647.38	2,641,022	1,565	37
Ekurhuleni (2 Mile)	128	102	3,471,177	1,775	243,481	14	2,110,225	60.79%	49.45	142,198.70	1,360,948	1,158	6
Joburg (1 Mile)	198	148	4,446,470	1,554	103,798	43	1,243,873	27.97%	3	97,856.00	3,202,687	1,268	31
Joburg (2 Mile)	198	148	4,446,470	1,554	241,069	18	3,020,605	67.93%	888.5	154,491.90	1,425,858	794	6
Tshwane (1 Mile)	161	130	2,865,638	5,230	48,171	59	667,877	23.31%	0.33	37,379.20	2,198,015	4,977	46
Tshwane (2 Mile)	161	130	2,865,638	5,230	158,603	18	1,722,001	60.09%	180.98	78,227.54	1,143,658	4,481	7

Figure E.1: Summary of output

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