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TOPIC: A study into Healthcare Service Location Problems, Location and Allocation in the Inanda area

FINAL DRAFT

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Abstract

Inanda is a predominantly rural area located on the northern coast of the province of Kwazulu Natal, South Africa. It is bordered by the areas of Phoenix, Verulam and Tongaat.

In the context of healthcare accessibility in the Inanda area, the research aimed at investigating the problem in service location planning. This was done by investigating level of accessibility to existing healthcare facilities available to the residents of Inanda. Following the classification of accessibility problems, recommendations were made on where the facility locations can be improved or expanded to provide better accessibility in terms of location-allocation.

Literature that has been reviewed focused on geographic location, GIS and accessibility measures, spatial accessibility, models used to test accessibility, service location planning and accessibility measures and metrics so as to provide a background and precedent for the service location planning carried out in the research.

The research aimed to confirm that accessibility to the healthcare facilities is indeed a problem and to propose alternative strategies to overcome the accessibility problems identified.

The access to healthcare service locations is dependent on a number of factors. Some of these factors include travel time and distance, available capacity at facilities, existing road network, and provision or lack thereof of an efficient public transport system. This accessibility to the health service locations was assessed by using available GIS information on healthcare facilities and using accessibility analysis to identify problems in terms of the services location as well as additional location-allocation of current and additional facilities. The analysis was based on the assumption that all service locations have unlimited capacity.

Flowmap was used as the tool to analyse the GIS data and conduct various accessibility models. The different models were Expansion Model Analysis, Relocation Model Analysis, Catchment Area and Clinic Allocation Analysis, Catchment Profile, Market share of Supply Locations, Regular Proximity Count, Average Distance in Competition, Proximity Count in Competition, Lowest Mean Trip Cost Alternate, Second Best Catchment Distance and Pareto Cover Set.

The results of the research showed that while the locations of the existing healthcare facilities are not ideal, most are accessible to the majority of the Inanda residents.

The information on actual capacity available at each of the locations was not available at the time of the research being carried out and would be worthwhile to research in the future.

1 Introduction

Healthcare is widely considered as a basic human right, and as such the most opportune scenario would be one in which healthcare is readily accessible to all persons, regardless of their ethnicity, gender, level of income, race group, or religious connotation (World Health Organisation, 2017). One of the characteristics of an ideal world would be healthcare available to everyone. In a quintessential setting, this would most certainly be the case. However, in reality, the access to universal healthcare is dependent on many factors and varies from place to place as well as country to country.

Healthcare should be universal and available to all citizens of a country. While this is a hopeful ideal, in some countries this is not the case with healthcare costs a burden to citizens as opposed to the government.

In some countries, the applicable legislation on healthcare determines how much of the population of that country are able to access universal healthcare. Some countries offer free basic healthcare which is available to every citizen. Others offer assistance in the form of medical aid schemes.

Another key factor is the demographic makeup of a country or area. In areas with a low income, public healthcare may be the only option available due to these residents not wanting to outlay money on expensive private healthcare.

The constitution of South Africa aims to provide all citizens of the country with the right to access this basic need. While basic healthcare might be provided to people in South Africa, the access to these services is the issue in question. The stark reality facing many people in the rural areas in South Africa, such as in KwaZulu Natal (KZN) is that not all residents have easy access to the healthcare amenities. While the government has provided healthcare facilities , these are only of real benefit if people are able to access them easily.(Department of Justice,2019)

South Africa is a case in point, with the population in the rural areas captive to public healthcare as this is the only means of healthcare they are able to afford. In the built-up urban areas, with a higher income bracket, residents here are able to afford private healthcare and have access to different medical aid options.

The geographic makeup of the country is such that there are still some areas of the population who have limited or no access to healthcare. In the built-up urban areas, medical facilities such as clinics and hospitals are accessible to almost every resident, due to road networks and pedestrian facilities being available in these areas to provide access. There are complete road networks, public transport services and private vehicle ownership that enables these residents to travel to the clinics or hospitals. On the other side of the spectrum are the rural areas. Inadequate or incomplete civil infrastructure lends to the problem of medical facilities not being accessible to all residents. This is due to people not being able to access the clinics or hospitals because either the road network does not provide enough routes to the facilities, i.e. inadequate public transport services are available, or the walking distance to these facilities are long and tedious and therefore not a preferred means of travel.

In the South African context, citizens have the option of receiving state health care which is funded by the government. Here there is a significant portion of the population that makes use of the public healthcare system. There is also the option of private healthcare by means of medical aid funds, however this coverage is expensive. Due to the large volume of population attempting to access the state healthcare, queues at health facilities are long and the service received not the best due to overcrowding, shortage of medical staff but most importantly lack of funding. For this reason, often the working class who earn enough choose to pay for private healthcare.

Yet, national policy requires that all people have the right to basic healthcare, in terms of the constitution of SA. The National Health Bill, No. 32 of 2005 confirms that the people of South Africa have access to healthcare services, in terms of their constitutional right. (Department of Health, 2005).

This necessitates that decision makers have access to methods and techniques of planning for the provision of basic healthcare for all citizens. One of the key considerations in this planning process, is the access to healthcare.

Accessibility is made up of a few criteria. These are related to travel time and distance. There are a number of techniques which can be used to determine accessibility, and these are explored in the subsequent chapters. Some of these techniques have been employed in this research in order to determine whether the healthcare facilities meet the criteria deemed accessible.

2 Research Design

Accessibility is described as the opportunity available to an individual at a given location to take part in a particular activity or in particular activities Jones (1981). The key word in this description being opportunity and the importance this has on the accessibility of a certain facility. To put this into a healthcare facility perspective, the level of accessibility of that particular facility will determine whether or not people are able to access the healthcare facilities.

Access is the chance of interaction, and mobility is the travel due to this chance of interaction with a particular place or facility. (Miller, 2018). So, in defining access it is the ability to travel to a location depending on its spatial characteristics. Access then can be further broken down in terms of being partly mobility as well as partly spatial spread. The level of access is dependent on how easily one is able to travel to a facility by means of transport system and road network or walking distance, as well as the spatial location of this facility which would influence the actual travel distance.

Healthcare services may be deemed difficult to access depending on several inherent factors. These factors include:

- the service is located far away and the distance to travel too cumbersome. (Guagliardo, 2004)
- the service provided is not sufficient to serve many people. Jensen et al. (2013)
- the healthcare facility is located in an area that is not well served by either a road network or an efficient public transport system so people are not able to travel to this location. LaMondia et al. (2010)

The key problem this thesis is addressing is therefore, how to use Geographic Information Systems (GIS) modelling to better understand problems of healthcare provision in rural areas and using this to optimize locations.

This is done by addressing the following objectives:

1. Identification of problems of healthcare provision in SA.

2. Literature on optimizing healthcare provision through service location planning.
3. Developing a geo-spatial model for the analysis and optimization of healthcare provision in a selected area in KZN.
4. Proposing alternative strategies to overcoming the accessibility problem.
5. Recommendations on policy to expand the insights to other areas of rural SA.

Figure 1 illustrates the research design employed.

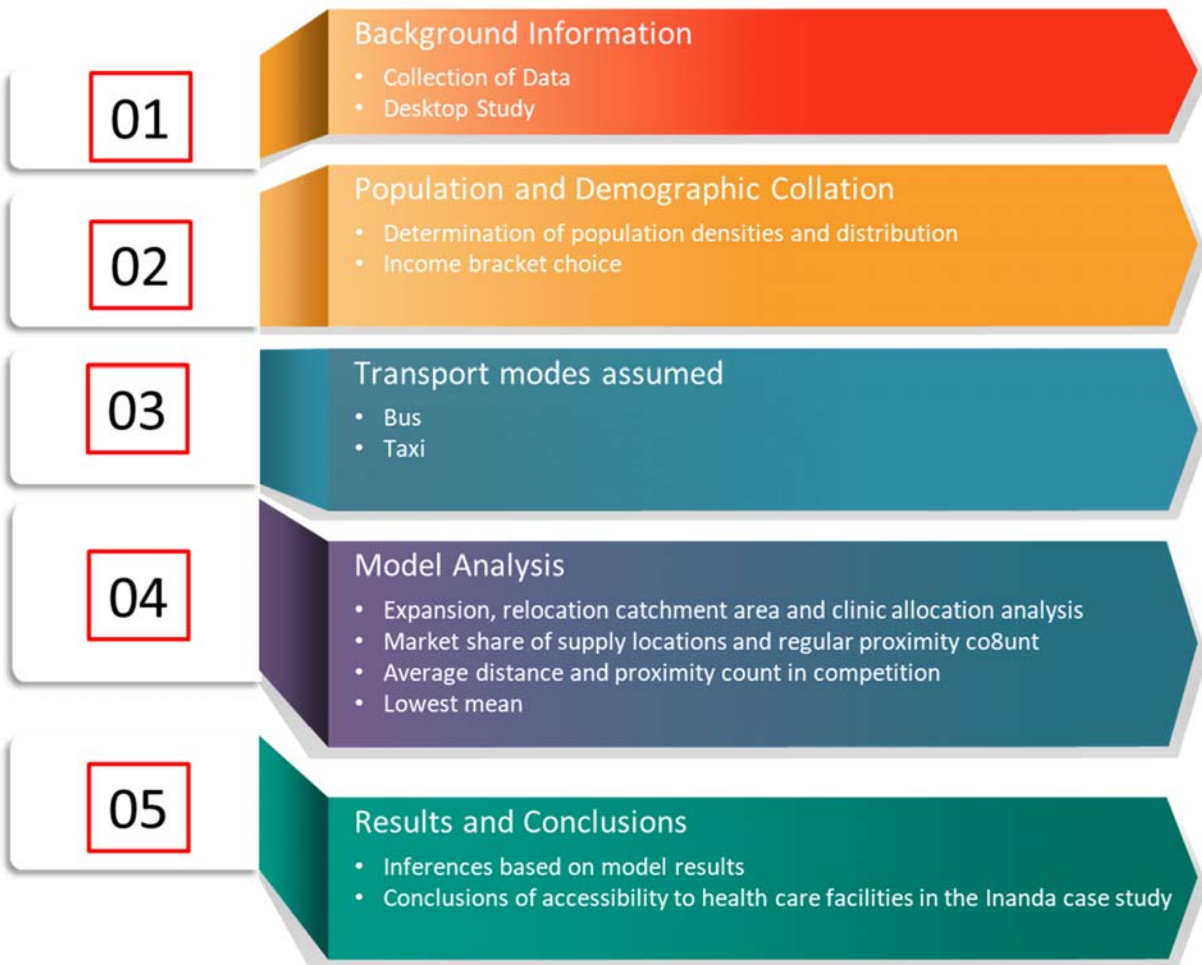


Figure 1: Flowchart showing Research Design

The objectives of the research will in part respond to universal healthcare problems as well as to the human rights as identified in the constitution.

3 Literature on Service Location Planning in the Context of Healthcare in Developing Countries

During the course of the research, evidence has shown that the location of healthcare facilities and the subsequent accessibility thereof has seven important considerations which are explored in more detail in this chapter:

- Geographic Location and Accessibility
- Accessibility concepts and metrics
- GIS and Measuring Accessibility
- Models Used to Test Accessibility
- Spatial Accessibility
- Service Location Planning
- Location-Allocation Models and Accessibility

3.1 Geographic Location and Accessibility

The geographic location of healthcare facilities has an impact on the actual accessibility. If facilities are located in hard to reach places, and not within convenient walking or travelling distance, this would in turn negatively impact the people's ability to gain access to the said facilities. People who have disabilities, as well as senior citizens, pregnant women, as well as people that travel with children would be affected by undesirable geographic locations. LaMondia et al. (2010) found that facilities providing healthcare are typically located quite a distance away from where older people live. This is turn means that it is difficult for the older generation to access these facilities. This study also found that with older people having to use paratransit as a means of transport to these healthcare facilities, the travel time to get to these facilities is very long. The location of healthcare facilities in terms of geographic desirability is one of the key factors in terms of ability to conveniently access these facilities.

Undesirable geographic locations will obviously render some facilities inaccessible. Foggin et al. (2009) conducted a study on the accessibility of healthcare for people in Tibet. Some of the key findings were that a vast majority of Tibetan women give birth at home and given the factors of altitude and poor electricity; there is an increased risk of complications for both the mother and infant. Another factor is that Tibet has the highest rate of tuberculosis in China. Due to geographic limitations in this part of the world the vast majority of the population does not reside close to healthcare facilities.

To find the correct location for a specific facility is quite an important consideration as this in turn would then affect the success of the said facility. There is no point in locating a facility in a location that will be geographically undesirable to most people. Owen et al. (2011) describes how the locations of some facilities are seen as investments and these are located with the hope that these facilities continue to be profitable well into the future. This is quite an interesting outlook in that these locations must withstand changes in the economy as well as topographical changes. Strategic planning is also explored as to how to locate facilities in the most favourable settings. This is interesting as a large amount of capital is invested at the outset to build these facilities and it would make sense to ensure that the location is well researched and planned to as to provide the most paramount benefits. Perry et al. (2000) conducted a study into the physical accessibility of primary healthcare available to the citizens of Andean Bolivia in South America. The study was centred around the region surrounded by the Andes mountain range to the one side, with rainforests to the other side. Most families in this area do not have access to private transport and a lot of travel is undertaken by foot. The study made use of available GIS information to determine the physical accessibility. The conclusion drawn from the study is that there is more investigation needed into other areas such as social, cultural and economic factors.

A study was carried out on the geographic locations of hospitals in four states in the United States of America, based on distances people travelled and travel times. Out of the four states studied, three of the states provided an optimal travel time, with the exception of the state of Tennessee. A conclusion drawn was that the trade-off between equity and efficiency in economic analysis is prevalent in the analysis of spatial accessibility as well. Another conclusion drawn was that by improving the efficiency of the location which in this case is related to the time the patient takes to reach the hospital, the accessibility is improved as well Burkey et al. (2012)

3.2 Acessibility Concepts and Metrics

From a transport planning perspective, the definition of accessibility is considered to be a function of various factors which are trip purpose, travel impedance, interaction and integration with opportunities (Miller, 2018). If we explore this definition a bit further, the level of accessibility to a particular service or location is dependent on the spatial location, distance to travel and any impediment to this travel as well as the purpose of the trip to the location.

In terms of measuring accessibility, research has shown that there are four measures.

The four measures of accessibility measurement are based on:

1. Distance to access the location.
2. Opportunities with regard to distance and time.
3. Gravity/entropy measures.
4. Utility-based measures,

according to Amer (2007), Handy et al (1997), Hansen (1959) and Ben-Akiva et al (1985).

Amer (2007) conducted a comparison of the various accessibility measures for health services and the relation to GIS. This is shown in Table 1.

Table 1 Comparison of Literature on Accessibility Analysis for Health Services

Author	Year	Approach	Measure	Spatial disaggregation	Socio-economic disaggregation	Friction of movement	Utility of opportunity	Focus	Country	GIS	Service
Truelove	1993	'What is'	Cumulative	Census tract, Enumeration area	Income, age	Euclidian	Yes	Urban	Canada	No	Day care center
Densham and Rushton	1996	Location allocation	Distance	Education district	Population, children	Euclidean + correction	No	Regional	United States	Yes	Education
Pacione	1989	'What if'	Composite	Postcode zone	Population, age	Euclidian	No	Urban	Great Britain	No	Education
Breheny	1978	'What is'	Cumulative	Census zone	Population, children	Travel cost	Yes	Urban	Great Britain	No	Education
Fortney	1996	Location allocation	Distance	Census tract	Population, children	Euclidian	Yes	Urban	United States	No	Education
Brent Hall et al.	1995	'What is'	Composite	District	Population, fertile females	Network	No	Regional	Costa Rica	Yes	Health service
Secondini et al.	1996	'What if'	Composite	Census tract	Population, size	Euclidean	Yes	Regional	Italy	Yes	Health service
de Jong et al	1991	'What if'	Cumulative	Tessellation	Population, size	Network	Yes	Urban	Canada	Yes	Health service
de Jong and Amer	2002	'What if'	Cumulative	Tessellation	No	Network	No	Urban	Tanzania	Yes	Health service
Martin et al.	2002	'What is'	Cumulative	Tessellation	Population, size	Network	No	Regional	United Kingdom	Yes	Health service
Marks et al.	1992	'What is'	Distance	Zipcode zone	Population, elderly	Euclidian	Yes	Regional	United States	Yes	Health service
Walsh et al.	1995	'What is'	Distance	Zipcode zone	Population, size	Network	Yes	Regional	United States	Yes	Health service
Bullen	1996	'What is'	Distance	Parish boundary Urban ward	Population, size	Euclidian	No	Regional	Great Britain	Yes	Health service
Doherty et al	1996	'What is'	Distance	No	Population, size	Euclidean + correction	Yes	Urban	South Africa	Yes	Health service
Hyndman et al	1997	'What is'	Distance	Census district	Population, age cohort	Network	Yes	Regional	Australia	Yes	Health service
Peters and Brent Hall	1999	'What is'	Distance	Tessellation	Emergency caller Population, size	Network	No	Regional	Canada	Yes	Health service
Perry and Gesler	2000	'What is'	Distance	Village (Point)	Population, size	Euclidian + Travel time	No	Regional	Bolivia	Yes	Health service
Hyndman et al.	2001	'What is'	Distance	Census district	Population, disadvantaged	Euclidian	Yes	Urban	Australia	Yes	Health service
Mallick and Routray	2001	'What is'	Distance	Village (Point)	No	Euclidean	Yes	Regional	India	Yes	Health service
Lovett et al.	2002	'What is'	Distance	Parish/Ward	Population, size	Network	No	Regional	United Kingdom	Yes	Health service
Parker and Campbell	1998	'What is'	Distances	Postcode zone	Patient number	Euclidian Network	No	Regional	Great Britain	Yes	Health service
Khan	1992	'What is'	Composite	SMSA	Population, size	Euclidean	No	Regional	United States	No	Health service
Wellings	1983	'What if'	Cumulative	Tessellation	Population, size	Euclidian	Yes	Regional	Lesotho	No	Health service
Massam et al.	1986	Location allocation	Distance	Village (Point)	Population, size	Euclidian	Yes	Regional	Zambia	No	Health service
Annis	1981	'What is'	Distance	Village (Point)	Population, size	Euclidean + correction	Yes	Regional	Guatemala	No	Health service
Knox	1982	'What is'	Distance Cumulative Composite	Census tract	Population, size	Network	No	Urban	United States	No	Health service
Ayeni et al.	1987	Location allocation	Distance	Village (Point)	Population, size	Euclidian	No	Regional	Nigeria	No	Health service
Hodgson	1988	Location allocation	Distance	County	Population, size	Euclidian	Yes	Regional	India	No	Health service
Mulvihill	1979	Location allocation	Distance	Home location of individual (Point)	Population, poor	Euclidean	Yes	Urban	Guatemala	No	Health service
Oppong and Hodgson	1994	Location allocation	Distance	Village (Point)	Population, size	Euclidian	Yes	Regional	Ghana	No	Health service
Geertman	1995	'What if'	Composite	Tessellation	Population, size	Network	-	Regional	Netherlands	Yes	Housing
de Jong and Ritsema van Eck	1997	'What if'	Cumulative	Tessellation	Population, size	Network	Yes	Regional	Netherlands	Yes	Jobs
Talen and Anselin	1998	'What is'	Container Composite	Census tract	Population, size	Network	No	Urban	United States	No	Playground
White et al	1997	'What is'	Distance	Enumeration district	Population, size	Euclidian	No	Regional	United Kingdom	Yes	Post office
Nicholls	1999	'What is'	Distance	Census unit	-	Euclidian Network	Yes	Urban	United States	Yes	Public park
Erkip	1997	Container	Container	Districts	Population, low income	Travel time	Yes	Urban	Turkey	No	Public parks

Source: SherifAmer (2007), Towards Spatial Justice in Urban Health Sciences Planning

Wan et al. (2012) proposed a different method of using Spatial Access Ratio (SPAR), which has its roots in the enhanced 2-step floating catchment area (E2SFCA). The SPAR method was found to be a stable model even with variations to distance impedance and could thus be useful in other spatial assess models which are gravity based.

There are different measures and metrics of measuring accessibility, with each having its own merits.

3.3 GIS and Measuring Accessibility

There is evidence of different methods being used to measure accessibility. One such method is making use of GIS information and correlating this to travel time and travel distance. McLafferty (2003) did some research into GIS and the subsequent relationship with health care, by making use of GIS information to establish health care needs of people in order to be able to meet the health care needs of these people. One point outlined is that people are willing to travel longer distances in order to get to health care specialists. So, in terms of location people are willing to travel further for specialised healthcare but not too far for normal primary health care facilities. The research concludes that with information being made more accessible to the population, this would enable people to know about health facilities and their locations.

Luo (2003) explored two GIS-based methods of measuring accessibility which would enable the United States Health Department to improve the population’s accessibility to medical services. The research is quite relevant to the Inanda research in that it considers travel time as a measure of accessibility.

Tanser et al. (2006) explored the accessibility to health care services in certain rural areas of South Africa by making use of geographical information systems. The study was conducted by means of conducting a survey of people to determine their travel patterns, and then modelling the travel time to get to the nearest health care facility. This seems to be quite accurate way to determine the travel time.

Lovett et al. (2002) conducted a study in East Anglia in the United Kingdomto determine the level of accessibility to doctors’ surgeries from both private and public transport modes by making use of GIS. The study found that about 13% of the population was not able to access doctors' surgeries via bus, while approximately 10% could reach the surgeries after a travel time of 10 minutes by private car. This research was conducted using patient registers and mapping the travel times using GIS systems.

Phillips, R.L. et al. (2000) explored the concept of using GIS to determine the accessibility to health care. in terms of the research, a study was conducted in the Boone County area in central Missouri in the United States of America (USA). The study analyzed patient records in the area and made use of GIS software to determine certain areas that had poor access to health care facilities. The study concluded that GIS was a useful tool in identifying areas that needed improvements in accessibility to health care facilities. This is a very useful conclusion in that GIS information is easily available from the relevant municipalities, although demographic information may be harder to come by. Census data may also be used as this information should be fairly accurate.

A study by (Bixby, 2004) was conducted in Costa Rica to determine the spatial accessibility to health care. The study made use of census data in terms of the population information and the correlation between health facilities. By making use of GIS, the study determined how accessible these facilities were to residents. The study found that the use of GIS was quite useful in determining the level of accessibility to health services in Costa Rica, as well as identifying areas that are in need of improved accessibility to health care. One very important issue raised was the aspect of decentralization which contributed to the lack of availability of data. This is quite an important aspect, as with the changing economic conditions and transport networks, land uses are changing in many countries around the world and thus accessibility to health care and other services is changing. This is an important point and is one which should not be overlooked. Any location studies conducted in the future should take cognisance of this fact and would do well to look at possible future scenarios and population changes Bixby (2004).

3.4 Models Used to Measure Acccessibility

Luo et al. (2009) found that access to health care services in a specific area is dependent on several factors. The population in that area, the availability of health care services and as socio-economic factors all contribute to the accessibility of that particular health care service. This study carried out an analysis using an enhanced two-step floating catchment area (E2SFCA) and assigned different weightings to zones with different travel times and found that there is a spatial accessibility pattern. The study concluded that this method can be used to determine health care services which are not as easily accessible to certain parts of the population.

Pacione (1998) examined the accessibility of secondary schools in Glasgow, England by making use of a gravity model. One of the conclusions drawn from this research is that social and political factors should also be taken cognisance of when considering the accessibility of schools. This does make sense in that while geography and land topography are important considerations when locating schools, other factors should be considered in the locations of schools as they play a part in determining whether or not schools are accessible. To put this into perspective for the Inanda area, the political and social factors prevalent during the apartheid era would have definitely played a part in the geographical locations of the clinics.

Field et al. (2001) conducted a study by making use of a questionnaire for 12 primary healthcare practices in the area of Northamptonshire, in the United Kingdom (UK). In terms of the results of this study, it was found that the availability of transport determines the level of access to primary healthcare. The findings in terms of travel were that patients living further away from the practice had a harder time to travel as opposed to those patients living closer. Another conclusion drawn was that as distance away from the practice increased, so too did the cost of the journey as well as the time spent travelling so this made the practice less accessible. This does make sense in retrospect as travel time and costs are major factors in determining the viability of a health care facility and its subsequent location.
Shariff et al. (2012) explored the concept of healthcare facility planning in one district of Malaysia by making use of algorithms. The study explored the positioning of healthcare facilities so as to ensure that the majority of the population living within that specific area have access to the facility. As part of the conclusions of this research, it was found that this analysis can assist in determining facility locations that are undesirable and that would in turn not serve a significant portion of the population. These finding would then contribute to future planning and location of facilities.

Zhang et al. (2009) explored the design of a network of preventative healthcare facilities in order to ensure that these facilities are readily available and the most accessible. This was quite an interesting study which explored the mammography-center network in Montreal, Canada. The model took into account traffic congestion as a measure of the participation of the population. The difference with preventative health care services, as opposed to primary health care, is that people can choose the facility they wish to visit. This is quite relevant in that people can choose different facilities based on their desire to avoid traffic congestion in getting to their chosen destination.

A study into rural healthcare in the area of Cornwall in England was conducted which included public and private transport information as well as GIS information in order to measure the accessibility of health service facility locations to the population of Cornwall. This study also looked at population information as well as travel times to general hospitals in Cornwall. The study concluded that there are other factors other than accessibility that need to be taken into consideration. Martin et al. (2002)

3.5 Spatial Accessibility

The concept of spatial accessibility to health care is an interesting one and very relevant. Guagliardo (2004) explored the spatial accessibility to health care in the United States. The study looked at how accessible primary health care is to most of the population and what factors directly affected the accessibility. One of the conclusions drawn was that more research needs to be conducted into travel, distance and the access to health care.

In an experiment conducted into the spatial accessibility of health care facilities in Ghana, one of the conclusions drawn was that more facilities are needed in order to make healthcare more accessible to the population. The experiment utilised location-allocation models and how these models could be utilised in order to improve the accessibility to healthcare in third world countries Oppong et al. (1994). This is similar to the research being conducted for the Inanda area, with the identification of service location problems, as well look location and allocation of the service locations.

3.6 Service Location Planning

Hertel and Sprague (2007) used GIS demographic information obtained from the United States Census data in the service planning of libraries. The data was then used to compare the library user locations with the library locations. This research follows a similar principle by making use of the demographic and geographic spatial information in the context of analysing the location problems, as well as location and allocation of the healthcare facilities.

In terms of the research being carried out in this thesis, there are a given number of healthcare service locations. These facilities are currently in existence in the Inanda area. The research aims to determine the level of accessibility to the said locations, in terms of maximum travel distance and the specific time period. Polo et al. (2015) explain a location-allocation model with maximum coverage but finite demand, in which facilities are chosen within a distance limit to cater for all or most of the demand. The model formula is as follows:

$$z = \sum_{i \in I} \alpha y_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.1$$

$$\sum_{j \in I} x \geq y_i\,, \qquad \forall i, \qquad ..\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2$$

$$\sum_{j \in J}^{n} x_j = P, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3$$

$$x_j = (0{,}1) \qquad \forall j, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..4$$

$$y_j = (0{,}1) \qquad \forall i, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..5$$

- I is the set of demand nodes,
- J is the set of facility sites,
- $x_j = 1$ for a facility located at j, and $x_j = 0$ If not.
- $y_i = 1$ if the demand from I is covered by a facility and $y_i = 0$, if not
- $N_i = \{j|d_{ij} \leq S\}$ is the set of facilities which are eligible to provide cover for the demand i.
- S is the distance limit, beyond which a demand point is considered to be uncovered,
- d_{ij} the shortest distance between i and j,

- P the number of facilities to be located,
- $\propto_i$ the population to be served at demand i Polo et al. (2005).

Kao and Lin (2002) proposed a model which looks for the minimum sum of distances between each of the demand points to the location serving them.

$$Min \ \sum_{i=J} di \quad \ldots\ldots\ldots 1a$$

Subject to the following constraints

$$\sum_{j\in N_i}(D_{ij}t_{ij}) \leq d_i \quad i \in I \ \ldots\ldots\ldots 1b$$

$$\sum_{j\in N_i} t_{ij} = 1 \quad i \in I \ \ldots\ldots\ldots 1c$$

$$t_{ij} \leq x_j \quad i \in I \ \ldots\ldots\ldots 1d$$

$$\sum_{j\in J} x_j = P \ \ldots\ldots\ldots 1e$$

$$x_j = (0,1) \quad j \in J \ \ldots\ldots\ldots 1f$$

- d_i is the distance between demand point I and the nearest collection location *i*
- $D_{ij}$is the distance between demand point i and service location j
- $t_{ij}$the dummy variable between 0 and 1 (with 1 implying that location j is the nearest of all serviceable locations from demand point j)
- x_j is a [0,1] integer variable with 1 implying the location is selected, and 0 not selected.
- J is the set of all candidate locations,
- I is the set of all demand points,
- $N_i = [j \in J \mid D_{ij} \leq S]$ is the set of candidate locations considered serviceable for demand point i(MSW generation point) within a certain maximum distance limit S; and D_{ij} is
- the distance between location j and demand point i.

3.7 Location-Allocation Models and Accessibility

Location-allocation models are described as playing a very important role in the accessibility of primary health care facilities. A study was conducted using data for Goa in India and one of the key findings was that location-allocation models could be useful in determining accessibility of health care facilities in third world countries. These findings are quite useful, in that accessibility to healthcare is a major problem in rural areas in some countries

Hodgson (1988). Added to this is that it should be a basic human right to be able to access health care easily. In many rural areas in South Arica in particular, quite a substantial portion of the population is not able to access these facilities and this leads in some cases to further health complications and in some severe cases even death.

Cho (1998) explored an approach to location-allocation modelling in the Chongju Metropolitan area of Korea. The model developed explored equity and efficiency in terms of the locations of medical facilities. The analysis concluded that the current location of medical facilities in the region are not optimum. One of the major aspects that is made note of, is the fact that this method of modelling does not take into account changes in population and social factors. This is quite important in that this type of location-allocation modelling would thus only be used in the short term as future conditions are not able to be modelled effectively.

A study into location-application modelling in rural areas of Ghana delved into the amount of data available and the type of data which would then inform the modelling process. Location-application modelling was used to model the distances from the health centres and how much of the population is served by the relevant centres. Jensen et al. (2013)

The method of location-allocation for specialized health care services in the United States of America was explored by Syam et al. (2012). The study was based on information obtained from the U.S. Department of Veteran Affairs. The research is focused on specialized health care services and a location-allocation model for these health care services. The study developed an optimization model to determine the service level provided to veteran patients. The model includes distances travelled to facilities as well as the inclusion of acuity levels. A further managerial experiment was carried out to determine the difference between a facility that is centrally located as opposed to a facility that is decentralized. An important finding was that while a facility might not be centrally located and cost more, this facility would ultimately serve a greater number of people being admitted.

Bennett (1981) conducted a study by using location-allocation to determine the optimal locations for health care centers in the area of Lansing, Michigan, in the United States of America. The results of this study found that instead of the five facilities originally proposed, four facilities would be more widely utilized by the population of this area and identified the best positions for these facilities to be located.

A study into the services planning for the city of Dar es Salaam in Tanzania was conducted by (Amer, 2007). In terms of this study GIS methods were explored in determining the accessibility of as well as location-allocation planning of health services in the urban context. The study focused on the cities in sub-Saharan Africa and used the city or Dar es Salaam in Tanzania as the case study. The study aimed to develop a GIS- based planning approach to analyse the provisions of health care service

The research was conducted in terms of exploring the concepts of urbanization and social justice in the connect of health care, and how these factors influenced the development of various cities in sub-Saharan Africa.

The objectives of this study were aimed at exploring mainly the inequality, economic development, existing health care system and delivery and socio-spatial factors. With the end-result being the development of a GIS-based approach to investigate the provision of and access to health care in Dar es Salaam.

The methodology of this study described accessibility and the relationship to spatial planning. While the research explains that all these approaches have merit, GIS-based accessibility analysis is also useful in health services location planning.

A survey was carried out on a sample area for both patient/household as well as health facilities. This together with GIS data for the Dar es Salaam area, was used to provide the data set for the accessibility analysis.

In terms of the analysis carried out, travel time was used as the measure to determine accessibility. Comparisons were also drawn between accessibility analysis and the neoclassical approach. Both travel time by walking as well as by bus were used to measure the accessibility by means of two scenarios:
(1) 40 mins walking time cut-off and 60 min PT time.
(2) 60 mins walking time cut-off and 60 min PT time.

The study concluded that while the GIS-based approach is useful in accessibility measurement, it is also dependent on the availability of data. (Amer, 2007).

4 Case Study of Inanda, KZN, South Africa

Inanda is located on the northern coast of KwaZulu Natal close to the areas of Phoenix, Verulam, KwaMashu and Tongaat. For the most part, the area is made up of low to medium income residents demographically.

Inanda is a remote area in KZN. The area is known for lacking basic healthcare facilities due to it being characteristically rural in nature. Based on this rural context, it is thus expected that residents need to travel some distance in order to gain access to the existing healthcare facilities. The measure of the actual accessibility to these facilities will be analysed within the service location planning, in order to ascertain whether the location of the healthcare facilities is deemed to be acceptable in terms of distance and travel time.

4.1 Historical Context

The history of Inanda has shaped the area into what it is today. In the past, Inanda formed a part of the series of townships that were segregated due to racial discrimination because of the Group Areas Act of 1950. This Act aimed to eliminate areas with mixed race groups and instead favoured racially segregated areas. This Act was passed during the apartheid regime and as a result of this history; the Inanda area to date is still predominantly rural and not very developed in terms of road networks and public transport services. While these services do exist, they are not on the same level as other developed areas. This area is still largely disadvantaged with regards to the access to opportunities and services as the area is still very much rural in context. In the more developed areas opportunities are more readily available and accessible. SA history,2019.

The location of the Inanda area in location to South Africa is shown in Figure 2.

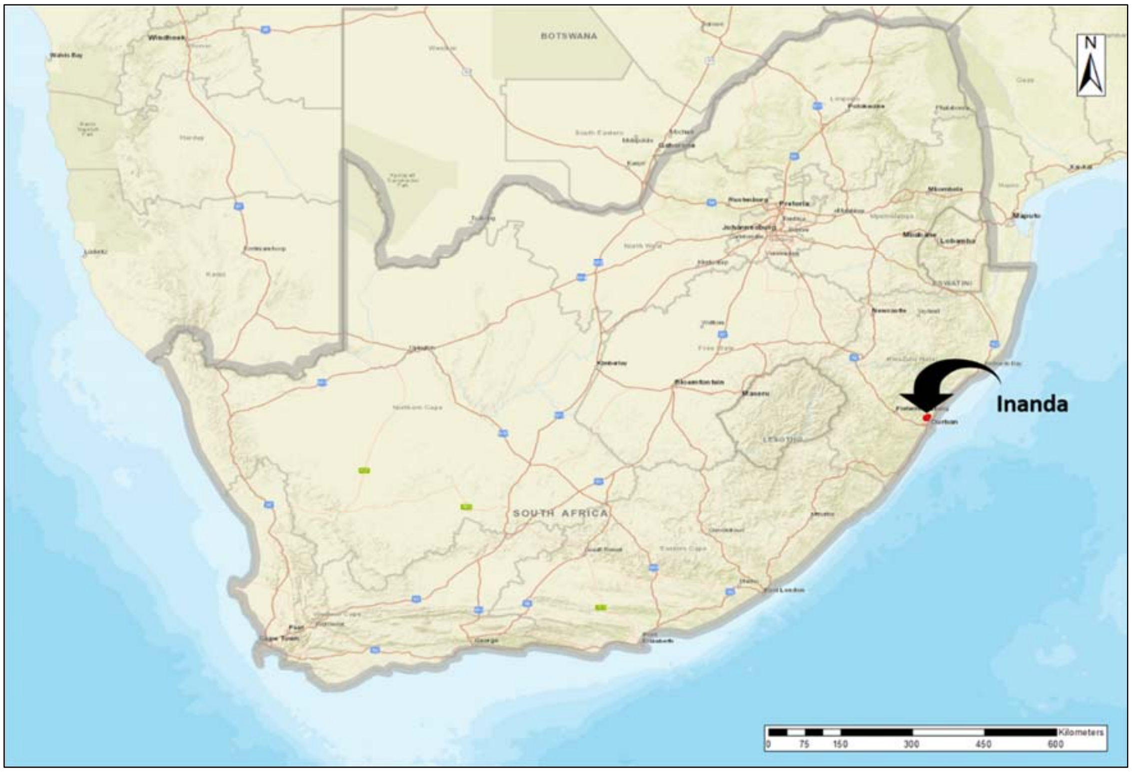


Figure 2: Location of Inanda in South Africa

Within the rural context, people in these areas sometimes walk for kilometres on end to get to either school, places of employment or healthcare facilities. While there are public transport services available in the area in the form of buses and minibus taxis, these services are not always accessible to all residents due to the strategic positioning of the road network. The Inanda area is comprised of a rural network in nature and as such, people travel in much the same way as other rural areas, by walking or making use of public transport services if they are fortunate to be able to access these services.

The Inanda area has a rich history dating back to the period of the 1800s, when this area was demarcated as a “settlement area” for the African population. The area in today’s terminology can best be described as an informal settlement (eThekwini Municipality, 2019).

4.2 Study Area

The town of Inanda is located to the north of Durban, in the province of Kwazulu Natal adjacent to the areas of KwaMashu and Umzinyathi.

The Inanda area falls to the east of the KZN area as shown in Figure 3.

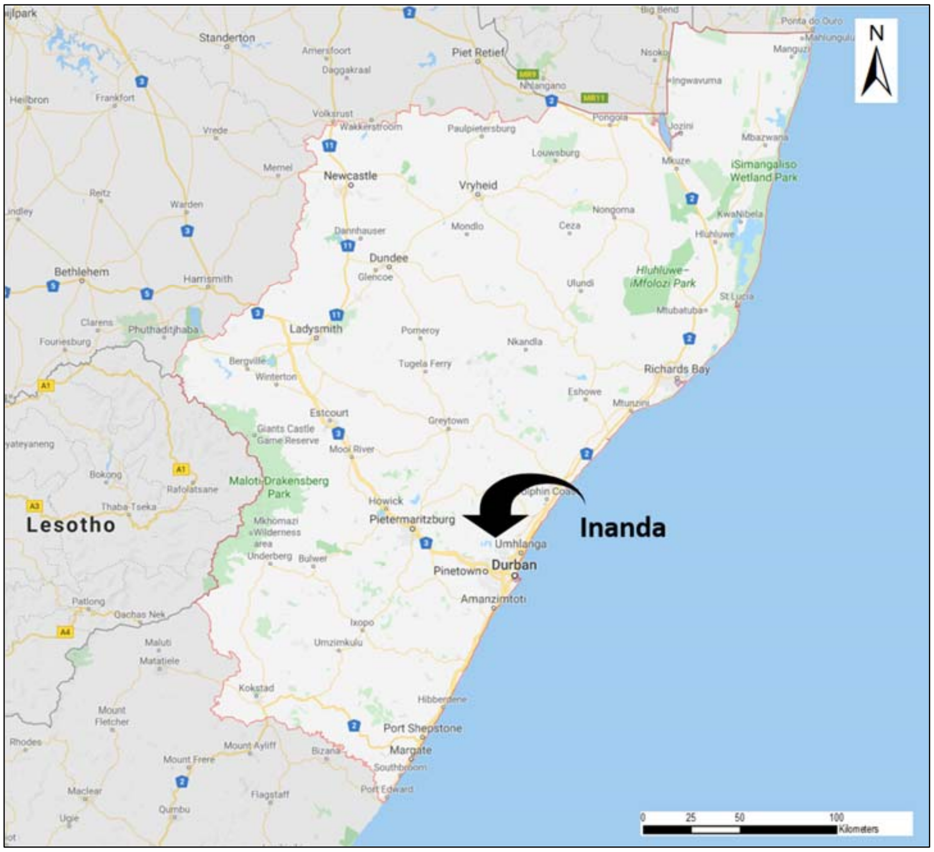


Figure 3: Location of Inanda within KZN

Inanda is found to the west of Phoenix, and to the north of KwaMashu. Figure 4 shows Inanda in relation to the rest of the Durban area.

Figure 4: Inanda in relation to the rest of Durban

4.3 Inanda in the rural context

The area of Inanda is predominantly rural in nature, with most residents being in the low to middle income category. It is by no means an affluent area, and it stands to reason that residents make use of public transport, private transport as well as walk trips to reach their destinations. Figure 5 shows the Inanda study area.

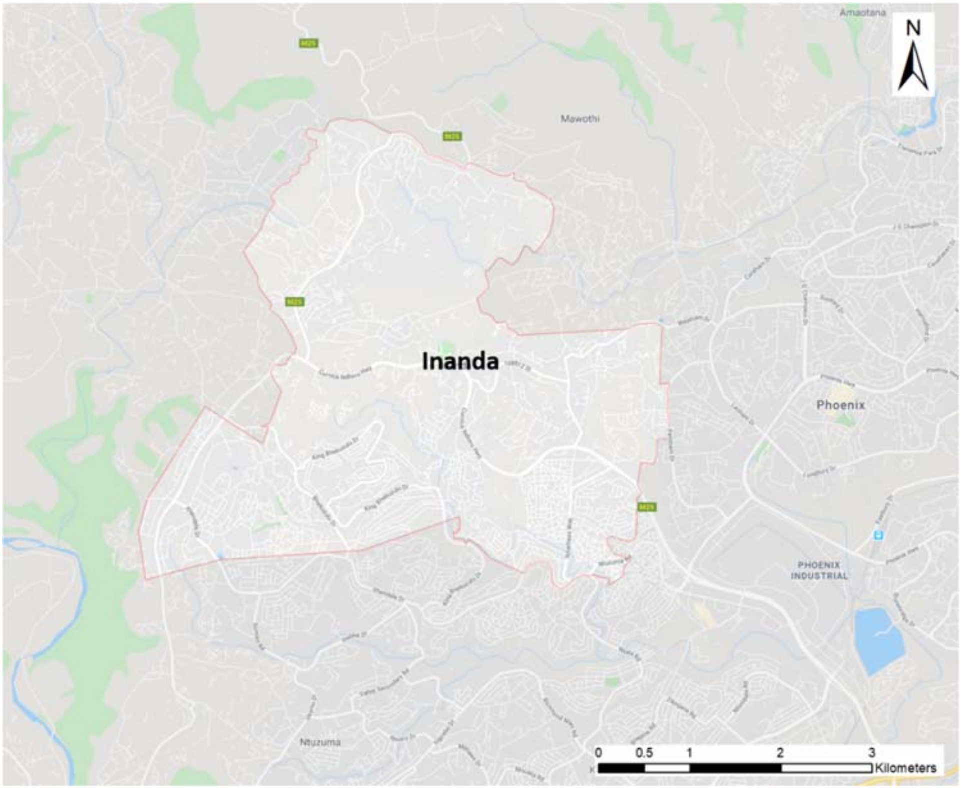
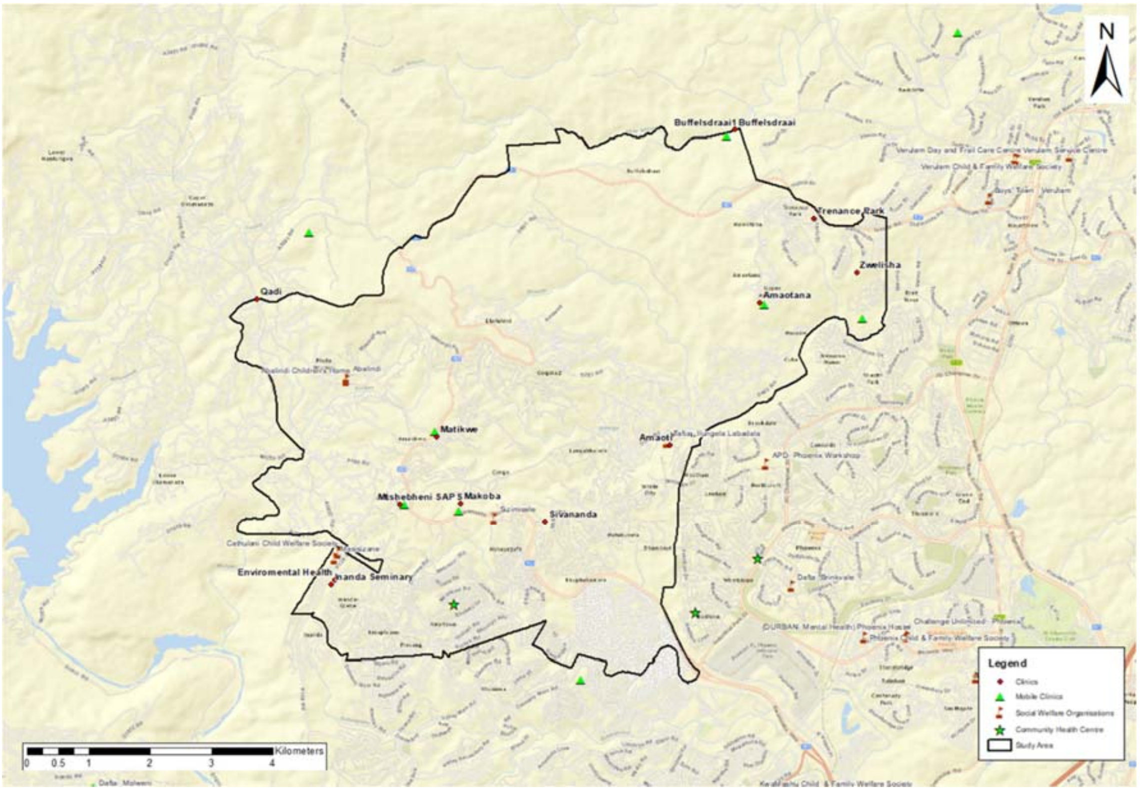


Figure 5: Inanda study area

4.4 Service Location Problems in Inanda

The analysis of the service locations in this thesis, hopes to ascertain which areas are not served by these healthcare facilities. Following this problem inventory, the analysis aims to determine how accessible the existing facilities are to residents in terms of distance to travel and time.



Source: *(Department of GIS eThekwini Municipality,2019).*

Figure 6: Inanda area showing healthcare facility locations

The study has shown that there are currently no hospitals located within the Inanda area. The nearest hospitals are located approximately 7 kilometres away outside the border of Inanda. Figure 6 shows the existing locations of health care facilities in the vicinity of the Inanda area.

The nearest state provincial hospital for the residents of Inanda is located approximately 8 kilometres away and this is Mahatma Gandhi Hospital which is situated in the Phoenix area. The other closest state provincial hospital is Osindisweni Provincial Hospital which is 7.5 kilometres away in the Verulam area.

In addition, there are two private hospitals located outside Inanda. These are Mount Edgecombe and Umhlanga Hospitals respectively. As these are both private hospitals, it may be concluded that very few residents of Inanda make use of these facilities due to the current demographic breakdown of the area being predominantly low or middle income.

There are five mobile clinics all located within the Inanda area. These clinics are spread out around the Inanda area and appear to serve quite a few areas of the area.

There are five fixed clinics. There is also a Community Health Centre located in the southern part of Inanda.These clinics are located at various locations around the area.

The research aims to ascertain whether the healthcare facility service locations are situated in optimal areas.

The Inanda road network that is more dense in the south and west parts of the area, while more sparse in the north and east areas. The research aims to investigate the effect this has on the level of accessibility to the health service locations.

4.5 Data Collection

Shapefiles for the Inanda area were obtained upon request from the GIS department of the eThekwini Municipality as well as from the eThekwini Transport Authority.

Health services information for the Inanda area was obtained via the eThekwini GIS website.

The following information was obtained:

- 2015 demographic information.
- 2015 employment information.
- Health services locations in Inanda and surrounding areas.
- 2017 Inanda road network.
- 2017 public transport routes and stops.
- 2017 Minibus taxi routes and stops.

4.5.1 Boundary and sub-areas

Within the Inanda boundary, there are 10 subareas which have been delineated according to traffic zone data obtained from eThekwini Municipality. No demographic data pertaining to suburb boundaries was available from eThekwini Municipality and in this regard traffic zone information was used to delineate the different areas within Inanda. Additional information was extracted from the 2001 Census information obtained from Statistics South Africa (2019). The subareas are shown in Figure 7.

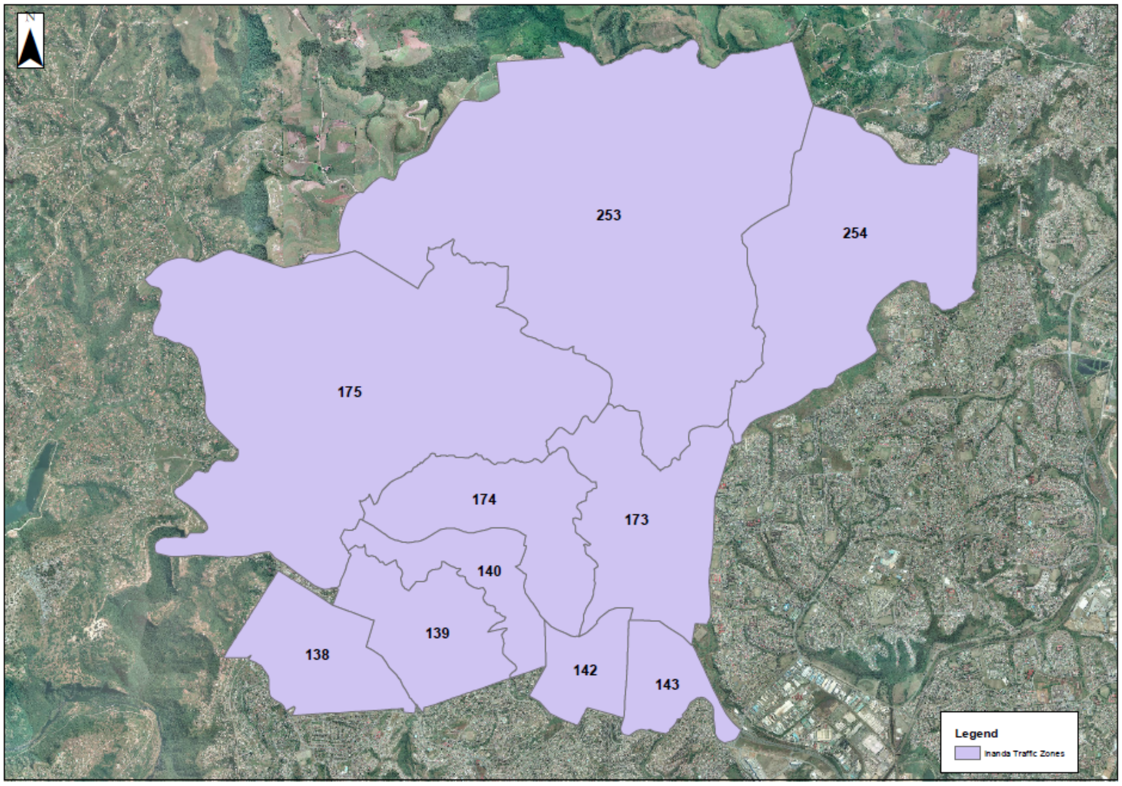


Figure 7: Traffic zone subareas

4.5.2 Demographic Characteristics

The existing demographic information in this regard has been obtained upon request from the eThekwini Transport Authority. For the purposes of the study, it is assumed that the income category for Inanda residents is low income. Based on this income, the 2015 employment figures were used in the analysis.

4.6 Population Density

The population density of the Inanda area is shown in Figure 8. Further information on population distribution was obtained from the 2001 Census information. The population density extracted in shown in Figure 8, with the height of the bars denoting the level of density.

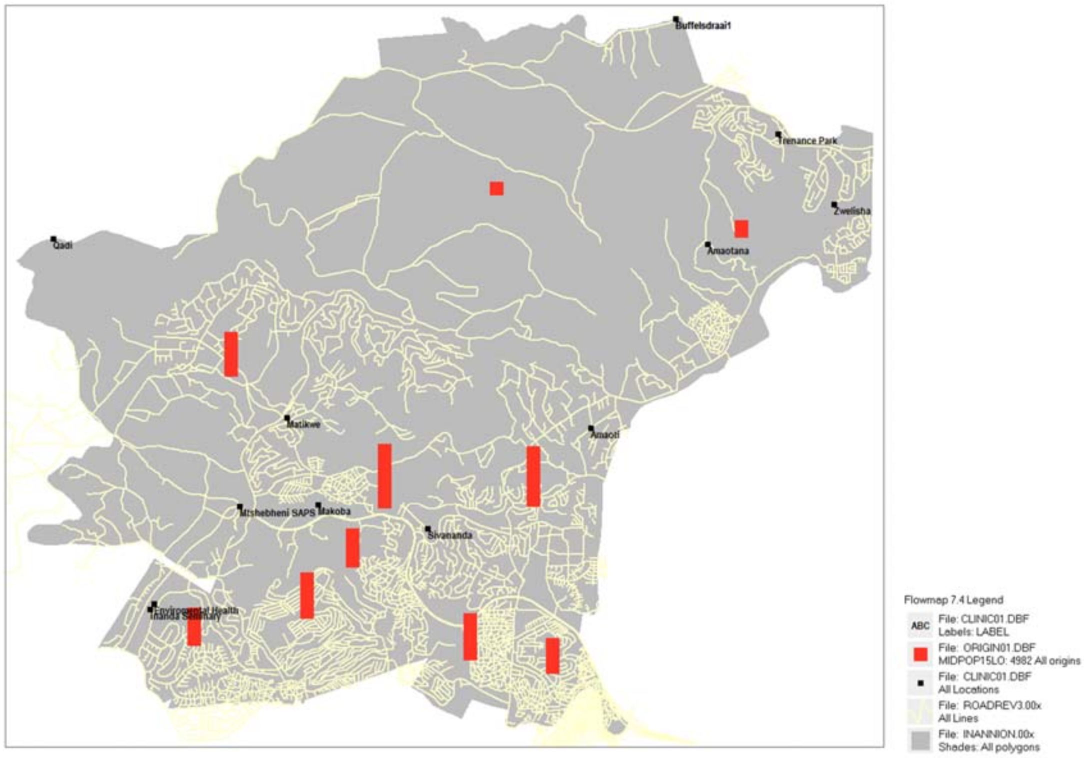


Figure 8: Bar chart showing population densities

4.7 Road Network

For the purposes of this study, traffic zones were taken from eThekwini's GIS database for the Inanda area in question. The GIS data obtained included both traffic zones as well as suburbs boundaries.

The existing road network was extracted from the GIS database obtained upon request from eThekwini Municipality, and used as a base input into the model.

The existing road network is quite dense in the southern part of Inanda, but very sparse in the northern areas, as shown in Figure 9. For this reason, accessibility is expected to be better in the south as compared to the north due to the density of the road network providing a better coverage.

Figure 9: Inanda Existing Road Network

4.8 Assumptions and Limitations

The latest demographic information available was obtained from the 2008 Household Travel Survey (HTS) from eThekwini Municipality. From this survey data, the 2015 forecasted year information was extracted for the analysis. In terms of this information, the medium growth population scenario was assumed to be the most suitable to be used in the analysis, as this gave the best approximation of the forecast data.

Only the low income demographic information was used in the analysis as the assumption was made that this income group would be the most affected in terms of accessibility to the provincial clinics.

5 Service Location Planning

The service location planning in this thesis was carried out based on the available geo-spatial information. The accessibility, location and allocation of the Inanda health care service locations was analysed using the tool Flowmap.

5.1 Flowmap

Flowmap was used in the thesis as the tool to conduct the service location planning. It has been used to analyse the GIS data and conduct the various accessibility models. Flowmap is a programme that uses GIS information to analyse locations. It has the capability to compute travel time, travel distance and the number of facilities required. The outputs from Flowmap are numerical and graphical in nature. de Jong et al (2007).
There are numerous model analyses that can be carried out in Flowmap such as:

- catchment area analysis,
- Coverage Model Analysis,
- Expansion Model Analysis, Relocation Model Analysis,
- Catchment Area and Clinic Allocation Analysis,
- Catchment Profile,
- Market share of Supply Locations,
- Regular Proximity Count,
- Average Distance in Competition,
- Proximity Count in Competition,
- Lowest Mean Trip Cost Alternate,
- Second Best Catchment Distance and
- Pareto Cover Set.

The location-allocation model (Polo, 2015) and minimum sum distance (Kao and Lin, 2002) as discussed previously, are operationalised in the analysis carried out in Flowmap in this thesis.

6 Data and Model Analysis

The GIS data and Flowmap were used to conduct the accessibility analysis. The following models were analysed.

6.1 Coverage Model Analysis

The coverage model in Flowmap aims to establish how many of the existing facility locations meet a minimum level of service. This analysis was carried out in the Inanda case to determine how many healthcare service locations are necessary in order to be accessible by residents utilising a mode of transport. For this analysis, using the chosen mode of transport as the bus, the number of clinics required so that people would not have to travel more than an hour to access the location was calculated. The results of the analysis shown in Figure 10, illustrate that there is one service location that is required to serve the area of Inanda based on residents travelling for the maximum allowable travel time of 1hour, by bus. It is also important to note that the road network is more dense in certain parts of the Inanda area, and sparse in the other areas which would mean that the level of accessibility to the bus via the road network differs in some areas. For this reason, having a single healthcare facility would not be practical, due to the fact that the degree of accessibility to this facility might not be uniform throughout the Inanda area.

Having one clinic to service the whole of the Inanda area is not a practical solution as this would mean all residents in the Inanda area would only have the option of being treated at a single clinic and this would not be efficient nor a pragmatic solution.

Due to one clinic not being considered a practical and workable solution, further research was carried out in order to determine location-allocation and expansion of the existing health care service locations. The following models investigate the health care locations in more detail.

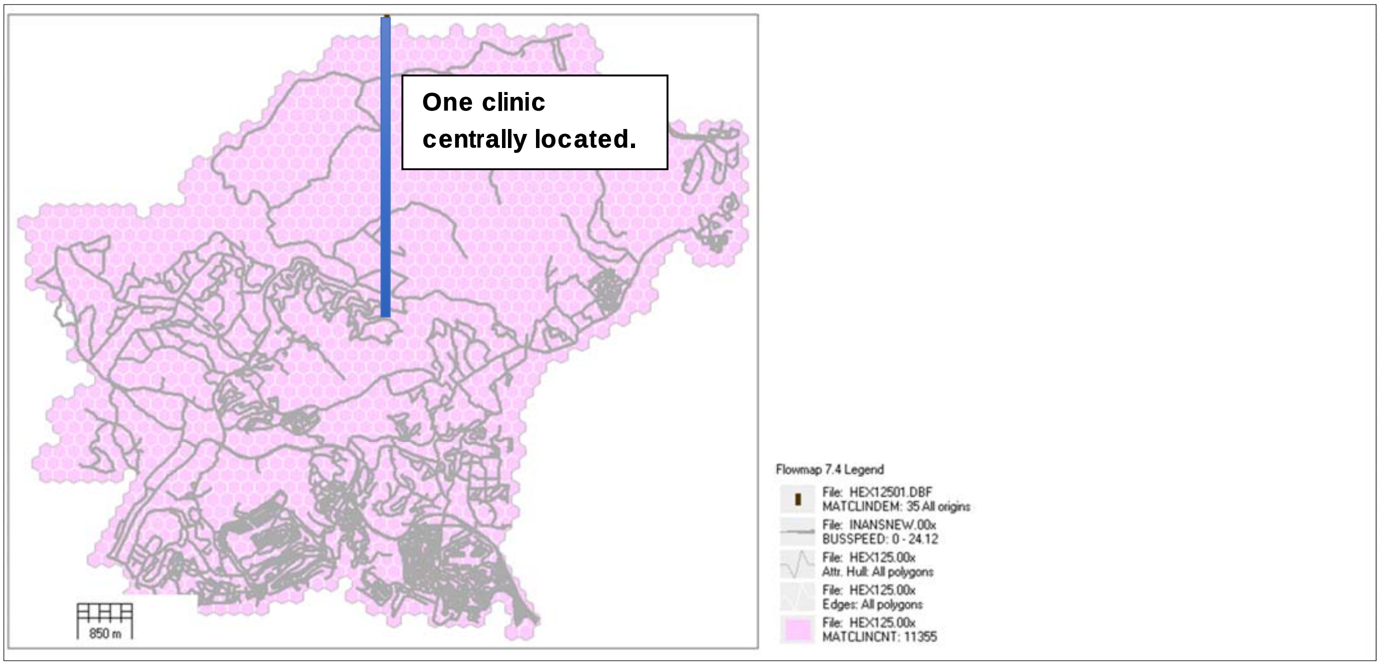


Figure 10: Clinics centrally located in Inanda

6.2 Expansion Model Analysis

The expansion model analysis aims to determine if there is a need for more clinics to serve the area, based on each clinic having maximum capacity available and assuming the maximum allowable travel time is 10 minutes by bus. For the previous coverage model analysis, the maximum travel time of 1 hour was not found to be practical and hence the maximum allowable travel time for the expansion model analysis was reduced to 10 minutes. According to the results depicted in Figure 11, there is a need for the service to be expanded in the north of the study area and more clinics or healthcare facilities should be located there. Based on the actual area of Inanda being approximately 6,300 hectares, the maximum allowable travel time of 10 minutes is realistic, but not achievable as can be seen from the red hatch on the map with these areas falling outside of the 10 minutes. More facilities are needed in the highlighted areas, and the services should be expanded to these areas.

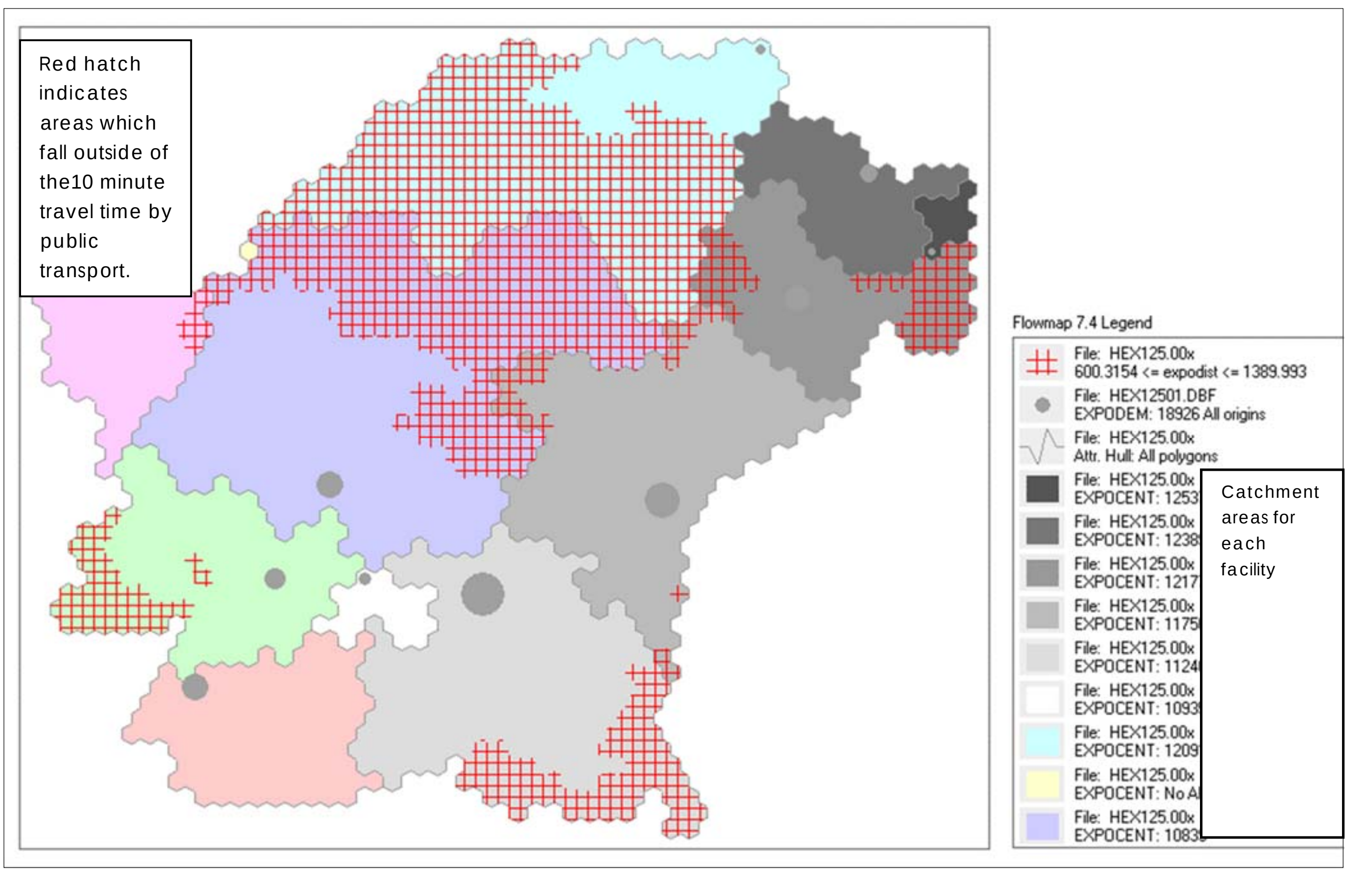


Figure 11: Location for additional healthcare locations

The interesting observation made in this analysis, is that while it is clear that more healthcare locations or clinics need to be built in the northern quadrant of the study area considering the demographic makeup of this area funding for these locations might prove to be a challenge. In addition, improvements to the existing road network could also be a consideration in improving accessibility to the clinics.

6.3 Relocation Model Analysis

The relocation model analysis aimed to determine the optimum locations of the service locations and where these sites could be moved to in order to minimise the total travel time. The analysis is based on minimising the travel distance to the clinics, and the model runs until the worst case distance is reduced and the service is located in the optimum location with the least travel time in seconds. These optimised locations are shown in Figure 12. The optimum locations have the least travel time to the clinics.

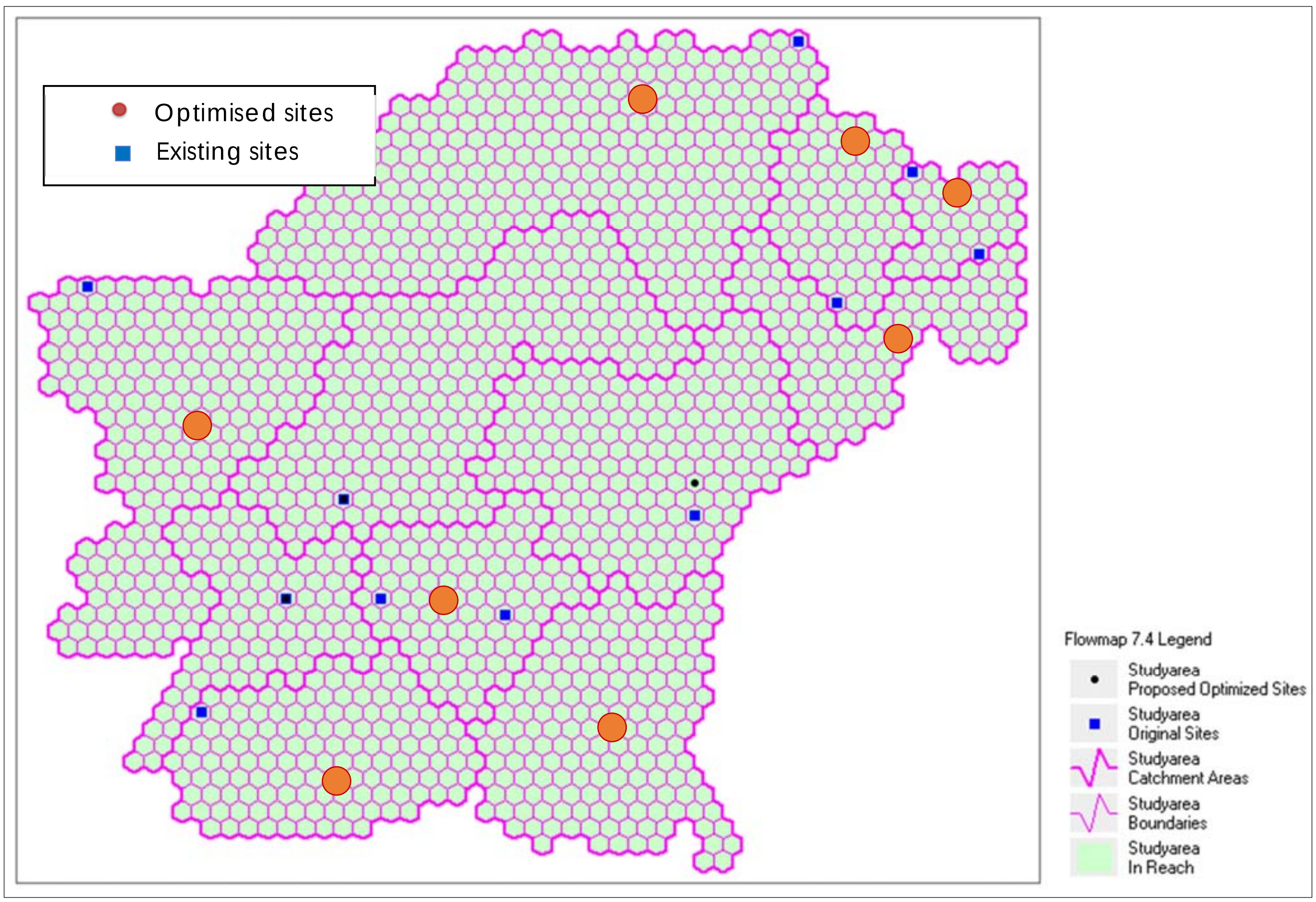


Figure 12: Proposed Optimum Locations

The locations optimal positions are shown to be in the centre of each catchment area, which would ideally make the sites more accessible to the residents within that area.

6.4 Catchment Area and Clinic Allocation Analysis

The catchment area analysis was conducted which aimed to determine which area is allocated to each of the clinics. The clinic allocation and relevant catchments are highlighted in Figure 13. The areas highlighted in orange are too far from an existing clinic and are not allocated to any clinic.

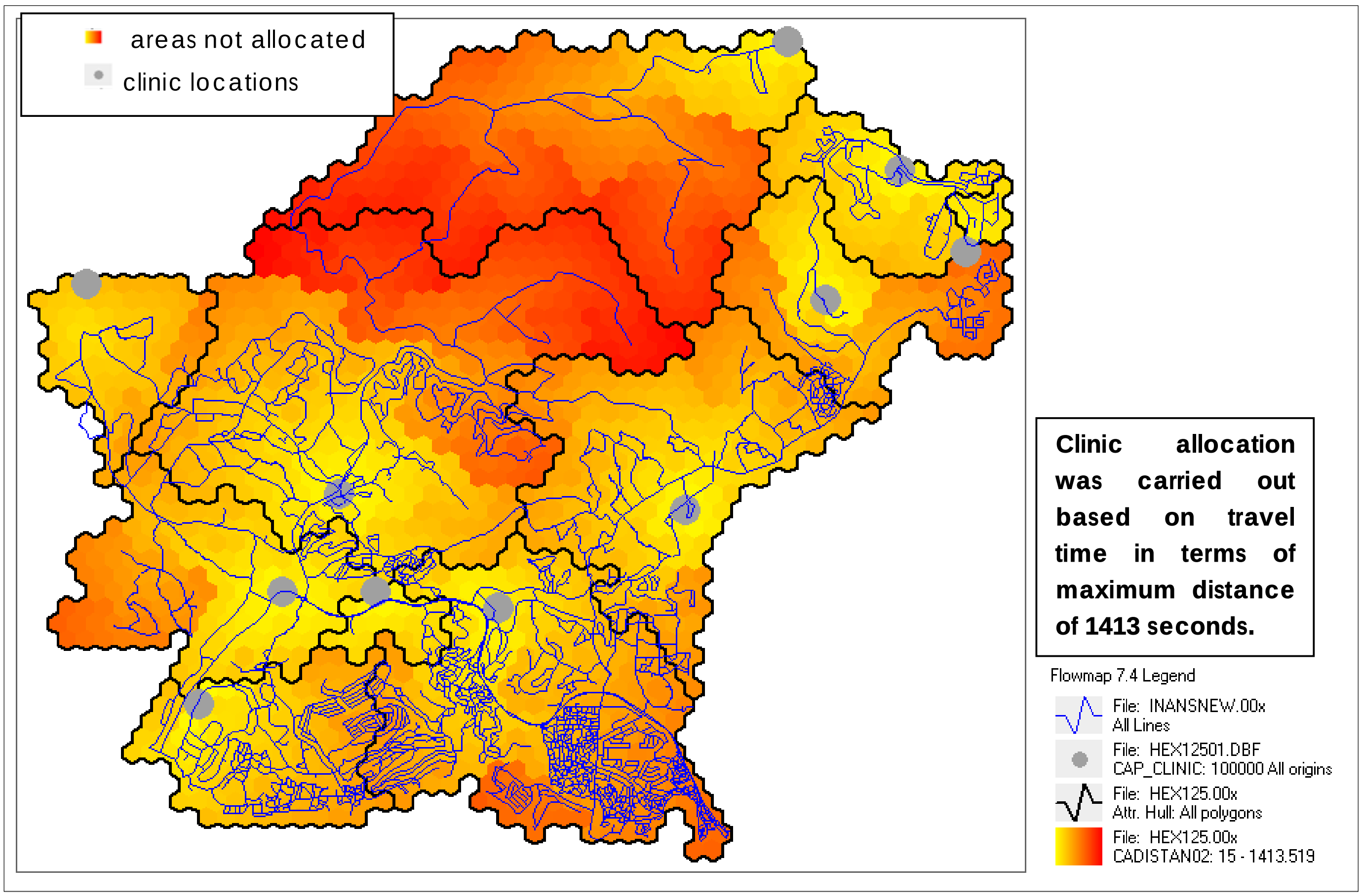


Figure 13: Catchments and allocated clinics

The different catchments areas and relevant existing clinic locations are illustrated in Figure 14.

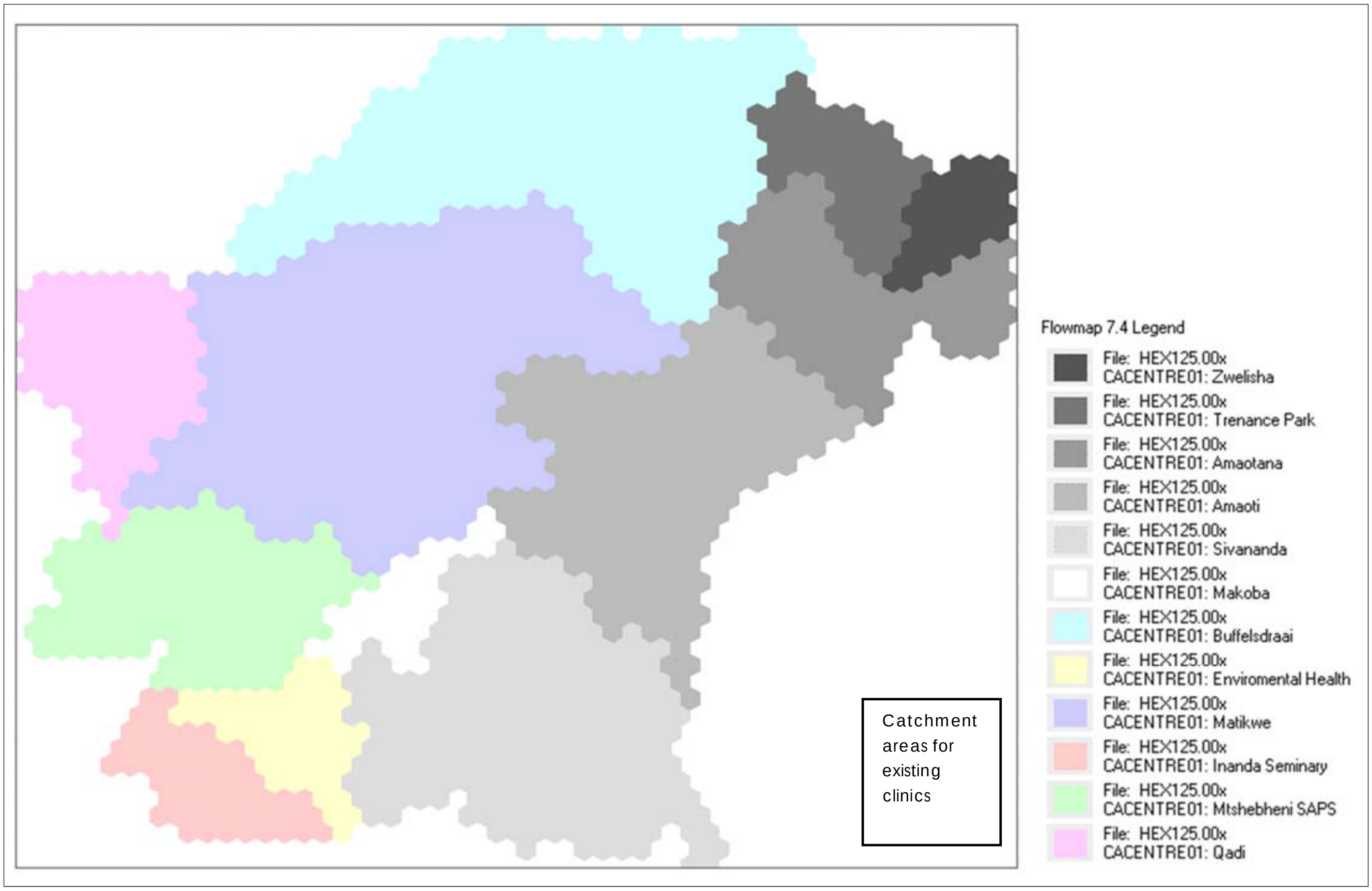


Figure 14: Catchments areas illustration

6.5 Catchment Profile

The catchment profile analysis carried out demonstrates that approximately 90% of the Inanda population fall within the parameters of the distance in seconds being in the middle range. The profile is shown in Figure 15. The minimum distance in seconds is 0.55 and the maximum distance in seconds is 1413.

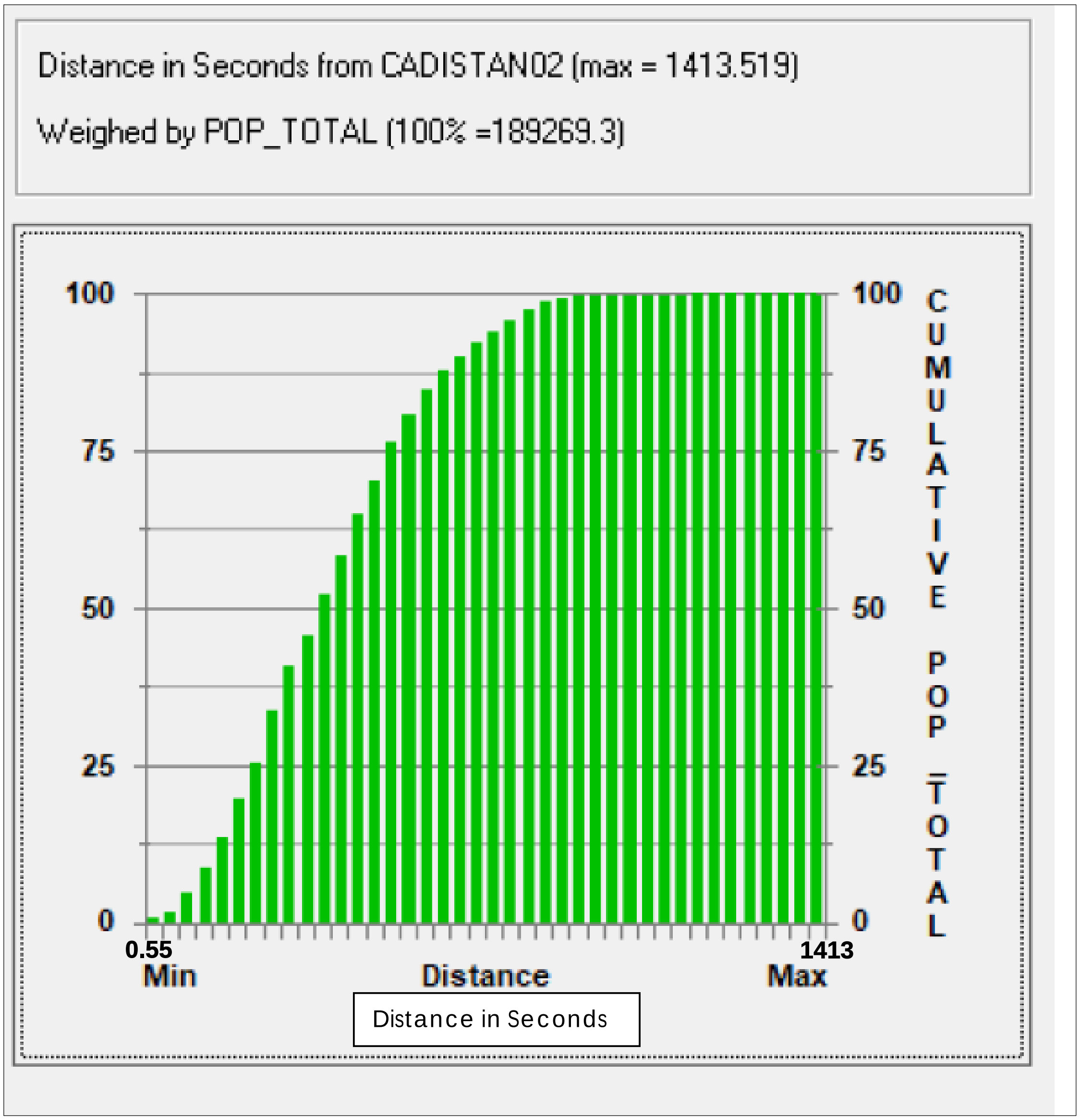


Figure 15: Catchment profile

6.6 Market share of Supply Locations

Each individual clinic supply location was assessed in terms of market share based on the proximity to people. The results of this analysis is shown in Figure 16.

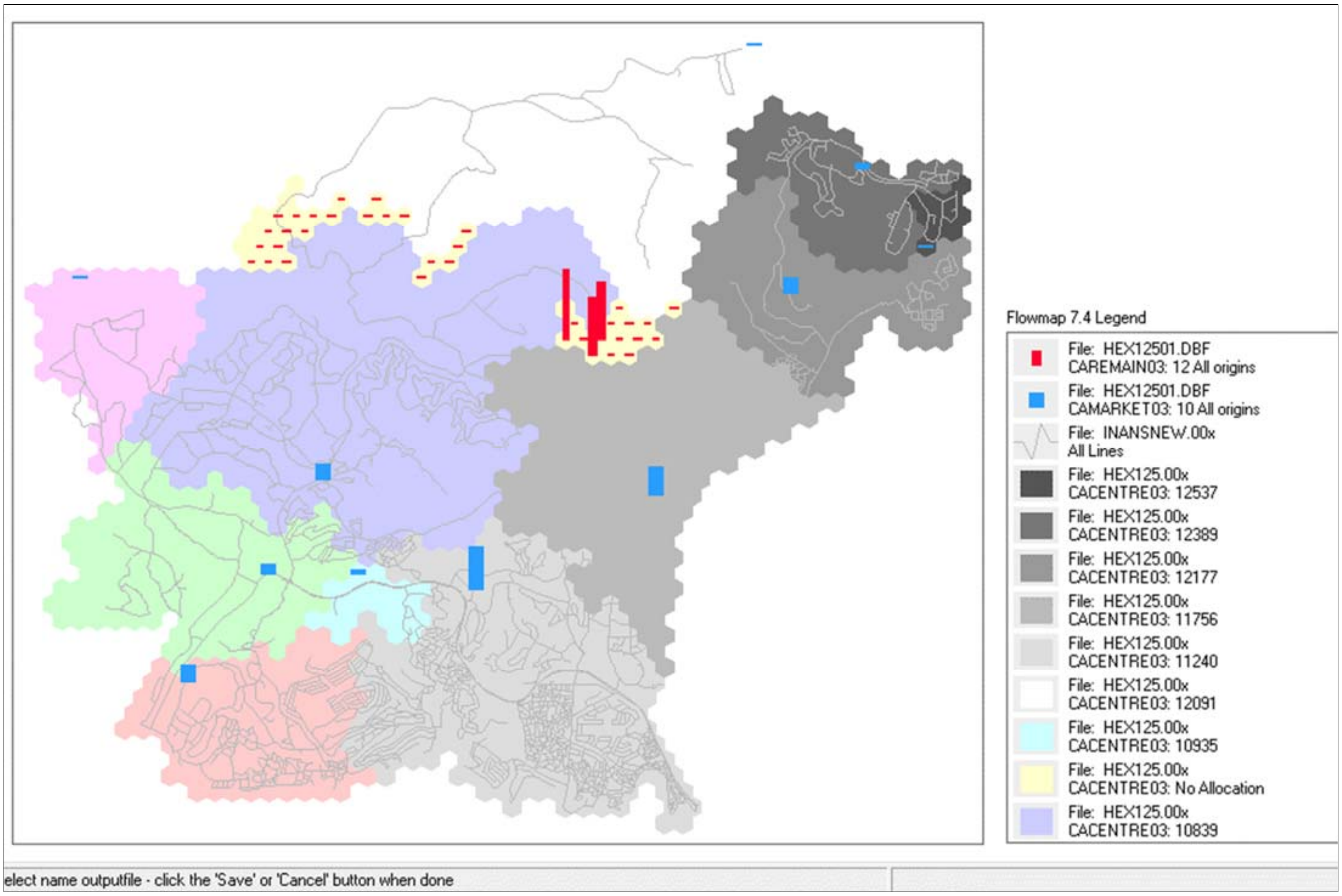


Figure 16: Locations with highest market share

The locations with the highest identified market share were identified and are highlighted in blue in Figure 16. In considering these results, the locations which are in close proximity to high population density areas, have the highest share.

6.7 Regular Proximity Count

This analysis was carried out to determine one additional new location to serve the previously unallocated population, based on travel time is excess of 30 minutes. The proposed location is highlighted in Figure 17. The gradient shading shows the red to orange area where the new facility will be located.

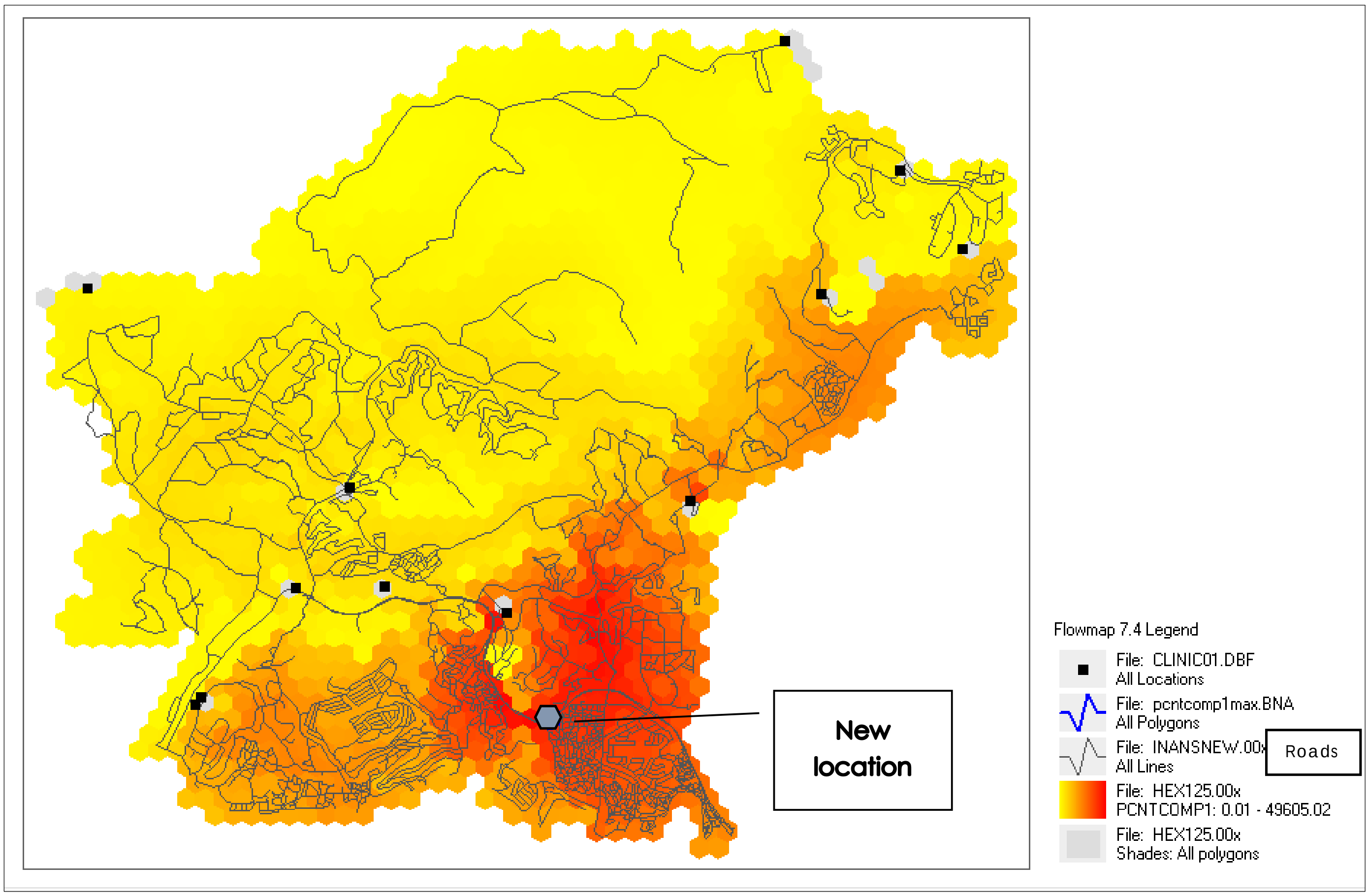


Figure 17: Proposed new location in proximity count

The identified new location is close to the densely populated areas and will provide access to the population not allocated previously.

6.8 Average Distance in Competition

The average distance in competition analysis was carried out to determine if any locations should be added in or moved in order to reduce the average travel distance between supply locations. The location identified is shown in Figure 18. The colour gradation shows the red area as where no additional locations will be provided, with the new location being located in the yellow region on the map.

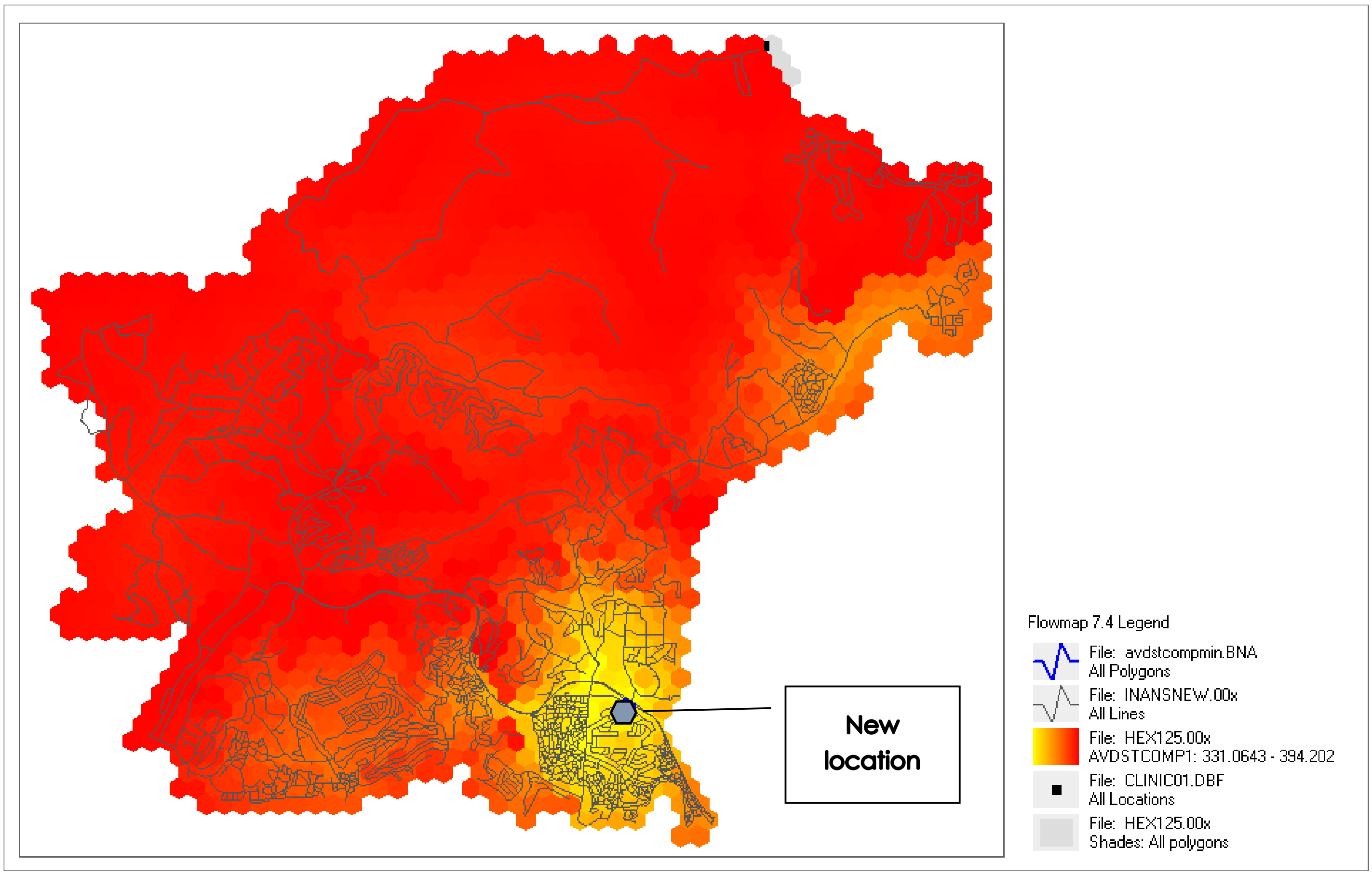


Figure 18: Average Distance new location

This new location would be agreeable, due to the location of the other clinic service locations. This new location would thus serve the adjacent area as there is no existing location serving this vicinity of the study area.

6.9 Proximity Count in Competition

The proximity count in competition analysis was carried out to determine the location of new locations which will have the best market position in competition, with having the best proximity to under serviced demand in this area. The new location is shown in Figure 19.

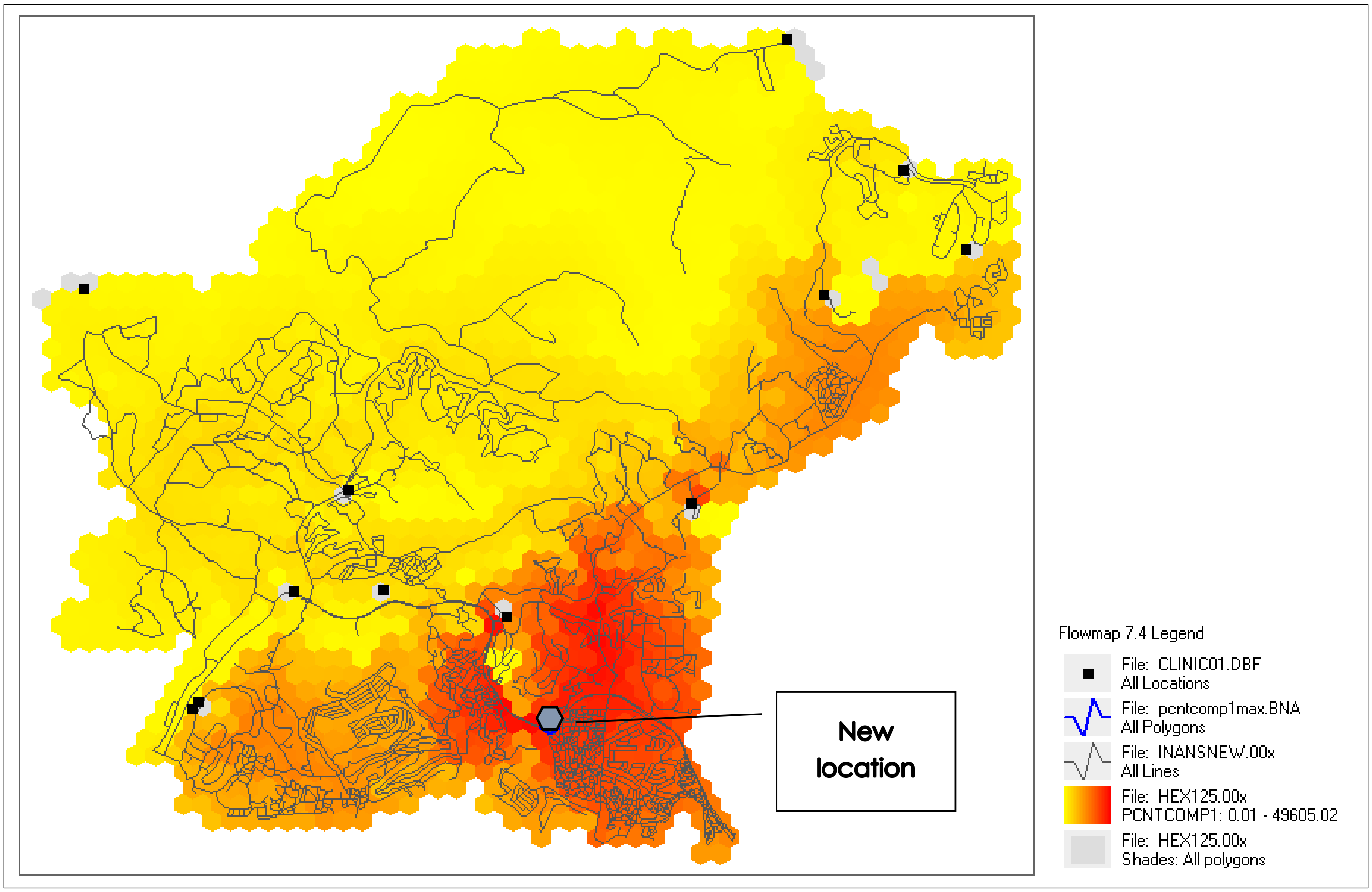


Figure 19: New Location as per Proximity Count in Competition

The new proposed location is located very close to the other existing location towards the south of the study area.

6.10 Lowest Mean Trip Cost Allternate

The lowest mean trip cost alternate analysis aims to determine if relocating any of the existing service locations would bring about an improvement in the local average distance. The results from this analysis are shown in Figure 20. The value of 394 seconds is the overall average distance reported as mean trip cost.

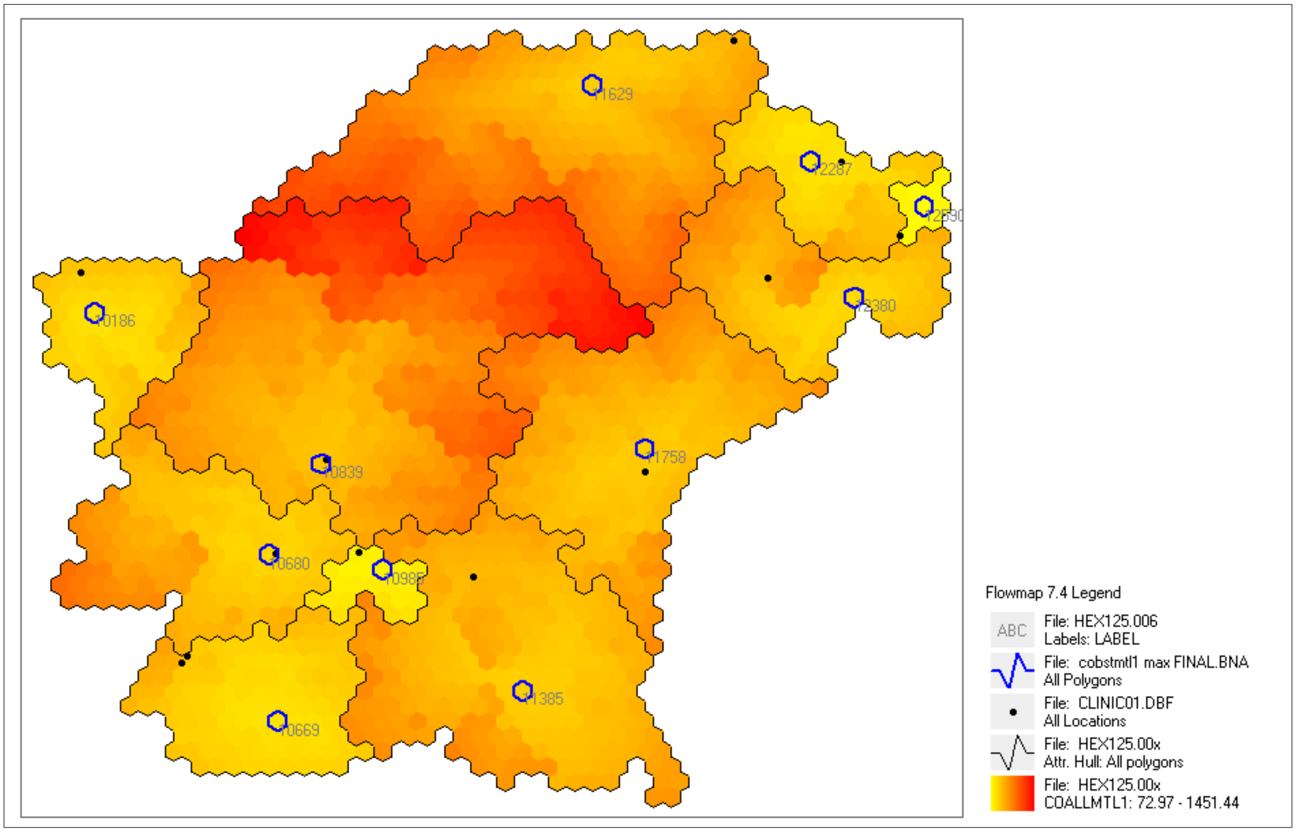


Figure 20: Relocation of service locations to improve local average distance

From the original 11 locations analysed, 9 could be relocated within the corresponding catchment areas in order to bring about an improvement in overall average distance. The remaining 2 locations would not require to be moved as there is no further improvement in distance expected from this change.

6.11 Pareto Cover Set

The catchment area analysis was conducted which aimed to assess how many clinics people are able to reach by determining the market share of each of the clinics. The first part of this analysis determines the Pareto Dominance in terms of how spatially efficient each of the facility locations are, and this is shown in Figure 21.For each of the facilities is determined to be spatially efficient, if the relevant catchment area of that facility is not overlapped by that of another facility location. In the results, the green highlighted areas contain facilities that are spatially efficient, while the purple highlighted areas contain facilities that are not spatially efficient.

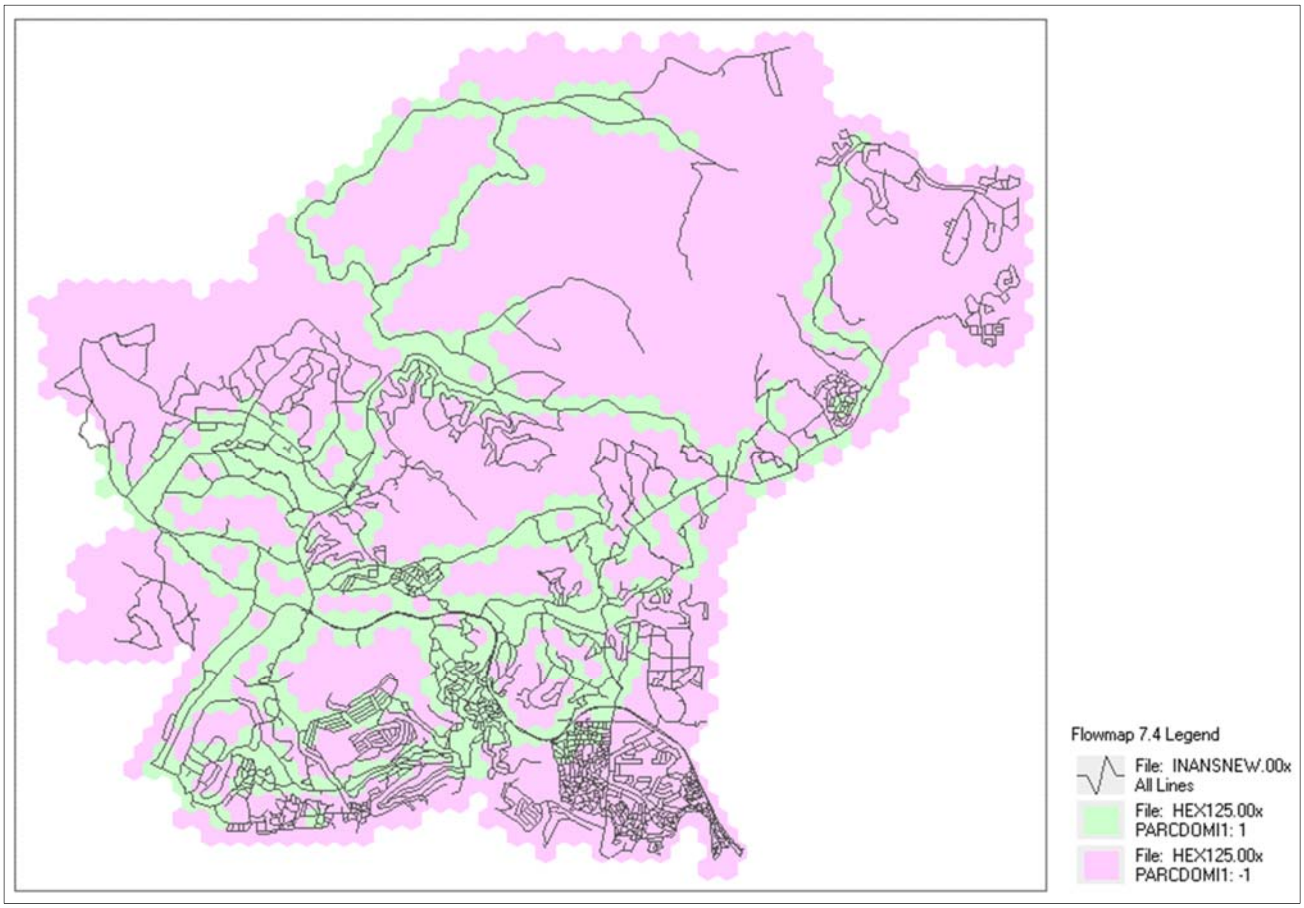


Figure 21: Pareto Dominance of Service Locations

The second part of this analysis was conducted to gauge where service locations should specifically be located in terms of being efficiently in reach from all other existing locations. This analysis was carried out to improve the overall average travel distance. Figure 22 shows the location of the new efficient service locations. The colour gradation shows the new locations to be located in the yellow areas which coincides with an improvement of overall average travel distance, with the orange to red shaded areas highlight the areas where there will be no improvement of average travel distance.

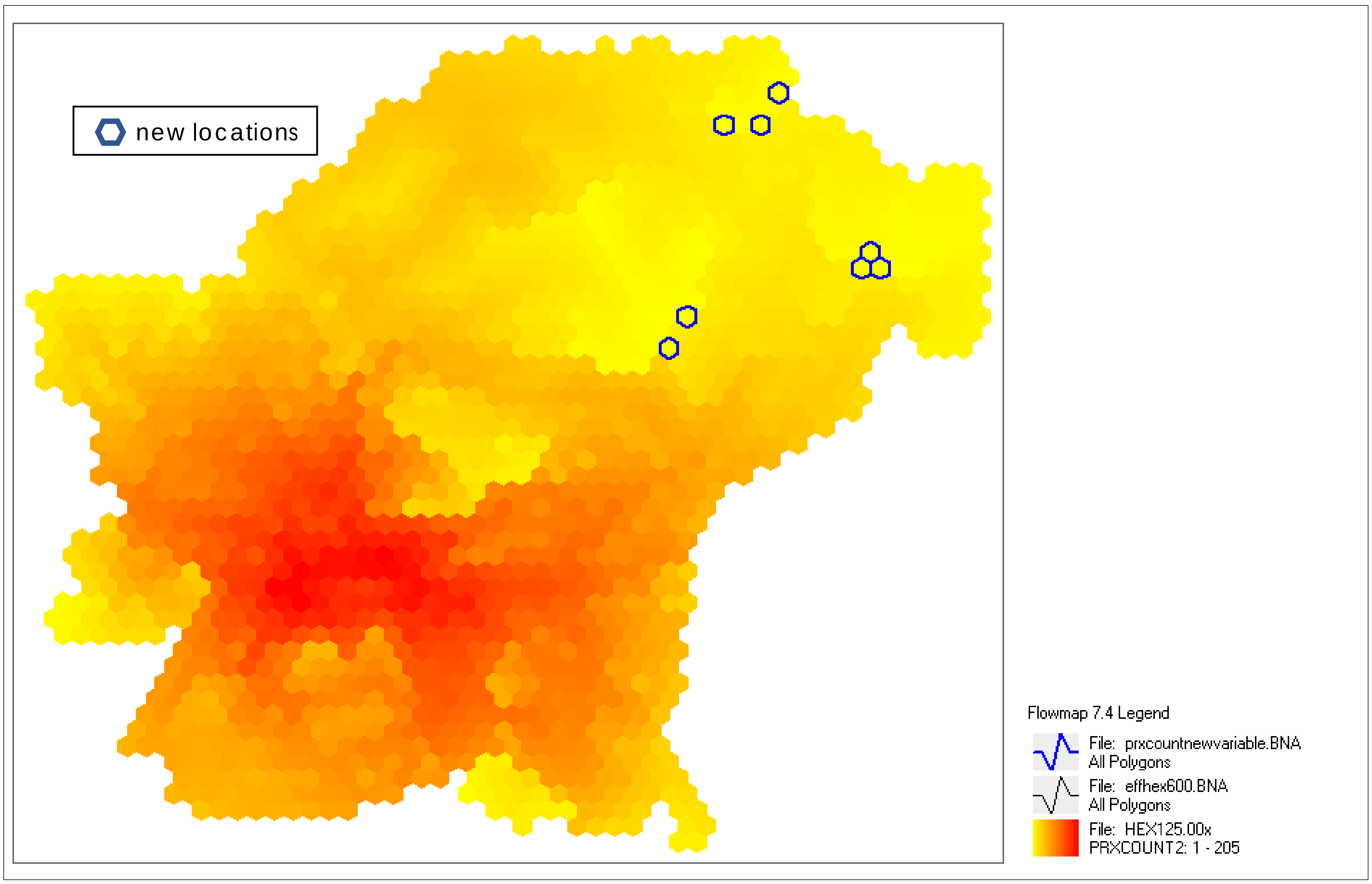


Figure 22: New Efficient Service Locations

From the results it is evident that locations situated towards the north and east of the study area would be most efficient in terms of reducing the travel distance in these areas. The new locations are located in new positions so as to be efficient in improving the overall average travel distance.

7 Results and Conclusions

The research has defined the accessibility to the health care facilities as a service location problem, in terms of the locations of the clinics and proximity to the Inanda road network.

While there are 11 existing healthcare service locations within the Inanda study area, 9 of these locations are not situated ideally. If these locations could be moved to the best and most efficient position in terms of being accessible by most residents within the catchment area serviced by that particular location, this would ensure that as many residents as possible would have access to the services provided by these facilities. However, this is not practical as the locations are existing and would be expensive and challenging to relocate them in terms of available land and other factors.

The 9 locations not situated in the best position are:

- Zwelisha
- Trenance Park
- Amaotana
- Amaoti
- Sivananda
- Makoba
- Buffelsdraai
- Environmental Health
- Inanda Seminary
- Qadi

The Matikwe and Mtshebeni clinics seem to be located in efficient and central locations and would not need to be relocated in terms of the findings from the analysis.

The extreme northern and southern extents of the study area are not serviced by any service locations. While they are in some proximity to other service locations, the distance to travel to these locations would be long. In these areas, there is a definite need for more service locations.

The extent of the road network being more dense in the south and west parts of the area, while more sparse in the north and east areas has a definite impact of the ability of Inanda residents to access these service locations. Within this context, the modelling results have shown that in the case of location of sites being optimised these sites would be located in closer proximity to the road network. This means then that the population will have better access to the road network and in turn better ability to access the service locations if these sites were relocated as proposed. This relocation of sites is however not practical and not a viable solution.

The study has focused on the actual locations of the healthcare locations in the Inanda study area, and the degree of accessibility available to the Inanda population based on the distance and travel time required to travel to these locations. It has been assumed that all the service locations have unlimited capacity in this case, so that the actual accessibility in terms of the locations could be measured.

The actual capacity available at these healthcare facilities is not known and has not been not received in the dataset obtained from the Municipality. This is a separate issue and would be worthwhile to explore, however this data is not available at this time.

Based on the data available in terms of the existing road network, population and the existing location of healthcare services, the analysis carried out was quite comprehensive and was able to test for different scenarios in expanding, reducing, relocating and the locating of new proposed service locations within the Inanda area. Flowmap was found to be quite a useful tool in accessibility analysis.

Overall, the conclusion drawn on the service location planning in Inanda, is that the current locations of the 11 healthcare locations are acceptable, and while they may not be ideal, they are accessible to the majority of the Inanda population as the analysis has shown.

Inanda is representative of many areas in South Africa due to its rural characteristics. The geographic makeup of the country is such that there are many areas which are rural in nature and would thus experience the same challenges with regard to the location of health care services. In these areas, one would expect the same factors to come into play in terms of accessibility to health care services. Factors which would affect accessibility would also be road network, travel distance, transport modes as well as location of the facilities.

In the context of South Africa as a whole, there are many areas which are rural in nature and accessibility issues are widespread and prevalent in these areas. With the rural population travelling to places of employment in the built-up areas, but at the end of the day still living in the rural areas. Besides the geo-spatial characteristics of areas, political and socio-economic factors also have an impact on accessibility.

Results can be carried to other areas of South Africa as Inanda is not a case by its own. Due to the rural nature of the area, it is representative of many other rural areas in the country.

While the accessibility analysis was carried out on the Inanda area as a case study, the common thread of accessibility should be thought to affect other areas in other countries.

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