SPATIAL MODELLING OF ACCESSIBILITY TO TUBERCULOSIS TREATMENT: THE CASE OF NGAKA MODIRI MOLEMA DISTRICT

K.N. RAMOTSONGWA

2022

NELSON MANDELA
UNIVERSITY

Change the World

SPATIAL MODELLING OF ACCESSIBILITY TO TUBERCULOSIS TREATMENT: THE CASE OF NGAKA MODIRI MOLEMA DISTRICT

RAMOTSONGWA K. N

216688051

Submitted in partial fulfilment of the requirement for the degree of MASTER OF SCIENCES IN GEOGRAPHY (MSc. Geography)

Faculty of Sciences, Nelson Mandela University, South Campus

South Africa

2022

Supervisor: Dr W Britz

Co- Supervisor- Mr David McKelly (Council for Scientific and Industrial Research (CSIR)

DECLARATION

DECLARATION BY CANDIDATE

NAME: Karabo Naome Ramotsongwa

STUDENT NUMBER: s216688051

QUALIFICATION: MSc Geography

TITLE OF PROJECT: SPATIAL MODELLING OF ACCESSIBILITY TO TUBERCULOSIS TREATMENT: THE CASE OF NGAKA MODIRI MOLEMA DISTRICT

DECLARATION

In accordance with Rule G5. 6. 3, I hereby declare that the dissertation for the above-mentioned qualification at the Nelson Mandela University has not been previously submitted by me in its entirety or in part for any other degree at this or any other institution. It is my own work in design and execution and all material contained herein has been acknowledged.

SIGNATURE: ______________________

DATE: 05 January 2022

ACKNOWLEDGEMENTS

I would like to extend my greatest gratitude to my supervisor Dr Wilma Britz of the Geoscience Department in the Nelson Mandela University, and co supervisor Mr David McKelly of the Council of Scientific and Industrial Research (CSIR) for their continued guidance, support, patience and encouragement throughout my research project; their pearls of knowledge are highly appreciated.

A special thanks to the National Research Foundation for the financial support that enabled me to meet the various research costs incurred. It really inspired me and brought me hope as a researcher and gave me one less thing to worry about during my study. I encourage them to continue doing the same for other researchers.

Many thanks to the North West Department of Health's Policy and Planning Department for the provision of the data necessary for my research project; this whole research would have been unsuccessful without the data.

No one has ever been more important to me in the pursuit of this research project than my family; my mom, dad, little sister and extended family, also my friends and colleague. If it wasn't for their love, support, and encouragement I wouldn't have forged on. They showed me the true meaning of the phrase "It takes a village to raise a child" and there aren't enough words express my gratitude. I cannot forget to thank the staff of the North West Provincial Nerve Centre, whom I have formed important friendships with, for their guidance, mentoring, resources, professional, and academic insights and support throughout my research. They have been a great role models and I will forever be grateful for that.

I would be doing myself a lot of injustice if I do not thank myself; - for not giving up even when the odds were against me, for putting in the work, staying up late, encouraging myself, for reminding myself why I was doing this degree in the first place and trying each day, even during a pandemic, and for doing all this while fighting mental health issues. I hope my little sisters, nieces and nephews and members of my community look at me as a beam of inspiration somehow and I hope they learn a lot about being a scientific researcher because of me.

This whole project would be so much different or almost impossible without all of you.

Thank You!!! Kealeboga!!! Baaie Dankie!!!

ABSTRACT

Accessibility to healthcare refers to the availability, or the provision of healthcare-by-healthcare professionals and stakeholders and individuals' ability to obtain care and treatment. It affects overall physical, social, and mental health; disease and disability prevention; detection and treatment of health conditions; standard of living; preventable death; and life expectancy, and it is crucial to the performance of health care systems around the world. If healthcare services are available and are in sufficient supply, people will be able to seek health care, and a population will have access to services.

The leading cause of death globally is Tuberculosis (TB) and South Africa is amongst the top 5 countries most affected by TB. This is aggravated by high HIV/AIDS statistics. Children belowthe age of 4, between the ages of 4- 15, and women and men of working ages are highly affected by TB and it is the primary cause of death in these groups in the Ngaka Modiri Molema District.

This study used study tools like Spatial Modelling, Geographic Information Systems and software like ArcGIS 10.5, TerrSet IDRISI 18.30, and secondary data from the North West Department of Health (Tier.net &DHIS) and also TB patients' home addresses to investigate the accessibility of TB treatment in Ngaka Modiri Molema, in order to spatially visualize the distribution of a communicable disease like TB and public healthcare facilities in the Ngaka Modiri Molema (NMM) District and suggest optimum sites for hospital facilities.

There is a highly equitable distribution of health facilities that is evident from the findings of this study, but geographic accessibility of TB treatment is low, because of overcrowded health facilities, long waiting times in queues, facilities not providing TB services or not operating 24hrs, and a lack of TB medications in facilities due to stock-outs. These factors cause patients to travel long distances and incur travel costs to access treatment in other facilities, which is also not guaranteed. This discourages patients and makes them default on treatment, making them susceptible to death or retreatment.

Finally, recommendations for future studies are made to try and transform the current situation of TB treatment accessibility in NMM health facilities for patients.

KEYWORDS: Geographic accessibility, accessibility, Tuberculosis, Treatment, retreatment, spatial modelling, Geographic Information Systems

TABLE OF CONTENTS

DECLARATION i

ACKNOWLEDGEMENTS ii

ABSTRACT iii

LIST OF ABBREVIATIONS x

LIST OF FIGURES xii

LIST OF TABLES xv

CHAPTER ONE 1

INTRODUCTION AND OVERVIEW 1

1.1. INTRODUCTION 1

1.2. BACKGROUND 2

1.3. STATEMENT OF THE PROBLEM 4

1.4. RESEARCH AIMS 5

1.5. RESEARCH OBJECTIVES 5

1.6. DELINIATION OF STUDY 6

1.7. ETHICAL CONSIDERATIONS 7

1.8. SUMMARY AND OUTLINE OF CHAPTERS 7

CHAPTER TWO 9

LITERATURE REVIEW 9

2.1. INTRODUCTION 9

2.2. THE CONCEPT OF ACCESSIBILITY 9

2.3. GEOGRAPHIC INFORMATION SYSTEMS 12

2.4. THE CONCEPT OF SPATIAL MODELLING 14

2.5. SPATIAL ACCESSIBILITY TO PUBLIC HEALTH CARE IN SOUTH AFRICA 18

2.6. PERCEPTIONS ABOUT ACCESSIBILITY TO HEALTH 22

2.7. SPATIAL ACCESSIBILITY TO TREATMENT FACILITIES AND TESTING SITES FOR PATIENTS WITH COMMUNICABLE DISEASES IN SOUTH

AFRICA 24

2.8. SPATIAL ACCESSIBILITY TO HEALTHCARE IN NGAKA MODIRI MOLEMA DISTRICT 30

2.9. CONCLUSION 32

CHAPTER THREE 34

RESEARCH DESIGN AND METHODOLOGY 34

3.1. INTRODUCTION 34

3.2. STUDY AREA 34

3.3. DATA ACQUISITION AND PREPARATION 36

3.3.1. Spatial Distribution Mapping 37

3.3.2. Elevation Mapping 38

3.3.3. Land Use and Land Cover Change Mapping 39

3.4. ACCESSIBILITY MEASUREMENT 46

3.5. SITE SELECTION 48

3.5.1. Criteria for Selecting a Site for Hospitals 49

3.7. CHAPTER SUMMARY 51

CHAPTER FOUR: 55

RESULTS AND DISCUSSION 55

4.1. INTRODUCTION 55

4.2. QUANTIFYING COLLECTED DATA AND SPATIAL DISTRIBUTION MAPPING 56

4.3. ASSESSMENT OF TOPOGRAPHIC CHARACTERISTICS OF STUDY AREA 65

4.4. LAND USE LAND COVER CHANGE DETECTION 69

4.5. ACCESSIBILITY 83

4.6. CHAPTER SUMMARY 87

CHAPTER FIVE 88

CONCLUSION, LIMITATIONS OF STUDY AND RECOMMENDATIONS 88

5.1. INTRODUCTION 88

5.2. SUMMARY OF FINDINGS 90

5.3. LIMITATIONS OF STUDY 92

5.4. RECOMMENDATIONS 93

5.5. CONCLUSION 94

REFERENCES 96

APPENDIX 1 105

LIST OF ABBREVIATIONS

AIDS	*ACQUIRED IMMUNODEFICIENCY SYNDROME*
CHC	*COMMUNITY HEALTH CENTRE*
DEM	*DIGITAL ELEVATION MODEL*
DS-TB	*DRUG SENSITIVE TUBERCULOSIS*
GIS	*GEOGRAPHIC INFORMATION SYSTEMS*
HIV	*HUMAN IMMUNIODEFICIANCY VIRUS*
KZN	*KWA-ZULU NATAL*
LMIC	*LOW- MIDDLE INCOME COUNTRIES*
LULC	*LAND USE LAND COVER CHANGE*
MAXLIKE	*MAXIMUM LIKELIHOOD*
MDG	*MILLENIUM DEVELOPMENT GOALS*
NMM	*NGAKA MODIRI MOLEMA*
NMMD	*NGAKA MODIRI MOLEMA DISTRICT*
NWDH	*NORTH WEST DEPARTMENT OF HEALTH*
PHC	*PUBLIC/PUBLIC HEALTH CARE*

PHF	*PUBLIC HEALTH FACILITIES*
RMM	*RAMOTSHERE MOILOA*
SA	*SPATIAL ACCESSIBILITY*
SSA	*SUB-SAHARAN AFRICA*
TB	*TUBERCULOSIS*
WHO	*WORLD HEALTH ORGANIZATION*
XDT TB	*EXTENSIVELY DRUG RESISTANT TUBERCULOSIS*

LIST OF FIGURES

FIGURE 1	*geographic accessibility barriers*
FIGURE 2	*An Example of Modifiable Area unit Problem. Modifiable Area Unit Problem*
FIGURE 3	*Factors Affecting Access to Public Healthcare in South Africa*
FIGURE 4	*Ngaka Modiri Molema District, North-West Province*
FIGURE 5	*Layout of Data Collection and Preparation*
FIGURE 6	*2013 Natural Color Satellite Image*
FIGURE 7	*2020 Natural Color Satellite Image*

FIGURE 8	*Spatial Distribution of NMM patients and Health Facilities*
FIGURE 9	*New 2019 TB patients per NMM health facility*
FIGURE 10	*2019 TB Retreatment patients per NMM health facility*
FIGURE 11	*Aspect Map of NMM*
FIGURE 12	*Slope map of Ratlou sub-district*
FIGURE 13	*Slope map of Tswaing sub-district*
FIGURE 14	*Slope map of Ditsobotla sub-district*
FIGURE 15	*Slope map of RMM sub-district*
FIGURE 16	*Slope map of Mahikeng sub-district*
FIGURE 17	*LULC 2013*

FIGURE 18	*LULC 2020*
FIGURE 19	*Differences in LULC Classes between 2013 and 2020*
FIGURE 20	*Accessibility to TB Treatment using 5km radius from health facilities*
FIGURE 21	*Accessibility Hospitals using 10km radius from health facilities*
FIGURE 22	*Optimum locations for new health facilities*
FIGURE 23:	*Optimum site locations for new health facilities (Location - Allocation approach)*

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
TABLE 1	*LAND COVER CLASSES*	*60*
TABLE 2	*LAYOUT OF COLLECTED GIS DATA*	*71*
TABLE 3	*QUANTIFYING COLLECTED DATA*	*73*
TABLE4A	*CONFUSION MATRIX RESULT AND GROUND TRUTH OF 2013 CLASSIFICATION*	*88*
TABLE 4B	*CONFUSION MATRIX RESULT AND GROUND TRUTH OF 2013 CLASSIFICATION*	*89*

TABLE 5A	*LULC ERROR MATRIX RESULT AND KAPPA COEFFICIENT OF 2020 CLASSIFICATION*	*91*
TABLE 5B	*CONFUSION MATRIX RESULT AND GROUND TRUTH OF 2020 CLASSIFICATION*	*92*
TABLE 6A	*CLASSIFICATION ERRORS (COMMISSION AND OMMISSION)*	*93*
TABLE 6B	*CLASSIFICATION ERRORS (COMMISIION AND OMMISION)*	*94*
TABLE 7A	*USER AND PRODUCER ACCURACIES OF 2020 CLASSIFICATION*	*94*

TABLE 7B	*USER AND PRODUCER ACCURACIES OF 2020 CLASSIFICATION*	*95*
TABLE 8	*DIFFERENCES IN LULC CLASSES BETWEEN 2013 AND 2020*	*96*

CHAPTER ONE:
INTRODUCTION AND OVERVIEW

1.1. INTRODUCTION

Human Immunodeficiency Virus (HIV), Tuberculosis (TB), lower respiratory tract diseases like COVID 19 and diarrheal diseases are amongst the biggest driving causes of deaths in South Africa (SA). These diseases in particular contribute significantly to the country's healthcare services (Boyles, Mendelson, Govender and Du Plessis, 2021). To meet global targets, millions of dollars are spent each year on prevention, diagnosis, treatment, and care of these diseases. This is because of increased mortality rates, mental health issues, substance addiction, and the resurgence of non-communicable illnesses, global demand meltdown, supply interruptions, and other socio-economic issues that have an impact on the health system. . It is estimated that around 450000 individuals are infected with TB every year, and 270 000 of those are living with HIV. TBis South Africa's main cause of death, with around 89 000 individuals dying from it every year; that amounts to 10 individuals every hour (Alexander, 2020).

Communicable diseases are those that are spread by infectious agent, such as bacteria, viruses, or parasites. Most of these illnesses can be passed from individual to individual so the words "contagious" or "infectious" are frequently used when talking about communicable illnesses (Hammer, Brainard and Hunter, 2018).

TB is a highly communicable disease caused by *Mycobacterium* tuberculosis, a bacterium. Tubercles (little knots) are a common indication of tuberculosis which is frequently found in the lungs. People with immune system complications, such as HIV, are more likely to get tuberculosis than the general population (Stöppler, 2021).

A study done in KwaZulu Natal, South Africa distinguished overlaps between illness patterns and geographical location. It was observed that regions with the highest predominance of TB were generally in remote areas situated in northern parts of the province (Wong, 2021).

Inequalities in geographic access to medical care result from the geographical location of health facilities, the setup of those health facilities, population distribution, and quality of transportation infrastructures. Health data mapping and Geographic Information Systems (GIS) are significant tools and assets for health planning and public health administration conveyance. This is especially true at the municipal level (Dalameter *et al.*, 2012).

The capability to visualize the spatial distribution of health status determinants and pointers can be an incredible advantage for allowing local government to improve the health of residents (Dalameter et al, 2012). Developing relevant, accessible, and usable spatial information models for communities and local businesses is a significant advance towards empowering people and communities to improve their health and increase control over it (Hanjagi *et al.*, 2007).

This study makes use of spatial modelling instruments and tools for analyzing routinely collected health data of a communicable disease such as TB in the Ngaka Modiri Molema District in the North West province of South Africa.

1.2. BACKGROUND

According to McGarigle (1998), funding for TB research, and progressively effective medications, as well as a more extensive use of advanced technologies are expected to continuously decrease the rate at which this disease spreads (McGarigle, 1998). Two generally new tools that are being used in communicable disease studies are DNA identification and spatial modelling.

The combined use of these technologies is opening new windows into the molecular character and mobility or spread of communicable diseases, encouraging health experts to pose accurate examinations about the nature of the disease. These technological advancements are still in their infancy and gaining popularity in research less than a decade ago(McGarigle, 1998).

Spatial Modelling is a kind of geographic investigation, which attempts to clarify human behavior and its spatial expression using mathematics and has a geographical location (Hall, 2019). A Geographic Information Systems (GIS) is a computer-based technology and spatial analysis tool for the storage, control, and examination of geographically referenced data (Couclelis, 2014). Attribute data and spatial data are coordinated in different layers for spatial analysis, which is acknowledged in two essential data models (i.e.,—raster and vector) using GIS software (Couclelis, 2014).

According to Gotz et al. (2009), GIS can be used to differentiate and show geographic patterns of diseases, to evaluate environmental patterns; predict and estimate rate and predominance of diseases, and visualize healthcare disparities in order to communicate clearly with the broader population, corporate leaders, and political leaders. (NCI, 2006).

Since communicable diseases are highly infectious, databases of genetic fingerprints and patient demographics can be used in a GIS to map outbreaks in terms of strain character (McGarigle, 1998). Researchers and analysts do this by observing the clustering of strain types of diseases in various areas; break down the physical, geographic and statistical associations between patients; spot routes of transmission; potentially identify sources of outbreaks; and track the relocation of strains to different regions - abilities which were impractical even 10 years prior (McGarigle, 1998).

An example of this type of analysis was done in the 1850 map produced by Dr John Snow in the 1800s, cholera was accepted to be spread by miasma in the air, germs were not yet comprehended and the unexpected and serious outbreak of cholera in London's Soho district was a mystery (Frerichs, 2003). Dr John Snow accomplished something done frequently in research today: he plotted and mapped the cholera cases. The map represented every death as a bar on a map. It became evident that the cases were grouped around the water pump in Broad Road (presently Broadwick). He was able to demonstrate that cholera was not a problem in Soho, with the exception of those who drank water from the Broad Street pump. He also looked at water samples from the pump and discovered white particles floating in them, which he assumed were the source of pollution. Dr John Snow is today regarded as a pioneer of public health research in the field of epidemiology, according to academics (Frerichs, 2003).

1.3. STATEMENT OF THE PROBLEM

Communicable Diseases, have a geographic component (location and time). Therefore, access to medical care facilities is essential in improving physical and mental wellness, as well as to avert illness and death, increase life expectancy and improving quality of life, thus advancing public health (Ursulica, 2016). The population's access to healthcare is molded by the availability of medical facilities, which is unevenly distributed in predominantly poor and rural areas. Ngaka Modiri Molema (NMM) district in the North-West Province; is a rural district characterized by socio-economic disparities resulting in high levels of poverty, a high population growth and increased risk of communicable diseases (Cooperative Governance and Traditional Affairs, 2020). Furthermore, absence of information access, social marginalization, or poverty are issues of geographical accessibility to healthcare that affect NMMD.

Therefore, understanding the spatial and temporal distribution of communicable disease and factors affecting health is focal in leading public health research. Evaluations of a geographic setting can also uncover patterns in data that would in some way or another go unnoticed. This study used spatial modelling tools to evaluate accessibility to TB treatment using secondary statistical data, and population data to evaluate the spatial and temporal distribution of the disease and uncover specific disparities in TB treatment accessibility.

1.4.RESEARCH AIMS:

The aim of this study was to evaluate the accessibility of TB treatment by using spatial modelling tools, such as GIS processes, population data and data from the surveillance systems of communicable disease

1.5. RESEARCH OBJECTIVES:

The research objectives of this study are to:

- Investigate the accessibility for health facilities for TB treatment in Ngaka Modiri Molema District

- Spatially visualize the distribution of a communicable disease like TB patients and public healthcare facilities

- Suggest site selection of new healthcare facilities

1.6.DELINIATION OF STUDY

This section of the study explains what information or subject is being investigated. While the scope of investigation is described in the delimitation of study, it will explain why certain features of a topic were chosen and others were not. It also mentions the study process and the theoretical framework that were employed to analyze the data.

This study models spatial accessibility to TB treatment in NMMD public health facilities. In this study, a health facility, is a hospital, clinic or other facility, either in or outside the boundaries of a city, which provides health care to human beings and/ or laboratory services to test human specimen.

Although this study includes literature pertaining to other types of accessibility, it is confined to studying physical accessibility to public healthcare facilities for TB treatment within the study area for TB patients. The research site for this study is the Ngaka Modiri Molema District (NMMD) (See Figure 4).

The sample size of this study depended upon the data received from the North West Department of Health. Furthermore, the researcher also decided to focus on TB in general, not the specific strains of the disease. This project was carried out in three years and on a shoestring budget.The amount of time taken to acquire and manipulate some of the data was only slightly affectedby the time it took to receive the data from the North West Department of Health.

1.7. ETHICAL CONSIDERATIONS:

Mouton (2001) reflects that a researcher has a moral obligation to search for truth and knowledge; he goes on to say that while doing research, researchers must protect the rights of individuals in society. Prior to the commencement of this research study, an application with ethics clearance reference number H20-SCIGEO-002 was made to the Nelson Mandela University Human Research Ethics Committee (REC-H) and ethical clearance was obtained (Refer to appendix 1).

1.8. SUMMARY AND OUTLINE OF CHAPTERS

This chapter describes the research problem, and stated the main research questions together with the study's aims and objectives.

Chapter two includes an expanded review of relevant literature while the research design and methodology is dealt with in more depth in Chapter three. The results generated via the quantitative data techniques and qualitative results are presented and recorded in Chapter four. These results are discussed in Chapter four with reference to the objectives of this study as well as the relevance and implications of the findings of the study. Chapter five summarizes and concludes the study as well discusses the limitations and recommendations for future studies.

Integrated communicable disease screening dependent on geospatial information can increase the effect of screening programmes composed by asset restricted health departments like Ngaka Modiri Molema. GIS investigation shows the potential for geographic-based community outreach to give coordinated disease screening to high-risk populations, with sensible yield and opportunities to reengage infected persons in healthcare. Continued advancements is needed to improve this methodology; intergrating this geospatial approach with informal communities may encourage further infiltration into the most at risk populations.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Medical Geography specializes on the application of concepts, strategies and quantitative procedures to address spatial issues in disease and medication (Meade, 2014; Franch-Pardo, 2020). It focuses on geographical concepts and categories on the population and demographic aspects concerning health (Delameter *et al.*,; 2012). This chapter used various literature to guide the theoretical development of the study, which aimed to evaluate accessibility of TB treatment in public health facilities in Ngaka Modiri Molema. This was done by using spatial modeling tools, GIS processes, population data, and statistical data of TB and then use those spatial tools and spatial analysis results of analysis for site selection of hospital facilities. It closes gaps between areas where a lot of research exists, and uncovers areas where research is needed by using spatial modeling and treatment accessibility in Ngaka Modiri Molema.

2.2.THE CONCEPT OF ACCESSIBILITY

Accessibility is described as the ability to reach one place with regard to another place from a point of geographical reference. In this study, accessibility alludes to the ease of reaching public health facilities offering Tuberculosis treatment. Individuals who are in areas that are more accessible tend to be able to reach activities and destinations quicker than those in inaccessible areas while those in inaccessible areas are incapable to reach the same amount of areas in a certain period of time (Rosenberg, 2018), therefore, “Accessibility determines equal access and opportunity” stated by Rosenberg (2018). Fortney *et al.* (2011) has contended for the following dimensions of access: geographical, temporal, financial, cultural, and digital. Geographic healthcare access refers to supply, differing qualities and distribution of healthcare services, and physical accessibility (Better explained by Figure 1) (Health and Places Initiative. 2014). Temporal access incorporates the time it takes to be seen by a supplier, times available at a supplier, or time gone through receiving a service. Economic or financial access alludes to the affordability of administrations, insurance access, etc. Social or cultural healthcare access tends to allude to adequacy of services, social standards, or dialect issues. Digital access alludes to latest advancements in technologies (Health and Places Initiative. 2014).

A number of barriers can obstruct movement from potential to realized access. Penchanskyand Thomas (1918) have conveniently assembled these barriers into five measurements: accessibility, availability, affordability, acceptability and settlement. Availability alludes to the number of nearby services points from which a client can select. Accessibility is determined by travel impedance (distance or time) between client area and service points. Whereas the distinction between accessibility and availability can be valuable, within the setting of urban regions where different service points are common, the measurements should be considered at the same time (Guagliardo, 2004). This fusion is referred to as spatial accessibility (SA), a term that's common within the geography and social sciences literature and is picking up favor within the healthcare geography literature (Guagliardo, 2004).

Issues of geographical accessibility (Figure1) influence certain groups more than others and these groups parallel those likely to suffer extra health issues due to physical vulnerability, lack of access to information, social marginalization, or those incapable of affording proper healthcare (Health and Places Initiative, 2014).

Generally, the further away service points are, the lower the use of those services (with a few restrictions and exemptions). In this manner, geographic access to healthcare can be more troublesome for individuals living in rural regions. In any case, being near to healthcare services doesn't ensure more noteworthy access to healthcare services due to issues such as damage and qualification (Health and Places Initiative, 2014). There are numerous social, financial, and natural components that influence health outcomes, which complicate healthcare access. Healthcare access tends to be worse for vulnerable groups (e.g. low-income, or the unemployed) (Health and Places Initiative, 2014). Advanced innovations or computerized frameworks, such as crisis screening protocols, GIS, and SMS arrangement updates, are technological instruments that can improve access to healthcare. The developing field of e-health technologies has the potential to extend health access, but also increase health disparities among those with and without the technology. Urban planners can increase geographic healthcare access through distinguishing regions with low geographic access (for example, more than 30 minutes travel time, low accessibility through transit service, low number of healthcare offices or specialists per capita) (Health and Places Initiative, 2014). They can come up with methods to improve future healthcare facility development and travel administrations so that geographic access is increased (Health and Places Initiative, 2014).

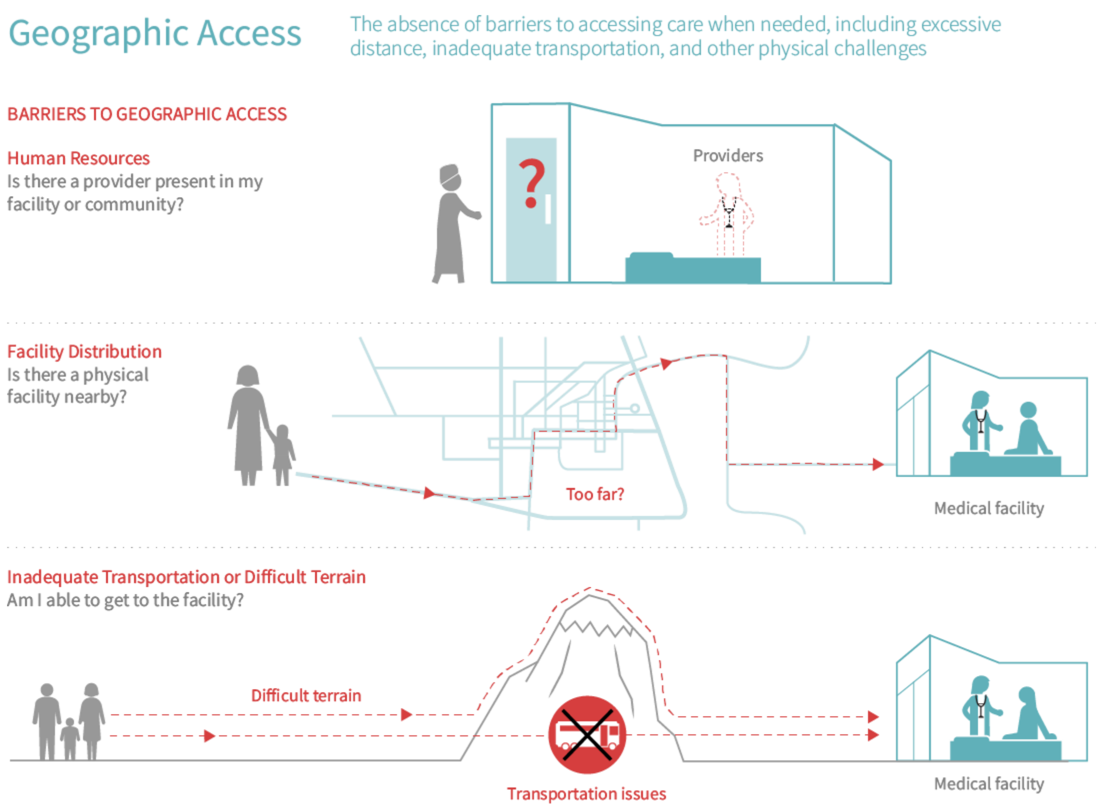


Figure 1: Geographic Accessibility Barriers Concept: (Source: - Primary Health Care Performance Initiative, 2018)

2.3.GEOGRAPHIC INFORMATION SYSTEMS

The use of Geographic Information Systems (GIS) for the estimation of physical accessibility is well established and has been applied in numerous sectors including retail location investigation, transport, crisis service and health care planning (Black *et al*, 2004).

GIS is a digital technology and spatial analytic tool for storing, controlling, and analyzing georeferenced data. It enables us to understand the world around us in a much-improved way and to better living standards (Couclelis, 2014).

Public health and healthcare sectors have been changed considerably by data innovation. It is proven beyond doubt that the fast development of computers and computer-driven data frameworks have changed how we organize health care, understand health needs, and provide services (Dash, Shakyawar, Sharma and Kaushik, 2019). Broadly distributed users with basic machines can now pair with large integrated systems in central places. This organizing structure has been called cyberspace and represents a geography or reality that in some cases named virtual to differentiate it from the more ordinary physical reality, related with individuals and places. However, the same computers and systems that have on the one hand removed users from the limitations of space—of geography—have permitted them to more intimately understand the part of place, space, and distance through the use of geographic information system (GIS) (Blaschke et al., 2018).

GIS has encouraged the improvement and application of what was once called "small area" studies, the investigation of geographic contrasts in health care delivery, disease distribution, and resource assignment. The portrayal of spatial contrasts in human activities, whether disease or health care delivery, has long been the subject of investigation by geographers. The portrayal of such variations by health services researchers as simple rate comparisons with denominators confined by political or postal boundaries missed a longstanding history of geographic analysis that showed how boundaries are not always the ideal approach to generate denominators. The development of suitable denominators that share the characteristics of adjacent zones and translate patterns of travel and sharing of space could be a huge portion of the more advanced work on spatial epidemiology and spatial-statistical investigation in public health (Ricketts, 2003).

Therefore, GIS can be viewed as a basic expansion of measurable examinations that connect epidemiological, sociological, clinical, and economic information with references to space (Ricketts, 2003).

A GIS framework does not make data but simply relates information employing a framework ofreferences that depict spatial relationships. Usually those are particular places on the Earth's surface, whether that place is close to a street or inside a building or basically open spaces. These places are related to each other by sections or indicators that certain points on the Earth are associated physically or through some system (Ricketts, 2003). Those sections represent the streets, the walls of buildings, the boundaries by which we organize space, and the characteristics of the Earth's surface within those segments—it may be water or a desert or a built-up region. These connectors are often assigned characteristics which will reflect their part in encouraging the movement of individuals or things over space, but they may also not pass on sufficient data basic to understanding human behaviour. For example, waterways may or may not show boundaries to movement, highway systems may not reflect temporal changes in streams caused by rush hours, and the perception of built or developed zones as impassable or unsafe may not be accounted for within the information (Ricketts, 2003).

2.4.THE CONCEPT OF SPATIAL MODELLING

In Spatial and Spatio-Temporal Data Models and Languages and Schneider, Markus (2013) statedthat a data model gives a formalism comprising of a notation for portraying information of interest and of a set of operations for controlling this information. It is conceptualized from reality and gives a generalized portrayal of information representing a particular and bounded scope of the real world. A spatial data model is a data model characterizing the properties and operations on static objects in space. These objects are portrayed by spatial data types like point, line, and polygons (Schneider&, Markus, 2013). Operations on spatial data types incorporate, for instance, the geometric intersection, union, and contrast of spatial objects, the computation of the length of a line or the area of a region, they test whether two spatial objects overlap or meet, and whether one object is north or southeast of another object (Schneider &, Markus, 2013).Spatial Modelling is developing models to anticipate potential results. It usually makes use of statistical models, or may use cartographic modelling strategies like overlay, extraction, and database operations, or likely a combination of the two (de Smith, Micheal, Goodchild and Longley 2013).

The advantage that a GIS can give is the capability of representing spatial data in order to reply to user-specified questions. As such, presentations and transformation of spatial information are frequently referred to as "Data Analysis" capabilities in a GIS context. Analysis is the method to resolve and separate the reference system into its parts to clarify their nature and inter-relationships, and to decide common standards of behaviour (de Smith, Goodchild and Longley, 2013). Therefore, spatial analysis is the method by which we turn raw data into useful data (Longley, Goodchild, Maguire and Rhind, 2010). Through spatial analysis, one is able to interact with a GIS and the related geospatial innovations (GPS, remote sensing systems, etc.) (Swift, 2014) which, in turn, depend on the fundamental geographic data science concepts and strategies to reply to questions, support decisions, and uncover patterns (Krishna and Geospatial World, 1970). Spatial analysis is in numerous ways the crux of a GIS, since it incorporates all of the changes, controls, and methods that can be connected to geographic datato turn it into useful information (Krishna and Geospatial World, 1970).

Strategies of spatial analysis are often used to create new data from geographic information. There are a few spatial analysis methods available, ranging from straightforward to complex. Visualization of spatial information could be a basic strategy for gaining data. GIS offers many capabilities for displaying information at varying scales and based on various attributes. Spatial analysis is also a source of new data from a GIS and is defined by any set of strategies whose results change when the locations of the objects being analysed change (Longley, Goodchild, Maguire and Rhind, 2010). Types of spatial investigation include queries and reasoning, measurements, transformations, descriptive summaries, optimization, and hypothesis testing (Longley, Goodchild, Maguire and Rhind, 2010). Queries and reasoning are the most basic of analysis operations, in which the GIS is used to answer basic questions posted by the user. No changes happen in the database and no new information are created (Longley, Goodchild, Maguire and Rhind, 2010).

Measurements are basic numerical values that portray viewpoints of geographic data. They incorporate measurement of basic properties of objects, such as length, area, or shape, and of the connections between sets of objects, such as distance or direction (Longley, Goodchild, Maguire and Rhind, 2010). Transformations are straightforward strategies of spatial investigation that alter information sets by combining them or comparing them to get new data sets and eventually new bits of knowledge. Transformations utilize basic geometric, mathematical, or logical rules, and they incorporate operations that change over raster data to vector data or vice versa. They may, moreover, create fields from collections of objects or identify collections of objects in fields (Longley, Goodchild, Maguire and Rhind, 2010).

Descriptive summaries attempt to capture the quintessence of a data set in one or two numbers. They are the spatial comparison of the descriptive statistics commonly used in statistical analysis, including the mean and standard deviation (Longley, Goodchild, Maguire and Rhind, 2010).

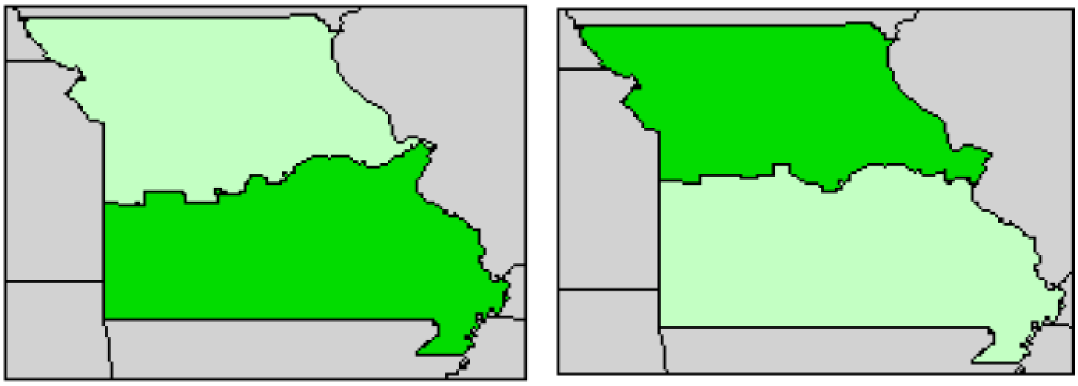
Optimization procedures are normative in nature, outlined to choose ideal locations for objects given certain well-defined criteria. They are widely used in market research, within the package delivery industry, and have other applications (Longley, Goodchild, Maguire and Rhind, 2010). Although spatial modelling techniques prove themselves to be advantageous, they can have uncertainties, vulnerability enters GIS at each stage. It happens within the conception or definition of spatial objects (Longley, Goodchild, Maguire and Rhind, 2010). For instance, what precisely characterizes the boundary of a desert? It also happens within the conception of attributes. For instance, what frequency of crime qualifies a neighbourhood as "high crime"?

Vulnerability also happens within the measurement of data. It is caused by imperfect instruments, mistakes within the conversion of non-digital information to digital form (digitizing), and the combination of data sets with distinctive characteristics (diverse datums, different scales, distinctive data preparing histories) (Longley, Goodchild, Maguire and Rhind, 2010).

Vulnerability happens within the basic representation of data as either vectors or rasters. Within the vector information structure, distortion is caused by the common practice of accumulating point information to polygons. Within the raster structure, it is caused by data generalization (Longley, Goodchild, Maguire and Rhind, 2010).

Finally, vulnerabilities within the analysis of data is shown within the environmental miscalculations and the Modifiable Area Unit Problem (Figure 2). The Modifiable Area Unit Problem has at least three aspects which are the results of analysis, influenced by the number, sizes, and shapes of zones. The number of ways in which fine-scale zones can be aggregated into larger units is frequently great and there are no objective criteria for choosing one zoning scheme over another.

An illustration of the impact of the number of zones on analysis is the 1950 (Figure 2) study by Yule and Kendall which found that the relationship inpopulation density in Missouri (beginning with 48 and finishing with 2) (Longley, Goodchild, Maguire and Rhind, 2010).



A simple illustration of the MAUP. State of Missouri county data have been aggregated and grouped into one of two zones. A quite minor change in the path of the zonal boundary leads to a different interpretation of whether the northern or southern portion of Missouri has a greater population (darker shade of green represents a higher population)..

Source: (Longley, Goodchild, Maguire and Rhind, 2010). GEO 465/565 - Lectures 11 and 12 - "Spatial Analysis"https://dusk.geo.orst.edu › gis › lec11_12

Figure 2: An Example of Modifiable Area unit Problem. Modifiable Area Unit Problem

2.5. SPATIAL ACCESSIBILITY TO PUBLIC HEALTH CARE IN SOUTH AFRICA

The South African government elected within the first law democratic elections in 1994, it inherited an exceedingly fragmented health system, with isolated public and private health divisions and a multiplicity of health divisions within the public sector, counting one for each of the 4 previous provinces and 10 previous ‘homelands’ (McIntyre and Ataguba, 2014). Whereas public sector health administrations had been formally desegregated in 1988, historically ‘black’ health care facilities and the ‘homelands’ health departments had been methodically underfunded during the apartheid period. For instance, average per capita public division health care consumption was R55 within the ‘homelands’ compared to an average of R172 within the rest of South Africa in the 1986/87 financial year (McIntyre and Ataguba, 2014). The health system had expansive incongruities in asset distribution between geographic regions and between individual facilities in the public sector. In spite of the fact that South

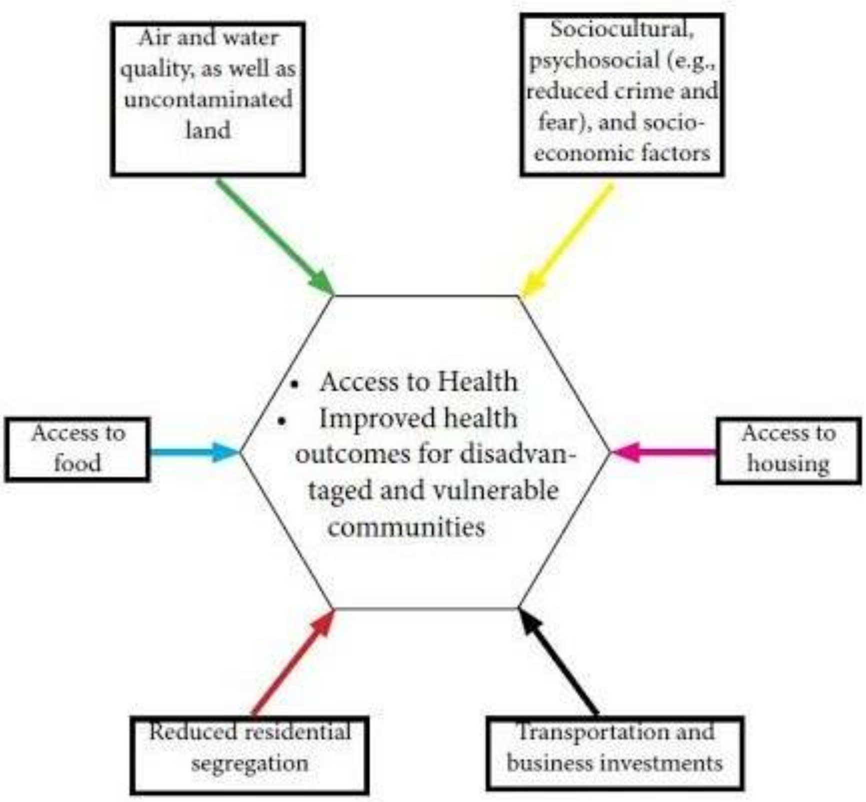
Africa was already committing a generally expansive sum of assets to the health sector (8.5% of GDP in 1992/93), it had exceptionally poor health status markers relative to comparable middle-income nations, showing poor use and dissemination of accessible health care resources (McIntyre and Ataguba, 2014). The disparities in healthcare between population groups of South Africa existed during the apartheid era and continues to exist between numerous population groups to date. This happens even though accessibility and affordability of healthcare is a human right (Stellenberg, 2015).

As mentioned above ("The concept of accessibility"), long distances to facilities, land limitations, inadequate service capacity of institutions and a deficieny or underdeveloped street and transportation network come full circle into unprecedented barriers to access. These obstructions are exacerbated in the presence of external factors like conflict and political disturbances (Verma and Dash, 2020). Therefore, the use of health services may change, depending on where the person lives. Patient variables are more vital than supply variables in clarifying the differential use of health services (Van der Heyden et al. 2003; Stellenberg, 2015).

Spatial planning within the urban and rural regions is far from similar. In areas like the Eastern Cape where the rural area is underdeveloped, health centres are exceptionally distant from each other, so are the hospitals. It is difficult to get an ambulance to a place on time due to the topographical terrain. The distance decay complicates the issue of bringing health care to the rural population. There are very large disparities between the urban and rural population (Chiwire and Dionisio, 2016). Therefore, performance indicators are subsequently organized differently; this is evident in the reaction rate for urban ambulances which is measured with a 15 minute target while in rural ranges it may be a 40 minute target. A couple of seconds can decide life or death. Forty minutes is just too long. The same applies to other rural areas (Chiwire and Dionisio, 2016).

According to Massyn et al. (2020), in 1994, the government decided that people should not have to travel more than five kilometres to get to a clinic. As a result, a large number of clinics were built in areas with the greatest need. Provinces were also expected to allocate resources in a way that favoured public health care (PHC) (Massyn et al., 2020). However, Chiwire and Dionisio (2016), state that, despite the fact that the 5km boundary between health centers has been properly stated in urban planning, access to such centers remains poor and funding are in short supply especially for transportation costs (Chiwire and Dionisio, 2016). Both studies, though, agree that distances between clinics and hospitals leave much to be desired. Within the urban areas, studies display that two thirds of South Africans dwell less than 2km from health centres, and 90% dwell inside a 7 km radius (McLaren, Ardington, & Leibbrandt, 2014; Chiwire and Dionisio, 2016). In spite of having a social security input, offered through the South Africa Social Security Agency (SASSA) grants and Unemployment Insurance Fund (UIF) for those unemployed, the sums are menial and cannot cover transport costs. In most cases assets are moved from family use to transportation when a client is already in a crisis situation, influencing their health results in a negative way (Chiwire and Dionisio, 2016).

Housing and infrastructure have contributed largely to lack of access to health care. The connection between poor housing infrastructure and poor health status is articulated within the South African setting. Lack of access to proper housing has unavoidably brought about factors contributing to the need for access to health care. The presence of gigantic informal settlements within the country, has the government looking to supply "better housing", by updating 750 000 households by 2019 inside informal settlements. The National Department of Human Settlements' primary aim is to supply family units, "with secure residency and access to fundamental services, such as water and sanitation," (The National Treasury, 2018). In 2011, access to piped water (inside the yard) was at 73.4%, an increment from 69.4% in 2007. Millennium Development Goal (MDG) No. 7 target of 74.7% had been outperformed by the year 2012. Improved access to sanitation had been accomplished for 75% of the populace (Chola, Michalow, Tugendhaft, & Hofman, 2015; Chiwire and Dionisio, 2016). Figure 3 below better explains the factors mentioned above.



Source: - Chiwire, P. and Dionisio, D., (2016) Figure 1: Built Environment Factors Affecting Public Health. [Online image] Available from: http://www.peah.it/2016/10/factors-influencing-access-to-health-care-in-south-africa/

Figure 3:- Factors Affecting Access to Public Healthcare in South Africa

2.6.PERCEPTIONS ABOUT ACCESSIBILITY TO HEALTH

The discussion about access to healthcare and access is still on going. As a result, there is no single technique for assessing healthcare access. Despite different perspectives on access, such as political perspectives, the ability to use healthcare, the first step toward universal health, and the usage and availability of healthcare resources, none of these definitions adequately explain access. Access is a broad term that refers to the extent to which consumers and the healthcare system are compatible. The availability, accessibility, accommodation, cost, and acceptability dimensions are a set of unique, distinct, and interrelated variables that help enhance and quantify access to healthcare (Woldemichael, Takian, Akbari Sari and Olyaeemanesh, 2019).

Health researchers used GIS to compute the Euclidean (straight line) distance from a patient's ZIP code centroid to a healthcare institution in the earlydays of calculating access. Performing these calculations for an entire hospital database may be time-consuming. Aggregating the data to the ZIP code level significantly reduces its relevance, but it provided a more practical option for those wishing to evaluate accessibility across communities (Geraghty, 2019).

Smart spatial strategists realized that the Euclidean distance calculation provided little insight into the actual distance travelled through a road network to reach a location, therefore they used the Manhattan distance computation as a simulation instead. In a stair-step pattern, the approach offered N–S or E–W movements. Whilst resulting distance was probably more appropriate in most circumstances, it was undeniably a poor method of determining distance along a road network. Understanding access to care from the patient's perspective has been a difficult technological task until recently (Geraghty, 2019).

The issue of access has also caught the attention of health providers. The notion has far-reaching implications for service planning, population management, and hospital readmission prevention. From this perspective, early GIS methods for access calculations included the use of buffers or pre-defined service zones. Dropping a point representing a hospital and creating a 10-mile circle buffer to symbolize an area of widespread accessibility to the facility is a pretty straightforward prospect. This method is basically equivalent to the Euclidean distance computation from the hospital's perspective (Geraghty, 2019).

Numerous changes in the meanings and conceptual frameworks of healthcare accessibility have persisted over time. In the early 1990s, it was defined as the degree of adjustment between the characteristics of healthcare resources and those of the population seeking and receiving care. This concept has been expanded to encompass the actual use of services, as well as their reliance and effectiveness. In order to evaluate access, it is now necessary to place a strong focus on the qualities of both the users and the services (Shibli, Aharonson-Daniel and Feder-Bubis, 2021).

To date, a lot of research has looked into the global obstacles to healthcare services. Financial constraints, much like the cost of medications and health insurance, are significant impediments to healthcare services, geographic impediments, such as a lack of public transport and a lengthy travel distance, as well as gender restrictions, exist. Due to disparities in health systems from country to country, access to healthcare services varies from one country to the next. However, research has shown that a lack of healthcare services causes people to delayor forego needed healthcare, which can have a severe impact on their health (Shibli, Aharonson-Daniel and Feder-Bubis, 2021).

2.7. SPATIAL ACCESSIBILITY TO TREATMENT FACILITIES AND TESTING SITES FOR PATIENTS WITH COMMUNICABLE DISEASES IN SOUTH AFRICA

Each year, the World Health Organization (WHO) African region records more epidemics, disasters and potential public healthcare crises than what is recorded in other WHO districts. A recent temporal investigation demonstrates that the risk of developing and re-emerging infectious disease epidemics has risen (Jones, 2008; Talisuna et al., 2020). This seem mostly to be due to better surveillance and progressed reporting, but it might also be due to realevents, counting: the development of cross-border movement and worldwide travel, expandinghuman population density, quick and spontaneous urbanization, repetitive political and other social conflicts and growth of informal settlements (Talisuna et al., 2020).

Health care facilities in sub-Saharan African nations are confronting a rising weight from developing populations and the rise of infectious illnesses such as the recent flare-ups of Ebola and COVID-19. Uneven dissemination of health care accessibility, in addition to constrained public healthcare financial resources and other monetary limitations, calls for better management for the following generation of health care facilities (Falchetta, Hammad and Shayegh, 2020).

Under the current COVID-19 pandemic, there is a solid requirement for modeling strategies that account for underreporting presented by insufficient surveillance capacity, to enable assignment of restricted assets, such as testing services, and other disease control procedures. Outbreak readiness, prediction, and control methodologies strongly depend on a country’s health framework and case detection capacity, which is frequently accepted to be low in low-and middle-income nations (LMICs) due to weak health care frameworks and shortage of human and budgetary resources (Hierink, Okiro, Flahault and Ray, 2021).

Ideally, every person ought to have access quality health care at whatever point they require it. The goal of all health systems is to accomplish this ideal of widespread scope by giving primary healthcare administrations that are accessible, impartial and responsive to the requirements of their target communities. As proper healthcare is a globally recognized human right recognized in both national and international law (Pieterse 2006:473). While numerous country health frameworks battle to accomplish universal scope, low-income nations like South Africa face especially complex challenges (Gonzales et al., 2012).

A quick extension of a public, affordable healthcare foundation is especially vital in sub-Saharan Africa (SSA), as communicable infections are the primary cause of death, new born child mortality rates are over 5%, and long journeys to health care facilities weaken the accessibility to essential health care for millions (Falchetta, Hammad and Shayegh, 2020). Currently, in SSA, at least one-sixth of the populace lives more than 2 hours away from a public hospital, and one in eight individuals is no less than 1 hour far away from the closest healthcare centre (Falchetta, Hammad and Shayegh, 2020).

Poverty stricken, Tuberculosis (TB) patients have major challenges in obtaining TB testing and treatment services. They need faster diagnostic and treatment choices as close to their homes as practical if TB management is to be effective. Access to TB treatment in low-income areas is difficult because of barriers like economic constraints, which means that providing care for the impoverished is a complicated process because of lack of resources, transportation, accommodation, and lost work time are all included in the costs. As such, patients with tuberculosis in low-income categories take longer to seek treatment than those in higher-income brackets. Communities' perceived costs of TB diagnosis and treatment were 2-5 times greater than the real expenses. There are geographical barriers which refer to distance from resources that diagnose and cure TB, social and cultural hurdles like stigma and a lackof awareness about tuberculosis and possible treatment and, limitations in the health-care system, which refers to a lack of response in the health-care system (EQUI-TB Knowledge Programme, 2007).

In a study by Falchetta, Hammad and Shayegh, (2020), high resolution data was combined on the location of different typologies of public healthcare facilities with population distribution maps and terrain specific accessibility algorithms to develop a multi objective GIS framework for assessing hospitals expansion requirements. This method encouraged increased accessibility targets for public healthcare service with specific travel time. The results of this study suggested that for universal healthcare accessibility to be met, Sub-Saharan African countries will need to build approximately 6200 facilities by 2030 (Falchetta, Hammad and Shayegh, 2020).

Similarly, Hierink, Emelda and Antoine (2021) followed the scoping review technique suggested by Arksey and O'Malley. They focused on publications capturing measures or intermediaries of geographical accessibility in connection with infectious illnesses. To cover the most extensive assortment of accessible literature they utilized geographical accessibility in its broadest sense and did not indicate certain measures of accessibility, such as time, distance or coverage (Hierink, Okiro, Flahault and Ray, 2021).

According to the results of the study by Hierink, Emelda and Antoine (2021), Human Immunodeficiency Virus (HIV)/Aids was the foremost infectious disease examined in connection to accessibility (n = 14), then tuberculosis (TB) (n = 8), cholera (n = 5), dengue (n

= 5), and measles (n = 2) and malaria (n = 2). More common measures of the impacts of infectious diseases comprised disease burden (n = 4), child mortality (n = 4), and childhood immunization (n = 3). Other examined infections included Ebola, Nipah, resting ailment, lockjaw, typhoid fever, and dog-bites. Out of the 64 studies included, 52 measurably analysed the affiliation between geographical accessibility and the effect on the studied infectious diseases (Hierink, Okiro, Flahault and Ray, 2021).

In general, the results of the included publications may well be broadly categorized into three categories which are, decreased geographical accessibility to health care is related to a higher infectious infection burden in remote communities, decreased accessibility is related to lower infection reporting, and the occurrence of an infectious disease outbreak influenced health care accessibility (Hierink, Okiro, Flahault and Ray, 2021).

This study will use TB as an example of a communicable disease to better explain the literature of accessibility. Tuberculosis is the tenth most common cause of death universally and the primary cause of death from a single infectious agent. In spite of the fact that around 10 million new TB cases were reported in 2017, over a third of assessed TB cases are not however identified globally (Asemahagn, Alene and Yimer, 2020). Developing nations like South Africa, are exceedingly affected by TB frequency, and deaths which could be related to high population development, a poor economy and nutrition, low healthcare coverage and service quality, drug resistance, and high comorbidities with HIV and diabetes mellitus. It is the leading cause of death in South Africa with a total of 58 000 deaths in 2019, 36 000 of these deaths were HIV positive (Kanabus, 2021). A national TB prevalence survey by Kanabus (2021), that took place in 2017 , showed an estimated high burden in South Africa with 773 prevalence (all ages, all forms per 100 000 population in 2018) (Kanabus, 2021).

This means that 80% of the South African population may be infected with TB bacteria. Of this 80%, majority may have latent TB rather than active TB. Furthermore, there was an estimated high prevalence of 88% latent TB among people aged between 30-39 years old living in rural areas and informal settlements (Kanabus, 2021).

With that being said, there appears to be very little information publically available about how TB occurrence may have shifted in provinces and districts since 2015 (Kanabus, 2021), meaning that, there is very little to no literature about TB treatment accessibility in South African provinces and districts. According to Hierink, Okiro, Flahault and Ray (2021), to their information, no survey has efficiently investigated the literature to recognize and examine the findings on considering geographical accessibility in infectious disease studies and more particularly on understanding the true infection burden (Hierink, Okiro, Flahault and Ray, 2021).

Although, TB may be a global health concern, insufficient case finding and case holding has been said to be a major obstruction to the control of TB. The TB literature is composed nearly totally from a biomedical point of view (Cramm, Finkenflügel, Møller and Nieboer, 2010). In addition, Chimoya et al (2020) conducted a scoping review of existing evidence on TB burden to assess the contribution of key populations to the epidemic in SA.

TB transmission often happens within a household or community, leading to differential spatial patterns. However, evident spatial clustering of TB can show continuing transmission or co-location of risk factors and can differ greatly depending on the type of data obtainable, the examination techniques used and the dynamics of the underlying population (Shaweno et al, 2018).

According to Asemahagn et al. (2020), within the early days of evaluating accessibility, health examiners would utilize Geographic Information System (GIS) to calculate the straight line distance from a patient's zip code centroid to a healthcare facility. Even if complete patient addresses were obtainable, it could be tedious to perform these calculations for an entire healthcare facility database. Though aggregating to the zip code level seriously decreases the value of data, the technique provides a more practical alternative for those wanting to contrast accessibility for various communities (Asemahagn et al, 2020).

A study, by Kapwata et al., (2017), employed this methodology, where adults and children with Extensively Drug Resistant TB (XDR-TB) diagnosed in KwaZulu-Natal were recruited, and the distance and time from participants to the closest hospital or clinic as well as the actual facility that diagnosed XDR TB was calculated, using tools within the ArcGIS network analyst. Speed of travel was assigned to road classes based on Department of Transport regulations. The results showed that during 2011-2014, 1021 new XDR TB cases were diagnosed throughout all 11 districts of KZN of whom 404 (39%) were enrolled and had geospatial data collected. Participants would have had to travel an average distance of 2.9 km (CI 95%: 1.8–4.1) to the closest clinic and 17.6 km (CI 95%: 11.4–23.8) to the closest clinic. Real distances that participants travelled to the health facility that analysed XDR TB ranged from <10 km (n = 143, 36%) to >50 km (n = 109, 27%), with a mean of 69 km. The majority (77%) of participants travelled more than the prescribed distance to a clinic (5 km) and 39% travelled more than the suggested distance to a hospital(30 km). About half (46%) of participants were analysed at a health facility in eThekwini area, of whom, 36% dwelled outside the Durban metropolitan range. Results were compared to guidelines for the provision of social facilities in South Africa: 5km to a clinic and 30km to a hospital. (Kapwata et al., 2017).

2.8.SPATIAL ACCESSIBILITY TO HEALTHCARE IN NGAKA MODIRI MOLEMA DISTRICT

In Ngaka Modiri Molema, the main cause of death for children under the age of 4 years are communicable diseases. For children between the ages 5 and 14 the main cause of deaths are communicable illnesses and injuries. 59% of males between the ages 15-24 pass on because of wounds while most females in that age category die because of HIV/AIDS and TB related illnesses. This is often moreover the case for females between the ages of 25 and 49 years. For a long time, this has been the leading cause of death among men aged 25 to 49. Males (66%) and females (79%) over the age of 50 mainly die of non-communicable illnesses (Cooperative Governance and Traditional Affairs, 2020).

Doctors without Border (Médecins Sans Frontières (MSF), sometimes rendered in English as Doctors Without Borders), a part of the Stop Stock Outs Projects , includes a medical group on the ground within the North West province surveying the status and needs of clinic and hospital administrations. On the 25th of April 2018 the group visited the Mahikeng District Clinic and adjacent clinics, and met with the North West MEC for health, Dr Magome Albanos Masike. With respect to clinics within the Ngaka Modiri Molema Locale District, the group was able to affirm with Dr Masike that in Mafikeng only 7 out of 30 clinics were open (MyPressportal Team, 2018).

All 10 clinics were closed in Tswaing while in Ramotshere Moilwa 15 out of 23 clinics were closed. In Ratlou, only 1 out of 12 clinics was closed. In Ditsobotla all 16 clinics were open. The regularly very busy Lobatshe street clinic close to the Botswana border was also closed. With respect to clinics, the group affirmed that the 105-bed Lehurutshe Clinic had been closed since 25 April. The 84-bed Zeerust Hospital has been closed since 20 April. Mafikeng public health facility which has 392 beds, was open, and recently 91 medical attendants were on duty. Gelukspan Hospital and Thusong Hospital were both open (MyPressportal Team, 2018).

These figures suggest that access to essential care is exceedingly confined, or non-existent, for communities in Ngaka Modiri Molema District. Those who can travel to facilities are finding that there's no medication. Hospital closures mean that the sick, as well as pregnant ladies would need to travel longer distances to get care (MyPressportal Team, 2018).

In contrast, three towns within the Ngaka Modiri Molema District were to get to comprehensive health administrations on their door step when the North West Wellbeing Office handed over three wellbeing offices to the communities in 2011. North West MEC for Health, Dr Magome Masike, was to hand over two-roomed facilities staffed by assistant medical caretakers, who will give essential health special and preventative administrations to the communities of Ramabesa, Moshawane and Mayaiyane villages (South African News Agency, 2011).

According to the Department, these offices will give a settled structure from which mobile health clinics can render a more comprehensive essential health administrations on planned visits, complementing and supporting the mobile clinics. In addition to 83 mobiles at the time servicing North West communities which did not operate as fully-fledged clinics, the Department included 11 new mobile clinics at a combined estimate of R2.2 million to its fleet of mobile clinics (South African News Agency, 2011).

Masike had committed himself to re-engineer the Primary Healthcare (PHC) programme as part of moving forward the face of health care at the local level. He said that in case the Department succeeds with the re-engineering of PHC programme, they were set to solve numerous challenges, not only at the PHC level but for health in general (South African News Agency, 2011).

This proves that there has been a decline in accessibility in Ngaka Modiri Molema District from 2011 to 2020 even during the COVID-19 pandemic.

2.9. CONCLUSION

According to Meade (2014) and Franch-Pardo (2020), medical geography is concerned with the application of concepts, techniques, and quantitative procedures to illness and drug geographical challenges. This study is a medical geography study which used Spatial modelling to assess accessibility to TB treatement in Ngaka Modiri Molema District since TB is one of the leading causes of death in the world, and particularly in- Ngaka Modiri Molema. This chapter of the study covered a wide variety of sources which informed the theoretical development of the study by assessing geographical modeling and treatment accessibility in Ngaka Modiri Molema, it bridged gaps between areas where there is a lot of study and identified areas wheremore research is needed. Having said that, there appears to be very little available information about how TB incidence has changed in provinces and districts since 2015.

Accessibility is interpreted as the capability to get from one location to another. People who live in more accessible locations will be able to get to activities and destinations faster than those who live in inaccessible areas. The latter will be unable to cover the same number of regions in the same length of time (Rosenberg, 2018). The concept of accessibility is characterized by the following dimensions as stated by Fortney et al (2011). They are; geographical, temporal, financial, cultural, and digital— to remodel the system and to incorporate later advancements in technologies (Health and Places Initiative. 2014). The planning system of urban and rural areas is vastly different. In areas like the Eastern Cape, where the rural region isn't well developed, health care facilities are extremely remote from one another. Due to the geographical topography, getting an ambulance to a location on time is challenging. The difficulty of providing health care to the rural population is complicated by distance deterioration. There are significant differences between the urban and rural populations (Chiwire and Dionisio, 2016). The debate over healthcare access and accessibility is currently ongoing. As a result, there is no single method for determining access to healthcare. Despite various interpretations of access, including political, the ability to use healthcare, the first step toward universal health, and the use and availability of healthcare resources, none of these categories explain fully the concept of access.

The application of Geographic Information Systems (GIS) for estimating physical accessibility is widely established and has been used in a variety of fields, including retail site analysis, transportation, emergency response, and health care planning (Black et al, 2004). GIS has aided the development and use of what were traditionally referred to as "small area" studies, which looked into spatial differences in health care delivery, illness prevalence, and resource allocation. Geographers have long requested that spatial contrasts in human activity, such as disease or health care delivery, be depicted.

The ability to represent spatial data in order to respond to user-specified inquiries is a benefit that a GIS can provide. As a result, in a GIS environment, presentations and transformations of spatial data are commonly referred to as "Data Analysis" skills. The procedure of resolving and separating the reference system into its components in order to define their nature and inter-relationships, as well as to establish common standards of behavior, is known as analysis (de Smith, Goodchild and Longley, 2013). As a result, spatial analysis is the process through which we convert unusable data into useful data (Krishna and Geospatial World, 1970).

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1. INTRODUCTION

The methodology explains and discusses how the research aims and objectives that make up the study were achieved, along with the description of the structure of research and methods. This methodology starts by describing the study area then examines data collection and preparation strategies, and data analysis methods.

This study is quantitative and based on secondary data analysis. It made use of data from the surveillance systems of TB and patient home addresses, which were then used to model physical accessibility of TB treatment in public health facilities in a GIS. It is descriptive and analytical in terms of its nature, methodology and how it is applied in terms of its objectives which are; to investigate the accessibility of TB treatment in Ngaka Modiri Molema District, to spatially visualize the distribution of TB patients and public healthcare facilities in the Ngaka Modiri Molema District and to suggest selection of sites of new hospital facilities

3.2. STUDY AREA

The study area is Ngaka Modiri Molema (NMM) District in the North West province South Africa, which has an area of 28 206km^2 (figure 4). The Ngaka Modiri Molema District Municipality is centrally located among the district municipalities of Bojanala Platinum, Dr Ruth Segomotsi Mompati and Dr Kenneth Kaunda in the North West province and shares a border with Botswana. It comprises of local municipalities Ratlou, Tswaing, Mafikeng, Ditsobotla and Ramotshere Moiloa. In 2016, the Ngaka Modiri Molema district had an estimated total population of around 88 9108.

The district is home to Mahikeng (previously known as Mafikeng), the capital of the province. Appropriately named, the capital is nicknamed 'The City of Goodwill', which is additionally the city's trademark. It is a rapidly developing, present day, private, regulatory and business town, which diverges from its captivating history. It is part of the former Western Transvaal and Bophuthatswana. (Municipal Demarcation Bard, 2002).

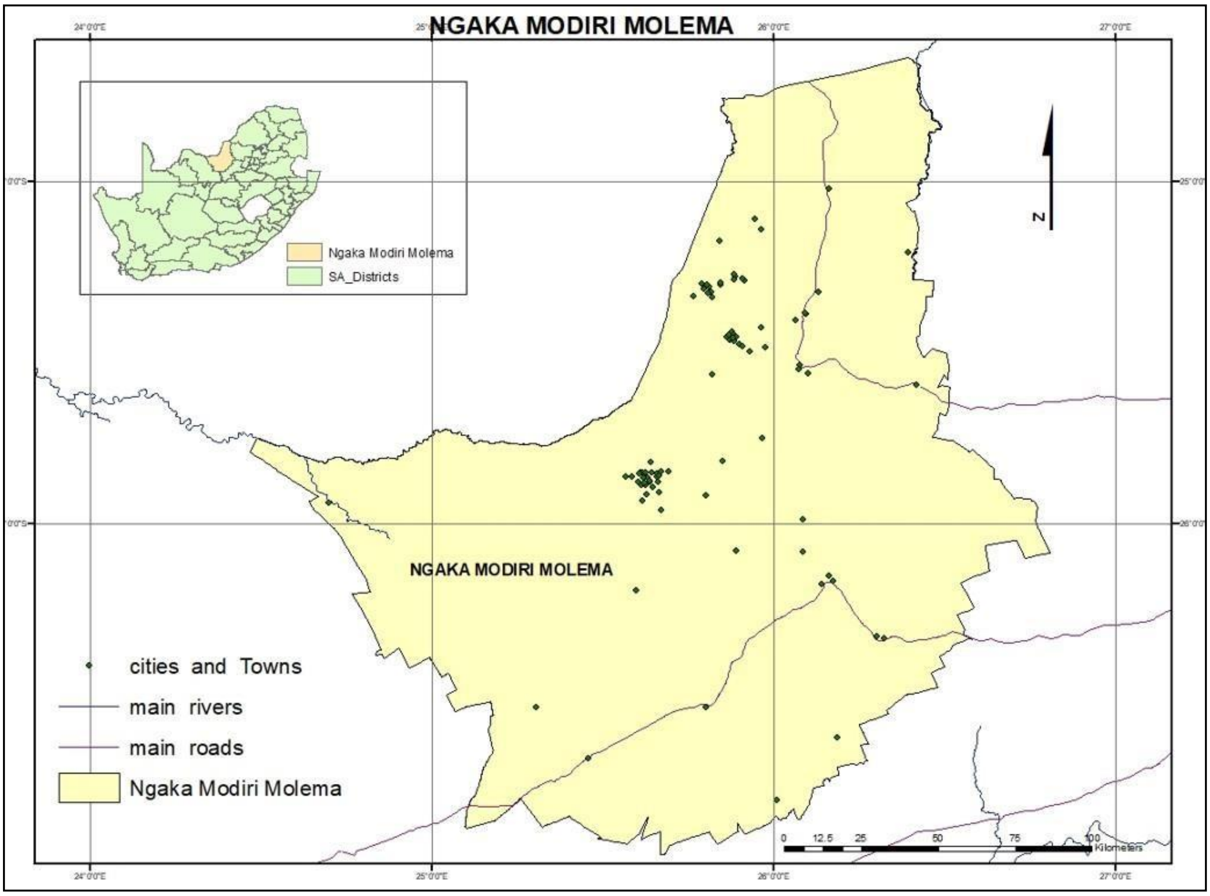


Figure 4: Ngaka Modiri Molema District, North-West Province

This study explores the geographic accessibility of TB treatment in public health facilities in Ngaka Modiri Molema District Municipality. The methodology is categorized into three key components which are data collection and preparation, accessibility measurement and site selection.

3.3. DATA ACQUISITION AND PREPARATION

This section of the study is categorized into three parts namely spatial distribution mapping, elevation mapping and land use land cover change detection, as shown in figure. Spatial distribution is the study of phenomena in terms of their physical locations; essentially, investigating where things happen and how they relate to one another. A spatial distribution study works by selecting a variable and charting incidences of that variable on a map (Muscato, 2017). Elevation is height above sea level. Elevations are measured in meters or feet. They can be exhibited on maps by contour lines, which interface points with the same height; by bands of colour; or by numbers giving the precise elevations of specific points on the Earth's surface (Rutledge et al., 2011).

Land use land cover (LULC) change detection based on remote sensing information is an imperative source of data for different decision making frameworks. Data inferred from land use and land cover change detection is critical to land preservation, economical advancement, and administration of water resources (Tewabe and Fentahun, 2020). The above mentioned factors form part of the crucial aspects of this study when coming to evaluating and determining the suitability of an area for construction of a public healthcare facility, to increase accessibility for TB treatment.

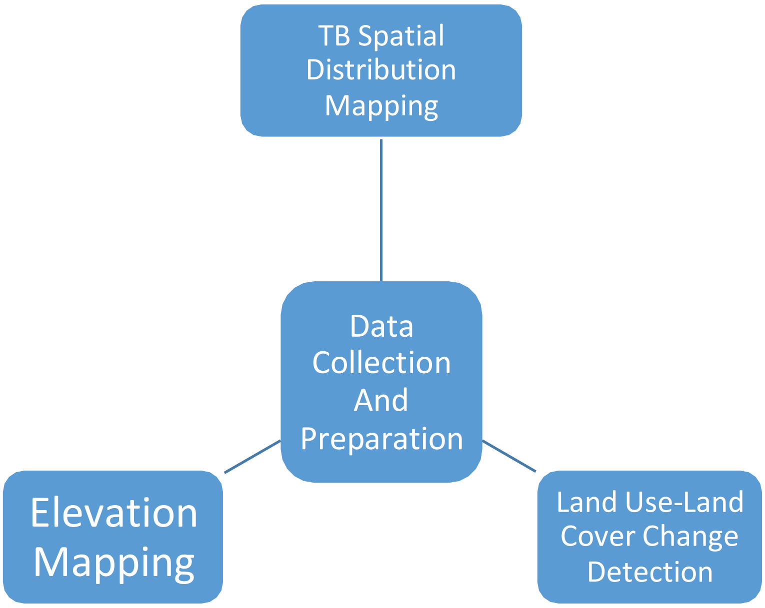


Figure 5: Layout of Data Collection and Preparation

3.3.1. Spatial Distribution Mapping

A variety of tools and data were used to suit the objectives of this study. Statistical data per healthcare facility and patient home addresses sourced from the North West Department of Health (NWDOH) Tier.net (Electronic Patient Management System) was used to assist in the modelling and analysis of the spatial distribution of TB as well as modelling TB treatment accessibility in Ngaka Modiri Molema. Microsoft Excel was used to tabulate the above mentioned data which was then used in ArcGIS 10.5, together with municipal administrative boundaries in shapefile format sourced from the municipal demarcation board website http://dataportal-mdb-sa.opendata.arcgis.com/. This was used for visualization and analysis.

For the table of addresses to appear on the map, they will be geocoded. Geocoding is the procedure of changing a description of an area, for example, a couple of coordinates, a location, or a name of a place, to a location on the world's surface (Chang, 2006). One can geocode by giving one location description at a time to zoom to an area on a map or convert a whole table that can be utilized for spatial analysis (Chang, 2006). GPS coordinates of clinics and patient addresses were geocoded in this study.

This study used ordered steps taken when geocoding as follows; The relevant tables of addresses “13July2021_Simulated data_KNR_Addresses” for patient home addresses and “TB data per facility” for health facilities were added to ArcMap 10.5,then it was Geocoded using the Geocode Addresses function on the geocoding toolbar in ArcMap.

3.3.2. Elevation Mapping

A Digital Elevation Model (DEM) of Ngaka Modiri Molema, sourced from Earth Explorer USGS website (https://earthexplorer.usgs.gov/), was used in ArcGIS for terrain modelling of the study area.

A terrain map is a specific sort of surface map. It demonstrates the distribution of surface deposits and related landforms on the world's surface. It additionally gives information about present day geomorphological forms (Bobrowsky *et al*., 1996).This study achieved terrain mapping by creating an aspect map and a slope map. A slope map is a topographic map that depicts variations in elevation in extensive detail and on an aspect map, the elevation and aspect information are combined and the isolines are shaded to indicate the direction of view on the map (Casey, 2003). Both these maps were important in visualizing the best locations for future hospitals in this study. A 30m DEM (SA_ SRT30 DEM) was used to create both maps.

The following steps were followed to create an aspect map. First, spatial analyst extension was enabled in ArcMap 10.5 to make it possible for the researcher to visualize the aspect. The aspect slope aspect map of the study area was generated through the use of the "Aspect" tool embedded in the ArcMap GIS software.

A slope map was made generally using the same steps as that of the Aspect map. The spatial analyst function was enabled then spatial analyst tool of Arctoolbox was selected, followed by surface tool, then SLOPE tool with SA_SRT30 DEM was used as the input rastertool while the output file was kept at default settings and the output measurement was kept at degrees.

For any organizational department, or construction project, site selection requires specific criteria. Of which elevation forms a part of, hence the need for the slope and aspect map. The choice of site is one of the fundamental decisions in the start-up procedure, and development. One of the main objectives in clinic site selection is finding the most appropriate site with desired conditions defined by the selection criteria. Tools of ArcGIS software overlaying hill shaded digital elevation model (DEM) on patient homes can be used, to visualize locations for where clinics or hospitals can be built with minimum distanceand better terrain conditions for each.

3.3.3. Land Use and Land Cover Change Mapping

Land-use change denotes a change in the way a specific area of land is utilized or managed by humans, whereas land-cover change refers to a change in some continuous characteristics of the land, such as vegetation type, soil conditions, and so on it requires specific data and methods to be followed (Verma, Singh, Singh and Raghubanshi, 2020). In this study, LULC is important for showing different land uses and predicting change so that when an optimum site is selected for hospital construction, it is in an appropriate area.

Data acquisition

Data was downloaded from the USGS (United States Geological Survey) earth explorer website. Two Landsat images were downloaded, the 2013 Landsat 5 and 2020 Landsat 8 which consists of seven bands for each year. The first image was captured on the 4th of June 2013 as indicated by figure 6, and the second image was captured on the 27th of August 2020, indicated by figure 7. The images were used as the base from various land use and land cover classes were generated.

Image enhancement

The process of enhancing satellite image quality without knowing what is causing the reduction is known as image enhancement. Enhancements are used to make it easier to interpret and comprehend imagery visually (Chaturved, 2006). The advantage of digital images is that they allow one to adjust the digital pixel values of the image (Chaturved, 2006). Image enhancement normally consist of composite, contrast stretch, digital filtering and pan sharpening. In this study, the composite generation was the only used image enhancement technique. It was used because colour composites take full advantage of the human eye's skills for visual processing (Ramachandra, Aithal, Setturu and Vinay, 2018).

Composite

When it comes to visual analysis, composite makes the most of the human eye's capabilities. The development of composites ranges from band selection to more complex techniques such as band combining with its accompanying contrast stretching, depending on the graphics employed (Ramachandra, Aithal, Setturu and Vinay, 2018).

Three bands were used to create a true colour image for both Landsat 5 (2011) and Landsat 8 (2020). For Landsat 5, the combination of RGB (red, green and blue) was used, which are bands 1, 2 and 3, respectively, as seen in figure 6. Then in Landsat 8 (2020), the combination of RGB (red, green and blue) was used, which is bands 2, 3 and 4, respectively on ArcMap, as seen in figure 7.

Remote Sensing image processing

Remote sensing image processing of data is essential in developing a linkage between biological phenomena, data and features which requires a number of processing steps for an improved identification of image features (Akter, 2006).

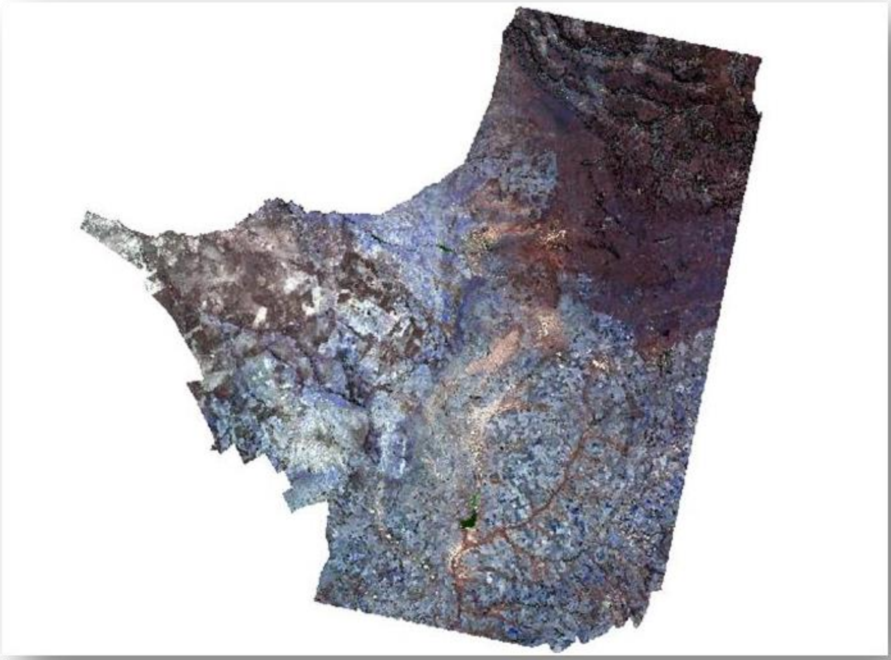


Figure 6: 2013 Natural Color Satellite Image

Figure 7: 2020 Natural Color Satellite Image

Image classification

Image classification is a computer vision process that can classify an image based on its visual information. It is the method of allocating pixels to land cover classes (Arora, 2010). There are two forms of classification: supervised and unsupervised, depending on the interaction between the analyst and the computer during categorization (Arora, 2010).Supervised classification was used for both images (Figures 6 and 7), because unsupervised classification is less precise than supervised classification. Supervised classification in a software depicts specific land cover classes that are based on statistical characterization of known features in the image (training site) (GISGeography, 2021)

The initial step in supervised classification is the identification of representative samples for each land cover class (i.e. land cover types) of interest from an image called “training sites”. Six land cover types were developed as shown in table 1. These training sites were collected by digitizing land cover types in ArcMap and applied them to the entire image. This in turn, generated a signature file, which stored all training samples spectral information.

Table 1: Land cover classes

Land cover classes	Description
Water	Water bodies found on the surface such as rivers, dam, ocean, lake etc.
Dense Vegetation	A cluster of trees and shrubs, making thick vegetation such as forest.
Dispersed Vegetation	Trees, shrubs and grass that are scattered around and not clustered as dense vegetation
Built Up Area	Buildings of commercial, residential and industrial areas
Bare Ground	Areas with no sign vegetation, buildings, water etc.

Supervised classification

The signature file was used to run the classification. A hard classifier- maximum likelihood (MAXLIKE) algorithm was used, which makes a distinctive decision by locating the land cover class to which every pixel belongs. MAXLIKE uses statistical characterization of training site data.

Accuracy assessment

The most important step in validating the classification made of images using remote sensing techniques and data is called the accuracy assessment. Any classification project must include an accuracy assessment. It compares the categorized image to data from another source that is thought to be accurate or ground truth. The classified Landsat images were used for classification. This was done using ArcGIS and MS (Microsoft) excel. A confusion matrix, which is a table that illustrates the correlation of ground truth points and the result of the classification, was used to generate and evaluate overall percent accuracies, user accuracies, and producer accuracies to assess image classification accuracy (Doaemo et al., 2020). Confusion matrix was the method utilized for accuracy assessment because it is among the most effective ways in representing Image Classification accuracy, as it has the ability to describe inclusion and exclusion errors (Scofield et al, 2015).

Confusion matrix was used for accuracy assessment which requires ground points. In this study, it was created in ArcMap as a point shapefile of 30 sample points for each land cover type. These shapefiles were identified using Landsat 5 and 8 images as reference points.

The point shapefile created from the Landsat images, were used to create an elevation raster. In other words, pixels of each land cover type sampled were created using the point to raster tool in ArcMap. Then, a feature attribute table was created using the pivot table tool in ArcMap, which consisted of a number of pixel of each land cover type. The feature attribute table was imported to Excel where statistical analysis was done. This created relationship tables that compared true land cover classes as seen on earth and land cover classes that were mapped; this also provided errors of omission and commission as tables. From the statistical analysis, user and producer’s accuracy indexes were produced.

User’s accuracy is an index characterizing the sum of errors of omission. It is the number of pixels that are correctly identified of a class, divided by the sum of pixels of the class in the image classified (Ukrainski, 2016). Ukrainski (2016) also describes the producer’s accuracy as the number of pixels that are correctly identified divided by the total number of pixels in the reference image.

To summarize the classification accuracy a Kappa coefficient and overall accuracy were produced. The Kappa coefficient is defined as the measure of how the classification results as compared to values that are assigned by chance (Ukrainski, 2016). It can take values from 0 to 1, 0 represent no agreement between the image classified and the image referenced (Ukrainski, 2016). If the kappa coefficient is equal to 1 this represent a total agreement between the image and the ground truth data, making them totally identical. This means the higher the kappa coefficient, the more accurate the classification is (Ukrainski, 2016).

Apart from the overall accuracy, class identification accuracy requires assessment. In order to do that, non-diagonal cells in the matrix are observed. These cells contain errors in classification, i.e. cases when the classified image and reference image do not match. These are two types of errors, which are underestimation (omission errors) and overestimation (commission errors) (Ukrainski, 2016) which are displayed and explained in chapter 4.

3.4. ACCESSIBILITY MEASUREMENT

In 1994, the Government decided to utilize a primary health care (PHC) approach to provide healthcare administrations through a district health framework (Dookie and Singh, 2012). Through this framework, all patients are anticipated to first get essential care at a clinic or health centre where an initial diagnosis is made and treatment conducted. In the event that more care is required, patients are at that point referred, managed, and if necessary, admitted to a district hospital (KwaZulu-Natal Department of Health, 2014). If the patient requires more particular care, s/he will be transferred to the suitable regional, provincial tertiary or national central hospital. Primary health care service is the primary level of contact with the national health system for individuals, families and communities, bringing care as near as conceivable to where individuals live and work; as such, it constitutes the first element in a proceeding health care process. Ideally, the distribution of PHC clinics and community health centres (CHCs) should be based fundamentally by need; however, a few clinics were built as a gift by evangelists, philanthropists and conventional pioneers (KwaZulu-Natal Department of Health, 2014). The government made a choice in 1994 that individuals must not travel more than five kilometres to get to a clinic. This led to the broad development of clinics in zones with the most prominent need. Provinces were also expected to be biased towards PHC within the assignment of assets (McIntyre and Ataguba, 2014). Based on the above-mentioned facts, this study will use proximity analysis tools of ArcGIS to determine accessibility to TB treatment by TB patients. Proximity tools together with other results produced by this study will be used in site selection for a new health facility or road. These can also influence the need to evaluate the post-Apartheid policies and Town planning, as far as distribution of healthcare is involved.

Proximity Analysis

Proximity tools can be partitioned into two classes depending upon the kind of input the tool accepts, in other words-features or rasters. The feature-based tools differ in the kinds of output they produce. For instance, the Buffer tool outputs polygon features, which can then be used as input to overlay or spatial selection tools such as Select Layer by Location (Chang, 2006).

3.4.1. Buffers

This study created feature-based buffers around selected points (public health facilities), by using the Buffer tool in ArcGIS 10.5. Buffered zone/space which is in the polygon form, for either a point, line or polygon feature. The buffer distance is given in kilometres.

Proximity analysis is necessary in this study for the purpose of measuring how far patients are from the roads, and how far healthcare facilities are from patients. A radius of 5km for all public health facilities was used to display accessibility. This kind of analysis advances and encourages the improvement of future healthcare facility plans comparable to actual demand and use, furthermore improving current access of overburdened central points (Public health facilities) that were not already realized (Mokgalaka, 2014).

3.5. SITE SELECTION

Mokgalaka (2014) stated that, from the viewpoint of the service provider, the challenge is subsequently to ideally provide services so that the health care needs of the largest number of individuals are served. The recent growth in the accessibility of Geographical Information Systems (GIS) and related modelling methods have given an appropriate foundation to the planning arrangements for the need of public services. For administrators and analysts, choosing a location is a difficult task. This process comprises not only technical requirements, but also economic, social, environmental, and political demands, all of which may conflict. The process of selecting locations that fulfill the selection criteria's desired parameters is known as site selection (Eldrandaly and Khalid, 2013). Site selection is one of the most important decisions made during the beginning process, expansion, or relocation of any organization.

Construction of a new business or system is a significant long-term investment, and identifying the location is a vital step in determining whether the system will succeed or fail. Finding the most suitable site with the necessary characteristics stated by the selection criteria is one of the key aims in industrial site selection (Rikalovic, Cosic and Lazarevic, 2014). Therefore, this study has selected sites for new hospitals based on data preparation, accessibility measurements and criteria that suits the selection for these sites. This operation was performed in ArcGIS.

3.5.1. Criteria for Selecting a Site for Hospitals

The following criteria were followed to select new sites for hospitals; A few healthcare facilities in a single area can have a negative impact as the traffic pressure turns out to be high for the area. So 5km encompassing of existing healthcare facilities zone is being proclaimed as the restricted zone, the healthcare facility ought to be situated close to the major road as the major road is the primary connection system of the city, the health facility should be situated in the best possible land use preferably in the residential regions as the residents are the primary clients of public healthcare facilities, the healthcare facility is required generally in the high population concentration areas, informal settlement areas can be used, as the principal client of public healthcare facilities are informal settlers, and, because communicable diseases are generally known to be more prevalent in informal settlements.

3.5.2. Site Selection

The most essential factor in determining whether a commercial or public-sector organization thrives is its location, whether it is a little coffee shop with a local audience or a multinational network of factories with distribution facilities and a worldwide chain of retail outlets. The right location can help keep fixed and overhead expenses low while increasing accessibility. When a good location is chosen, public-sector facilities like schools, hospitals, libraries, fire stations, and emergency response services (ERS) centers can provide high-quality service to the community at a cheap cost (ESRI, 2019). After reviewing literature and analyzing accessibility of TB treatment using methods used in the study, the researcher realized that hospital accessibility is low in Ngaka Modiri Molema. To increase hospital accessibility, new hospitals need to be constructed, therefore using the criteria mentioned in this study, the researcher selected several suitable areas that meet the criteria.

Site selection was done by first creating buffers around existing hospitals using the buffer command in ArcGIS 10.5 and selecting suitable sites using the Editor tool. Feature based buffers around existing hospitals were created, by using the Buffer command in ArcGIS 10.5. Buffered features were created as polygon features using the settings of the chosen feature template. The buffer distance is given in kilometres. The researcher decide on a 10km buffer distance to represent an area of general accessibility.

On ArCatalog, a new shapefile named “new hospitals” was created. It was assigned an appropriate geographic coordinate system “GCS_WGS_1984” because it matched that of the Data frame. The Editor tool was used to manually create the new points. For these user- defined points, x and y coordinates were derived using the “XY

Coordinates" tool found in Data Management, feature tools in Arctoolbox. "New hospitals" was used as the relevant input point data during this process. After this, each user-defined point will be assigned its accurate X and Y coordinate.

3.6. ETHICAL CONSIDERATIONS

Prior to the commencement of this research study, an application with ethics clearance reference number H20-SCIGEO-002 was made to the Nelson Mandela University Human Research Ethics Committee (REC-H) to obtain ethical clearance(Refer to Appendix 1).

3.7. CHAPTER SUMMARY

This chapter describes the methods and techniques used in this study to achieve the objectives. It details the research design of this study, clarifies the work approach, criteria, information and information source, data preparation, GIS steps, instruments and procedures to direct suggestions to increase accessibility.

This is a quantitative study that is based on the examination of secondary data. It employed secondary statistics data and patient addresses to predict physical accessibility of TB treatment in public health institutions using a GIS.

The research site was the Ngaka Modiri Molema (NMM) district in the North West province of South Africa (figure 4), which covers an area of 28 206km2. In the Northwest province, the Ngaka Modiri Molema District Municipality is situated between the Bojanala Platinum District Municipality, Dr Ruth Segomotsi Mompati, and Dr Kenneth Kaunda, and shares a border with Botswana. Ratlou, Tswaing, Mafikeng, Ditsobotla, and Ramotshere Moiloa are among the local municipalities.

Spatial distribution mapping, elevation mapping, and Land Use Land Cover change detection are the three aspects of the study. The study of phenomena in terms of their physical locations is known as spatial distribution. Elevation mapping depicts the different altitudes of a region on a map. With reference to sea level, elevations are commonly measured in metres or feet. It might be either above or below the surface of the water. In a map, elevation is shown by contour lines, bands of the same colour, or numerical values indicating the exact elevation details. Detecting changes in land use and land cover (LULC) using remote sensing data is an essential source of information for many decision support systems. Land conservation, sustainable development, and water resource management all benefit from data produced from land use and land cover change detection.

CHAPTER FOUR:

RESULTS AND DISCUSSION

4.1. INTRODUCTION

Inequalities in access to health care are a critical concern for health policies in developing countries. Since health status impacts human capital procurement, financial status and the inter-generational transmission of socio-economic status, access to healthcare plays a part in determining and strengthening other measures of imbalance (Yazbeck, 2009; Wilkinson and Pickett, 2009; McLaren, Ardington, and Leibbrandt, 2013). To eradicate this, public health service providers are regularly subsidized to promote non- discriminatory access. In post-apartheid South Africa, the government has emphasized equity and made access to clinics the cornerstone of essential health care. This makes it vital to understand which individuals in the population benefit more from these services and who is being left behind (McLaren, Z., Ardington, C., Leibbrandt, M., 2013).

Even when health services are given free of charge, financial costs and the costs of travel to a neighborhood clinic also represent the cost of access to health care. These costs may pose a significant barrier for vulnerable members of the population (poverty stricken, women and children, the elderly and foreign nationals), leading to generally poorer health. Even after more than twenty years post-apartheid, residential areas remain largely racially characterized and this residential isolation can compound obstructions if health facilities are found distant from non-white neighborhoods (Christopher, 2001; McLaren, Ardington, Leibbrandt, 2013). Travel costs in South Africa are especially excessive relative to other developing nations in Africa and elsewhere, which implies that small contrasts in distance can interpret into huge contrasts in access.

The previous chapter discussed the data collection strategies as well as the methodology used in this study. This chapter analyses and interprets the findings of the study and correlates the results with literature to support these findings. Data analysis in this study is divided into five major tasks to meet its objectives: Quantifying collected data and preparing it for representing spatial distribution, Elevation Mapping which includes an aspect map and a slope map, Land Use and Land Cover change detection, measuring accessibility, represented by maps with buffers and site selection. This chapter also shows how all parts of the study correlate with each other to show accessibility and how these findings are used for site selection

4.2. QUANTIFYING COLLECTED DATA AND SPATIAL DISTRIBUTION MAPPING

Surveillance and data management frameworks need to be a priority for all TB management programs. Information technology can enhance the care of patients with TB illness through a standardized series of data collection, information, and monitoring of results (Lee, Raviglione and Flahault, 2020).

All TB studies should account for spatial aspects because all TB cases occur at a specific location at a specific time. TB is a contagious illness and transmitted through the air. Consequently, TB prevalence statistics are not independent, as comparable values are positioned close, leading to a correlation amongst statistics. Basically, TB prevalence statistics incorporate spatial dependence (Im and Kim, 2021). TB has geographic variations, often focused in densely populated, low-earning areas. This small-scale geographic variations, is visible amongst town neighborhoods, which might additionally reflect neighborhood transmission and is frequently related to community traits which include crowding or poverty (Im and Kim, 2021; Robsky et al., 2020). Table 2 shows how data collected for this study is used to account for the spatial aspects of TB.

Table 2: Layout of collected GIS Data

DATA	DATA TYPE	DATA SOURCE	CONTENTS	FEATURE TYPE	DATA CLASSIFICATION
TB Register-2019	Vector	NWDH-TIERNET	Patient Addresses, age, gender and HIV status	Points	Secondary
Health facilities register 2020	Vector	NWDH-DHIS	Names of health facilities, statistical data per health facility	Points	Secondary
Roads, Rivers and dams	Vector	Dept. of forestry, fisheries and the environment	Roads, rivers and dams	Lines	Secondary
Landsat8 imagery: Ngaka Modiri Molema	Raster	USGS	Ngaka Modiri Molema Elevation, land use and land cover change 2013-2020	Pixels	Secondary

A scientific project needs data acquisition, the need for a clearly enunciated plan, satisfactory resources, fitting financing, and sufficient time. A main choice facing researchers of such projects is whether to search for a methodology that is gradual (Systematic) or fast collection (DANIEL, 2016). Another imperative choice is whether data collection should to use in-house or external resources. This study made use of external resources (secondary data) in requesting TB data from the NWDOH and by using shape files, digital elevation models and satellite images from various internet sources.

There are two essential types of data capture, which are primary data sources and secondary data sources. Primary data is new data collected by the user/ researcher for their own use or use within an organization, while secondary data is information that has previously been gathered from primary sources and made available to researchers for use in their own studies (DANIEL, 2016). Table 2 shows a detailed plan of the kind of data collected, the source of the data, what the data contains, and how the data will be represented in a GIS environment for this study. Planning incorporates building up user requirements, gathering assets, and developing a project plan. Preparation includes getting information, redrafting poor-quality map sources, editing scanned map images, expelling noise, setting up suitable GIS equipment and software frameworks to accept information. Altering and enhancement covers numerous strategies planned to validate data, as well as rectify mistakes and improve quality. Evaluation is the method of distinguishing project successes and failures. Table 2 organized the data in a way that it would fit the study’s methodology. It also takes into account the alterations and enhancements that were made to the data to remove errors and ensure that it meets the objectives of this study. Table 3 is a summary and analysis of the data received from the NWDOH, it contains information that will help this study express its points and meanings.

Table 3: Quantifying collected data

	N	n (%)
GENDER		
• Males	• 1078	• 43.12
• Females	• 1422	• 56.88
	Grand Total- 2500	
AGE GROUPS		
• 0-4	• 203	• 8,12
• 5-9	• 195	• 7.8
• 10-14	• 186	• 7,44
• 15-19	• 199	• 7,96
• 20-24	• 208	• 8,32
• 25-29	• 204	• 8,16
• 30-34	• 219	• 8,76
• 35-39	• 209	• 8,36
• 40-44	• 191	• 7,64
• 45-49	• 217	• 8,68
• 50-54	• 214	• 8,56
• 55-59	• 184	• 7,36
• 60-64	• 71	• 2,84
	Grand Total- 2500	
SUB DISTRICT		
• Ditsobotla LM	• 503	• 20.12
• Mahikeng LM	• 492	• 19.68
• R Moiloa LM	• 508	• 20.32
• Ratlou LM	• 472	• 18.88
• Tswaing LM	• 525	• 21
	Grand Total- 2500	
HIV STATUS		
• Negative	• 607	• 24.28
• Positive	• 677	• 27.08
• Unknown	• 1216	• 48.68
	Grand Total- 2500	

A total of 2500 patients' records were sampled for this study, from public health facilities in the district. Data was captured in an unbiased manner to ensure accurate representation of individuals without discriminating against others. The analysis of this sampling is shown in Table 3, where "n" represents the number of patients within a category, and "n (%)" is the percentage of patients within that category. The purpose of this is to give an overview of what the data includes before it was manipulated to fit the objectives of this study.

Patient ages ranged between 0-65 years with females (1422) dominating and an average age of 30 years being the central age in the set of data. The dominance of females was mainly because females make up most of the general population in South Africa as well as in the North West province, and females between the ages of 14-24 years are the most affected by TB and HIV/AIDS. This is shown in the NMMD report where females comprise of 51.31% of the population while males make up 48.69% (Ngaka Modiri Molema District Municipality, 2021). It can also be due to the fact that a lot of households are headed by females in the district, making them the main bread winners, thus more exposed and susceptible to the disease. This is supported by the NMMD report where it is stated that women head around 41.2% of households in the NgakaModiri Molema District Municipality.

The results also show that; the highest number of TB cases is 219, found in people between the ages of 30-34 followed by the 45-49 (217) age group and 50-54 (214) age group making up 17.44% of the data, these particular age groups are key participants in South Africa's economy, they are men and women participating in labor and business services. The age groups 25-44 years is known as the working age category and 45-65 years age group is the higher working ages according to NMMD Municipality (2021). This supports the above statement about the age groups being the major players in the economy, which means they are more exposed to the disease in either their work places or in their commuting to work.

It is noted that children within the ages 0-4 years appear to be the next most highly affected age groups following the working ages, this is because children's immune systems are maturing, and more susceptible to contracting pathogens as toddlers learn how to walk and explore their surroundings. They are also frequently in closer proximity with one another in daycare establishments, which makes contagious illness transmission very simple. The Ngaka Modiri Molema District report proves this by stating that the major cause of death for children below the age of 4years is communicable diseases (Ngaka Modiri Molema District Municipality, 2021).

Tswaing was noted to have the highest number of cases with 525, followed by Ramotshere Moiloa (508) and Ditsobotla (503) making them the most affected sub districts. NMMD is characterized by high levels of poverty and poor levels of education, In the Ngaka Modiri Molema District Municipality, 67.66 % of the people are living in poverty, according to the upper poverty line classification (Ngaka Modiri Molema District Municipality, 2021). As financial status is closely related to family income which has an impact on day-by-day living patterns such as food consumption and wellbeing,a head of the family who has a wage beneath the average minimum wage which means the family will consume nourishment with nutritional levels that are not in accordance with the requirements of each family member so that they are in need of sustenance, which can encourage infectious diseases including pulmonary TB (Rusnoto, Nasriyah, Meitasari and Nisa, 2020). Therefore, without financial means, and education, the Ngaka Modiri Molema District will continue to display high levels of TB cases. The above results could also be attributed to population growth, as it is one of the factors that contribute to rising TB statistics in the world. Population growth of NMMD increased from 0.6% to 1.58% between 2018 and 2019. Ditsobotla local Municipality was the highest with an average annual growth rate of 1.7% while Ratlou Local Municipality had the lowest with 0.55% (Ngaka Modiri Molema District Municipality, 2021). Although Mahikeng Local Municipality has a relatively low number of cases (As seen in Table 3), it is subject to high vulnerability as well because of a rapid increase in population and close contact situations (crowding) in places like Mahikeng and Mmabatho, the district's economic hub and capital city of the province, which are directly affected by high levels of poor education and poverty, like other sub districts.

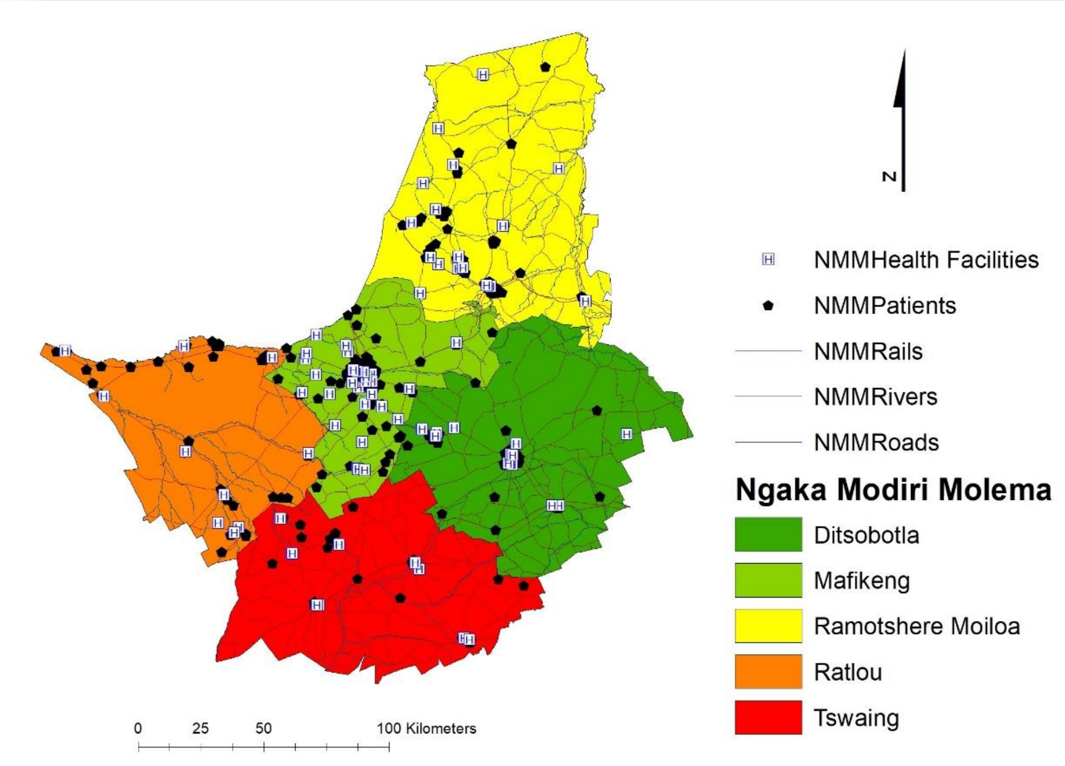


Figure 8: Spatial Distribution of NMM patients and Health Facilities

According to Ngaka Modiri Molema District Municipality (2021), the district is essentially rural and is made of 8 towns, 21 townships, 198 villages, and 103 wards. Like most of South Africa's rural communities, Ngaka Modiri Molema is characterizedby socio- economic inequalities, which lead to excessive poverty and illnesses within the areas (Ngaka Modiri Molema District Municipality, 2021).

Figure 8 shows the results of Spatial Distribution of NMM TB patients and public health facilities as per objective two of the study. Ratlou (Orange) Local Municipality shows that most patients are located along the North and South boundaries of the sub districts with few to no patients in the central parts of the sub district. Most health care facilities in the sub-districts are located along the South parts of the sub-district and few in the North. The distribution of patients is dispersed because Ratlou is predominantly a rural municipality and does not have big economic centers. Key towns include Disaneng, Kraaipan, Madibogo and Setlagole.

In Tswaing (red) Local Municipality, patients are located along the north boundary of the sub-district, towards Mafikeng sub district and Ratlou. Health facilities are, however, located towards the central parts of the sub district. Tswaing is predominantly rural and faces some service delivery challenges, with regards to backlogs within the provision of water, electricity, sanitation, roads, and road lighting (Ngaka Modiri Molema District Municipality, 2021). The location of patients is also partially because of evictions of people from the surrounding farms and partly due to the natural increase of the populace, its main economic sectors are agriculture and small-scale farming (Ngaka Modiri Molema District Municipality, 2021).

Ditsobotla (green) municipality shows patients and public health facilities in the central part of the sub district, in Lichtenburg which the socio- economic hub of the sub district. Few patients and health facilities are located towards the North boundary of the sub district.

Mahikeng (As shown as Lime in figure 8) sub district is home to the town of Mafikeng, which is in the centre of the sub district. Public health facilities are scattered throughout the sub district except for the north and southeastern parts of the district. A reason for this distribution is attributed to the fact that Mahikeng Local Municipality, formerly called Mafikeng Local Municipality consists of the capital town of the North West Province, Mafikeng, and is neighboring the Botswana border. Its key cities within the municipality consist of Mahikeng, Mmabatho, and Ottoshoop. Mahikeng's major financial sectors are agriculture, mining, manufacturing, trade, and tourism making it the primary economic hub of the district (Ngaka Modiri Molema District Municipality, 2021).

In Ramotshere Moiloa (shown in yellow in figure 8) sub district, most patients are located towards the southern parts of the sub district and public healthcare facilities in the same areas, with a few towards the north. Ramotshere Moiloa Local Municipality is the biggest municipality within the district, accounting for a quarter of its geographical area (Ngaka Modiri Molema District Municipality, 2021). Therefore, patients are distributed towards the most accessible basic services.

Because of the general rural nature of the district, and socio-economic disparities, people will choose to live in areas that have high access to water, employment, sanitation, roads and other drivers of the economy. This will result in a general increase of squatter camps and illegal settlements and overcrowding in those settlements. It is stated that, in the Ngaka Modiri Molema District, informal employment increased from 27 000 in 2009 to an estimated 36 972 in 2019, according to the NMMD municipality report (2021). This then influences the location of TB patients in each sub district. If a communicable disease like TB is to affect the overcrowded informal settlements, the prospects of morbidity and mortality are very high. Therefore, an emergency or crisis in South Africa could have catastrophic wider regional consequences (United Nations, 2020). This makes it key to analyze the data at district level. As maintained by Coetzee, Cassim and Glencross (2017), analyzing information at a local level includes vital data that's married by national or provincial average reported and this is what is done throughout this study.

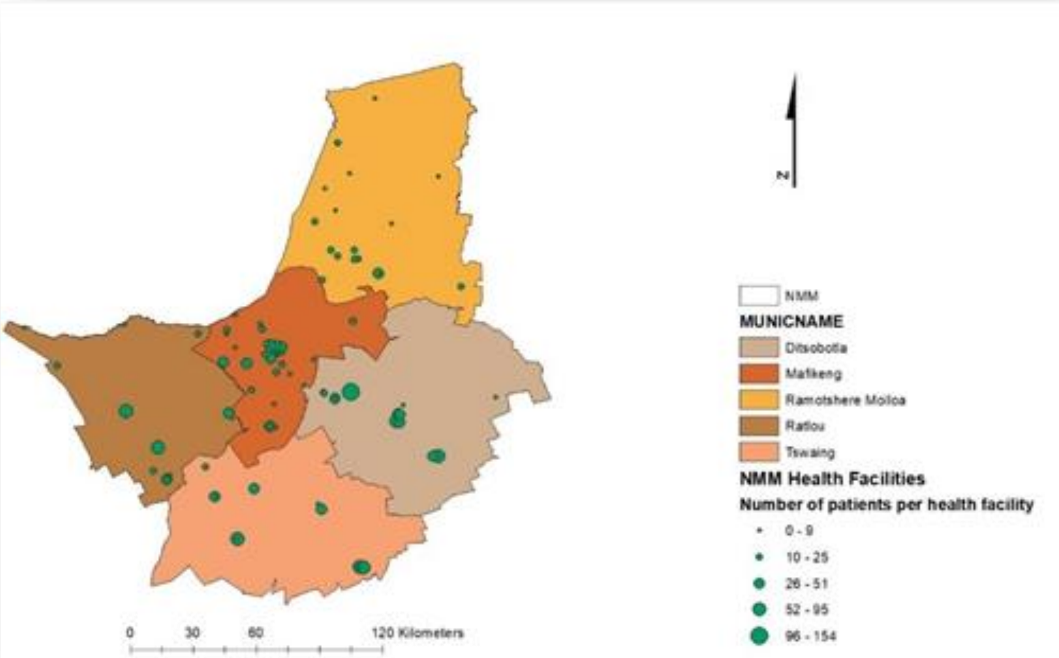


Figure 9: New 2019 TB patients per NMM health facility

A comparison between the number of patients that started treatment and the number of patients that get retreated will be assessed in figure 9 and 10. Figure 9 shows the number of new TB patients per health facility in Ngaka Modiri Molema for the year 2019. Mahikeng, Ditsobotla and Tswaing appear to have the greatest number of patients per health facility as compared to Ratlou and Ramotshere Moiloa. Although Mafikeng appears to have more patients, the top five facilities with the highest number of TB patients are Thusong Hospital, Setlagole Clinic, Delareyville Community Health

Centre, Letsopa Clinic and Ratlou Community Health Centre, none of which are found in Mafikeng sub district.

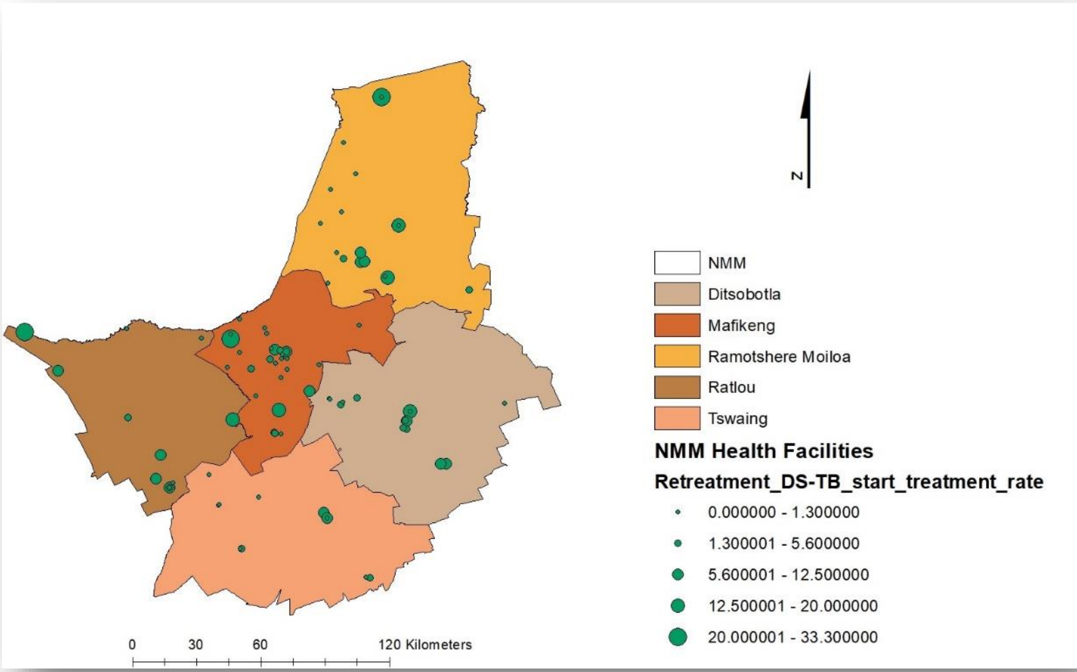


Figure 10: 2019 TB Retreatment patients per NMM health facility

A TB retreatment case is described as a person previously treated with anti-TB medication for a month or more and who is being treated again (Nabukenya-Mudiope et al., 2015). Figure 10 above shows that Ratlou, Ditsobotla, and Mahikeng sub districts has the highest total number of retreatment patients in 2019, with the top 5 public health facilities being Mareetsane clinic in Ratlou, Setlagole Clinic in Ratlou, Coligny Community Health Centre in Ditsobotla, Mahikeng Gateway Clinic in Mahikeng and Thusong Hospital in Ditsobotla. Subdistricts showing the lowest number of retreatment patients are Ramotshere Moiloa and Tswaing. Apart from the previously mentioned reasons of poverty, rural nature and poor levels of education of individuals in the district, patients tend to relapse or abandon treatment because of the following factors, understaffed public health facilities, patients failing to respond to the first line drug regimen due to being too weak to get to the facilities, or being unable to afford travel costs to the nearest facilities, which is made worse by overcrowding and long queues at public health facilities and, rude staff at the facilities which may discourage patients to take their medication or collect it, or, under resourced facilities. These above mentioned factors are some of the major factors that affect spatial accessibility to TB treatment. Because of these factors, patients will need hospitalization as a consequence of their worsened TB conditions due to their relapse.

The above-mentioned factors are supported by the results of a survey conducted by Ritshidze Community Monitoring Systems in Ngaka Modiri Molema Health facilities. It revealed that 94% of the patients agreed that the queues at the facilities were too long and the average waiting time at facilities is 5 hours, 17 minutes, this simply does not work for people going to work and those in school. Having HIV and TB patients spend a long time at a healthcare facility to collect medication increases the risk of patients disengaging from care. Another thing that the report revealed about patients disengaging from care is the reports of and ongoing crisis of stock outs and shortages of TB medications in NMM facilities. This causes disruptions, confusion, extra costs and discouragement amongst patients and therefore affects treatment adherence, as patients do not want to stand in long queues for hours, travel long distances and incur travel costs just to collect medication (Ritshidze, 2021).

4.3.ASSESSMENT OF TOPOGRAPHIC CHARACTERISTICS OF THE STUDY AREA

4.3.1. Slope aspect/orientation

An elevation map represents the different heights in a region portrayed on a map. Elevations are often measured in meters or feet with reference to the ocean level. It can be either above sea level or below sea level. Elevation in a map is portrayed utilizing contour lines, bands of colors or by numerical values giving the precise height details (Ansumant, 2020). Elevation maps are crucial for this study to help with planning, designing and selection for new sites as well as to assess how elevation may affect TB treatment spatial accessibility, as per the first and second objectives of this study.

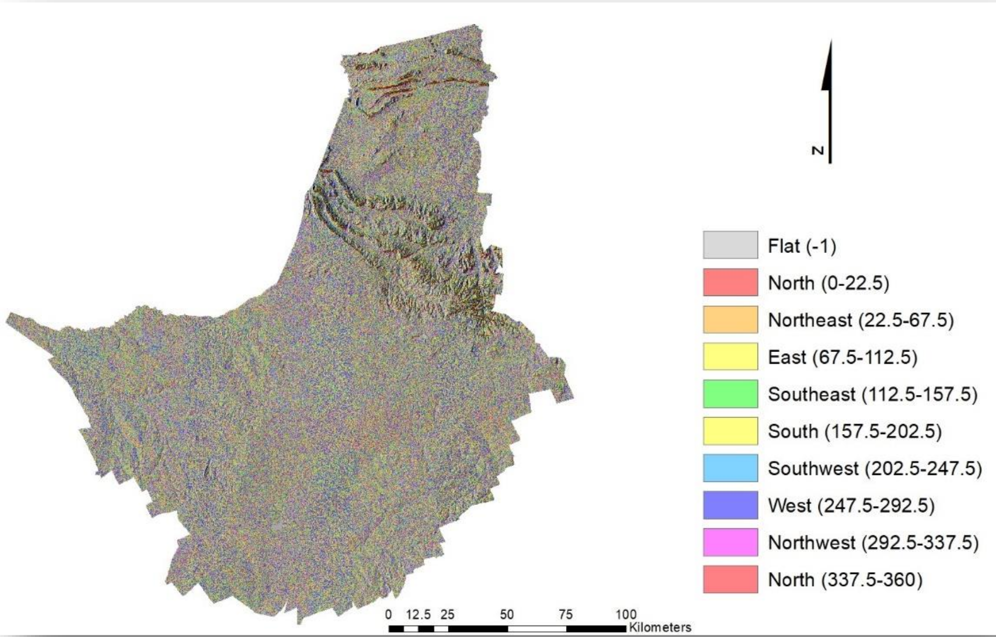


Figure 11: Aspect Map of NMM

The compass direction that the incline faces is the slope's aspect (GISGeography, 2021). When an area is flat, there is no slope (The general aspect of Ngaka Modiri Molema as displayed by figure 12) which also means that there is no aspect. Although, there is little to no aspect in Ngaka Modiri Molema, there is however a slight slant in the northeast (Ramotshere Moiloa) part of the district, which may be attributed to the hilly landscapes of the district. There are north-facing, west-facing, south-facing and east-facing slopes, which might indicate differences in vegetation. Ramotshere Moiloa is generally flat with a slight North South and East west sloping. It is surrounded by residential houses and a tarred road to the North, East and West.

Figures 12, 13, 14, 15 and 16 will look at different slopes of the district per sub district to better explain the different slope directions displayed in figure 11.

NMM Slope per sub-district

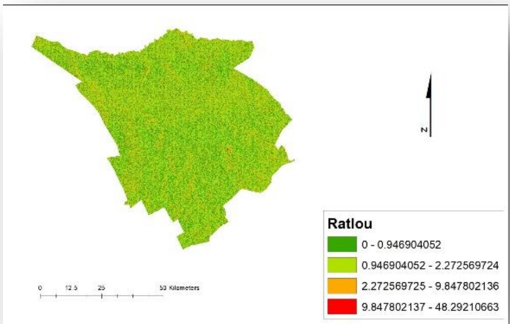


Figure 12: Slope map of Ratlou sub-district

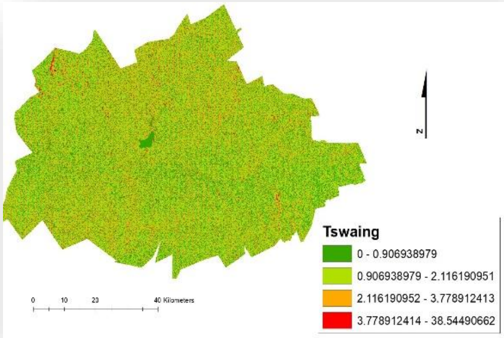


Figure 13: Slope map of Tswaing sub-district

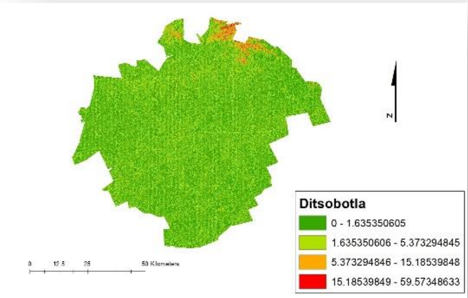


Figure 14: Slope map of Ditsobotla sub-district

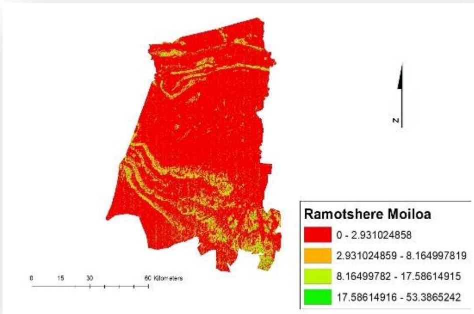


Figure 15: Slope map of RMM sub-district

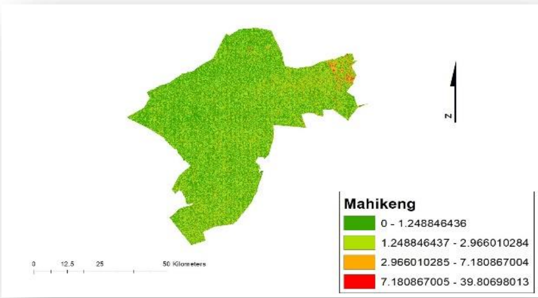


Figure 16: Slope map of Mahikeng sub-district

As mentioned in chapter 3, Ngaka Modiri Molema district is one of four area districts within the North West province and covers a region of around $28\ 114 km^2$. The municipal region is fairly flat and dry within the west, with bushveld on the east. It is leaning northwesterly at a modest angle. The northern half of the area is characterized by hills and plains. The region's topography consists of a variety of terrains, including flat to moderately sloping plains, rocks, bottomlands (drainage canals), and mildly sloping hills (Henning, 2015).

The estimate landscape height above sea level is 1404m and it has an average elevation of 1264m, minimum elevation of 926m, and a maximum elevation of 1729m according to literature. Mahikeng Local Municipality has a minimum elevation of 1033m, an average elevation of 1345m, and a maximum elevation of 1644m. Ramotshere Moiloa local municipality has a maximum elevation of 1657m, and average elevation of 1185m and a minimum elevation of 927m. Ditsobotla is a third order administrative division located in Ngaka Modiri Molema District with an estimated terrain elevation of 1488m above sea level. Tswaing Local Municipality has a minimum elevation of 1460m, a maximum elevation of 1546m, and an average elevation of 1503m. The results are important because, the classification of a slope and aspect in a given location is a critical factor in determining whether a piece of land is suitable for crop cultivation or construction of a building. Wherever the researcher chooses a site for the construction of a hospital to be, slope and aspect should have been thoroughly considered. The use of mechanical traction is influenced by slope, and the rate of soil erosion is influenced by soil textural classes. This is supported by a report compiled by Dr Henning for Exigo Sustainability (2015), where it is stated that by channeling pools of soil water, field topography can have a direct impact on crop development and output. Slope has an indirect effect on the distribution of chemical and physical parameters such as organic matter content, base saturation, soil temperature, and particle size (Henning, 2015). Given the results of this section, the direction in which a slope faces the sun — north or south – has an impact on the climate that develops on it and the type of vegetation found on it (Williams, 2015). Ngaka Modiri Molema is characterized by woody, scattered vegetation which impacts health facility accessibility because, the vegetation makes it difficult to travel to and from health facilities, as such, transport accessibility is also impacted. Similarly, transport accessibility will also be affected in high lying areas.

The slope's steepness depends on the depth of soil on the slope, whether it faces north or south. The higher the inclination, the faster the soil is eroded by rain runoff. Because particles of lightweight organic matter, such as leaves, wash away before decomposing into soil on steep slopes, the soil is mostly made up of rock fragments. Slopes with a gentle gradient tend to develop a thicker layer of soil than those with a steeper incline (Williams, 2015). This implies that public health facilities should be constructed in areas of the land surface with homogenous form and slope.

4.4.LAND USE LAND COVER CHANGE DETECTION

In this research, land cover classification was performed to outline major land cover classes by using Landsat images. This is important for the application of the third objective as new facilities must be constructed in appropriate land classes so as to be accessible. The classification produced from MAXLIKE classification, which is a supervised classification process produced maps that have 5 land cover types- water, built up area, dense vegetation, dispersed vegetation, and bare ground as shown in Figures 17 and 18.

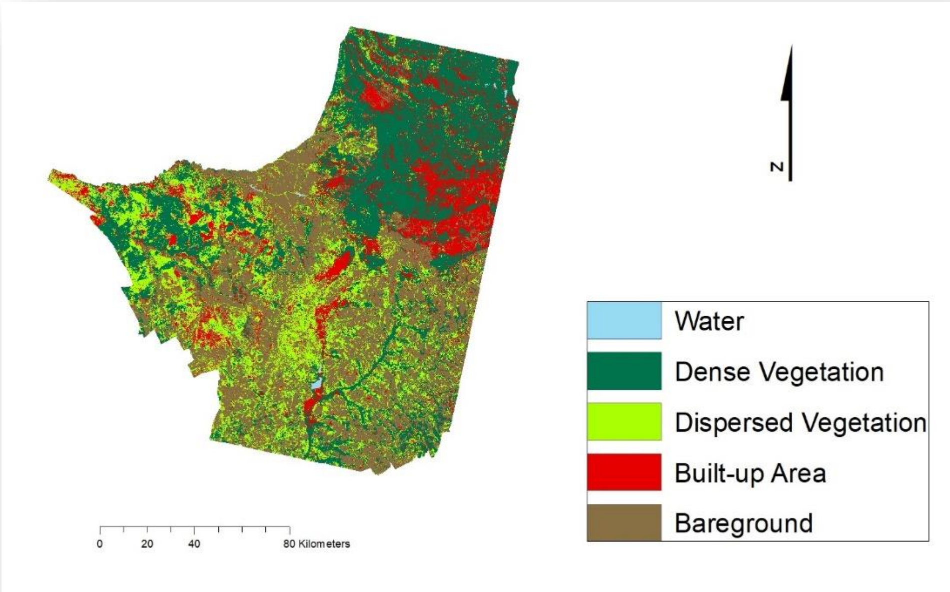


Figure 17: LULC 2013

Figure 17 shows land use and land cover change of the year 2013. There was more dense vegetation than dispersed vegetation and sparsely populated levels of built-up areas, as well as high levels of bare ground. Water bodies are in small quantities because of the semi-arid conditions of the study area.

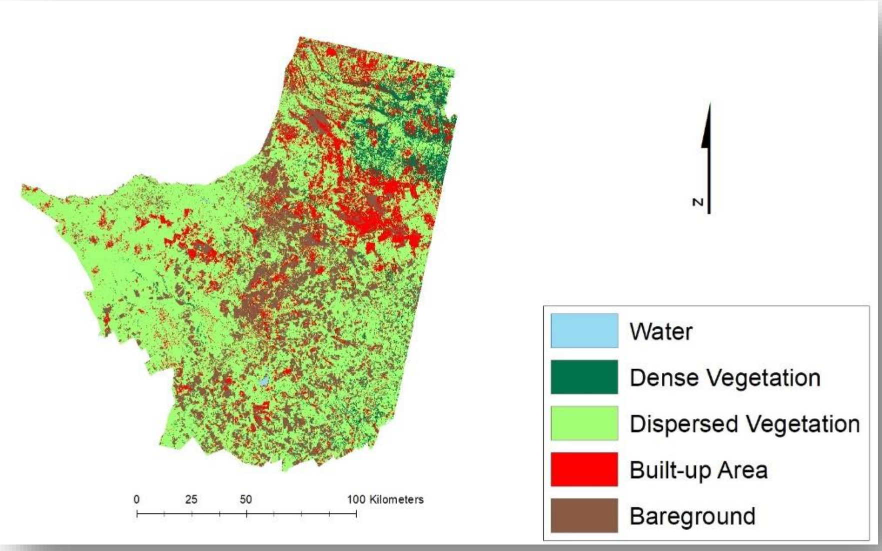


Figure 18: LULC 2020

As compared to figure 17, figure 18 shows an increased level of dispersed vegetation and a decrease in dense vegetation. Built up areas are sparsely populated because of the district being characterized by being largely rural, and bare ground has now decreased because of factors like population growth, as the population grows, buildings need to constructed for them to live in and conduct business in.

Accuracy Assessment

Accuracy assessment was done by selecting test pixels from the image and confirming their labels against classes determined from reference information. The extent of pixels from each class labelled in the image accurately by the classifier was evaluated as well as the proportion of pixels from each class erroneously named into every other class. These outcomes were enunciated in tabular form treated as the 'error matrix'. The land cover classification precision is mainly affected by: categorical resolution (number of land cover classes) and, spectral resolution (employing a few spectral groups instead of all groups).

In this study, maximum likelihood classification yielded an overall accuracy of 0.60 (table 4a) and a kappa coefficient of 0.50 (as seen on table 4a), generally with the Kappa index in agreement with the fact that the higher the kappa coefficient, the more accurate the classification is meaning that both classifications are satisfying in terms of accuracy.

Table 4a: Confusion Matrix result and ground truth of 2013 classification

2013 LULC Error Matrix

Overall accuracy	**0.60**					
Kappa coefficient	0.50					
Water	30.00	6	0	0	0	36
Dense Vegetation	0.00	11	0	0	26	37
Dispersed Vegetation	0.00	2	25	5	0	32
Built-up Area	0.00	10	2	24	4	40
Bareground	0.00	1	3	1	0	5
Total	30.00	30	30	30	30	150

Table 4b: Confusion Matrix result and ground truth of 2013 classification

Ground Truth					
Water	100.00	20	0	0	0
Dense Vegetation	0.00	36.66666667	0	0	86.66666667
Dispersed Vegetation	0.00	6.666666667	83.33333333	16.66666667	0
Built-up Area	0.00	33.33333333	6.666666667	80	13.33333333
Bareground	0.00	3.333333333	10	3.333333333	0
Total	100	129.8	99.9	99,9	99.9

Table 4b represents the confusion matrix results and ground truth of 2013. The values are shown in percentages so the readings will be done as percentages as well. It is indicated that 100% of water values were classified correctly and 20% of values that should be dense vegetation were classified as water. It also shows that 36% of dense vegetation values were classified correctly while 86% of bare ground was confused with dense vegetation.

Furthermore, 6% of dense vegetation was classified as dispersed vegetation while 83% of dispersed vegetation was classified correctly and 16% of built- up area was classified as dispersed vegetation as well. 33% of dense vegetation was classified as built-up area, and 6% dispersed vegetation was classified as built-up area as well, while 80% of built- up area was classified correctly and 13% of bareground was confused with built-up area during the classification process. Lastly, 3% of dense vegetation was confused with bareground and another 3% of built-up area was confused with bareground.

In summary, examining accuracy statistics produced from a confusion matrix in figure 4b. 100% accuracy for water, 80% for built up area, 90% for dense vegetation, 86.6% for dispersed vegetation and 10% for bare ground accuracy. The low accuracy may be attributed to similar spectral signatures of land cover classes in the study area. The misclassifications may be accounted for by the fact that built up area pixels may be classified as bare ground, because ofsimilarities in spectral reflectance and physical structure.

Table 5a: LULC Error Matrix result and Kappa coefficient of 2020 classification

2020 LULC Error Matrix

Overall accuracy	**0.68**					
Kappa	0.60					
Water	30.00	0	0	0	0	30
Dense Vegetation	0.00	10	0	0	0	10
Dispersed Vegetation	0.00	19	29	18	1	67
Built-up Area	0.00	1	0	10	6	17
Bareground	0.00	0	1	2	23	26
Total	30.00	30	30	30	30	150

According to the results of the maximum likelihood classification of 2020 shown by table 5a, the overall classification accuracy was 0.68 while the kappa coefficient was 0.60. The Kappa coefficient was slightly above average which indicates a fairly satisfactory classification. According to table 5a, a total of 30% of water was incorrectly identified as other classes while, 10% of dense vegetation was erroneously classified. Additionally, a total of 67% of dispersed vegetation was incorrectly classified and 17% of built-up area was incorrectly classified. Lastly, 26% of bareground was erroneously identified as other classes. Table 5b will explain the above-mentioned results in detail.

The fraction of values that were projected to be in a class, but are not in that class is referred toas commission errors. They are a measure for the number of false positives. Except for the values along the diagonal, commission errors are displayed in the rows of the confusion matrix (L3 Harris Geospatial, n.d.). The fraction of values that belong to a class, but were projected tobe in a different class is known as omission errors. They are a metric for the number of false negatives. Except for the values along the main diagonal, omission errors are displayed in the columns of the confusion matrix (L3 Harris Geospatial, n.d.).

Table 5b: Confusion Matrix result and ground truth of 2020 classification

Ground Truth					
Water	100.00	0	0	0	0
Dense Vegetation	0.00	33.33333333	0	0	0
Dispersed Vegetation	0.00	63.33333333	96.66666667	60	3.333333333
Built-up Area	0.00	3.333333333	0	33.33333333	20
Bareground	0.00	0	3.333333333	6.666666667	76.66666667

Maximum likelihood classification yielded on overall accuracy of 0.68 and 0.60 kappa coefficient for 2020 as indicated by table 7a. A kappa index above 60% indicates moderate agreement with ground truth (Table 5a).

Like table 4b, table 5b shows the confusion matrix results and ground truth. The real classifications are represented by columns, and the classifier's predictions are represented by rows. As such, 100% of water was classified correctly. 33% of dense vegetation was classified correctly, and 63% of dense vegetation was classified as dispersed vegetation while 96% of dispersed vegetation was classified correctly. 60% of built-up area was correctly classified, while 3% of bareground was classified as built-up area. Furthermore, 3% of dense vegetation was classified as built-up area while 33% of built-up area was classified correctly. The last class, bareground was correctly classified with 76% values, while 6% of built-up area was classified as bareground and 3% of dense vegetation was classified as bareground. These errors are mainly due to the fact that the woody vegetation that is characterized by Ngaka Modiri Molema is close to a lot of built area and bare ground because of the rural nature of the district. As such, spectral signatures of these classes may be confused as one another due to the fact that they are too close to each other in proximity causing a decrease in reflectance of some and an increase of some elements and may share similar material properties. Roads have spectral qualities that are comparable to those of other urban features, in part because they are made of similar materials. As a result, spectral confusion between roadways and specific roofing materials may occur. Likewise, particle size distribution and height variations are factors influencing scattering properties of soil. The user included the commission errors and omission errors of 2020 only as they are more recent and results are relevant to the accessibility study.

Table 6a: Classification errors (commission and omission)

Comission			
Water	0.00	30	0
Dense Vegetation	0.00	10	0
Dispersed Vegetation	38.00	67	56.71641791
Built-up Area	7.00	17	41.17647059
Bareground	3.00	26	11.53846154

Table 6a shows classification errors of commission. It shows total errors in percentages. According to table 6a, 56% of Dispersed vegetation was classified in other classes, while 41% of built-up area was classified in other classes and 11% of bareground was misclassified as well.

Table 6b: Classification errors (commission and omission)

Omission			
Water	**0**	**30**	**0**
Dense Vegetation	0.00	30	0
Dispersed Vegetation	0.00	30	0
Built-up Area	0.00	30	0
Bareground	30.00	100	0.3

It is evident according to table 6a and 6b that there appears to be more commissions than omissions. Very few land classes have been left out of the classification. This indicates that remote sensing is highly effective in mapping land- use for this study.

The likelihood that a value in a particular class was correctly categorized is known as producer accuracy, while the chance that a value predicted to be in a specific class is actually in that class is known as user accuracy. The percentage of accurately predicted values to the total number of values projected to be in a class determines the likelihood.

Table 7a: user and producer accuracies of 2020 classification.

Producers			
Water	**30**	**302**	**100**
Dense Vegetation	10.00	30	33.33333333
Dispersed Vegetation	29.00	30	96.66666667
Built-up Area	10.00	30	33.33333333
Bareground	23.00	30	76.66666667

Table 7b: user and producer accuracies of 2020 classification.

Users			
Water	**30**	**302**	**100**
Dense Vegetation	10.00	10	100
Dispersed Vegetation	19.00	67	28.35820896
Built-up Area	10.00	17	58.82352941
Bareground	23.00	26	88.46153846

Both tables 8a and 8b show a total of satisfactory accuracies for both users and producers, except for the dispersed vegetation. This highlights the difficulty is in spectrally separating them from other land use classes. Some difficulties were experienced when spectrally removing the vegetation to bare ground; grass, and herbaceous vegetation could have been classified into a single class. The spectral reflectance of built up areas as is very hard to extract and distinguish the built up area alone.

Change detection

Figures17, 18 and 19 and, Table 8 show change in land cover classes between 2013 and 2020. Water bodies have displayed a decrease because Ngaka Modiri Molema is a semi-arid area with minimum rainfall and susceptibility to drought. The semi- arid parts of Southern Africa are characterized by low and profoundly variable precipitation in space and time. In Ngaka Modiri Molema, precipitation is regular with most rain happening as rainstorms during the summer period of October to April. Soil moisture management in this bone-dry and semi dry zone is faced with constrained precipitation as well (Gudeta Fajji, Palamuleni and Mlambo, 2018).

Table 8: Differences in LULC Classes between 2013 and 2020

CLASS	2013	2020
Water	55279	33967
Dense Vegetation	7791862	3427727
Dispersed Vegetation	4523657	10484703
Built-up Area	3333149	6478147
Bare ground	7359515	3901740

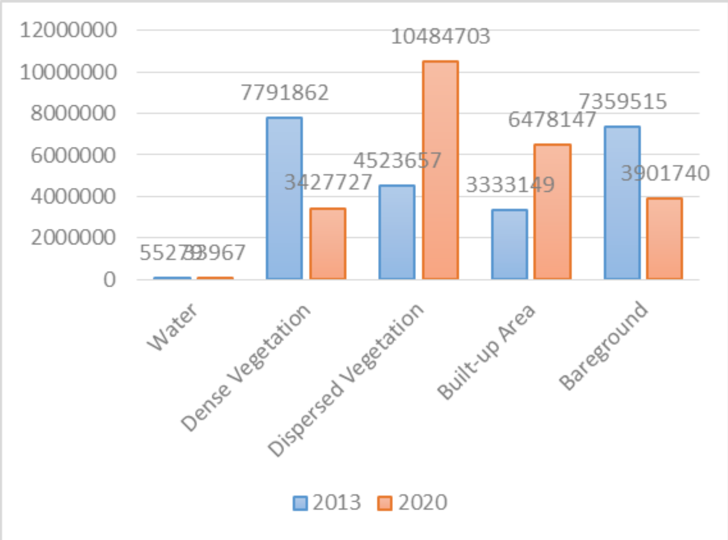


Figure 19: Differences in LULC Classes between 2013 and 2020

In 2013, dense vegetation decreased from 55279 pixels to 33967 in 2020, whereas dense vegetation increased from 4523657 to 10484703 pixels between the two years (Table 8 and Figure 19). Dispersion of precipitation encompasses a major effect in general abundance of vegetation. The low and greatly sporadic precipitation has a clear impact on the development of vegetation in low precipitation zones, subsequently, plants with low reliance on water will survive more. The nature of precipitation conveyance can cause modification in a steady state of rangelands resulting in decreased biomass production (Gudeta Fajji, Palamuleni and Mlambo, 2018). Ngaka Modiri Molema's main economic driver is characterized by small-scale farming. Persistent and unchecked grazing conditions result in communal rangelands losing vegetation cover and land degradation as well as woody plant encroachment. This may partially explain the decrease in bare ground over the years.

The built-up area increased from 3333149 pixels to 6478147 and bare ground decreased from 7359515 to 3901740 pixels between the years. This is attributed to the natural population growth and the urban sprawl. Dense rural zones such as the North Western mining and farming locales of South Africa appeared as more prominent densification in ranges along those routes connecting such hubs, therefore resulting in far more concentrated development of residential and land used (Parliamentary Monitoring Group, 2019). In addition, smaller towns in rural regions encounter sizeable counter urbanization as developing numbers of retiring middle income South Africans move from urban regions, settling for more quiet lives within the rural parts of the nation, this facilitates construction and upgrading of houses by individuals and families.

4.5.ACCESSIBILITY

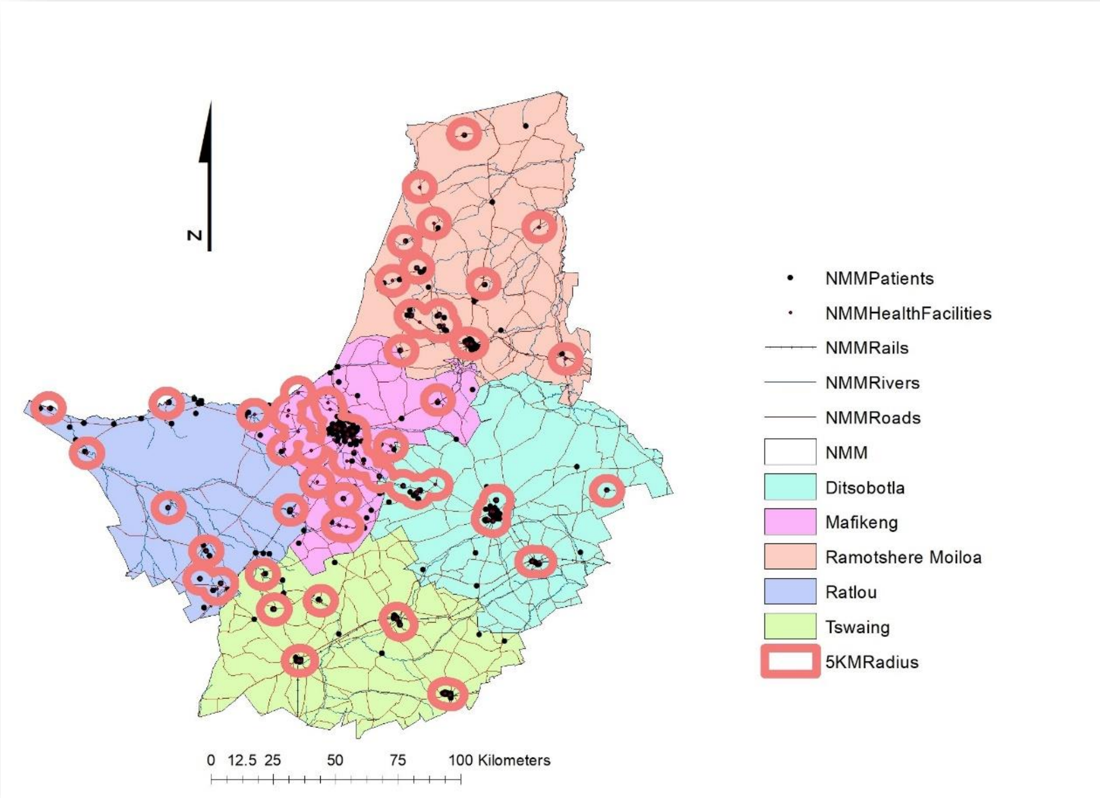


Figure 20: Accessibility to TB Treatment using 5km radius from health facilities

As mentioned in chapter 2 and various literature, the researcher decided on a 5km radius (figure 20) because in 1994, the government decided that people should not have to travel more than 5km to get to a clinic. The results displayed in figure 20 shows that NMMD displays a high physical accessibility to TB treatment. This may be because NMMD had 79 clinics, 16 community health centers, 5 district hospitals, 1 regional hospital, and 1 mental hospital in 2018 that can provide comprehensive care to the district's population (Cooperative Governance and Traditional Affairs, 2020), and as compared to the province's other districts NMMD has the most health facilities in the province. However, there is still an issue in terms of health care facility accessibility, as some clinics do not run 24 hours a day, and communities find it difficult to receive health care services when they are needed (Cooperative Governance and Traditional Affairs, 2020). This may cause patients to be unable to access TB treatment and need hospitalization in the long run. Because of this and other factors affecting spatial accessibility mentioned in the spatial distribution section of this study, Figure 21 will be used to evaluate TB patient accessibility to hospitals

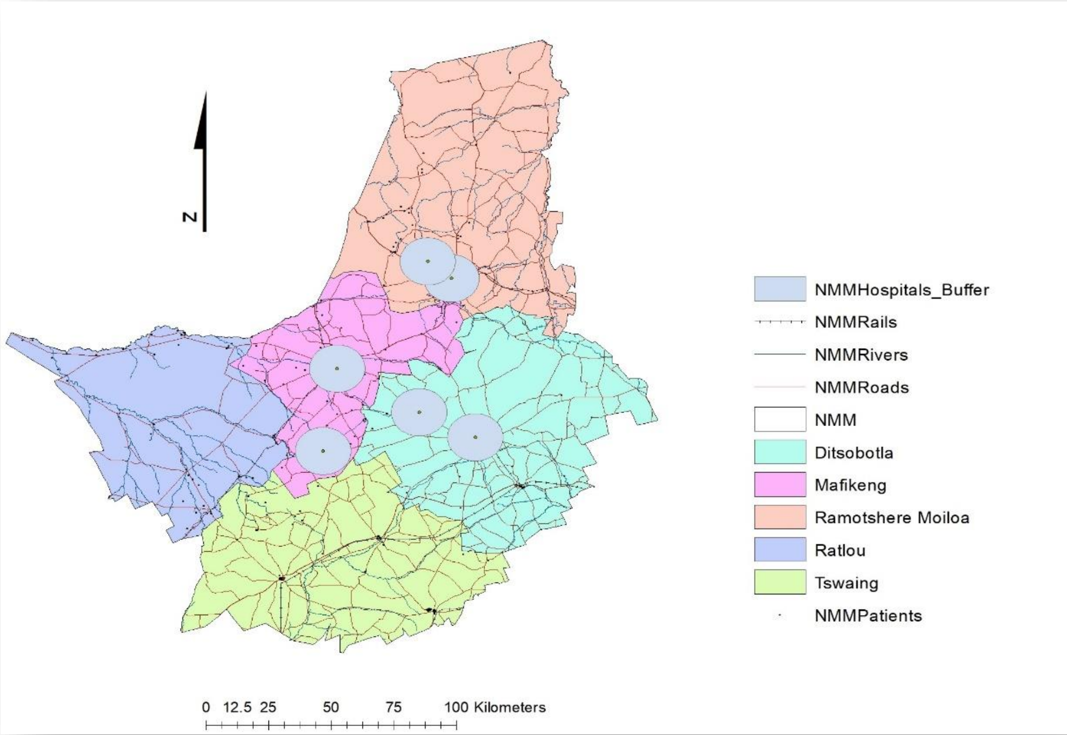


Figure 21: Accessibility to Hospitals using 10km radius from health facilities

Based on observing figure 21, Hospital Accessibility is very low in NMMD. It is evident that Ratlou Local Municipality and Tswaing Local Municipality do not have any hospitals, which means that patients in need of hospital care cannot access hospitals in these two local districts. This implies that patients will have to travel to other sub districts to access hospitals. The Ngaka Modiri Molema District has large road networks, including major roads such as the N4, N18, and N14, which SANRAL upgrades and maintains (Cooperative Governance and Traditional Affairs, 2020). However, there are 3 688 km of gravel roads and 1 548 km of paved roads in Ngaka Modiri Molema, which means that access to transport is already limited, leading to detrimental effects on hospital access. These hospitals are far away from most patients and mostly inaccessible. Ramotshere Moiloa is characterized by hilly landscapes (Figure 16) and the hospitals are found in low-lying areas and they are within a 10km radius from each other. This indicates that they cater to and are more accessible to patients in low lying areas and are inaccessible to patients living in high lying areas. In the Ditsobotla and Mafikeng Local Municipalities, hospital care is mostly centralized because for both, most economic activities are centralized as well. The provincial hospital is located in Mafikeng, as it is the capital city of the province and economic hub of the district, which means that most patients in need are referred to this hospital. This implies that it caters for all patients in the province as well as the district making it susceptible to overcrowding (shortage of beds) - the casualty ward being filled up to capacity, long queues, staff shortages, little to no social distancing (which leads to spread of infectious diseases) and medication running out. Therefore, it contributes to a decline in TB treatment physical accessibility in the district.

4.1. SITE SELECTION

The three domains of government are currently compelled to respond quickly and effectively to health-related problems in infection clusters around the country as a result of recent COVID19 outbreaks. The COVID-19 pandemic has revealed the insufficiency of public health efforts, as well as the continuance of deep economic and social inequalities. As a response to this and some factors mentioned in previous sections, and the results displayed by the spatial distribution, elevation, LULC and accessibility mapping this study will select sites for new hospitals in the NMMD to increase accessibility.

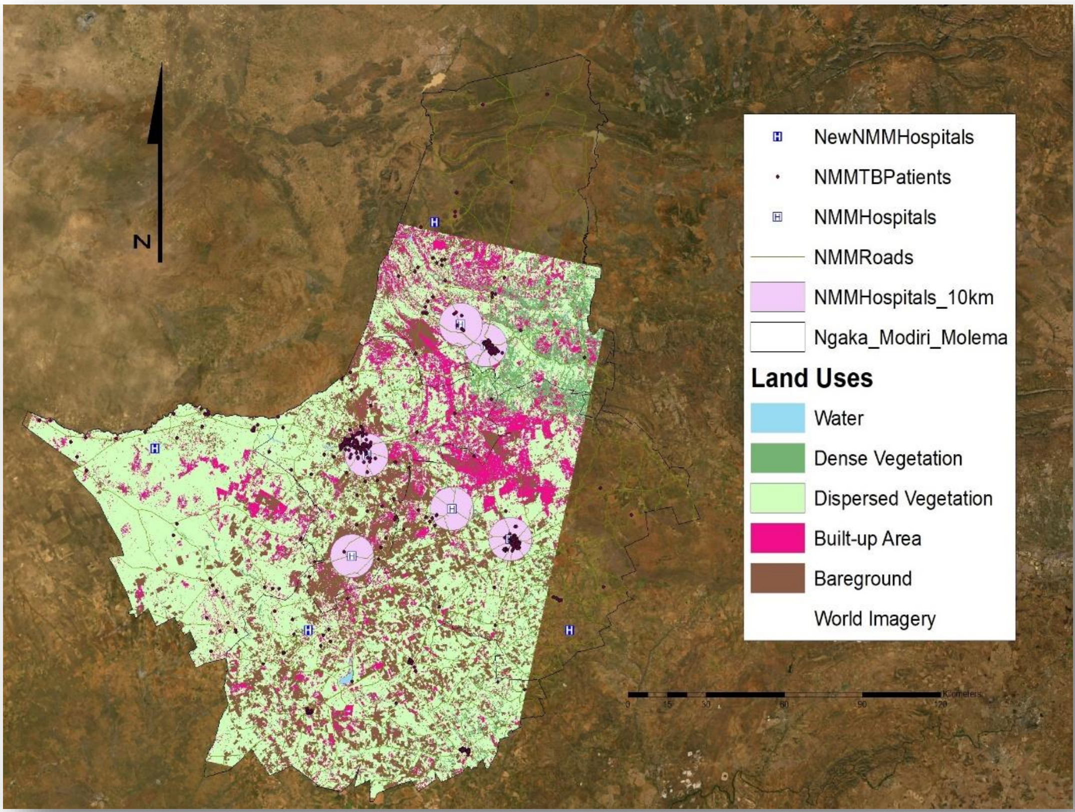


Figure 22: Optimum locations for new health facilities

The sites selected in this study are located where there is ether built-up area or bare ground and is near road networks. The sites are also situated on flat land and where thereis an increased saturation of TB patients, who cannot access treatment. The built-up areas where the sites are selected indicate that the area is either residential or very close to other important services. The researcher also made sure that the selected sites are also situated in such a way that they will cater for the increased urban-rural sprawl that is common in NMMD.

4.6. CHAPTER SUMMARY

The findings in this study reports that there is generally a high physical accessibility to TB treatment in Ngaka Modiri Molema, meaning that, most public health facilities meet the government's 5km radius policy. NMMD has the highest number of health facilities, compared to other districts in the province. Even though this is the case, it is evident that should patients need hospital care, it will be inaccessible based on the location of existing hospitals. Therefore, this study took into account the elevation of the study area, different land uses of the study area, and spatial distribution of the patients. Using this data, the study aimed to select optimum sites for hospitals to increase physical accessibility to hospitals. As shown, Tswaing and Ratlou local municipalities do not have hospitals, this implies a need for hospitals in both the districts. Upon examining the literature, it became evident that Mahikeng local municipality housed the provincial hospital which caters to all members of the province in need of hospitalization in the province, this can subject the hospital to overcrowding and depletion, as well as shortage of resources.

CHAPTER FIVE:

CONCLUSION, LIMITATIONS OF STUDY AND RECOMMENDATIONS

5.1. INTRODUCTION

The appropriate use of health care services to obtain the best health outcomes is what access to health services entails. People who do not have proper access to healthcare and health services risk having their heath requirements unmet, often delaying care to the point where they end up in a hospital when preventative care or primary care services may have helped. Individuals and their families may become impoverished as a result of these hospitalizations, and healthcare organizations that provide free services may suffer as a result. Poor tuberculosis (TB) patients have significant challenges in obtaining TB screening and treatment. They need faster diagnostic and treatment choices as close to their homes as feasible if TB control is to be effective. The ability to display the spatial distribution of TB conditions determinants and indicators can be a huge help to local governments in their efforts to improve populations' health (Dalameter et al, 2012). Developing relevant, accessible, and useable spatial information models for networks and surrounding entities is a major step forward in empowering people and communities to improve their health and gain control over it (Hanjagi et al, 2007). Spatial modelling is a crucial step in the geographical data analysis. It is used in conjunction with a GIS to properly analyze and graphically lay out data for better understanding by readers by using models or rules and methods for evaluating spatial data. A geographic information system (GIS) is a platform for capturing, analyzing, storing, manipulating, presenting, and managing all sorts of geospatial data, such as data from maps, global positioning systems

(GPS), and survey data, including the positions of landmarks and disaster regions. It can depict data relating to positions on the Earth's surface on a map, letting viewers see numerous data patterns and connections. This study used spatial modelling instruments for analysing secondary data of TB in the Ngaka Modiri Molema District in the Northwest province of South Africa. It was descriptive and analytical in terms of its nature, methodology and how it is applied in terms of its objectives. It explored the geographic accessibility of TB treatment in the Ngaka Modiri Molema (NMM) District Municipality. The methodology was categorized into three key components which are data collection and preparation, accessibility measurement and site selection. TB statistical data per public healthcare facility and patient home addresses sourced from the Northwest Department of Health (NWDOH) was used to assist in the modelling and analysis of the spatial distribution of TB in Ngaka Modiri Molema. Online sources like the United State of Geological Survey (USGS) and the municipal Demarcation board website was responsible for the provision of “shapefiles” (ESRI Geo-spatial file), satellite imagery and Digital Elevation Models that was used for data visualization purposes. The methodology intended to explain and examine the research questions, aims and objectives that make up the study, which are to spatially visualize distribution of a communicable disease like TB patients and public healthcare facilities in the Ngaka Modiri Molema District and suggest optimum sites of a new healthcare facility along with the description of the research structure and methods. The aim of this chapter is to provide conclusions as well as highlight some of the circumstances that limited this study and make recommendation for future studies based on key findings of this study, as well as the limitations.

5.2. SUMMARY OF FINDINGS

In developing countries, differences in healthcare access are a major source of concern. Access to healthcare is important in deciding and reinforcing other measures of imbalance since health affects human capital acquisition, financial status, and intergenerational transmission of socioeconomic status (Yazbeck, 2009; Wilkinson and Pickett, 2009; McLaren, Ardington, Leibbrandt, 2013). To counteract this, public health authorities are routinely financed in order to encourage nondiscriminatory access to healthcare. Tuberculosis has a spatial component in that it is location-based. Therefore, studies about TB need to account for this spatial aspect of TB. Spatial distribution describes how dispersed a population or a phenomenon is in a region of treatment (Gwitira et al., 2021).

The aim of this study was to evaluate the accessibility of TB treatment by using spatial modelling tools, such as GIS processes, population data and data from the surveillance systems of communicable disease. Consequently, the objectives of this study were to investigate the accessibility of health facilities for TB treatment in Ngaka Modiri Molema District, to spatially visualize the distribution of a communicable disease like TB patients and public healthcare facilities and lastly, to suggest site selection of new healthcare facilities.

As such, to accomplish the study's goals, data analysis was separated into five primary tasks: Quantifying collected data and preparing it for representing spatial distribution, Elevation Mapping which includes an aspect map and a slope map, Land Use and Land Cover changing detection, measuring accessibility, represented by maps with buffers and site selection. This was a clear plan that included a summary of how or where data would be collected, and how it would be represented in maps generated in the study. NMMD is generally flat with increasing elevation towards the northeastern part of it accounted for by the hilly landscape in Ramotshere Moiloa. Land cover classification was used in this study to define key land cover classes and to identify different types of land cover using Landsat images. The MAXLIKE classification, which is a supervised classification, created maps with five different types of land cover: water, built-up areas, dense vegetation, dispersed vegetation, and bare ground. It found that between the years there was an increased level of dispersed vegetation and a decrease in dense vegetation while the built-up area is sparsely distributed because the district is characterized by being largely rural, and bare ground has now decreased because of population increase in the district, and urban- rural sprawl (Parliamentary Monitoring Group, 2019). More people are moving to rural areas for peace of mind and building more houses to live in and water bodies showing a reduction between 2013 and 2020, because of Low and highly variable precipitation in location and time characterizes the semi-arid regions of Southern Africa (Gudeta Fajji, Palamuleni and Mlambo, 2018) where the study area is found. This part of the study formed the second objective, which was necessary for the selection of a new site at the end of the study, to increase accessibility. The hospital should be located in the area with the best possible land use, preferably in residential areas, as residents are the primary client of public healthcare facilities, the hospital is generally required in areas of high population concentration, and informal settlement areas can be used as the primary clients of public healthcare facilities, and communicable diseases are generally known to be more prevalent in poor infrastructural settings.

A register consisting of 2500 patient records was analyzed and manipulated. As mentioned before, spatial considerations should be considered when evaluating TB. Analysis ofthe data showed that of the 2500 patients, the ages ranged from0-64 years with females dominating. The highest number of cases was 219(ages 30-34) and the lowest was 71 (ages 60-64). The 30-34years age range is characterized by being the working age, which means that working class people were highly exposed to the disease, while 60-64years is characterized by people reaching retirement or in some cases, are retiring this means that because of age, they are spending mostof their time at home and less exposed to the disease.

A register consisting of 2500 patient records was analyzed and manipulated. As mentioned before, spatial considerations should be considered when evaluating TB. Analysis ofthe data showed that of the 2500 patients, the ages ranged from0-64 years with females dominating. The highest number of cases was 219(ages 30-34) and the lowest was 71 (ages 60-64). The 30-34years age range is characterized by being the working age, which means that working class people were highly exposed to the disease, while 60-64years is characterized by people reaching retirement or in some cases, are retiring this means that because of age, they are spending mostof their time at home and less exposed to the disease.

The top three subdistricts with the highest number of cases are Tswaing, Ramotshere Moiloa and Ditsobotla (See Table 3). They are characterized by high levels of poverty, close contact settlements and high levels of people with little to no education. Individuals living with poverty do not have enough finances to keep themselves well nourished, which means that overtime, their immune systems weaken, and this makes them susceptible to disease while uneducated individuals have little to no knowledge about TB, which mean they probably will not take measures to prevent or minimize the risk of exposing themselves to the disease or spreading it. Although Mahikeng has a low number of cases, at 492, it is still vulnerable to TBbecause it is the economic hub of the district and it has close contact towns like Mafikeng and Mmabatho, and a high-rate rate of population growth.

With that being said, after careful consideration and analysis, the previously mentioned methods were for analysis were basic and overly simplified for the magnitude of this study and, the suitability methods were manual, nevertheless, they were satisfactory for the achievement of each objective and the aim of this study.

5.3. LIMITATIONS OF STUDY

This section of the study describes the limitations of the project. They are those aspects of the design or methodology that impacted or influenced how the results of the research were interpreted. They are limitations on generalization, practice applicability, and/or usability of findings. Acknowledging a study's limitations allows the researcher to make recommendations for future research.

The limitations of this study are as follows:

- The study uses secondary data which prevents deeper exploration of the root causes and trends noted.
- It focused on the public health sector of South Africa and is generalizable to similarly rural resource limited settings.
- This study took longer than expected to be completed because of the COVID-19 pandemic, which forced the researcher to change the direction in which the study was initially intended,
- Data acquisition of this study also delayed the intended period of study. This was due to miscommunication and misunderstandings between different departments within the North West Department of Health.

- The data received from the NWDOH did not include patient ethnicity. This limited the spectrum to which the data was analyzed and represented.
- There appears to be very little information about TB treatment accessibility and incidence rate publicly at a local level. Therefore, creating a timeline and bridging the gap in the timeline becomes almost impossible.
- This study's methodological approach was rudimentary and basic. Furthermore, the suitability mapping approach used was manual therefore, it lacked an in-depth review because it was not based on any geospatial methodology, such as the multi-criteria analysis approach.

5.4. RECOMMENDATIONS

This section of the study describes the research recommendations. Recommendations argue for particular measures to be made in policy, practice, theory, or future research. They are precise recommendations for future research on the subject. For example, if there is a need to generalize the findings beyond the study's boundaries, the researcher can give recommendations on future research that can be done. Future studies can build on this study and correct for some of the approaches discussed in Chapter 3 in order to contribute to the increasing domain of research.

Other studies could use literature, patient surveys and other spatial modelling methods and methods used in this study for other districts to provide and in-depth insight into TB studies. The surveys will provide data on an association between perceived accessibility and measured spatial accessibility, and they could use more than one district as a study area to create a comparative study of TB treatment accessibility between predominantly urban and predominantly rural districts to uncover disparities in South Africa. A comparative study of TB treatment accessibility between the public sector and the private sector could also be done in future.

Future studies should consider methods like location allocation (figure 22) and multiple criteria approach to recommend and device new locations for new healthcare facilities. In addition, should researchers require to use LULC in their accessibility studies, they should run the program as many times as they possibly can to ensure that the results are high in accuracy.

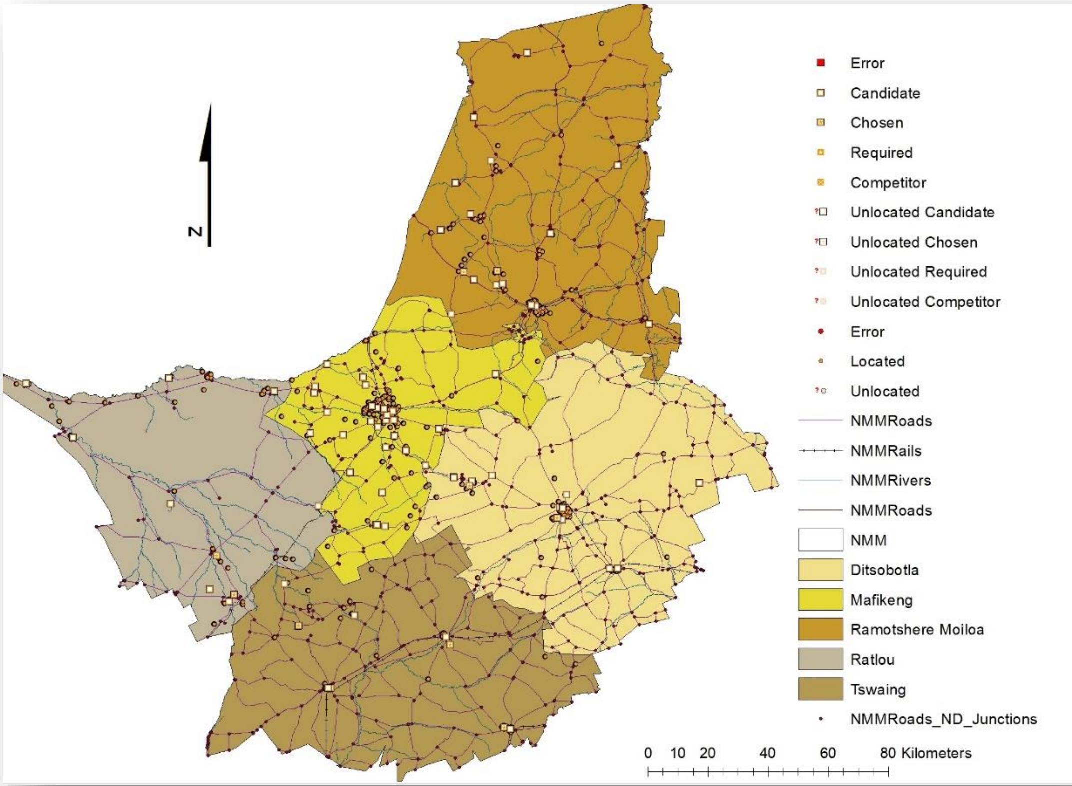


Figure 23: Optimum site locations for new health facilities (Location -Allocation approach)

Municipalities should prioritize and support spatial TB treatment studies at local level to increase literature on the subject and not only focus on the medical aspects of the subject. More studies are needed on strategies to increase spatial accessibility to treatment or healthcare in rural South Africa. The studies could be on a smaller scale than districts, they could be town specific as well. This could assist in discovering hidden disease hotspots and areas that need more resources.

Ngaka Modiri Molema District Municipality should conduct regular field work to monitor Treatment accessibility. Since the researcher experienced trouble with acquiring data, other stakeholders should provide support and conduct education on data collection, TB data control and environmental education to encourage understanding and dissemination of data. The district should also conduct a study comparing the old and new policies on increasing accessibility and how they both influence current spatial accessibility in different areas.

5.5. CONCLUSION

According to different literature, one of the most important geographic variables that might affect health status and outcomes, as well as contribute to disparities, is the distance to health care. In poor regions like NMMD, TB control is also complicated by gender, age, socioeconomic level, and inadequate health services. These are the common barriers that affect spatial accessibility to TB treatment. The findings of this study highlights some barriers that have been overlooked in terms of monitoring spatial accessibility of TB treatment since moderately equitable distribution of public health facilities is evident in this study, which means that distance may not be a barrier in this study. These barriers are long waiting periods in queues when patients go collect their medication, overcrowding in health facilities which may be caused by some facilities not being operational, some facilities do not provide TB services and some do not operate on a 24/7 basis, shortage of nursing staff and practitioners which may cause overcrowding and long waiting queues at facilities, unavailability of medication or lack thereof in facilities. These factors encourage patients to travel long distances in pursuit of medication and thereby incurring travel costs. NMMD is characterized by high levels of poverty, so patients may not be able to afford travel costs as such rendering TB treatment geographically inaccessible.

REFERENCES

1. *A Southern Africa Labour and Development Research Unit Working Paper Number 97.Cape Town: SALDRU, University of Cape Town*
2. *al, Gonzales & B., Akosa & M, Chowdhury & de-Graft Aikins, Ama. (2012). Health systems research and infectious diseases of poverty: from the margins to the mainstream..*
3. *Ansumant, 2020. Elevation Map | Meaning, Interpretation, Uses and Examples. [online] https://planningtank.com/. Available at: <https://planningtank.com/geographic-information-system/elevation-map> [Accessed 16 November 2021].*
4. *Asemahagn, M., Alene, G. and Yimer, S., 2020. <p>Geographic Accessibility, Readiness, and Barriers of Health Facilities to Offer Tuberculosis Services in East Gojjam Zone, Ethiopia: A Convergent Parallel Design</p>. Research and Reports in Tropical Medicine, [online] Volume 11, pp.3-16. Available at: <https://www.dovepress.com/geographic-accessibility-readiness-and-barriers-of-health-facilities-t-peer-reviewed-fulltext-article-RRTM> [Accessed 23 April 2021].*
5. *Black, Michael & Ebener, Steeve & Najera-Aguilar, Patricia & Vidaurre, Manuel & Zine, El & El Morjani, Zine El Abidine. (2004). Using GIS to measure physical accessibility to health care.*
6. *Blaschke, T., Merschdorf, H., Cabrera-Barona, P., Gao, S., Papadakis, E. and Kovacs-Györi, A., 2018. Place versus Space: From Points, Lines and Polygons in GIS to Place-Based Representations Reflecting Language and Culture. ISPRS International Journal of Geo-Information, 7(11), p.452.*
7. *Boyles, T., Mendelson, M., Govender, N. and Du Plessis, N., 2021. The infectious diseases specialty in South Africa is in crisis. [online] Available at: <http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0256-95742019000900002> [Accessed 16 July 2021].*
8. *Chaturved, R., 2006. Digital Image Processing Chapter 5: Image Restoration 23 June 2006. [online] SlideServe. Available at: <https://www.slideserve.com/begayr/digital-image-processing-chapter-5-image-restoration-23-june-2006-powerpoint-ppt-presentation>.*
9. *Chimoyi LA, Lienhardt C, Moodley N, et alEstimating the yield of tuberculosis from key populations to inform targeted interventions in South Africa: a scoping reviewBMJ Global Health 2020;5:e002355.*
10. *Chiwire, P. and Dionisio, D., 2016. Factors Influencing Access to Health Care in South Africa – PEAH – Policies for Equitable Access to Health. [online] Peah.it. Available at: <http://www.peah.it/2016/10/factors-influencing-access-to-health-care-in-south-africa/> [Accessed 22 April 2021].*
11. *Civil Engineering Notes. 2019. What is Geographic Information System (GIS) ? - Civil Engineering Notes. [online] Available at:*

<https://civilengineeringnotes.com/geographic-information-system/> [Accessed 18 April 2021].

12. Coetzee, L., Cassim, N. and Glencross, D., 2017. Analysis of HIV disease burden by calculating the percentages of patients with CD4 counts <100 cells/µL across 52 districts reveals hot spots for intensified commitment to programmatic support. South African Medical Journal, [online] 107(6), p.507. Available at: <https://journals.co.za/doi/pdf/10.7196/SAMJ.2017.v107i6.11311> [Accessed 3 November 2021].
13. Cooperative Governance and Traditional Affairs, 2020. PROFILE AND ANALYSIS DISTRICT DEVELOPMENT NGAKA MODIRI MOLEMA. DISTRICT DEVELOPMENT MODEL. [online] Cooperative Governance and Traditional Affairs, p.10. Available at: <https://www.cogta.gov.za/ddm/wp-content/uploads/2020/08/DistrictProfile_NgakaModiriM11072020.pdf> [Accessed 20 July 2021].
14. Cramm, J., Finkenflügel, H., Møller, V. and Nieboer, A., 2010. TB treatment initiation and adherence in a South African community influenced more by perceptions than by knowledge of tuberculosis. BMC Public Health, 10(1).
15. DANIEL, E., 2016. The Usefulness of Qualitative and Quantitative Approaches and Methods in Researching Problem-Solving Ability in Science Education Curriculum. Journal of Education and Practice, 7(15), pp.91-100.
16. Dash, S., Shakyawar, S., Sharma, M. and Kaushik, S., 2019. Big data in healthcare: management, analysis and future prospects. Journal of Big Data, [online] 6(1). Available at: <https://journalofbigdata.springeropen.com/articles/10.1186/s40537-019-0217-0>.
17. Dawn Wright, D., n.d. GIS Data Collection.
18. de Smith, Micheal, Micheal Goodchild and Paul Longley 2013. Geospatial Analysis. 4th Edition. Winchelsea Press. Available at http://www.spatialanalysisonline.com/HTML/index.html
19. Delamater, P., Messina, J., Shortridge, A. and Grady, S., 2012. Measuring geographic access to health care: raster and network-based methods. International Journal of Health Geographics, 11(1), p.15.
20. Doaemo, W., Mohan, M., Adrah, E., Srinivasan, S. and Dalla Corte, A., 2020. Exploring Forest Change Spatial Patterns in Papua New Guinea: A Pilot Study in the Bumbu River Basin. Land, [online] 9(9), p.282. Available at: <https://www.researchgate.net/publication/343778961_Exploring_Forest_Change_Spatial_Patterns_in_Papua_New_Guinea_A_Pilot_Study_in_the_Bumbu_River_Basin>.
21. Dookie, S., Singh, S. Primary health services at district level in South Africa: a critique of the primary health care approach. BMC Fam Pract 13, 67 (2012). https://doi.org/10.1186/1471-2296-13-67
22. Eldrandaly, Khalid. (2013). Developing a GIS-based MCE site selection tool in arcGIS using COM technology. International Arab Journal of Information Technology. 10. 268-274.

23. *EQUI-TB Knowledge Programme, n.d. Barriers to accessing TB care: how can people overcome them?. [online] Who.int. Available at: <https://www.who.int/management/BarrierstoAccessingTBCare.pdf>.*
24. *ESRI, 2019., Location-allocation analysis—ArcMap | Documentation. [online]Desktop.arcgis.com. Available at: <https://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/location-allocation.htm>.*
25. *Falchetta, G., Hammad, A. and Shayegh, S., 2020. Planning universal accessibility to public health care in sub-Saharan Africa. Proceedings of the National Academy of Sciences, [online] 117(50), pp.31760-31769. Available at: <https://www.pnas.org/content/117/50/31760#abstract-2> [Accessed 19 July 2021].*
26. *Franch-Pardo, I., Napoletano, B., Rosete-Verges, F. and Billa, L., 2020. Spatial analysis and GIS in the study of COVID-19. A review. Science of The Total Environment, 739, p.140033.*
27. *Frerichs, R., 2003. John Snow and the Broad Street Pump: On the Trail of an Epidemic. [online] Ph.ucla.edu. Available at: <https://www.ph.ucla.edu/epi/snow/snowcricketarticle.html>.*
28. *Geraghty, E., 2019. The Geography of Access to Health Services – AAG Newsletter. [online] News.aag.org. Available at: <http://news.aag.org/2019/08/the-geography-of-access-to-health-services/>.*
29. *GISGeography, 2015. 10 Open Source Remote Sensing Software Packages, https://gisgeography.com/open-source-remote-sensing-software-packages/ (Accessed October 23, 2021).*
30. *GISGeography, 2021. Image Classification Techniques in Remote Sensing. [online] GIS Geography. Available at: <https://gisgeography.com/image-classification-techniques-remote-sensing/>.*
31. *GISGeography, 2021. What is an Aspect Map? - GIS Geography. [online] GIS Geography. Available at: <https://gisgeography.com/aspect-map/> [Accessed 9 November 2021].*
32. *Gogoi, B., n.d. IMAGE CLASSIFICATION # WHAT IS IMAGE CLASSIFICATION?. [online] Bhattadevuniversity.ac.in. Available at: <https://www.bhattadevuniversity.ac.in/docs/studyMaterial/Dr.BharatiGogoi_Geo*
33. *Guagliardo, M., 2004. Spatial accessibility of primary care: concepts, methods and challenges. International Journal of Health Geographics, [online] 3(1), p.3. Available at: <https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-3-3#Tab1> [Accessed 16 April 2021].*
34. *Gudeta Fajji, N., Palamuleni, L. and Mlambo, V., 2018. Application of SPOT Imagery for Landcover Mapping and Assessing Indicators of Erosion and Proportion of Bareground in Arid and Semi-arid Environment. Journal of Remote Sensing & GIS, 07(02).*
35. *Gwitira, I., Karumazondo, N., Shekede, M., Sandy, C., Siziba, N. and Chirenda, J., 2021. Spatial patterns of pulmonary tuberculosis (TB) cases in Zimbabwe from 2015 to 2018. PLOS ONE, [online] 16(4), p.e0249523. Available at: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0249523>.*

36. *Hammer, C., Brainard, J. and Hunter, P., 2018. Risk factors and risk factor cascades for communicable disease outbreaks in complex humanitarian emergencies: a qualitative systematic review. BMJ Global Health, [online] 3(4), p.e000647. Available at: <https://gh.bmj.com/content/3/4/e000647.abstract> [Accessed 16 July 2021].*
37. *Health and Places Initiative. 2014. Geographic Healthcare Access and Place. A Research Brief. Version 1.0. http://research.gsd.harvard.edu/hapi/*
38. *Henning, B., 2015. A SPECIALIST REPORT ON THE SOILS, AGRICULTURAL POTENTIAL AND LAND CAPABILITY FOR THE DOORNHOEK FLUORSPAR MINING RIGHT APPLICATION IN THE NGAKA MODIRI MOLEMA DISTRICT, NORTH WEST PROVINCE. [online] Cape Town: South African Heritage Resources Agency (SAHRA). Available at: <https://sahris.sahra.org.za/sites/default/files/additionaldocs/Appendix%207.5%2*
39. *Hierink, F., Okiro, E., Flahault, A. and Ray, N., 2021. The winding road to health: A systematic scoping review on the effect of geographical accessibility to health care on infectious diseases in low- and middle-income countries. PLOS ONE, [online] 16(1), p.e0244921. Available at: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0244921> [Accessed 19 July 2021].*
40. *Im, C. and Kim, Y., 2021. Spatial pattern of tuberculosis (TB) and related socio-environmental factors in South Korea, 2008-2016. PLOS ONE, [online] 16(8), p.e0255727. Available at: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0255727> [Accessed 15 November 2021].*
41. *Info, A., 2021. Mahikeng: Access to primary healthcare still highly restricted or non-existent in Ngaka Modiri Molema District (South Africa). [online] Africa-newsroom.com. Available at: <https://www.africa-newsroom.com/press/mahikeng-access-to-primary-healthcare-still-highly-restricted-or-nonexistent-in-ngaka-modiri-molema-district-south-africa?lang=en> [Accessed 20 July 2021].*
42. *Jiang, B., Claramunt, C. and Batty, M., 1999. Geometric accessibility and geographic information: extending desktop GIS to space syntax. Computers, Environment and Urban Systems, 23(2), pp.127-146.*
43. *Kapwata, T., Morris, N., Campbell, A., Mthiyane, T., Mpangase, P., Nelson, K., Allana, S., Brust, J., Moodley, P., Mlisana, K., Gandhi, N. and Shah, N., 2017. Spatial distribution of extensively drug-resistant tuberculosis (XDR TB) patients in KwaZulu-Natal, South Africa. PLOS ONE, [online] 12(10), p.e0181797. Available at: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0181797> [Accessed 29 April 2021].*
44. *Krishna, G. and Geospatial World, 1970. Spatial analysis & modelling - Geospatial World. [online] Geospatial World. Available at: <https://www.geospatialworld.net/article/spatial-analysis-modelling/> [Accessed 19 April 2021].*
45. *KwaZulu-Natal Department of Health, 2014. Referral system - levels of care. [online] Kznhealth.gov.za. Available at: <http://www.kznhealth.gov.za/Referral-system.htm>.*

46. *Lamichhane, Angad. (2021). Re: Out of User's and Producer's accuracy, which of these two is relatively important?. Retrieved from: https://www.researchgate.net/post/Out-of-Users-and-Producers-accuracy-which-of-these-two-is-relatively-important/60fa11d6f7f5f8640c0720eb/citation/download.*
47. *Longley, P., Goodchild, M., Maguire, D. and Rhind, D., 2005. Geographical information systems. 2nd ed. New York: Wiley, p.157.*
48. *Longley, P., Goodchild, M., Maguire, D. and Rhind, D., 2010. Geographic information science and systems. 3rd ed. New Jersey: Wiley.*
49. *M.J. Casey, M., 2003. What Is a Slope Map? (with pictures). [online] https://www.wise-geek.com/. Available at: <https://www.wise-geek.com/what-is-a-slope-map.htm>.*
50. *Makhado, L., 2018. Integration of Tuberculosis and Human Immunodeficiency Virus Services in Nacka Modern Molina District, North West Province. JOURNAL OF HUMAN ECOLOGY, [online] 62(1-3). Available at: <https://www.researchgate.net/publication/328905512_Integration_of_Tuberculosis_and_Human_Immunodeficiency_Virus_Services_in_Ngaka_Modiri_Molema_District_North_West_Province> [Accessed 28 October 2021].*
51. *Manoj K Arora, M., 2010. Land cover classification from Remote Sensing data. [online] Geospatial World. Available at: <https://www.geospatialworld.net/article/land-cover-classification-from-remote-sensing-data/> [Accessed 15 March 2022].*
52. *McIntyre, D. and Ataguba, J., 2014. Access to quality health care in South Africa: Is the health sector contributing to addressing the inequality challenge?. [online] Cape Town: Resilient and Responsive Health Systems (RESYST). Available at: <https://www.parliament.gov.za/storage/app/media/Pages/2017/october/High_Level_Panel/Commissioned_reports_for_triple_challenges_of_poverty_unemployment_and_inequality/Diagnostic_Report_on_Access_to_Quality_Healthcare> [Accessed 22 April 2021].*
53. *McLaren, Z., Ardington, C., Leibbrandt, M., (2013). Distance as a barrier to health care access*
54. *Muscato, C., 2017. Spatial Distribution: Definition, Patterns & Example. [online] study.com. Available at: <https://study.com/academy/lesson/spatial-distribution-definition-patterns-example.html>.*
55. *Nabukenya-Mudiope, M., Kawuma, H., Brouwer, M., Mudiope, P. and Vassall, A., 2015. Tuberculosis retreatment 'others' in comparison with classical retreatment cases; a retrospective cohort review. BMC Public Health, [online] 15(1). Available at: <http://www.msh.org/sites/msh.org/files/nabukenya-mudiope_tuberculosis_retreatment_in…> [Accessed 16 November 2021].*
56. *Ngaka Modiri Molema District Municipality, 2021. FINAL DISTRICT IDP REVIEW 2021/22 (DISTRICT DEVELOPMENT MODEL). [ebook] Mmabatho: Ngaka Modir Molema District Municipality, pp.24-36. Available at: <https://www.nmmdm.gov.za/sites/default/files/documents/FINAL%20NMMDM%20IDP%202021-22%20IDP.pdf> [Accessed 28 October 2021].*
57. *Parliamentary Monitoring Group, 2019. DRAFT NATIONAL SPATIAL DEVELOPMENT FRAMEWORK. [pdf] Parliamentary Monitoring Group. Available at: <https://static.pmg.org.za/200120Draft_NSDF.pdf>*

58. *Paul A. Longley, Michael F. Goodchild, David J. Maguire, David W. Rhind © 2005 John Wiley and Sons, Ltd*
59. *primary Health Care Performance Initiative, 2018. Geographic Access. [online] PHCPI. Available at: <https://improvingphc.org/improvement-strategies/access/geographic-access> [Accessed 15 April 2021].*
60. *Ramachandra, T., Aithal, B., Setturu, B. and Vinay, S., 2018. WASTE MANAGEMENT. [online] Wgbis.ces.iisc.ernet.in. Available at: <http://wgbis.ces.iisc.ernet.in/energy/paper/ETR143/section3.html>.*
61. *Ricketts, T., 2003. Geographic Information Systems and Public Health. Annual Review of Public Health, [online] 24(1), pp.1-6. Available at: <https://scholar.google.com/scholar_url?url=https://www.annualreviews.org/doi/pdf/10.1146/annurev.publhealth.24.100901.140924&hl=en&sa=T&oi=ucasa&ct=ufr&ei=riN9YJLSE5OtmwG3o68g&scisig=AAGBfm0RdX5PDk1YjBElrOwziKv37Z8Otg> [Accessed 19 April 2021].*
62. *Rikalovic, A., Cosic, I. and Lazarevic, D., 2014. GIS Based Multi-criteria Analysis for Industrial Site Selection. Procedia Engineering, 69, pp.1054-1063.*
63. *Ritshidze, 2021. NORTH WEST STATE OF HEALTH JUNE 2021. [online] Johannesburg: Ritshidze, pp.6-16. Available at: <https://ritshidze.org.za/category/resources/> [Accessed 16 November 2021].*
64. *Robsky, K., Kitonsa, P., Mukiibi, J., Nakasolya, O., Isooba, D., Nalutaaya, A., Salvatore, P., Kendall, E., Katamba, A. and Dowdy, D., 2020. Spatial distribution of people diagnosed with tuberculosis through routine and active case finding: a community-based study in Kampala, Uganda. Infectious Diseases of Poverty, [online] 9(1). Available at: <https://idpjournal.biomedcentral.com/articles/10.1186/s40249-020-00687-2> [Accessed 15 November 2021].*
65. *Rosenberg, M., 2018. Defining Accessibility and Mobility in Transportation and Geography. [online] ThoughtCo. Available at: <https://www.thoughtco.com/accessibility-definition-geography-1434629> [Accessed 15 April 2021].*
66. *Rusnoto, & Nasriyah, & Meitasari, Putri & nisa, Ana. (2020). The Relationship Between Education and Economic Status on Pulmonary Tuberculosis. 10.2991/ahsr.k.200311.030.*
67. *Rutledge, K., Ramroop, T., Boudreau, D., McDaniel, M., Teng, S., Sprout, E., Costa, H., Hall, H. and Hunt, J., 2011. Elevation. [online] National Geographic Society. Available at: <https://www.nationalgeographic.org/encyclopedia/elevation/> [Accessed 16 November 2021].*
68. *Schneider, Markus. (2013). Spatial and Spatio-Temporal Data Models and Languages.*
69. *semahagn, M., Alene, G. and Yimer, S., 2020. <p>Geographic Accessibility, Readiness, and Barriers of Health Facilities to Offer Tuberculosis Services in East Gojjam Zone, Ethiopia: A Convergent Parallel Design</p>. Research and Reports in Tropical Medicine, [online] Volume 11, pp.3-16. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7007782/#CIT0032> [Accessed 22 April 2021].*

70. *South African News Agency, 2011. Better access to health care for N West villages. [online] SAnews. Available at: <https://www.sanews.gov.za/south-africa/better-access-health-care-n-west-villages> [Accessed 20 July 2021].*
71. *Stellenberg, E., 2015. Accessibility, affordability and use of health services in an urban area in South Africa. Curationis, [online] 38(1). Available at: <http://www.scielo.org.za/scielo.php?pid=S2223-62792015000100004&script=sci_arttext&tlng=es> [Accessed 22 April 2021].*
72. *Swift, D., 2014. SSCI 382L: PRINCIPLES OF GEOGRAPHIC INFORMATION SCIENCE.*
73. *TALISUNA, A., OKIRO, E., YAHAYA, A., STEPHEN, M., BONKOUNGOU, B., MUSA, E., MINKOULOU, E., OKEIBUNOR, J., IMPOUMA, B., DJINGAREY, H., YAO, N., OKA, S., YOTI, Z. and FALL, I., 2020. Spatial and temporal distribution of infectious disease epidemics, disasters and other potential public health emergencies in the World Health Organisation Africa region, 2016–2018. Globalization and Health, [online] 16(1). Available at: <https://globalizationandhealth.biomedcentral.com/articles/10.1186/s12992-019-0540-4> [Accessed 19 July 2021].*
74. *Tewabe, D. and Fentahun, T., 2020. Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. Cogent Environmental Science, [online] 6(1), p.1778998. Available at: <https://www.tandfonline.com/doi/full/10.1080/23311843.2020.1778998?_cf_chl_jschl_tk_=4s03534E91cZIQdPrrLhFTH_4eQx0m.5Ult9HzdhWos-1637074513-0-gaNycGzNCKU> [Accessed 16 November 2021].*
75. *Ukrainski, P. (2016). Classification accuracy assessment. Confusion matrix method. [Online] 50 North | GIS blog from Ukraine. Available at: http://www.50northspatial.org/classification-accuracy-assessment-confusion-matrix-method/ [Accessed 22 October 2021].*
76. *United Nations, 2020. Emergency Appeal for the Impact of COVID19 in South Africa. [online] South Africa. Available at: <https://southafrica.un.org/en/104643-emergency-appeal-impact-covid19-south-africa> [Accessed 10 November 2021].*
77. *Ursulica, Teodora. (2016). The Relationship between Health Care Needs and Accessibility to Health Care Services in Botosani County- Romania. Procedia Environmental Sciences. 32. 300-310. 10.1016/j.proenv.2016.03.035.*
78. *Verma VR, Dash U (2020) Geographical accessibility and spatial coverage modelling of public health care network in rural and remote India. PLoS ONE 15(10): e0239326. https://doi.org/10.1371/journal.pone.0239326*
79. *Verma, P., Singh, R., Singh, P. and Raghubanshi, A., 2020. Urban ecology – current state of research and concepts. Urban Ecology, [online] pp.3-16. Available at: <https://doi.org/10.1016/B978-0-12-820730-7.00001-X>.*
80. *Williams, D., 2015. Differences Between North- and South-Facing Slopes. [online] Sciencing. Available at: <https://sciencing.com/differences-between-north-southfacing-slopes-8568075.html>.*
81. *Wong, E., 2021. Study shows a huge burden of undiagnosed disease in a rural South African district. [online] The Conversation. Available at:*

<https://theconversation.com/study-shows-a-huge-burden-of-undiagnosed-disease-in-a-rural-south-african-district-163029> [Accessed 16 July 2021].

APPENDIX 1

NELSON MANDELA UNIVERSITY

PO Box 77000, Nelson Mandela University, Port Elizabeth, 6031, South Africa mandela.ac.za

Chairperson: Research Ethics Committee (Human)
Tel: +27 (0)41 504 2347
sharlene.govender@mandela.ac.za

NHREC registration nr: REC-042508-025

Ref: [H20-SCI-GEO-002] / Approval]

6 April 2021

Dr W Britz
Faculty: Science

Dear Dr Britz

SPATIAL MODELLING OF TUBERCULOSIS TREATMENT ACCESSIBILITY: THE CASE OF NGAKA MODIRI MOLEMA

PRP: Dr W Britz
PI: Ms K Ramotsongwa

Your above-entitled application served at the Research Ethics Committee (Human) (*24 February 2021*) for approval. The study is classified as a medium risk study. The ethics clearance reference number is **H20-SCI-GEO-002** and approval is subject to the following conditions:

1. The immediate completion and return of the attached acknowledgement to Imtiaz.Khan@mandela.ac.za, the date of receipt of such returned acknowledgement determining the final date of approval for the study where after data collection may commence.
2. Approval for data collection is for 1 calendar year from date of receipt of above mentioned acknowledgement.
3. The submission of an annual progress report by the PRP on the data collection activities of the study (form RECH-004 available on Research Ethics Committee (Human) portal) by 15 November this year for studies approved/extended in the period October of the previous year up to and including September of this year, or 15 November next year for studies approved/extended after September this year.
4. In the event of a requirement to extend the period of data collection (i.e. for a period in excess of 1 calendar year from date of approval), completion of an extension request is required (form RECH-005 available on Research Ethics Committee (Human) portal).
5. In the event of any changes made to the study (excluding extension of the study), RECH will have to approve such amendments and completion of an amendments form is required PRIOR to implementation (form RECH-006 available on Research Ethics Committee (Human) portal).
6. Immediate submission (and possible discontinuation of the study in the case of serious events) of the relevant report to RECH (form RECH-007 available on Research Ethics Committee (Human) portal) in the event of any unanticipated problems, serious incidents or adverse events observed during the course of the study.
7. Immediate submission of a Study Termination Report to RECH (form RECH-008 available on Research Ethics Committee (Human) portal) upon expected or unexpected closure/termination of study.
8. Immediate submission of a Study Exception Report of RECH (form RECH-009 available on Research Ethics Committee (Human) portal) in the event of any study deviations, violations and/or exceptions.
9. Acknowledgement that the study could be subjected to passive and/or active monitoring without prior notice at the discretion of Research Ethics Committee (Human).

Please quote the ethics clearance reference number in all correspondence and enquiries related to the study. For speedy processing of email queries (to be directed to Imtiaz.Khan@mandela.ac.za), it is recommended that the ethics clearance reference number together with an indication of the query appear in the subject line of the email.

We wish you well with the study.

Yours sincerely

Dr S Govender
Chairperson: Research Ethics Committee (Human)

Cc: Department of Research Development
Faculty Manager: Science

Appendix 1: Acknowledgement of conditions for ethical approval

ACKNOWLEDGEMENT OF CONDITIONS FOR ETHICS APPROVAL

I, **DR W BRITZ** (PRP) of the study entitled **[H20-SCI-GEO-002] SPATIAL MODELLING OF TUBERCULOSIS TREATMENT ACCESSIBILITY: THE CASE OF NGAKA MODIRI MOLEMA**, do hereby agree to the following approval conditions:

1. The submission of an annual progress report by myself on the data collection activities of the study by 15 November this year for studies approved in the period October of the previous year up to and including September of this year, or 15 November next year for studies approved after September this year. It is noted that there will be no call for the submission thereof. The onus for submission of the annual report by the stipulated date rests on myself. I am aware of the guidelines (available on Research Ethics Committee (Human) portal) pertinent to the submission of the annual report.

2. Submission of the relevant request to RECH in the event of any amendments to the study for approval by RECH prior to any partial or full implementation thereof. I am aware of the guidelines (available on Research Ethics Committee (Human) portal) pertinent to the requesting for any amendments to the study.

3. Submission of the relevant request to RECH in the event of any extension to the study for approval by RECH prior to the implementation thereof.

4. Immediate submission of the relevant report to RECH in the event of any unanticipated problems, serious incidents or adverse events. I am aware of the guidelines (available on Research Ethics Committee (Human) portal) pertinent to the reporting of any unanticipated problems, serious incidents or adverse events.

5. Immediate discontinuation of the study in the event of any serious unanticipated problems, serious incidents or serious adverse events.

6. Immediate submission of the relevant report to RECH in the event of the unexpected closure/discontinuation of the study (for example, de-registration of the PI).

7. Immediate submission of the relevant report to RECH in the event of study deviations, violations and/or exceptions. I am aware of the guidelines (available on Research Ethics Committee (Human) portal) pertinent to the reporting of any study deviations, violations and/or exceptions.

8. Acknowledgement that the study could be subjected to passive and/or active monitoring without prior notice at the discretion of RECH. I am aware of the guidelines (available on Research Ethics Committee (Human) portal) pertinent to the active monitoring of a study.

Signed: ________________________________ Date: _____________________