GIS-Based Location-Allocation Modelling of School Accessibility in the Bojanala Platinum District Municipality, South Africa

By

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Research Report

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DECLARATION

I, Kebarileng Christinah Molefe, declare that this research report is entirely my own work and that I have properly cited and credited all the sources I utilized. This research report is being submitted to the University of the Witwatersrand, Johannesburg, for the Degree of Master of Science in Geographic Information Systems and Remote Sensing. It has never been submitted in for a certification or another degree at another university.

Signature of Candidate: ___________

Date: 19 September 2024

Place: Madikwe

ABSTRACT

School accessibility modelling performs a crucial part in guaranteeing that educational institutions are physically and practically reachable by every student, irrespective of their abilities, disabilities, or socioeconomic status. Neglecting school accessibility perpetuates inequality, reinforces negative stereotypes, and isolates affected students. Therefore, the principal goal of this research was to evaluate the distribution of schools across the Bojanala Platinum District Municipality, focusing on their accessibility to local communities. The study employed an integrated approach, combining geostatistical techniques, location-allocation modelling, and multicriteria decision analysis. By considering both quantitative data and spatial relationships, these methodologies contributed to robust decision-making and informed policy recommendations. The study utilized population data and school-related information sourced from the Department of Education and the HUMDATA websites, both dated to the year 2020. The study examined the distribution of schools in the Bojanala Platinum District Municipality. It was discovered that the schools were clustered, with a concentration in the Rustenburg local municipality, followed by Madibeng. However, a significant inequality in school access was evident. Secondary school students faced the greatest vulnerability, as most accessible schools primarily served primary students. To address this, potential school sites were proposed across the district. The study emphasizes the need for effective interventions by educational administrators and policymakers to eliminate this inequality. This study recommends the establishment of new schools in underserved regions, strategically enhance existing schools, and maximize school accessibility for all residents. Adequate school provision promotes equity, reduces travel burdens, and strengthens community bonds.

Keywords: Geographic Information Systems, Location-Allocation Modelling, Weighted Overlay Analysis, Accessibility, Education.

DEDICATION

In loving memory of Ramphetshana, Mamogaladi, Mabonyana, Meikie, Mmadijo, Ntobi and Mmadikgongnyane.

Continue to Fly High!

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"The LORD is my shepherd; I shall not want"- Psalms 23:1

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APIs	Application Programming Interface
AHP	Analytic Hierarchy Process
ANN	Average Nearest Neighbor
BCE	Before the Common Era
BPDM	Bojanala Platinum District Municipality
CA	Consumer’s Accuracy
CART	Classification and Regression Trees
CGIS	Canadian Geographic Information System
CO	Carbon Monoxide
COVID-19	Coronavirus Disease of 2019
DBE	Department of Basic Education
DEM	Digital Elevation Model
DET	Department of Education and Training
DT	Decision Trees
EVI	Enhanced Vegetation Index
FET	Further Education and Training
GEE	Google Earth Engine
GET	General Education and Training
GIS	Geographic Information System
IDP	Integrated Development Plan
INDS	Integrated National Disability Strategy
KDE	Kernel Density Estimation
LM-BP	Levenberg–Marquardt Back Propagation
LSA	Late Stone Age
LULC	Land Use and Land Cover
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision-Making
ML	Machine Learning
MSI	Multispectral Instrument

N.A.	Not Applicable
N.D.	No Date
NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NEPA	National Education Policy Act
NN	Neural Network
NNR	Nearest Neighbor Ratio
NO	Nitrogen Monoxide
O_3	Ozone
OA	Overall Accuracy
PA	Producer's Accuracy
SDE	Standard Deviational Ellipse
SRTM	Shuttle Radar Topography Mission
SVM	Support Vector Machine
TIN	Triangulated Irregular Network
UNESCO	United Nations Educational, Scientific and Cultural Organization
VNIR	Visible and Near Infrared
WPRPD	White Paper on the Rights of Persons with Disabilities

CHAPTER 1

General Introduction

1.1. Introduction

This study focuses on examining school accessibility in the Bojanala Platinum District Municipality (BPDM). This chapter provides the background to the study (1.2), the research problem statement (1.3), and the research aim and objectives. Additionally, it also includes the structure of the report (1.5) and a summary of the chapter (1.6).

1.2. Background

Global organizations such as UNESCO (United Nations Educational, Scientific and Cultural Organization) regard the right to education as paramount. They tirelessly strive to ensure that every individual, regardless of age, gender, or ability, has access to quality education (UNESCO, 2023). As Nelson Mandela wisely stated, “Education is the most powerful weapon which you can use to change the world.” Education has proven to be pivotal in providing stability in life and opening better career opportunities. Education offers financial security and equips individuals with the skills needed to manage their finances effectively. Education is crucial in promoting equality by providing everyone with the same opportunities. It contributes to creating a safer world by teaching people the difference between right and wrong. It fosters self-dependency, allowing individuals to rely on themselves and make their own choices (University of the People, N.D.). Therefore, it can be asserted that the world needs educated individuals; informed minds drive progress, foster innovation, and address global challenges (UNESCO, 2023).

The colonial era, which began in 1652 at the Cape, has become the basis of South Africa's educational history. According to literature, the first school was established by the Dutch East India Company for the children of the Amersfoort slaves whom they brought to the Cape (South African History Online, N.D.). This school was founded on the 17th of April 1658 and later more schools for non-slave children and children of colonists were built over time. The Cape Colony passed its first educational law in 1714, which set rules and a council to monitor education. Anglicisation efforts of Cape society during the British administration, which started in 1795, resulted in significant social, political, and economic advancements. However, important advancements in South Africa's educational system did not occur long ago (South African History Online, N.D.).

The present state of education in South Africa is an intricate issue. Even though there has been a little bit of progress since apartheid ended, a certain number of issues still need to be resolved. According to a report, South Africa's educational system continues to face severe inequality and persistent underperformance. Most of the school's struggle with deteriorating facilities, overcrowded classrooms, and subpar learning results. Although apartheid's legacy contributes to these difficulties, the current administration has not done enough to address them (Amnesty International, 2020). Municipalities such as the Bojanala Platinum District Municipality (BPDM) are still yet to resolve some of these challenges (Bojanala Platinum District Municipality, N.D.). Moreover, in 2021, a certain number of students dropped out of school (Statistics South Africa, N.D.). This infers that the COVID-19 (Coronavirus Disease of 2019) pandemic also had a crucial impact on the school system in South Africa and the Department of Education (DBE) faced immense challenges in facilitating education during that period (Statistics South Africa, N.D.).

To tackle the challenges encountered by the education sector, educational administrators and planners in various regions have employed Geographic Information System (GIS) school mapping. This process involves creating maps that convey essential information about schools and their geographical positions. Details captured may encompass the total number of schools within an area, their proximity to other facilities or resources, and demographic data related to the student population attending these schools. GIS empowers education planners by providing spatial insights, optimizing school locations, ensuring resource equity, enhancing transportation systems, and promoting community engagement. By leveraging GIS, planners can create more effective and inclusive educational environments (Ghosh, 2018).

To create an inclusive educational environment, it is important to understand how educational facilities are distributed across space. An equitable distribution of schools ensures that education is accessible to all children, regardless of their geographical location. It helps to identify areas with limited access to education and enables policymakers to allocate resources effectively. This can lead to improved educational outcomes and increased opportunities for students. Moreover, understanding the distribution of schools promotes social justice and equality by ensuring that educational opportunities are available to everyone (UNESCO, N.D.). By mapping the distribution of schools, policymakers can also identify areas with a high concentration of underserved students and implement targeted interventions to improve educational outcomes (Lagrab & Aknin, 2015).

GIS school mapping has made use of a variety of methodologies, such as network analysis, overlay analysis, and walkability analysis. In this study, the location-allocation model, weighted overlay analysis and geostatistical techniques such as kernel density estimation (KDE), average nearest neighbour (ANN), standard distance, directional distribution, buffering analysis, and Thiessen polygons were employed. Location-allocation models use approximated distances to optimize facility placement, benefiting both service providers and users (Al- Sabbagh, 2022). Weighted overlay analysis is a technique used to address multicriteria issues like site selection and suitability models. It involves combining multiple raster layers, each representing a different criterion, to create a composite suitability map. Each criterion in this analysis is given a weight determined by its relative importance. The values of each criterion are scaled using the weights to obtain a single suitability score for each location (Nebey, Taye, & Workineh, 2020). In GIS school mapping, weighted overlay analysis is employed to identify the ideal site for new schools depending on a variety of factors such as the road network, slope, existing schools and Land Use and Land Cover (LULC) (Al-Sabbagh, 2022). The geostatistical techniques in this study were used to discover trends or patterns in the observed schools' data (SAGE Ocean, N.D.). Recognizing trends and patterns enables effective planning and ensures the efficient allocation of resources to avoid shortages and excesses (Al-Sabbagh, 2022).

When evaluating school accessibility using GIS, there are several challenges and limitations to consider such as lack of complete data, environmental hazards, road quality and temporal constraints. Temporal factors such as peak traffic hours can significantly impact travel time to schools. Researchers have proposed spatio-temporal models for traffic patterns and emission estimation to circumvent this challenge (Ren, Guo, Wu, & Singh, 2023). Lack of complete data on school locations, transportation networks, and population distribution hinders accurate accessibility modelling as it limits the effectiveness of analytical models. Uneven road surfaces, potholes, and road conditions affect travel time and safety making the use of techniques such as network analysis less effective as it relies on network datasets with good data (Mindahun & Asefa, 2019). Additionally, Mindahun and Asefa (2019) have noted that environmental hazards such as floods and unsafe areas can impact school accessibility and advise that if an area is vulnerable to floods a flood hazard risk assessment should be done.

Therefore, it is recommended that educational administrators go beyond subjectivity and incorporate quantitative analyses of educational facilities specific to the needs of any community. As the DBE becomes more focused on ensuring the equitable distribution of quality education, by integrating research methodologies educational administrators can gain a holistic view and assess national and local educational demand, service delivery, and other critical information related to education (Al-Sabbagh, 2022).

1.3. Research Problem Statement

The South African educational system grapples with persistent challenges, impacting students, teachers, and communities nationwide (Zwane, 2018). Among these challenges, school inaccessibility stands out as a critical issue within the BPDM. Learners in the BPDM often travel lengthy distances to reach school due to the scattered nature of the villages and underdeveloped roads (Bojanala Platinum District Municipality, N.D.). This geographical barrier affects attendance, learning outcomes, and overall educational equity. Historical factors, including the legacy of apartheid, inequitable resource allocation, and chronic underperformance, contribute to this accessibility gap (Du Plessis & Mestry, 2019). Addressing school inaccessibility requires acknowledging historical injustices, advocating for equitable resource allocation, and ensuring safe, well-equipped learning environments for all children.

The apartheid era left a profound impact on South Africa's education system. During apartheid, schools were segregated based on skin colour, with well-resourced schools serving white communities and disadvantaged schools serving black communities (South African History Online, N.D.). The consequences of this historical segregation persist today, affecting infrastructure, funding, and educational opportunities (Amnesty International, 2020). Under apartheid, unequal distribution of resources favoured white schools. These schools received better funding, infrastructure, and qualified teachers. In contrast, black schools faced overcrowding, inadequate facilities, and limited access to quality education (South African History Online, N.D.). The spatial legacy of apartheid continues to shape educational experiences today (Amnesty International, 2020). Children's ability to attend school is influenced by their socioeconomic status, where they are born, and the colour of their skin (Du Plessis & Mestry, 2019).

Areas like the BPDM which is mainly made up of villages often suffer from poor infrastructure, making schools less accessible (Bojanala Platinum District Municipality, N.D.). This means that the historical and present neglect of infrastructure in disadvantaged areas affects school accessibility (Du Plessis &

Mestry, 2019). The pressing need for reform is highlighted by the fact that secondary school-age children (14–17 years old) are more likely to travel lengthy distances to get to school (Hall, 2023). The DBE repeatedly fails to meet infrastructure targets, and this perpetuates inequality, as learners in poorly resourced schools struggle to access quality education (Amnesty International, 2020).

According to our understanding, this study is the first to apply multiple spatial analyses to assess school distribution and accessibility in the BPDM, offering new insights into where schools are clustered, dispersed, and inaccessible and further putting forth alternatives on where potential schools can be placed. Although, there are multiple accessibility studies found in the literature, including Al-Sabbagh (2022), Al-Enazi, Mesbah, & Anwar (2016) and Mindahun & Asefa (2019). Another gap that needed to be filled that earlier research did not address was the lack of presentation of the mapping outcomes related to the accessibility mapping of different school types within the framework of district educational planning. This is also the first study to apply these methods within the specific context of school accessibility planning as a recommended approach for educational administrators and policymakers looking to model and characterize school accessibility within the BPDM.

1.4. Aims and Objectives

1.4.1. Aim

This research aims to assess the school's distribution and accessibility in the Bojanala Platinum District Municipality using geospatial techniques.

1.4.2. Objectives

1. To analyse the spatial distribution of schools within the Bojanala Platinum District Municipality.
2. To assess the school accessibility using a GIS-based location-allocation model.
3. To map the optimal sites for potential new schools using GIS-based Multi-Criteria Decision Analysis (MCDA).

1.5. Research Report Outline

To guarantee educational equality, Chapter 1 provides an explanation of the problem's origin, the setting of education, and the application of GIS techniques. The goals and objectives of the study are further described in this chapter. The research problem statement provides an explanation of the pertinent issue that will be the focus of this report's inquiry.

A review of the literature is presented in Chapter 2 to give readers a thorough knowledge of some of the major concepts covered in this research report. The history and current state of the South African education system are examined. A discussion of GIS's function in location-based issue solving is expanded upon by examining the numerous case studies in which it has been used.

The methods and tools involved are described in Chapter 3. The study's focus and the analytical methods employed to evaluate the distribution of schools in the BPDM are covered in detail in this chapter. In addition, more information is provided about the techniques employed to evaluate the appropriateness and accessibility of schools.

Chapter 4 presents the findings that are needed to address the research objectives. The resulting figures and tables are supplied to aid in understanding the findings.

Chapter 5 contains the whole set of study project insights. The observations are discussed and linked to relevant scholarly works.

In Chapter 6, all the conclusions regarding the research objectives that were set in in the first chapter are summarized in accordance with the discussion and the findings. The study's limitations and prospective future development areas are also covered in this chapter.

1.6. Summary of the Chapter

This chapter has put forth GIS techniques as an alternative to address the educational challenges that the BPDM faces. Although the presented techniques have not been used extensively in South Africa, the use of these techniques has been researched thoroughly. Therefore, this study intends to use these techniques to evaluate school distribution, accessibility, and suitability within the BPDM. Moreover, this chapter presents a summary of the research report’s overall structure.

CHAPTER 2

Literature Review

2.1. Introduction

The BPDM in South Africa faces challenges in providing basic services such as education to its local population. One of the approaches that can be used to address this issue is using GIS- based location-allocation modelling, which can help to address school accessibility based on factors such as population and existing schools' data. This literature review's goal is to assess the efficacy of GIS-based techniques in examining school distribution, accessibility, and suitability in the BPDM. Specifically, this review will outline South Africa's educational system and look at some of the challenges it faces (2.2). Technologies that have been used to assess accessibility and suitability are examined in 2.4. Lastly, the review will also examine various geostatistical techniques that can be used to analyse school's spatial distribution (2.3). Section 2.5 presents the summary of the chapter.

2.2. Education System

An education system is a collection of laws, customs, and practices intended to give people access to educational opportunities. It is a systematic method of teaching that aims to provide pupils with the knowledge and abilities they need to succeed in life (Adeaga, 2019).

2.2.1. History of Education in South Africa

Education in South Africa has a rich history, stretching back to pre-colonial times around 1000 BCE (before the common era). During this era, the Late Stone Age (LSA) people (San/Tsam//Xam) imparted essential skills to their children, including hunting, gathering food, and using stone tools. However, formal schooling began with the Dutch East India Company, which opened the first school in South Africa on the 17th of April 1658. This school specifically catered to the children of slaves brought from Amersfoort. Over time, various laws and regulations shaped education in the country, with one of the most significant being the Bantu Education Act of 1953. Many mission schools and night schools were forced to close because of this contentious law, which required all African schools to register with the government. Its purpose was to consolidate Bantu education and uniformly implement discriminatory practices across South Africa. In 1979, the Education and Training Act replaced the Bantu Education Act, placing African education under the Department of Education and Training (DET). These changes were driven by movements, demonstrations, and political parties advocating for educational reform (South African History Online, N.D.).

Despite persistent inequality, a significant turning point occurred in 1994. It was during that year that the government introduced an education system aimed at providing equal opportunities for all South Africans, based on principles of non-racialism, non-sexism, and democracy. Policies were implemented to address past disparities and enhance educational access for disadvantaged groups (South African History Online, N.D.).

2.2.2. Structure of the Education System in South Africa

Universal access to fundamental education is ensured for every child in South Africa due to the efficient functioning of the educational system. Children are mandated to attend school from the age of 7 until 15. It is expected that each child receive an education from grade 1 through grade 9. The South African educational system comprises of three divisions: primary, secondary, and tertiary education. Grades 1 through 9 make up the primary level, which is for pupils aged 7 to 15 years old. The secondary level, which consists of 2 stages called General Education and Training (GET) and Further Education and Training (FET), is for pupils who have finished primary school. GET is for students in grades 10 through 12, whereas FET is for those who have finished GET and want to continue their academic or vocational courses. Students who have finished their secondary education and desire to attend colleges or universities for higher education are enrolled in tertiary education (Adeaga, 2019).

2.2.3. Current State of South African Schools

A school is an educational institution specifically created to offer learning environments for students, guided by educators. It is crucial that learners in both rural and urban contexts receive quality education to drive accelerated development in any country and mitigate the prevalence of poverty and unemployment (Du Plessis & Mestry, 2019).

Rural School

A rural school can be defined as an educational institution situated far from urban centres, serving students residing in remote areas. These schools often face geographical isolation and have smaller populations (Gutierrez & Terrones, 2023). In South Africa, rural communities still shoulder the heaviest burden of historical injustices compared to their urban counterparts. As a result, rural learners still encounter challenges that hinder their constitutional right to basic education (Carelse, 2018). These challenges include multigrade teaching, lack of parental involvement, and inadequate transportation facilities within the school areas (Du Plessis & Mestry, 2019).

Furthermore, many rural schools suffer from inadequate infrastructure, lacking essentials such as water, sanitation, proper classrooms, and electricity. This situation often arises due to underdevelopment in these areas. Additionally, the rural population typically engages in low- skilled work and has limited education, leading to a diminished emphasis on the value of education. Financial challenges restrict parents in rural areas from being fully involved in their children's education. Consequently, students may attend irregularly, lacking support at home. Unfortunately, many end up dropping out, following in their parents' footsteps by taking on menial jobs, such as farm work. Despite increased government efforts to ensure access to basic education, some rural communities still struggle to provide this fundamental right, accentuating the neglect faced by schools situated in rural areas (Du Plessis & Mestry, 2019).

Urban School

An urban area in South Africa can be characterised by its population density; the higher the population the more acceptable that the area can be constituted as urban. The built environment of urban regions includes a dense population of buildings made of humans, such as residences, places of business, and railroads (URBANET, 2020). Although this characterization may apply to other urban areas in South Africa, not all urban areas fulfil this mandate. Most urban areas are surrounded by areas that are considered peri-urban or townships. As such, most of the services that are offered in these areas are usually shared with the population that resides in the nearby settlements. Therefore, services that were offered to meet a certain threshold end up not being able to as it is now expected to meet the needs beyond the means it was created for (Hlalele, 2012). In Early 2023, in the beginning of the year when schools were about to open the was a shortage of schools in the Gauteng province, whereby schools located in the towns and cities were unable to cater for all the learners that had made applications to those schools. This situation resulted in numerous children being without schools, prompting the creation of emergency classes to accommodate the additional learners (Makhoali, 2023).

This phenomenon can be attributed to many factors such as migration within the country; some people leave the villages to seek a better life in the cities and in most cases, they leave with their children. Also, some children get placed further away from their homes which causes them to spend most of their time travelling to and from school. This led the premier of Gauteng to deduce that the is a lack of schools in the province (Makhoali, 2023). However, these challenges do not apply to all the schools situated in urban areas as most schools within these localities are highly advantaged (Du Plessis & Mestry, 2019). For instance, urban schools are much more resourced, and the area's conditions do not limit the curriculum that is offered to the students (South African History Online, N.D.). Most urban schools do not have a shortage of teachers as many prefer urban settings due to the quality of the classroom facilities, higher student-teacher ratio, and school resources. All these advantages enable students who attend schools in urban areas to outperform their peers from other schools (Du Plessis & Mestry, 2019).

2.2.4. 1994, Current Laws and Policies

The South African education system operates under a comprehensive legal framework, including various laws and regulations. These include the South African Constitution of 1996, the South African Schools Act (1996), the National Education Policy Act (NEPA) (1996), the Integrated National Disability Strategy (INDS) (1997), the White Paper on the Rights of Persons with Disabilities (WPRPD) (2015), the National Development Plan (NDP) 2030 (2011), the Employment of Educators Act, 1998 (Act No. 76 of 1998), the South African Council for Educators Act, 2000 (Act No. 31 of 2000), and the General and Further Education and Training Quality Assurance Act, 2001 (Act No. 58 of 2001). The South African Schools Act outlines the roles of different stakeholders in school governance, while the National Education Policy Act offers a framework for educational policies and programs. These laws and rules are fundamental to the organization and direction of South Africa's educational system (Mansfield-Barry & Stwayi , 2017).

The South African Schools Act (1996) holds significant importance as it ensures that South African schools adhere to legal standards in terms of organization, financing, administration, and training procedures. Additionally, the Act mandates that all public school governing bodies strive to elevate the standard of education within their schools. Furthermore, the Act aims to drive societal transformation by combating sexism, racism, and other forms of unjustified discrimination (Mansfield-Barry & Stwayi , 2017).

Role of Children, Parents, Educators, and the General Public

In education, there are differences between the roles that parents, teachers, children, and the larger community play. For instance, since education mostly benefits children, consistent attendance, participation in class activities, and timely assignment completion are expected of them. They are also expected to observe the norms and regulations of the school and be respectful to their teachers and fellow students (Banger, 2022). Parents are required to make sure that their children attend school regularly, finish their homework on time, and participate in extracurricular activities because they also play an integral part in their education. To monitor their children's development and address any concerns, parents should consistently communicate with their children's teachers. Teachers must give children a high-quality education by establishing a welcoming, secure learning atmosphere that encourages innovation, critical thinking, and problem-solving abilities. Additionally, teachers should collaborate with parents to assist student learning and give pupils regular feedback on their progress (Capriola, 2019). The public contributes significantly to the support of by volunteering at schools, offering students mentorship opportunities, and donating materials. They can also recommend laws to guarantee that every child has access to a quality education (NEEDU, 2018).

2.3. Advancing Accessibility Mapping Technologies

Technology has become an intrinsic part of our everyday life, making it easier, and better. Technology has brought advancements in agriculture, engineering, architecture, business, communication, education, and entertainment (Arthur, 2010). In the field of accessibility mapping, technology has contributed significantly to its development. With the advent of digital technologies, accessibility maps have become more interactive, user-friendly, and accurate.

2.3.1. GIS and Remote Sensing

GIS is a computer program that collects, saves, processes, and displays information about the surface of the earth. GIS can be used to display a variety of data, including streets, buildings, and plants. This method has been assistive in mapping LULC, assessing the dangers of crime, and performing demographic analysis. The locations of numerous things can be compared using GIS technology to ascertain their relationship with each other. For instance, engineers can create transportation infrastructure and road networks using GIS. A map like that may be used to analyse traffic patterns, optimize routes, plan intersections, and ensure smooth traffic flow (National Geographic, N.D.). Consequently, due to its limitless capabilities, GIS is characterized as, "a decision support system involving the integration of spatially referenced data in a problem-solving environment" (Cowen, 1988).

The process of monitoring an area's reflected and emitted radiation from a distance to identify and track its physical attributes is known as remote sensing. Remotely sensed images are obtained by special cameras on aircrafts and satellites that detect radiation (such microwave, infrared, or visible light) reflected or released from the surface of the Earth. These images provide valuable information about land, oceans, atmosphere, and other natural features. Since both technologies offer varying advantages, integrating them in research empowers us to make informed decisions, protect the environment, and plan for a sustainable future (Navalgund, Jayaraman, & Roy, 2007).

History of GIS in Mapping Accessibility

GIS was first used in 1854 when John Snow used a map to identify the source of a cholera outbreak in London (Steenson, 2019). This occurred despite the prevailing belief that the disease spread through the air. Snow meticulously mapped outbreak locations, roads, property boundaries, and water pumps. His groundbreaking discovery revealed that cholera was not airborne but transmitted through contaminated water sources, pinpointing a specific infected water pump. This pivotal moment connected the 'what' (the disease) with the 'where' (its spatial distribution), laying the foundation for spatial analysis and the field of epidemiology. John Snow's work demonstrated that GIS is a powerful problem-solving tool for understanding spatially related issues (Steenson, 2019).

Roger Tomlinson directed the creation of the Canadian Geographic Information System (CGIS) in the 1960s. According to Steenson (2019), CGIS was distinctive in that it adopted a layering strategy for processing maps. GIS technology developed during the ensuing decades, and by the 1990s, it had established itself as a crucial tool for urban planning and environmental management (Steenson, 2019). GIS has been used to produce maps that depict school locations, catchment areas, and student numbers in the context of school mapping. This data can be used to pinpoint locations that either require more schools or that have become overcrowded. Additionally, GIS can be used to analyse student performance data and pinpoint locations in which more funding is required to enhance educational results (Waldheim, 2011).

Location-Allocation Model

Location-allocation models play a crucial role in identifying optimal sites for new facilities to meet population needs. These models consider two key elements: the potential facility locations and the allocation of services or products from those facilities to areas of demand. The ultimate objective is to strategically position facilities so that supply efficiently meets demand points. The location-allocation solver selects the most suitable candidate facilities based on problem type and specified criteria. When applied to GIS school mapping, this approach assists education planners in making informed decisions regarding school locations, resource allocation, and transportation planning. By analysing school distribution, policymakers can identify regions with limited educational access and implement targeted interventions to enhance educational outcome. Furthermore, location-allocation models help pinpoint areas with a high concentration of underserved students, enabling focused efforts to improve educational access (Al-Sabbagh, 2022).

Numerous studies have employed the location-allocation modelling approach, yielding promising results (Al-Sabbagh, 2022). Notably, Al-Sabbagh (2022) carried out a study in Egypt to improve accessibility to Mansura city's elementary schools using GIS location-allocation models. By exploring spatial modelling and location analysis, the study demonstrated how this technique supports spatial decision-making. Alhothali, et al. (2022) employed a similar methodology to enhance the dispersion of COVID-19 vaccination centres in Jeddah City, Saudi Arabia. Their goal was to optimize service facility placement, minimize costs while maximizing accessibility. Public-sector facilities such as COVID-19 centres can effectively save lives and offer the community high-quality services when placed properly. The study also highlighted disparities in existing facility allocation across different districts, especially when considering capacity (Alhothali, et al., 2022).

In their study, Rahman et al. (2021) employed the location-allocation model to assess existing emergency evacuation centres in the context of flood risk reduction. The approach was complemented by the Levenberg–Marquardt Back Propagation (LM-BP), neural network (NN), decision trees (DT), and multi-criteria decision-making (MCDM) methods. The researchers observed that the current distribution of emergency evacuation centres was suboptimal, leaving some areas underserved. As a result, not every demand point could be reached in the allotted 60 minutes for travel (Rahman, et al., 2021). Similarly, Mindahun & Asefa (2019) utilized the location-allocation model to enhance primary school coverage and accessibility for all school-age populations in Yeka Sub-City, Addis Ababa, Ethiopia. Their findings revealed uneven school distribution, with schools densely concentrated around transportation facilities and road networks, often without proper separation from noisy areas (Mindahun & Asefa, 2019).

While location-allocation models provide insights into spatial relationships, it is noteworthy that some of the limitations presented by them be noted. Using the study by Al-Sabbagh (2022) as a reference the following can be considered as drawbacks:

- ✓ Population Density Oversimplification

The location-allocation model assumed that each school served the population within its service area (buffer). However, in densely populated urban areas like Mansura City, this oversimplification may not accurately reflect the actual demand for educational services. High- density neighbourhoods may require more schools, but the models do not account for this variation.

- ✓ Uniform Service Radius

The model assumed a uniform service radius for all schools. Schools may have different capacities, grade levels, and specialized programs. Ignoring these variations can lead to suboptimal facility planning.

- ✓ Spatial Discontinuity

The location-allocation model created abrupt boundaries between service areas based on distance. Urban environments often exhibit gradual transitions in facility access due to transportation networks, land use, and socioeconomic factors. The models' simplicity overlooked these spatial nuances.

- ✓ Lack of Contextual Information

The location-allocation model did not consider external factors such as public transportation availability, traffic congestion and safety. These factors significantly impact accessibility to schools. Incorporating context-specific information is crucial for effective planning.

Multi-Criteria Decision Analysis

Integrating Multi-Criteria Decision Analysis (MCDA) yields a powerful process for assessing and selecting optimal locations across various domains when used with GIS. GIS operates at several geographical, temporal, and scale levels to provide effective administration, processing, and archiving of complex georeferenced data from various sources. This digital database facilitates long-term monitoring. Combining GIS with MCDA uses complex map overlay methods to find the best location. Decision rules fall into two categories: multi-objective and multi-attribute methods. In the multi-objective approach, alternatives are generated by considering factors and constraints. Criteria, measured on numerical scales, guide the assessment, with weights representing their relative importance. Evaluating land use performance for each criterion yields suitability scores or classes. Expert opinions significantly influence the decision-making process. Whether determining weights through pairwise comparisons or basic component analysis, expert insights enhance the robustness of the GIS- MCDA fusion. Ultimately, this integration optimizes site selection by leveraging spatial data, criteria assessment, and expert insights, ensuring informed and efficient decision-making (Kuru & Terzi, 2018).

Weighted Overlay Analysis

In GIS, weighted overlay analysis is a technique used to address multicriteria issues like site selection and suitability models. It involves combining multiple raster layers, each representing a different criterion, to create a composite suitability map. Based on each criterion's relative importance, a weight is assigned to it. Each criteria's value is scaled using the weights, and the results are combined into a single suitability score for every location. Weighted overlay analysis is applied in GIS school mapping to determine the best location for new schools based on multiple criteria. The criteria can include factors such as proximity to transportation, population density, and availability of resources (Mallick, et al., 2019).

Weighted overlay analysis has been widely employed in various fields, including studies by Jabbar, Grote, and Tucker (2019) and Hoque, Pradhan, and Ahmed (2020). In their research conducted in Indiana, USA, Jabbar, Grote, and Tucker (2019) used weighted overlay analysis to assess watershed susceptibility. The study used weighted overlay analysis and the analytical hierarchy process (AHP) to identify locations that needed more research based on geological, hydrogeological, and climate criteria. The suggested approach made use of the six main variables that affect water quality which were rainfall, the gradient, level of groundwater, bedrock type, use of land, and the type of soil. Their findings suggest that this approach could be applied to other watersheds for accurate assessment of watershed susceptibility (Jabbar, Grote, & Tucker, 2019). Similarly, Hoque, Pradhan, and Ahmed (2020) employed weighted overlay analysis to create an overall drought vulnerability index in the northwestern part of Bangladesh. Their results demonstrate that this approach effectively maps comprehensive drought vulnerability, aiding in the formulation of robust drought mitigation strategies (Hoque, Pradhan, & Ahmed, 2020).

Although the weighted overlay analysis approach has several advantages considering the studies stated above and has managed to yield positive results, the are some studies whereby the shortcomings presented by the approach cannot be overlooked. Some of the studies include Kuru & Terzi (2018) and Alharbi (2024). In their study, Kuru and Terzi (2018) aimed to identify suitable new development areas using weighted overlay analysis. Slope, aspect, land use, soil classifications, erosion state, geological structure, closeness to natural drainage systems, transit hubs, urban facilities, and populated areas were among the many factors they took into account. While the study's results serve as a foundation for planning, Kuru and Terzi (2018) noted that assigning weights to criteria is subjective and relies on expert opinions. This subjectivity c an potentially lead to suboptimal site selection. Notably, the omission of social and economic criteria limits the model's effectiveness, rendering the study's results insufficient for direct decision-making processes (Kuru & Terzi, 2018).

Alharbi (2024) used GIS to locate and forecast possible flood risk areas in Saudi Arabia's Riyadh City. Using weighted overlay analysis, zones ranging from low to very high risk of flooding were identified within the area. Although the study provided a thorough evaluation of Riyadh's flood risk, it neglected to take climate change projections into consideration, which could have an impact on the accuracy of future flood risk estimates. Additionally, the model assumed that land use and development would not change, highlighting the necessity of frequent updates and continuous improvement of the employed criteria (Alharbi, 2024).

2.4. Geostatistical Analysis

Geostatistical analysis is a statistical method used to analyse spatial data. It is commonly used in spatial accessibility research to identify spatial patterns and relationships between different variables. In spatial accessibility research, geostatistical analysis can be used to identify places that are poorly served by public transit, healthcare facilities, or other essential services. By analysing spatial data, researchers can identify patterns of accessibility and develop strategies to improve access to essential services for different population groups. Geostatistical analysis can also be employed to determine risky locations of environmental hazards, such as air pollution or natural disasters. By analysing spatial data, researchers can identify areas that are most vulnerable to these hazards and develop strategies to mitigate their impact (ArcGIS Desktop, N.D.)

2.4.1. Applications of Geostatistics on Spatial Accessibility Studies

There are several geostatistical techniques commonly used to analyse spatial data. In this study, the primary methods used are KDE, standard distance, ANN, Thiessen Polygons, and directional distribution.

Geostatistical Techniques

Tanveer, Balz, Sumari, Shan, and Tanweer (2020) analysed the distribution of schools in Abbottabad using geospatial technologies tailored to the area's geographic conditions. Among the methods employed, the KDE produced a density map of schools, revealing their concentration patterns. Notably, the southern and eastern regions had a higher concentration of schools, whilst the northern and western regions had fewer schools (Tanveer, Balz, Sumari, Shan, & Tanweer, 2020). Similarly, Hussein and Mohameed (2020) investigated the distribution of educational facilities in the Al-Jihad neighbourhood. They utilized six ArcGIS analytical methods, including Thiessen polygons. The analysis of primary schools indicated that only five schools fell within the standard service area, while other schools served smaller regions. Preparatory schools covered relatively small areas, with none located inside the standard service area (Hussein & Mohameed, 2020).

Cahyadi et al. (2022) used confirmed case data from April 28 to October 26, 2021, to study the spatiotemporal dissemination pattern of COVID-19 in Surabaya. Additionally, they explored the relationship between pollutant parameters, such as carbon monoxide (CO) and ozone (O3). Employing various methods, including directional distribution, the researchers identified the spatial pattern of the virus within the area. Notably, the results indicated a significant reduction in COVID-19 spread in Surabaya by the end of the study (Cahyadi, et al., 2022). Furthermore, Fadahunsi, Kufoniyi, & Babatimehin (2017) conducted a study in Osun State, Nigeria, aiming to examine distribution patterns and develop a model for determining optimal healthcare facility locations. The goal was to ensure equitable access to healthcare services and enhance the spatial distribution of these facilities. The study revealed inequalities in the distribution of healthcare facilities. Buffer analysis results suggested that additional facilities were needed within a 10 km buffer distance to meet established standards (Fadahunsi, Kufoniyi, & Babatimehin, 2017).

Melyantono, Susetya, Widayani, Hartawan, and Tenaya (2021) aimed to describe the spatial distribution of rabies in the Karangasem District. They stressed that the knowledge gained from their research was essential for creating successful disease management plans. 38 confirmed positive cases of rabies were used in an observational study by the researchers between September 2018 and September 2019 at the Disease Investigation Centre in Denpasar, utilizing the direct fluorescent antibody test for diagnosis. Employing the ANN method in ArcGIS version 10.3, they analysed the distribution pattern of rabies in dogs. The observed results indicated that the disease distribution in the Karangasem District exhibited clustering, although it was not statistically significant. Their findings suggested that for effective rabies control in the Karangasem District, targeted efforts of stray dogs should be concentrated on heavily crowded areas (Melyantono, Susetya, Widayani, Hartawan, & Tenaya, 2021). In addition, Al- Sabbagh (2020) conducted a study in Mansura City, Egypt, evaluating school locations and assessing their accessibility. The motivation behind this study was the high rates of early school dropout. Using GIS spatial analysis tools, including ANN, hotspot, and grouping analysis, the distribution of schools was analysed. Notably, the standard distance results revealed that 65.79% of schools were concentrated within an area representing 24.77%, while 60.51% of residential blocks fell within an area of 24.99% (Al-Sabbagh, 2022).

Although these methods proved useful in spatial analyses, they have their own challenges. Ghodousi, Sadeghi-Niaraki, Rabiee, & Choi (2020) used the optimal hot spot analysis and ANN techniques to ascertain the overall spatial distribution of the schools in Bojnourd City. The authors identified several limitations associated with the ANN method in the spatial analysis of schools and one of the limitations is that the method assumed a random distribution as its null hypothesis. This makes the ANN results to be misleading as real-world patterns deviate from randomness (Ghodousi, Sadeghi-Niaraki, Rabiee, & Choi, 2020). Wu, Zheng, Sheng, & You (2020) investigated the spatial equity of primary school facilities in Hangzhou, China, using GIS technology. They discovered that the Thiessen Polygon method did not account for other relevant factors, such as land use, transportation networks, or socioeconomic conditions and the resulting facility distribution did not fully align with the actual demand (Wu, Zheng, Sheng, & You, 2020).

In their study, Jiang et al. (2024) explored the spatial distribution and accessibility of primary school facilities in Megacities. Their findings revealed that primary school-age children in Chengdu exhibit a decentralized distribution pattern with varying population densities. Moreover, the spatial arrangement of primary school facilities closely mirrors the population distribution, resulting in imbalances in facility construction. Since the geographical arrangement of primary schools was heavily influenced by population distribution the KDE results were dominated by population patterns, which may not fully account for other relevant factors. In the very same study, Jiang, et al., 2024) further noted that the buffering analysis method assumed that each facility served the population within its buffer. The standard distance was noted to assume a circular distribution around the mean centre, which may not be realistic for schools; this was observed by Tanveer, Balz, Sumari, Shan, & Tanweer (2020). Reshadat, Zangeneh, Saeidi, Teimouri, & Yigitcanlar (2019) observed that directional distribution diagrams show directional patterns but do not capture complex interactions such as land use hence to obtain a comprehensive analysis it has been suggested to combine them with other methods such as KDE, ANN and Thiessen polygons.

The above-mentioned studies have demonstrated that geostatistical methods are powerful tools for analysing spatial data. These methods can be used to identify spatial patterns, relationships between variables, and areas that are underserved. By analysing spatial data, researchers can develop strategies to improve access to essential services and determine which places are vulnerable to environmental risks. While each method has its strengths and limitations, when used together, they can offer a thorough comprehension of spatial patterns and relationships.

2.5. Summary of the Chapter

This chapter presented a thorough literature analysis of the educational system and the geographic modelling approaches that can be applied to model the distribution, suitability, and accessibility of schools. The literature review described how the GIS-based location-allocation model is an effective tool to improve school accessibility in the BPDM. This is based on the various studies that have been done across the world. GIS-based location-allocation modelling enabled the effective determination of optimal school locations based on factors such as population density, transportation infrastructure, and existing school locations. This helped to ensure that schools are in areas that are easily accessible to students, improve educational outcomes and reduce disparities in access to education. Furthermore, the literature review highlighted the importance of using GIS-based MCDA, and geostatistical analysis to improve school accessibility in the BPDM. By leveraging these tools, it is possible to create a more inclusive and accessible education system that benefits all students in the region. However, future research can look at examining the impact of school accessibility on educational outcomes such as student performance and graduation rates. This could help to further justify the importance of school accessibility and inform policy decisions.

CHAPTER 3

Materials and Methods

3.1. Introduction

This chapter delves into the methodological foundations of this study. The goal is to provide a comprehensive understanding of how the research process was approached. Section 3.2 defines the geographical context within which the research takes place. Section 3.3 outlines the overall structure, data collection methods, and analytical techniques. Section 3.4 specifies the types of data that was collected and where it was collected. Section 3.5 specifies the geospatial techniques used.

3.2. Study Area

The Bojanala Platinum District Municipality (BPDM) is situated at coordinates 25°38′24″S and 27°36′16″E in the North West province of South Africa (see Figure 1). It was established in December 2000 after the dissolution of the former Rustenburg and Eastern Transitional District Councils (Bojanala, N.D.). The BPDM encompasses five local municipalities which are the Kgetleng Rivier, Moretele, Moses Kotane, Madibeng, and Rustenburg. The district's administrative offices are in the town of Rustenburg. Classified as a Category C municipality, the BPDM shares borders with the Dr. Kenneth Kaunda district, Ngaka Modiri Molema district, the Waterberg district, the Tshwane Metropolitan Municipality, and the West Rand District Municipality. The names of cities and towns that exist within the district are Derby, Hartbeesfontein-A, Hartbeespoort, Koster, Madikwe, Marikana, Mooinooi, Phatsima, Rustenburg, Swartruggens, and Tlhabane (Municipalities, N.D.). Notably, the BPDM accounts for nearly 47% of the total population in the North West province (Rakolote, 2022). The district's economy is driven by various sectors, which are mining, community services, banking, trade, transportation, and manufacturing (Municipalities, N.D.). Interestingly, the Integrated Development Plan (IDP) reveals that males constitute 53.34%, while females make up 46.66% of the population (Rakolote, 2022). According to Rakolote (2022), the prevalence of male dominance within the BPDM can be linked to the influence of the mining sector in the region.

The BPDM has set up its educational zones per municipal divisions. As of 2020, there were 566 schools in the municipality and 38 of those were independent schools (Bojanala Platinum District Municipality, N.D.). For this research, 527 schools were retained for analysis after excluding those that fell outside the boundary of the BPDM (36) or lacked geographical coordinates (3). This deliberate selection helped establish the research focus. Figure 2 demonstrates how the schools are distributed geographically within the district municipality.

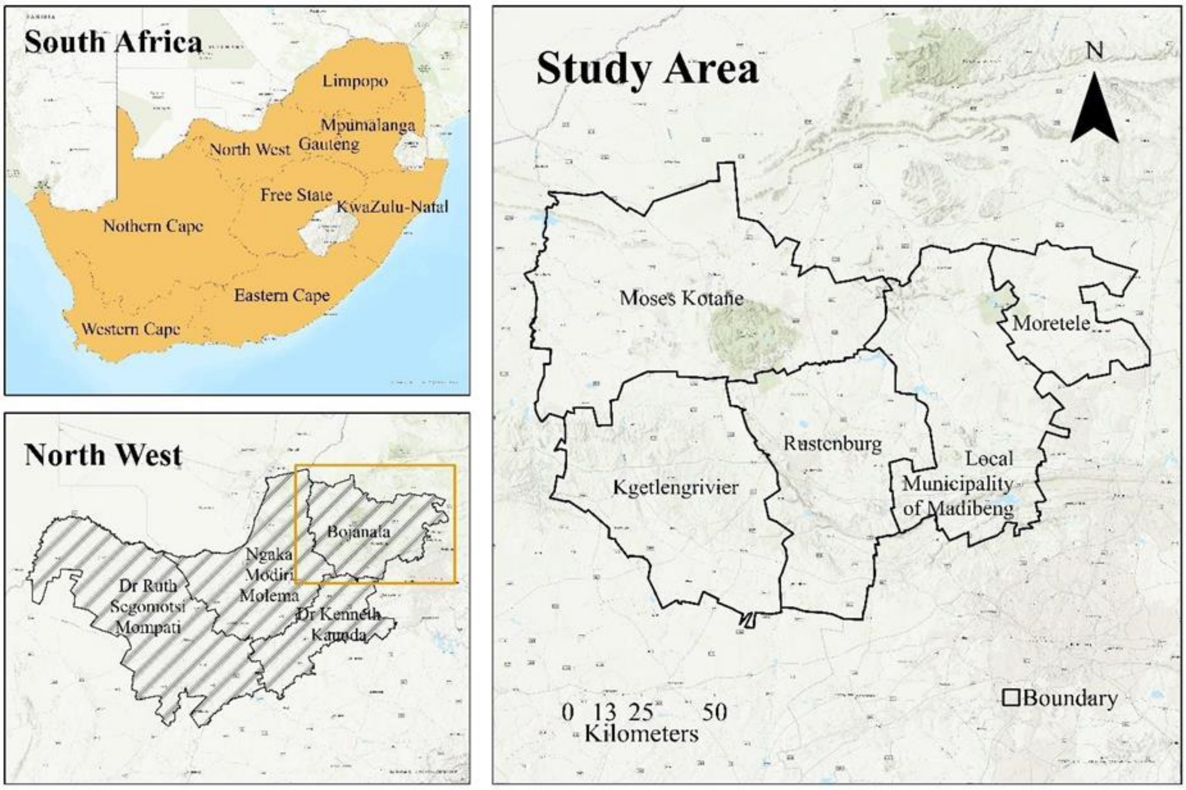

Figure 1: Location map of the BPDM and the local municipalities that are situated within it.

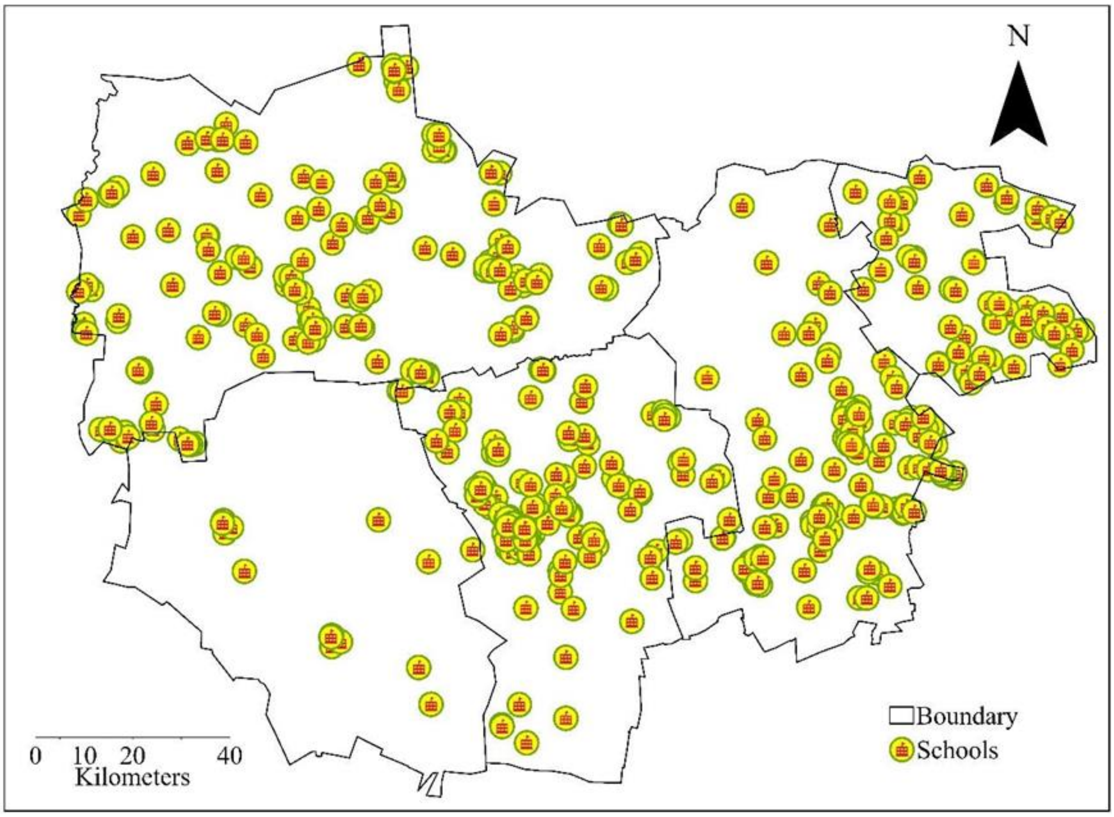

Figure 2: The distribution of the schools located within the study area.

3.3. Research Design

In this study, a systematic research approach was used to address the study's objectives. Relevant data pertaining to the study was collected. The data was then processed and used in line with the objectives. A LULC map was created using the Random Forest machine learning classifier. Population, elevation, and school data was also sorted and organised. Lastly, a network dataset based on the road network map was created. The study's analyses included geostatistical assessments, location-allocation modelling, and MCDA. By integrating these steps, the study aimed to optimize school facilities and enhance accessibility in the BPDM. Figure 3 below depicts the comprehensive workflow as explained above. Licensed Arc GIS 10.7, Arc GIS Pro 3.0, QGIS 3.30, Microsoft Excel 365 and Google Earth Engine (GEE) were utilised to perform the required analysis.

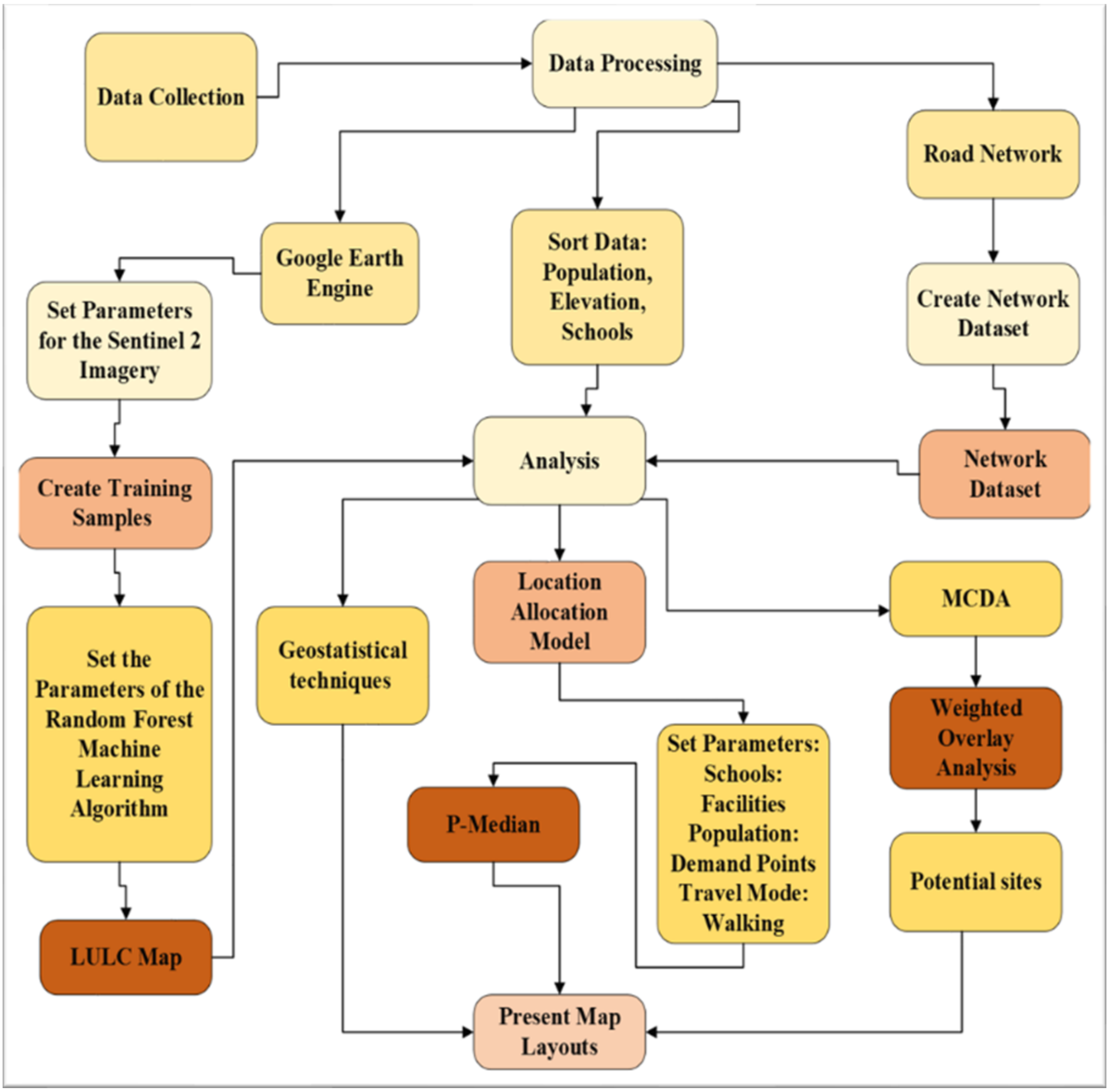

Figure 3: The comprehensive workflow used in this study.

3.4. Data Requirements

In this study, several key datasets were used for geospatial analysis. The Administrative Boundary Map which provides delineations of administrative regions within the study area was sourced from the Humanitarian Data Exchange (HDX). The population counts were derived from the HUMDATA dataset which was available in CSV format. The Elevation-SRTM DEM, obtained from EarthData, provided elevation information for terrain analysis. Road network data was obtained from HOTOSM South Africa, while Sentinel Imagery, was generated using GEE. The Schools data was sourced from the

Department of Basic Education and includes information on school locations and attributes. Table 1 presents detailed information on the data used.

Table 1: An overview of the information used.

Data	Source	Format	Date of Acquisition
Administrative boundary map for the study area.	Humanitarian Data Exchange	Vector	2020
Population Count	HUMDATA	CSV	2020
Elevation-SRTM DEM	EarthData	Raster	2015
Road Data	HOTOSM South Africa	Vector	N.D.
Sentinel Imagery	Generated using GEE	Raster	2020
Schools Data	Department of Basic Education	Excel	2020

3.5. Methods

The examination of school accessibility within the BPDM framework was methodically segmented into three key phases to align with the outlined research objectives. The first phase involved analysing the spatial distribution of schools to understand the current educational landscape. The second phase focused on assessing the accessibility of these schools, considering factors such as distance and transportation. The final phase was dedicated to mapping out the optimal sites for new schools, ensuring future educational facilities are strategically placed to serve the community effectively.

3.5.1. Analysing the Spatial Distribution of Schools

Gathering data and analysing the distribution of schools are important tasks in the field of spatial analysis. The data that was collected to use to perform spatial analysis is explained and the techniques used to analyse it are described below.

3.5.1.1. Data Collection

To analyse the spatial distribution of schools within the BPDM, this study utilized quantified data from the DBE for the 2020 academic year. The dataset included information on school names, school status, and the sectors to which the schools belonged. Additionally, it provided details about whether a school was primary or secondary, its specializations, ownership of the land and buildings, GIS coordinates, and the number of learners and educators at each school.

3.5.1.2. Spatial Analysis

The geostatistical techniques in this study were used to analyse the schools' distribution. According to Al-Sabbagh (2022), the user can be informed by these methods as to whether the points are scattered, clustered, or randomly distributed. This enables a better comprehension of the results by the user (Al-Sabbagh, 2022). The techniques employed in this study include KDE, buffering, directional distribution, standard distance, and Thiessen Polygons. Additionally, the mean centre, median centre, and central feature were incorporated to enhance the results.

Kernel Density Estimation

The Kernel Density Estimation (KDE) approach uses kernels as weights for estimating a random variable's probability density function. This method assisted in determining if the was a cluster or dispersion of schools within the district (Blazquez & Celis, 2013).

Given a univariate dataset with independent and identically distributed samples (x_1, x_2, …, x_n) drawn from an unknown density function (*f*) at any given point (x), the kernel density estimator is defined as:

$$(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \quad (3.1)$$

Here:

- *x* represents the value of the random variable,
- *n* the total number of observed data points,
- *h* the bandwidth,
- *K(u)* the kernel function,
- *(x - x_i) / h* represents the distance between the point *(x)* and each observed data point *(x_i)*, normalized by the bandwidth (h),

- $\sum_{(i=1)}^n$ represents the summation over all data points (i) in the sample,
- $1/nh$ normalizes the estimate.

Buffering

In GIS, buffer analysis involves creating a region surrounding a geographic feature that is made up of places that are situated a certain distance from the feature. This zone is known as the buffer zone or the buffer. The buffer is measured in units of distance (e.g., feet, meters, or kilometres) and represents a specific radius or width around the feature. Buffers help answer questions related to spatial relationships within a certain distance from a given point or feature. This method can enable planners to locate and map out the locations of educational facilities and see if they fall within the required school distance as set out by the educational authorities (Al-Enazi, Mesbah, & Anwar, 2016). In this study, multiple buffers was performed to analyse the spatial distribution of features using the Multiple Ring Buffer extension in ArcGIS Pro. The ranges of buffer zones used were 0-5000 meters, 5000-10000 meters, 10000-15000 meters, 15000-20000 meters. 20000-25000 meters and 25000-30000 meters. This technique was used in this study to evaluate if the schools in the BPDM fall within the 5km school distance that the South African government assert that every school should be located within at a minimum (DBE, 2012).

Directional Distribution

The directional distribution, also known as the standard deviational ellipse (SDE) technique, generates ellipses to characterize the spatial properties of geographic features. In this study, the tool was employed to summarize the spatial arrangement of schools. It helped provide insights into how schools are distributed across the geographic area (Newman & Kim, 2017). To conduct this analysis, the SDE tool in ArcGIS Pro was used. The SDE tool was applied to the school location data to generate an ellipse that represent the spatial distribution of schools.

The SDE is as follows:

$$C = \begin{pmatrix} \text{var}\,(x) & \text{cov}\,(x,y) \\ \text{cov}\,(y,x) & \text{var}\,(y) \end{pmatrix} = \frac{1}{n}\begin{pmatrix} \sum_{i=1}^{n} \tilde{x}_i^2 & \sum_{i=1}^{n} \tilde{x}_i\tilde{y}_i \\ \sum_{i=1}^{n} \tilde{x}_i\tilde{y}_i & \sum_{i=1}^{n} \tilde{y}_i^2 \end{pmatrix} \text{ where} \quad (3.2)$$

$$\text{var}\,(x) = \frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})^2 = \frac{1}{n}\sum_{i=1}^{n} \tilde{x}_i^2 \quad (3.3)$$

$$\text{cov}\,(x,y) = \frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) = \frac{1}{n}\sum_{i=1}^{n} \tilde{x}_i\tilde{y}_i \quad (3.4)$$

$$\text{var}\,(y) = \frac{1}{n}\sum_{i=1}^{n} (y_i - \bar{y})^2 = \frac{1}{n}\sum_{i=1}^{n} \tilde{y}_i^2 \quad (3.5)$$

Here:

- The coordinates of feature *i* are *x* and *y*,
- $\{\bar{x}, \bar{y}\}$ symbolize the features' Mean Centre.
- The total number of features is represented by *n*.

Standard Distance

The standard distance technique evaluates how compact a distribution. In this study, this tool assessed whether residents could travel the minimal distance mandated by the government to get to the schools of 5 kilometres' (Al-Sabbagh, 2022). The standard distance was calculated using ArcGIS Pro to determine the average distance needed to travel to reach the nearest school. This involved computing the Euclidean distance between each resident's home and the closest school.

The Standard Distance is given by the following equation:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n} + \frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n} + \frac{\sum_{i=1}^{n}(z_i - \bar{Z})^2}{n}} \quad (3.6)$$

Here:

- The coordinates for feature *i* are *xi*, *yi* and *zi*,
- $\{\bar{x}, \bar{y}, \bar{z}\}$ symbolize the features' Mean Centre,
- The total number of features is represented by *n*.

Thiessen Polygon

A Thiessen polygon (see Figure 4) is a 2-dimensional shape whose borders include all the space that is nearer to a certain point inside the area than it is to any other point outside it. Thiessen polygons help analyse the spatial distribution of points by defining areas of influence around each point. According to research, Thiessen polygons are used for city planning, emergency response, and resource allocation and they have been regarded as a powerful tool for understanding spatial relationships and optimizing resource allocation in the GIS environment (Hussein & Mohameed, 2020). In this study, Thiessen polygons were used to determine whether schools are clustered or dispersed polygons and to assess spatial equity in educational access (Wu, Zheng, Sheng, & You, 2020).

The Thiessen polygons are constructed as follows (ESRI, N.Da):

- Left-to-right and to-bottom scans are performed on the input locations. Relative to previously scanned points, points that are closer than the selected proximal tolerance are ignored.
- Triangulating each point results in a triangulated irregular network (TIN) that meets the Delaunay criterion.

- Each triangle edge's perpendicular bisector forms one of the Thiessen polygons' edges. The intersections of the bisectors represent the locations of the vertices of the Thiessen polygon.
- The purpose of the Thiessen polygons is to produce polygon topology. The Thiessen polygons' label points are determined by the point positions.

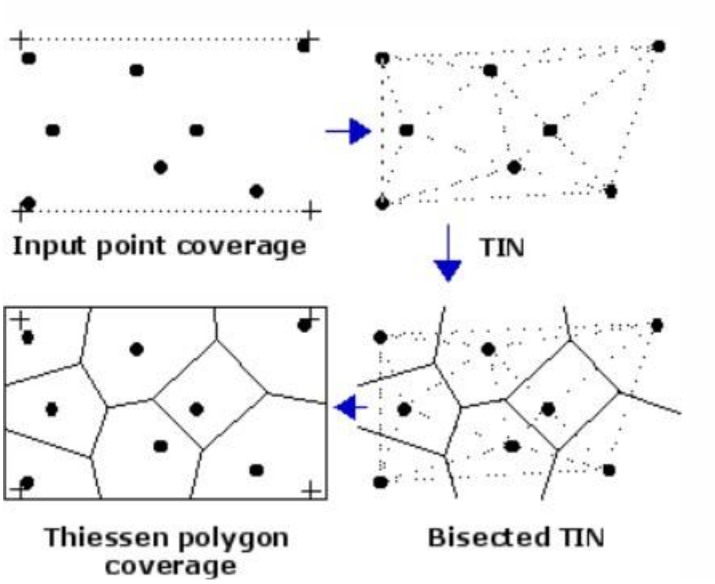

Figure 4: Thiessen Polygons made from points (ESRI, N.Da).

Average Nearest Neighbour

The average nearest neighbour (ANN) technique is a spatial statistic used to assess the clustering or dispersion of features within a dataset. The ANN ratio compares the observed average distance between feature centroids to the expected average distance based on a hypothetical random distribution. The features typically cluster if the observed average distance is less than the expected average distance. If the observed average distance is greater, the features are dispersed. The expected average distance is determined by comparing a random distribution with the same number of features covering an equivalent total area. When the ANN ratio is less than 1, the pattern indicates clustering. Conversely, if the ratio exceeds 1, the trend leans toward dispersion (ESRI, N.Db). The ANN returns several values which include (ESRI, N.Db):

- Observed Mean Distance: The actual average distance between feature centroids.

$$\overline{D}_O = \frac{\sum_{i=1}^{n} d_i}{n} \quad (3.7)$$

- Expected Mean Distance: The average distance expected under a random distribution.

$$\overline{D}_E = \frac{0.5}{\sqrt{n/A}} \quad (3.8)$$

- Nearest Neighbour Index: The ANN ratio.

- z-score: A statistical measure indicating how far the observed value deviates from the expected value. The ANN z-score for the statistic is calculated as:

$$z = \frac{\bar{D}_O - \bar{D}_E}{SE} \quad (3.9)$$

Where:

$$SE = \frac{0.26136}{\sqrt{n^2/A}} \quad (3.10)$$

- p-value: A significance level for the test. The ANN ratio is given as follows:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E} \quad (3.11)$$

Mean Centre

The mean centre represents the average location of a set of features within a study area. It is helpful for comparing the distributions of various feature and for tracking changes in the geographic distribution of characteristics over time. It identifies the central point for allocating resources and ensures equitable distribution based on proximity to the mean centre (Hussein & Mohameed, 2020). The mean centre was calculated in ArcGIS Pro by averaging the coordinates of all the schools. This provided a central point that represented the average location of the schools within the study area.

The mean centre is given as:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}, \bar{Y} = \frac{\sum_{i=1}^{n} y_i}{n} \quad (3.12)$$

Where:

- The coordinates for feature *i* are *xi* and *yi*,
- The total number of features is represented by *n*.

Central Feature

The central feature refers to the most centrally located feature within a dataset of points, lines, or polygons. The central feature identifies the optimal point for allocating resources and helps determine where to place new facilities (Hussein & Mohameed, 2020). The Central Feature tool in ArcGIS Pro was used to calculate the central feature. This involved calculating distances from each school to every other school and summing them up.

Median Centre

The median centre measures central tendency and identifies the location that minimizes travel distance to all other features in a dataset. Unlike the mean centre, which is influenced by extreme values, the median centre is less affected by outliers and provides a more balanced representation of the overall distribution. The median centre contributes to informed decision- making and equitable resource distribution (Hussein & Mohameed, 2020). The median centre was calculated in ArcGIS Pro using the median centre tool which calculates the median x and y coordinates that minimize the total travel distance to all other schools.

3.5.2. Assessing School Accessibility

According to literature, assessing school accessibility ensures that schools are accessible to all students and promotes equity in education (Mindahun & Asefa, 2019). GIS school mapping addresses obstacles that affects students, making essential for community development and education planning. Therefore, it can be understood that GIS school mapping advances community well-being, equitable education, and effective use of resources (Meena, Tripathi, & Agrawal, 2022). The datasets that were used to assess school accessibility are defined and the processes that were taken to prepare them are explained below.

3.5.2.1. Data Definition and Preparation

Defining and preparing data are crucial steps in any data analysis or modelling process as it lays down the foundation for robust analyses, accurate models, and informed decision-making.

Schools

Schools' data plays a crucial role in GIS modelling, especially when planning and managing educational infrastructure (Mindahun & Asefa, 2019). The data that was used in this project is briefly explained above in section 3.5.1.

Population

According to research, sustainable planning requires accurate population statistics. Every country needs to be conscious of the number and composition of its people as it helps in allocating the proper amount of funding and resources to various infrastructure and social programs. Additionally, it helps measure and monitor the socio-economic, political, and cultural progress of a country (De Wet- Billings, 2019). Figure 5 below presents the BPDM population distribution.

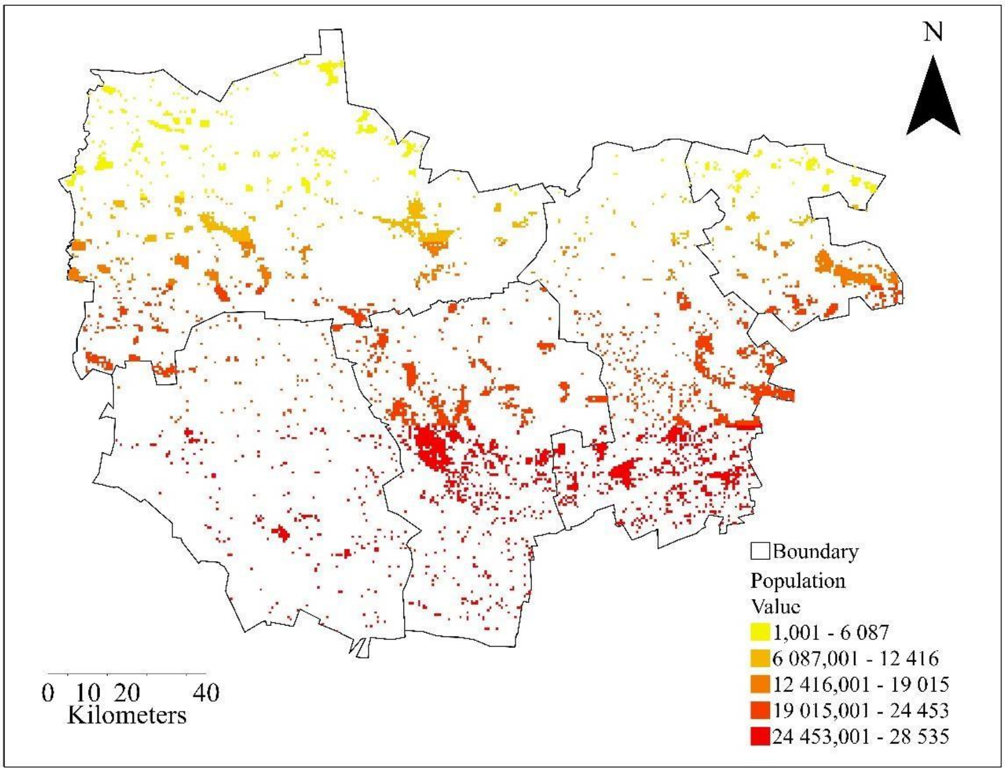

Figure 5: The population distribution within the study area.

Road Network

A road is a route on land that allows the movement of traffic, including vehicles and pedestrians (Emakoji & Otah, 2018). It is important to know the road network within the study area because it affects the mobility, accessibility, development, and disaster prevention of the area (Włodarczyk & Szajowski, 2022). The BPDM road network is presented in Figure 6 below.

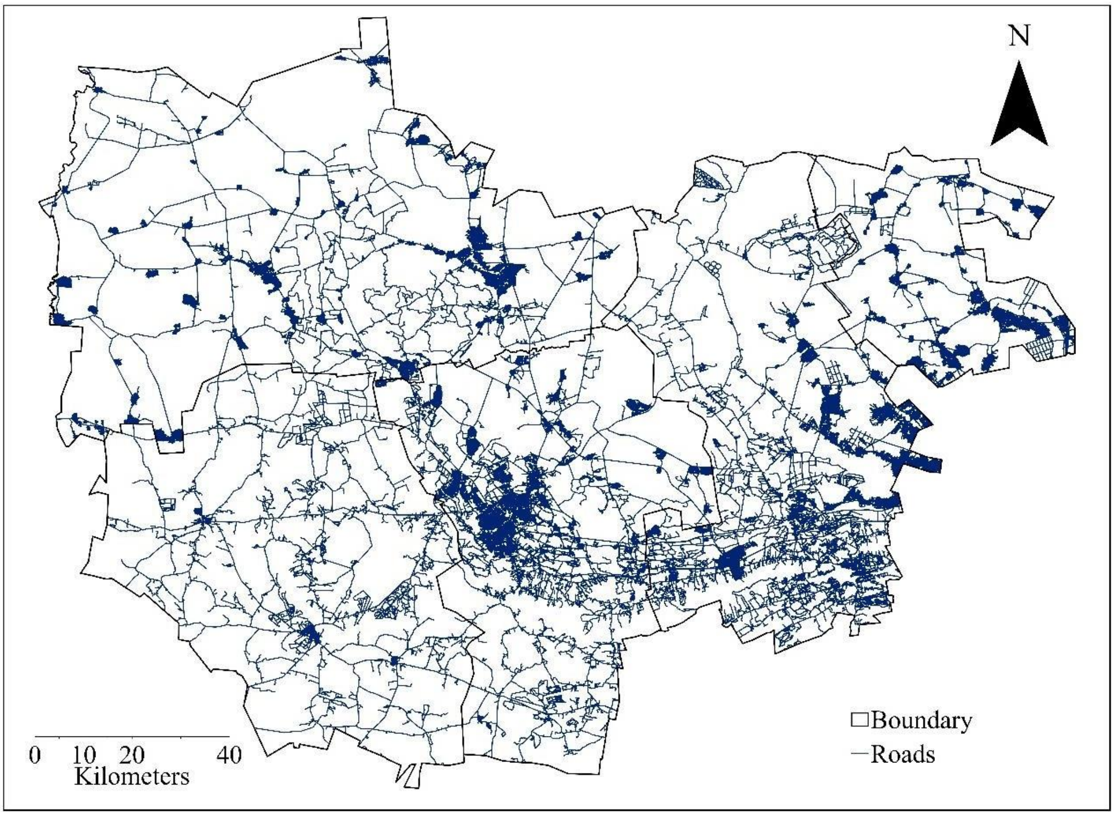

Figure 6: The road network of the study area.

Network Dataset

A network dataset in GIS is a customized dataset used to model transit networks. A network dataset represents a street network with features like roads, turns, and connectivity. It includes information on one-way streets, turn restrictions, and overpasses/tunnels. Network datasets are essential for performing analyses like routing, service area, and location-allocation modelling. In location allocation modelling it is used to determine ideal locations for new facilities and determine how services or products provided by these facilities are allocated to demand locations (Al-Sabbagh, 2022). Network datasets help calculate travel distances, service coverage, and optimal facility placement (Mindahun & Asefa, 2019). The Create Network Dataset tool in ArcGIS Pro was used to create the network dataset for the BPDM. The road network (see Figure 6) of the BPDM was used to create the network dataset that was used.

3.5.2.2. Model Selection

Selecting an appropriate model for school accessibility modelling is crucial. It determines how efficiently resources are allocated. Literature has significantly influenced the model used in this study, as many previous studies have produced satisfactory results after its application. Some of the studies which influenced the model selection include Tomintz, Clarke, & Alfadhli, (2015), Mindahun & Asefa (2019), Al-Sabbagh (2022) and Murad, Faruque, Naji, & Tiwari (2021).

Location-Allocation Model

The location-allocation model is a technique that is used to identify optimal service sites based on specific criteria. It helps understand the relationship between access and facility location across different contexts and time frames. By analysing current service patterns and potential future trends, this approach informs decision-making. Location-allocation models are often used in conjunction with GIS such as ArcGIS. The extension for network analysts in ArcGIS facilitates location-based allocation modelling, addressing various concerns. These include minimizing impedance, maximizing coverage, and optimizing attendance. Public amenities such as hospitals, libraries, and schools' benefit from this approach (Tomintz, Clarke, & Alfadhli, 2015).

Model Assumptions

In this study, several assumptions were considered when modelling school accessibility using the location-allocation model, and they are outlined below:

- ✓ Spatial Distribution of Schools

The model assumed that schools are distributed across the study area, and their locations are known. The model only considered existing schools.

- ✓ Facilities

The existing schools were considered as facilities.

- ✓ Demand Points

The local population (students, parents, or residents) was considered as demand points seeking access to schools.

- ✓ Travel Impedance

The model assumed that travel impedance (distance) can be estimated based on the transportation network (roads).

- ✓ Objective Function

The model aimed to optimize and minimize travel distance.

- ✓ Uniform Service Quality

The model assumed that all schools provide similar educational quality, but differences in school performance were not explicitly considered.

P-Median

In this study, minimize impedance (p-median problem) was used to examine if the schools located in the BPDM are within acceptable distances from the local population. Figure 7 below shows that the distance between all demand locations serves as the model's focal point (Murad, Faruque, Naji, & Tiwari, 2021). Before computation the population data which was in csv format was imported into ArcGIS Pro and was converted to a vector format (points) so that it can be used in location-allocation modelling. Thereafter, it was converted to raster format as can be seen in Figure 5 above to examine areas with high and low population density. To compute the p-median problem, the facilities and demand points were imported into the location-allocation layer. Thereafter various distance scenarios were drawn using previous works done by Mindahun & Asefa (2019), Murad, Faruque, Naji, & Tiwari (2021) and Al- Sabbagh (2022) as a guide.

Additionally, the DBE (2012) states that every school should have a feeder zone with a maximum radius of 5 kilometres and the total walking distance to and from school must not exceed 10 km. Therefore, the distances were set to 500m, 1500m, 2500m, 3500m, 4500m and 5000m. The facilities were left constant at 527 and the demand points were 28535. The search tolerance for the facilities was left at 5000m and the search tolerance for the demand points was increased to 10000m. A larger search tolerance allowed the model to consider a broader area around each demand point. During the visualization of the results, the output produced cluttered visualizations which were difficult to interpret. Hence, to circumvent this challenge only 50 schools were visualized to display the results, this was done to effectively demonstrate how the model operates. The figure pertaining to this is presented in Chapter 4. A similar challenge was noted by Torrent-Fontbona, Muñoz Solà, & López Ibáñez (2013). To address this problem, clustering techniques and simulated annealing was applied which helped to convert the initial large location-allocation problem into several simpler ones (Torrent- Fontbona, Muñoz Solà, & López Ibáñez, 2013). Future school accessibility studies in the BPDM or any other region can use the same or similar approach if they encounter the same challenges.

According to Murad, Faruque, Naji, & Tiwari (2021), the p-median method can be understood in five steps as follows:

- The goal is to minimize Z as much as possible:

$Z = \sum i \in I \sum j \in J \; ai \; dijxij$ …………………………………………………………….. (3.13)

- Each facility will be designated a unique demand site, subject to any limits described as:

$\sum j \in$ J xij = 1 for all i ……………………………………………………………… (3.14)

- For an open facility, the following demand must be assigned:

$xij \leq \sum xij$ for all (i, j) …………………………………………………………… (3.15)

- The number of communities assigned to each facility (p) must match the number of facilities that need to be located:

$\sum j \in J\ xij = p$……………………………………………………………………….. (3.16)

- One facility receives the entirety of the demand from each demand site:

$Xij = (0,1)$ for all (i, j) …………………………………………………………… (3.17)

Where:

- Z is the primary objective,
- I is the collection of demand sites,
- the subscript i is an index indicating a particular demand region,
- J is the list of possible locations for the facility,
- the subscript j is an index indicating the location of a particular facility,
- ai is the number of users using the demand site at i.
- dij is the time or distance between the location i from the potential facility location j,
- $dij = 1$ if demand at a place i is assigned to a facility opened at site j or $= 0$ if demand at a place i is not assigned to that site and p is the number of facilities to be located.

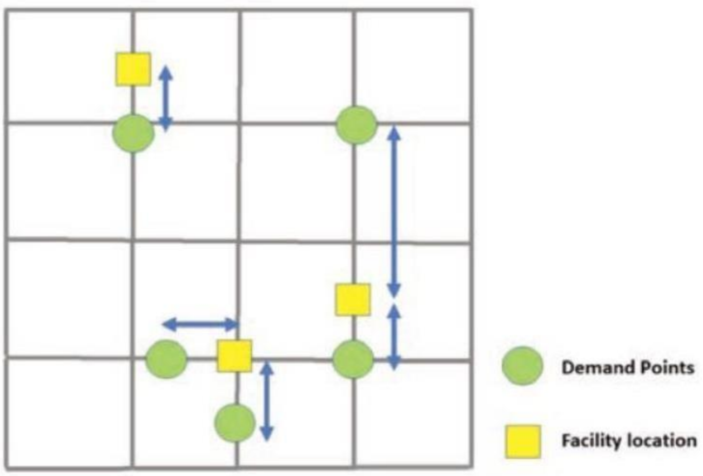

Figure 7: The P-Median Model process (Murad, Faruque, Naji, & Tiwari, 2021).

3.5.3. Mapping Optimal Sites for New Schools

According to Yazdani, Zarate, Zavadskas, & Turskis (2019), Multi-Criteria Decision Analysis (MCDA) is a valuable tool for handling complex challenges. It aids decision-making in intricate spatial contexts with an appropriate level of accuracy. When faced with multiple criteria simultaneously, MCDAhelps rank or select among various options. One specific spatial MCDA approach used for overlay analysis is the weighted overlay, also known as the crisp method. In this method, prerequisite factors are combined based on a common measurement weight and scale, and each layer is then weighted according to its significance (Papadopoulou & Hatzichristos, 2019).

The weighted overlay was used to identify suitable areas where potential schools could be placed. Schools, road network, Digital Elevation Model (DEM) and land use and land cover (LULC) were used as inputs to develop the suitability map. This is attributed to the various factors that these criteria encapsulate. For instance, schools play a critical role in the community, affecting accessibility, education quality, and social well-being (Du Plessis & Mestry, 2019). Therefore, including them in the analysis was crucial. By incorporating school data informed models that benefit communities and enhance educational infrastructure can be created. Roads play a significant role in determining how accessible a location is (Emakoji & Otah, 2018). Schools need to be easily reachable by students, teachers, and parents. Proximity to roads affects travel time, transportation costs, and overall convenience. Schools located near well-connected roads are more desirable (Mindahun & Asefa, 2019). Therefore, including the road network (see section 3.5.2) in weighted overlay analysis ensured that school suitability model account for accessibility, cost-effectiveness, safety, and community integration.

A digital elevation model (DEM) is a depiction of Earth's topography that can be used for several tasks, such as terrain study, land use planning, and hydrological modelling. The DEM provides information about the elevation and terrain of an area. The slope, which is derived from the DEM, affects the suitability of a location for schools. Flat areas are generally more favourable for construction and accessibility than steep areas. The inclusion of this criteria enabled the identification of areas with suitable slopes that will not pose challenges for building infrastructure, playgrounds and accessing roads (Tulu, 2005). The Shuttle Radar Topography Mission (SRTM) DEM that was used in this study is presented in Figure 8 below and is observed in meters. The SRTM DEM was chosen for this study because it is open-source and freely accessible. In addition, it exhibits high vertical accuracy, provides global coverage with consistent data quality, and offers a 30-meter spatial resolution (1 arc-second), which is suitable for regional and local- scale analyses (Ganie, et al., 2023). Therefore, educational planners, and policymakers can use it without cost barriers.

The Land Use and Land Cover (LULC) map plays a pivotal role in identifying suitable locations for new schools. By analysing LULC patterns, insights are gained into how different areas are utilized whether for residential, commercial, agricultural, or natural purposes (Mengistu & Salami, 2007). For school site selection, factors such as proximity to existing educational facilities, accessibility, safety, and land availability are always considered. LULC maps provide a foundation for assessing spatial relationships, allowing users to make informed decisions about where to establish schools (Mandal & Mondal, 2019). For instance, areas with low residential density and ample green spaces may be ideal for school construction, promoting efficient land use and enhancing educational access.

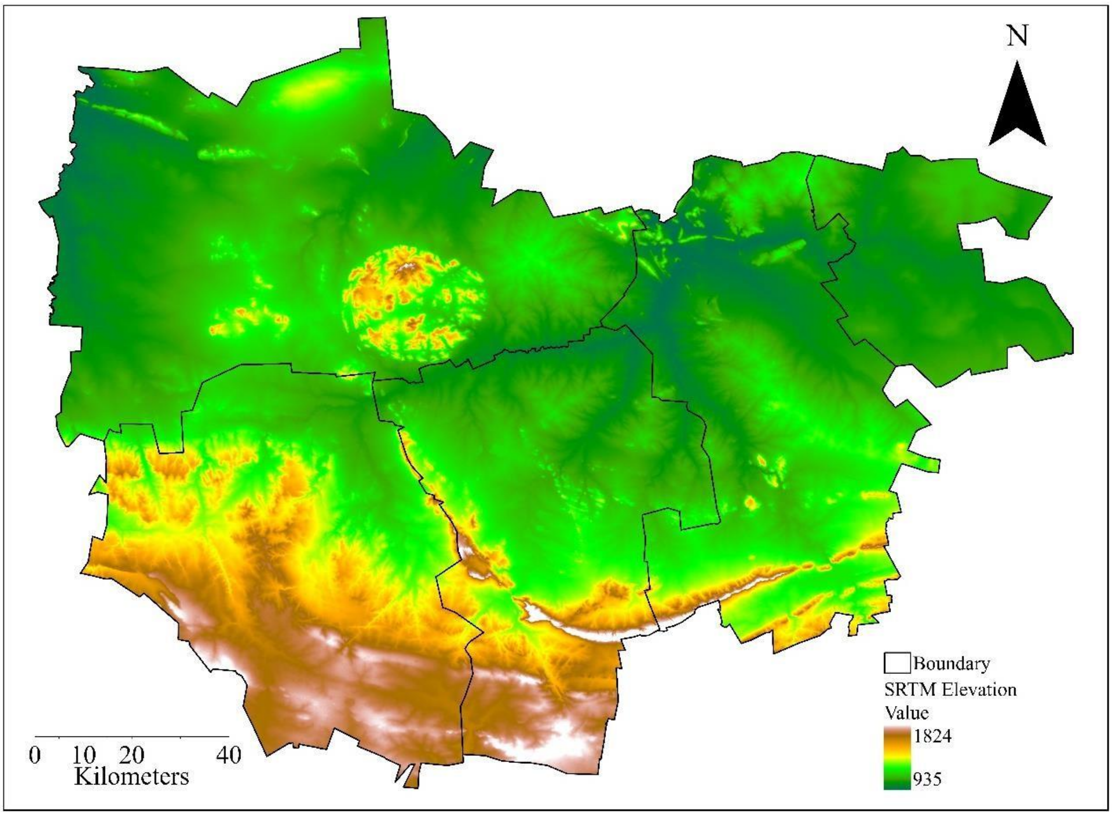

Figure 8: The SRTM DEM of the study area.

3.5.3.1. Google Earth Engine for Environmental Monitoring

Google Earth Engine (GEE) is a powerful cloud-based platform that has revolutionized geospatial data analysis. GEE hosts an extensive repository of remotely sensed data, spanning decades and encompassing sources like Landsat, MODIS, and Sentinel satellites. Additionally, GEE provides readyto-use products such as the Enhanced Vegetation Index (EVI) and the Normalized Difference Vegetation Index (NDVI). Its scalability and parallel processing capabilities allow researchers and developers to efficiently analyse vast datasets. With APIs (Application Programming Interface) for JavaScript and Python, GEE fosters collaboration and script versioning. Therefore, it can be said that GEE empowers users to explore, classify, and monitor LULC globally, making it an indispensable tool for environmental research and decision-making (Tamiminia, et al., 2020).

Image Acquisition for Land Use and Land Cover Mapping

In this study, multispectral imagery captured by the Sentinel-2 satellite sensor was utilized. The imagery used was acquired in 2020. The Sentinel-2 sensor consists of two identical satellites, and this are Sentinel-2A and Sentinel-2B. Together, they provide a combined constellation revisit every 5 days. The Sentinel-2 satellite is equipped with an optical payload that includes sensors for visible, near-infrared, and shortwave infrared regions. It features a total of 13 spectral bands. Four bands provide imagery at a 10-meter spatial resolution. Six bands offer imagery at a 20-meter spatial resolution. Additionally, there are three bands dedicated to 60- meter spatial resolution for tasks such as atmospheric corrections and cloud screening. The satellite's swath width covers 290 kilometres (ESA, N.D.). Table 2 below shows the characteristics of the bands used in this study.

Table 2: Features of Sentinel-2 Multispectral Instrument (MSI) data.

Band Name	**Wavelength (nm)**	**Description**	**Spatial Resolution (m)**
B2	490	Blue	10
B3	560	Green	10
B4	665	Red	10
B5	705	VNIR*	20
B6	740	VNIR*	20
B7	783	VNIR*	20

*VNIR- Visible and near Infrared

Image Preprocessing

The Sentinel data that was used in this study was already atmospherically corrected (Tamiminia, et al., 2020). The atmospheric correction includes the correction of surface reflectance, making the data suitable for vegetation analysis and land cover classification (Sentinel Online, N.D.). In addition to this, when the Sentinel data was selected for analysis, the cloud cover was set to 1%. This meant that in the Sentinel 2 data repository, only imagery with less than 1% of cloud cover would be selected. Clouds can cause shadows on the Earth's surface which can make it difficult to interpret images. Therefore, a low cloud cover was a prerequisite in this aspect.

Random Forest

The Random Forest (RF) machine learning (ML) algorithm was used to classify Sentinel-2 imagery into six distinct land cover classes. These classes were bare, settlement, vegetation, water, open mining area, and forest. The RF model, an ensemble technique, combines multiple decision trees (DTs) to create a robust and accurate classification model. RF builds an ensemble of DTs, each trained on a bootstrapped sample of the data. By aggregating predictions from individual trees, it achieves better accuracy than any single DT. At each split during tree construction, only a random subset of features was considered. This randomness reduces overfitting and enhances generalization. The final prediction for a pixel or region is determined by majority voting across all individual trees. This robust approach minimizes the impact of noisy data. RF is particularly effective for analysing multispectral satellite imagery, such as Sentinel-2 data. RF provides insights into important features driving land cover patterns (Srivastava, Bharadwaj, Dubey, Sharma, & Biswas, 2022). Additionally, a total of 322 labelled points were collected for training and validation. These points were obtained through GEE, which facilitated efficient data processing and feature extraction (Tamiminia, et al., 2020). 70% of the data was set for training the RF model and 30% for validation. This split ensured model performance assessment while avoiding overfitting (Vrigazova, 2021).

Accuracy Assessment

The accuracy assessment was done on the Sentinel-2 imagery to evaluate the ability of the sensor to discriminate the selected LULC classes. The confusion matrices were construed for the imagery to determine the overall (OA), producer's (PA) and consumer's accuracies (CA). These accuracy measures shed light on how accurate and dependable land cover classifications are (Stehman, 1997). Furthermore, the Kappa coefficient was also calculated, which provided insight into the difference between the actual agreement observed in the collected data and the algorithm's classification, compared to the probability of agreement by chance (Sim & Wright, 2005). According to Cohen (1960), as cited by McHugh (2012), the Kappa coefficient can range from -1 to +1. Values less than or equal to 0 indicate no agreement, while values between 0.01 and 0.20 represent slight agreement, 0.21 to 0.40 as fair, 0.41 to 0.60 as moderate, 0.61 to 0.80 as substantial, and 0.81 to 1.00 as almost perfect agreement (McHugh, 2012).

Table 3 displays the class names and the corresponding number of collected points for each class. Table 4 shows the confusion matrix results, and Table 5 shows the OA, Kappa, PA, and CA results. The resultant LULC map is presented in Figure 9 below.

Table 3: Classification data that was used for training and validation.

LULC Class Name	GEE Feature Collection ID	Total Points	Validation (30%)	Training (70%)
Bare	0	143	42.9	100.1
Settlement	1	210	63	147
Vegetation	2	173	51.9	121.1
Water	3	212	63.6	148.4
Open Mining Area	4	149	44.7	104.3
Forest	5	101	30.3	70.7

Table 4: Confusion Matrix

LULC Class Name	Bare	Settlement	Vegetation	Water	Open Mining Area	Forest	Total
Bare	29	2	1	0	0	1	33
Settlement	7	64	1	0	3	0	75
Vegetation	0	8	55	0	0	0	63
Water	1	0	0	60	0	4	65
Open Mining Area	0	2	0	0	45	0	47
Forest	0	0	4	4	0	31	39
Total	37	76	61	64	48	36	322

Table 5: OA, Kappa, PA, and CA

Class	PA (%)	CA (%)
Bare	87.9	78.4
Settlement	85.3	84.2
Vegetation	87.3	90.2
Water	92.3	93.8
Open Mining Area	95.7	93.8
Forest	79.5	86.1
OA (%)	88.2	
Kappa	0.856	

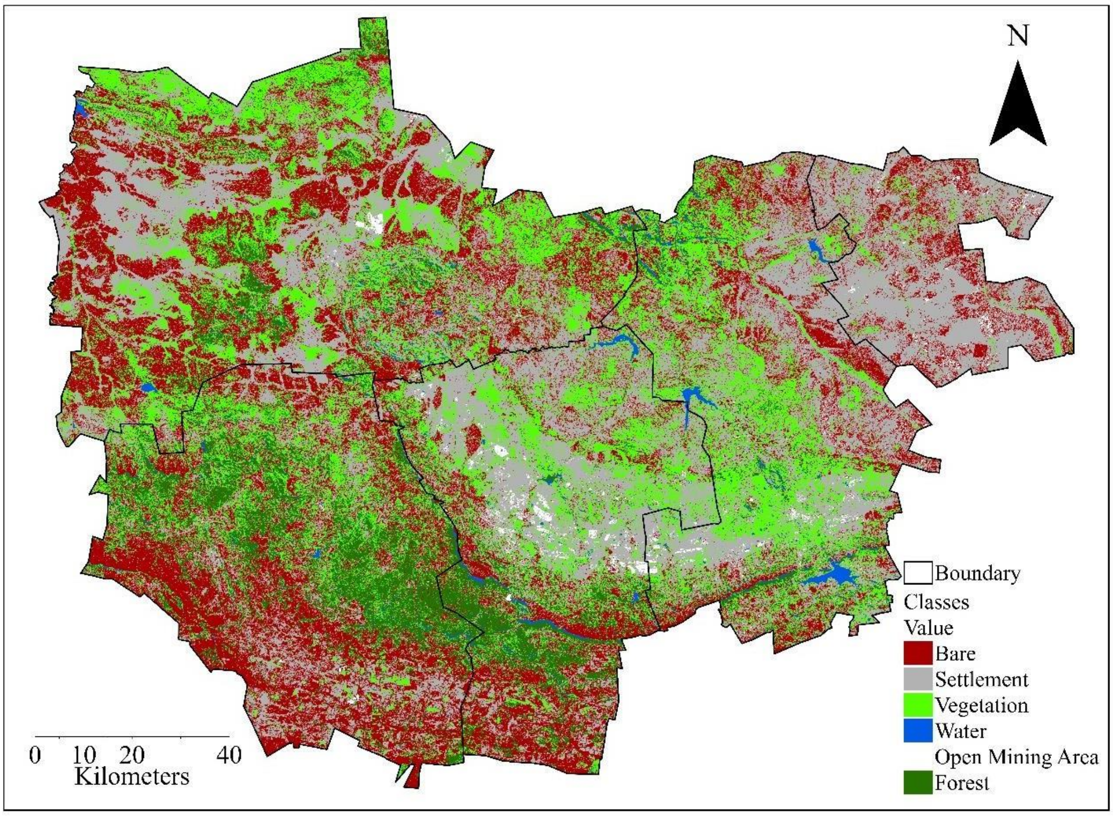

Figure 9: The study area's LULC map.

3.5.3.2. Weighted Overlay Analysis

To assess potential locations for future schools using a weighted overlay approach, a systematic process was followed. This included deriving, reclassifying, weighting and combining of criteria and selecting optimal areas.

Deriving Criteria

Deriving criteria is important for creating suitability maps as it involves preparing and organizing important information. By deriving the criteria, one ensures that the input information aligns with the parameters necessary for the suitability map which will lead to accurate and meaningful results (Kuru & Terzi, 2018). In this project, the derived criteria was based on three factors which are the slope from the elevation dataset using the slope tool, distance from roads using the road network, and distance from existing schools using the school dataset. The distances from roads and existing schools were determined using the Euclidean distance tool.

Reclassifying Criteria

To create a suitability map, the derived criteria needed to be reclassified since it is not possible to combine them in the form that they were in. Reclassification in this context involved assigning new values to existing data. This ensured that the is consistency in the information used for suitability analysis and emphasizes the elements that are most relevant to the suitability. This simplification aided in reducing the complexity of the analysis while retaining the essential information needed for suitability mapping. In this project, enhancing data interpretability was crucial for meaningful context (City University of New York, N.D.). To achieve this, criteria was standardized using a common measurement scale of 1 to 10. This scale determined the suitability of specific locations for new school construction. Higher values indicated more favourable sites, while lower values represented less suitable areas (Kaliraj et al., 2015). During the reclassification of slope output, a value of 10 was assigned to areas with gentle slopes and a value of 1 to the steepest slopes. By reversing these values, gentle slopes were prioritized, ensuring that higher values correspond to more favourable terrain.

According to the literature, a school should be close to roads to ensure ease of access to the facility (Meena et al., 2022). During the reclassification of the distance from road output, areas closest to roads were assigned a value of 10 and the value 1 was assigned to areas far from roads. Similarly, to the slope output, the obtained new values were reversed. Reversing values ensured that distances close to roads receive higher suitability scores. When reclassifying the distance from schools' output, locations farthest from existing schools were assigned a value of 10. These areas represent the most suitable locations due to their distance from schools. Locations near existing schools received a value of 1. These areas were less preferable for new school placement. Unlike the previous outputs, the obtained new values were not reversed. This approach helped identify areas near and far from existing schools.

Weighting and Combining of Criteria

The best sites were then determined by combining the reclassification criteria with the LULC information. As part of the weighted overlay procedure, To make the LULC dataset's cell values like other inputs, they were weighted. When setting the weighted overlay operation, the evaluation scale was set to a scale of 1 to 10. For the reclassified slope, high slope values (scale values of 1, 2 and 3) were set to restricted as it was not ideal to build a school in a high-lying area. The other reclassified criteria were left as they were during computation. Table 6 shows the scale values for the LULC classes. Each raster was assigned a percentage reflecting its relative importance, which influenced the selection of criteria used in the study (Morales & de Vries, 2021). This method allowed for the criteria to be replicated, enhanced, or adjusted according to specific contextual objectives as asserted by Morales & de Vries (2021). The weights of the selected criteria as influenced by literature are presented in Table 7

Table 6: Scale values for the LULC classes.

Code	LULC Name	Value
0	Bare	8
1	Settlement	10
2	Vegetation	6
3	Water	Restricted
4	Open Mining Area	Restricted
5	Forest	4

Table 7: Weights assigned to the raster layers.

Layer	% Influence
Reclassified Slope	15
Reclassified Distance from Roads	40
Reclassified Distance from Schools	25
LULC	20

Selection of Optimal Areas

Every pixel on the final suitability map has a value that represents how appropriate the area is for a new school. The weighted overlay analysis returned a suitability map with 5 values indicating the levels of suitability; this is shown in Table 8 and how they were interpreted. The suitability map showed that pixels with a value of 9 were the most suitable while pixels with a value of 0 were not. As a result, the project's ideal location for a new school earned a rating of 9. Additionally, the chosen location is characterized by the size of that area which was 5 hectares (50000 square meters). This value was derived using the information presented in the report titled "Guidelines Relating to Planning For Public School Infrastructure". In that report, it is stated that 2.8 hectares is the total minimum size for a primary school and 4.8 hectares is the total minimum for a secondary school (DBE, 2012). Therefore, the selection of 5 hectares in this project was primarily based on this notion.

Table 8: Levels of Suitability

Value	**Suitability Level**
0	Not Suitable
6	Least Suitable
7	Moderately Suitable
8	Highly Suitable
9	Optimally Suitable

3.6. Summary of the Chapter

This chapter explored the methodological foundations of the study, aiming to provide a comprehensive understanding of the research process. This approach was chosen for its systematic and thorough nature, ensuring that each aspect of the research is meticulously planned and executed. By clearly defining the study area, employing robust data collection and processing methods, and utilizing advanced geospatial techniques, this methodology enhances the reliability and validity of the findings, ultimately contributing to more informed decision-making and effective solutions.

CHAPTER 4

Results

4.1. Introduction

The purpose of this chapter is to present the obtained findings. The study's findings are categorised into themes using the research objectives as a guide. 4.2 Presents the spatial analysis of the schools within the BPDM. 4.3 Presents the location-allocation model analysis of the schools within the district. 4.4. Presents the final suitability map for where future schools can be placed. A summary of the chapter is provided in 4.5.

4.2. Spatial Distribution Analysis of Schools

This section aims to provide the results of the schools' geographical arrangement. It looks at the main trends and patterns in the locations of the schools. 4.2.1 Presents the KDE results, 4.2.2 presents the buffering results, 4.2.3 presents the Thiessen polygon results, and 4.2.4 presents the distance metrics results which includes the standard distance, SDE, mean centre, central feature, and median centre. Lastly, 4.2.5 presents the results of the ANN.

4.2.1. Kernel Density Estimation

The KDE analysis provides insights into the spatial arrangement of schools within the BPDM. The KDE reveals a minimum kernel density of 0, indicating areas with no schools or very sparse distribution. Conversely, a maximum kernel density of 2832.5 signifies dense clusters of schools in specific regions. Hotspot schools are primarily centralized in the Rustenburg local municipality, followed by the local municipality of Madibeng. These concentrations can be attributed to historical land use, including mining, township development, and transportation infrastructure. The KDE map shows that school densities are generally higher from the centre towards the eastern and southeastern sides of the study area. Conversely, areas with the lowest school density are scattered around the periphery of the hotspots.

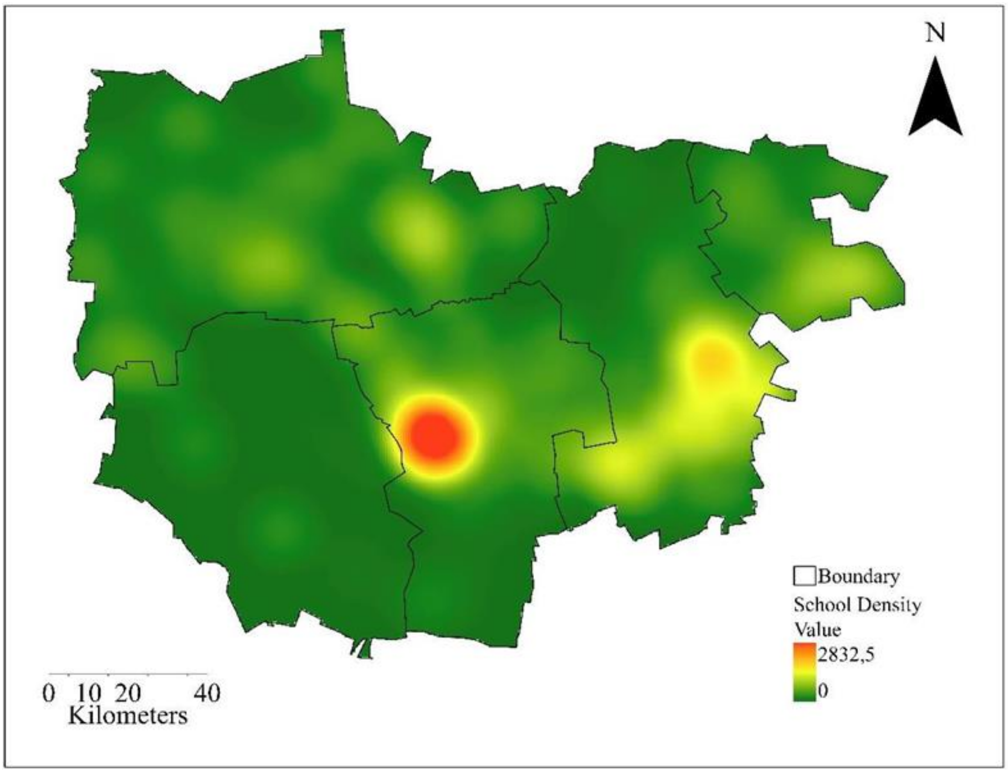

Figure 10: School density map of the schools located within the study area.

4.2.2. Buffering

Figure 11 displays the buffering analysis results. The schools are concentrated within the 0-5 km buffer zone. This distribution benefits residents living within this buffer. This implies that residents within the 0-5 km buffer have high accessibility to schools. This is advantageous as short travel distances enhance convenience and reduce transportation costs. Residents above the 0-5 km buffer have low accessibility to schools which results in longer travel time to school.

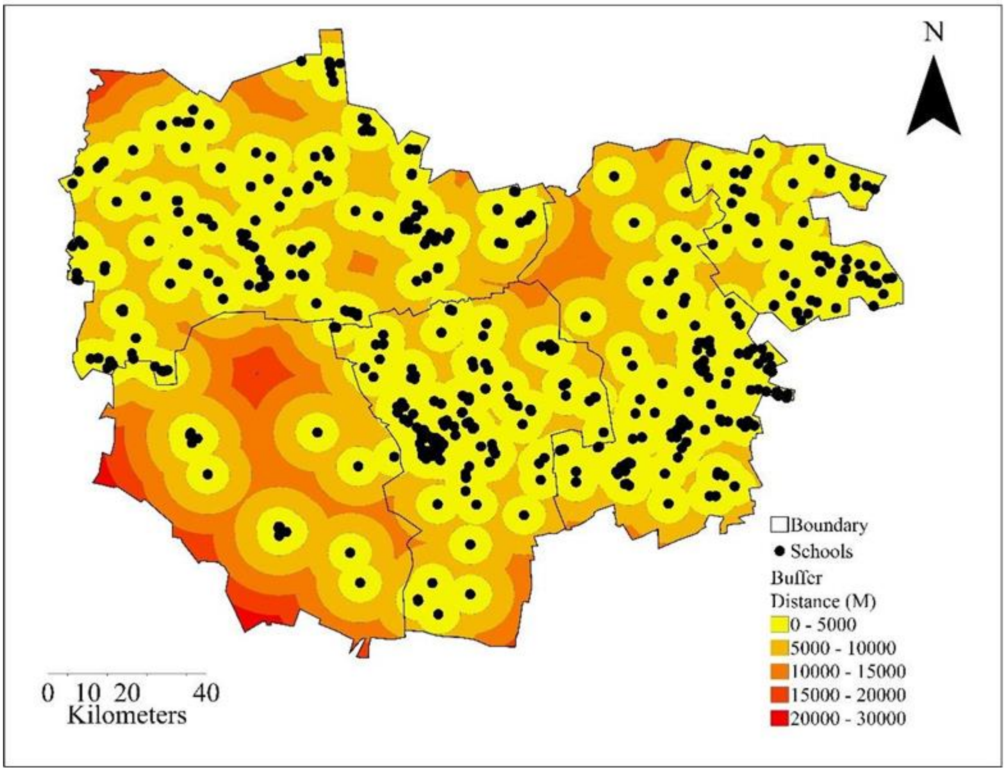

Figure 11: Multiple-ring buffer zones of the schools located within the study area.

4.2.3. Thiessen Polygons

Thiessen polygons results are displayed in Figure 12. The figure indicates that the study region's schools in the north, northwest, centre, southeast, and east serve a relatively small area. These schools likely cater to localized neighbourhoods within their proximity. Schools in the southwest, northeast, and some patches in the northwest serve a very large area including more distant areas. Therefore, these schools play a big role in providing educational access to a wider population.

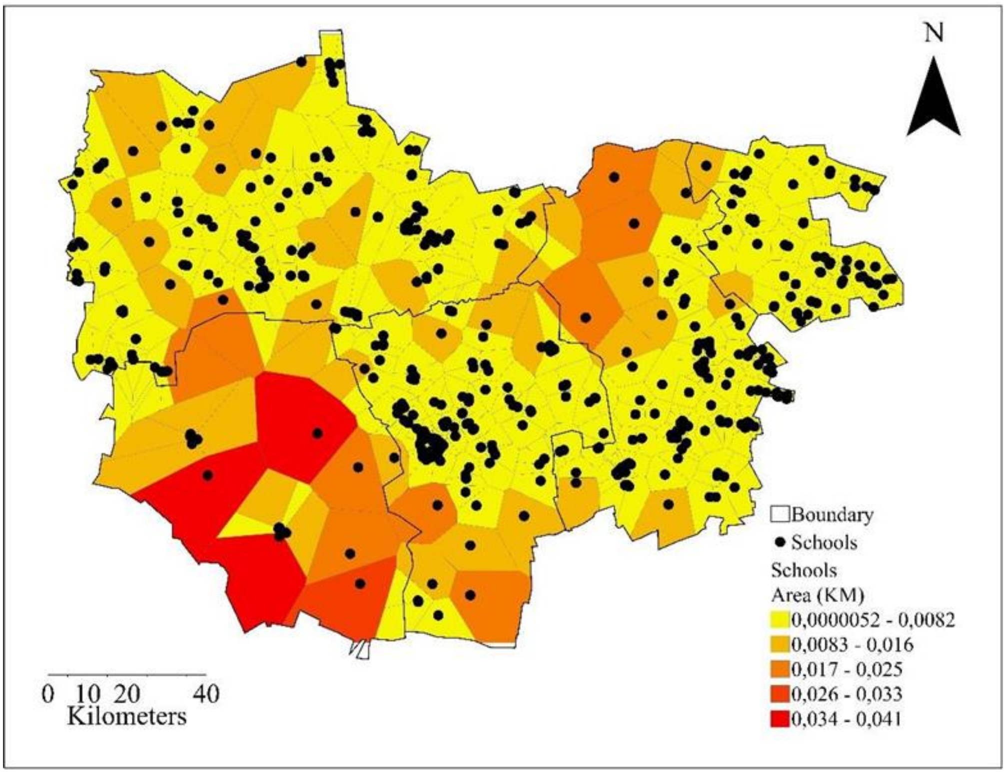

Figure 12: Thiessen Polygons of the schools in the study area.

4.2.4. Distance Metrics

Figure 13 shows the results of the mean centre, median centre, central feature, standard distance, and the SDE. These results indicate that most of the schools are located within the centre of the district. The standard distance had a value of 0.54. A smaller standard distance indicates that schools tend to cluster closely around the mean centre. In this case, the standard distance suggests the schools are relatively close to the mean centre in the BPDM. This implies that schools within this radius are likely to serve the same catchment area and efficient resource allocation can be targeted within this compact zone. Additionally, this further implies that students within this range have relatively equal access to schools.

The shape area of the directional distribution had a value of 0.73. A value close to 1 indicates a relatively compact distribution. In this case, the value of 0.73 suggests moderate elongation. This may imply that students face extended travel distances which affects accessibility. The directional distribution had a rotation angle of 96.63°. The rotation angle indicates the orientation of the ellipsoid. This implies that the ellipse is tilted counterclockwise by approximately 96.63° from the x-axis. This means the schools are oriented in this direction. Hussein & Mohameed, (2020) argues that, when the mean centre, median centre and central feature align these indicate that schools are clustered tightly around that specific location. This also implies that there is a high population density around that location. Accordingly, the shared location of these centres corresponds with a central hub within the study area. According to Hussein & Mohameed (2020), schools often gravitate toward such central areas due to accessibility, convenience, and community services.

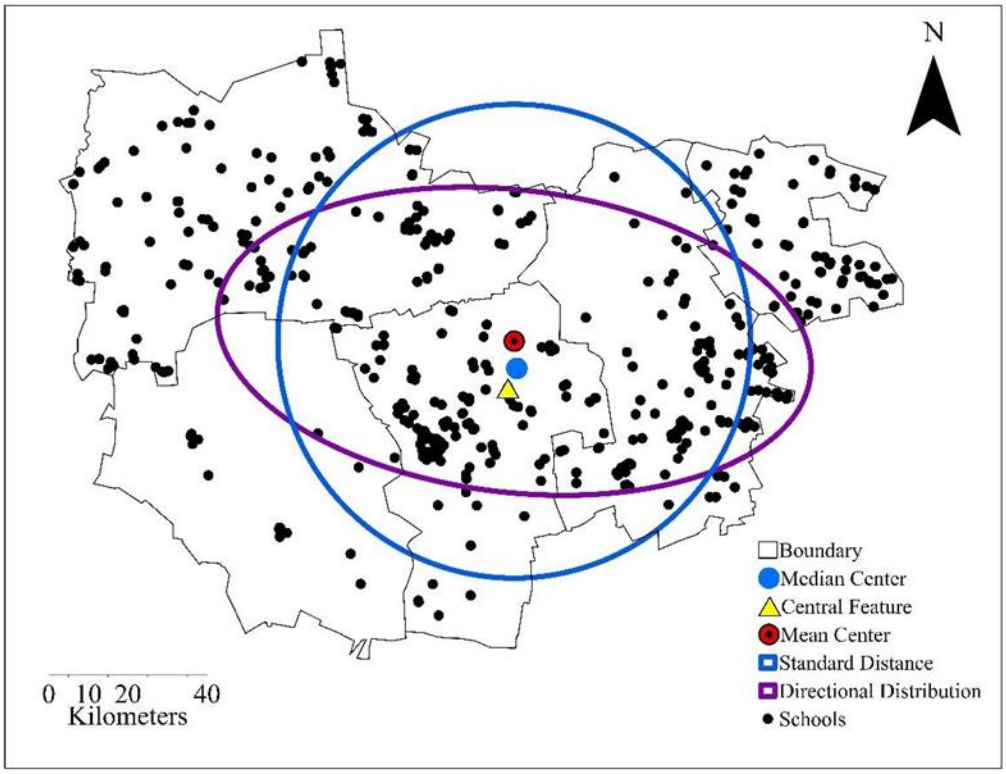

Figure 13: The Standard Distance and Directional Distribution of the schools in the study area.

4.2.5. Average Nearest Neighbour

Figure 14 and Table 9 show that the spatial organization of schools in the BPDM follows a clustered pattern. The nearest neighbour ratio (NNR) is 0.426 and if the NNR is less than 1 it exhibits clustering. The p-value is 0.000000 and it suggests strong evidence against the null hypothesis (random distribution). The z-score is -25,187963, a large negative z-score indicates significant clustering (Reshadat, Zangeneh, Saeidi, Teimouri, & Yigitcanlar, 2019). These results provide strong evidence for observed clustering. Therefore, it can be deduced that the schools in the BPDM follow a clustered pattern.

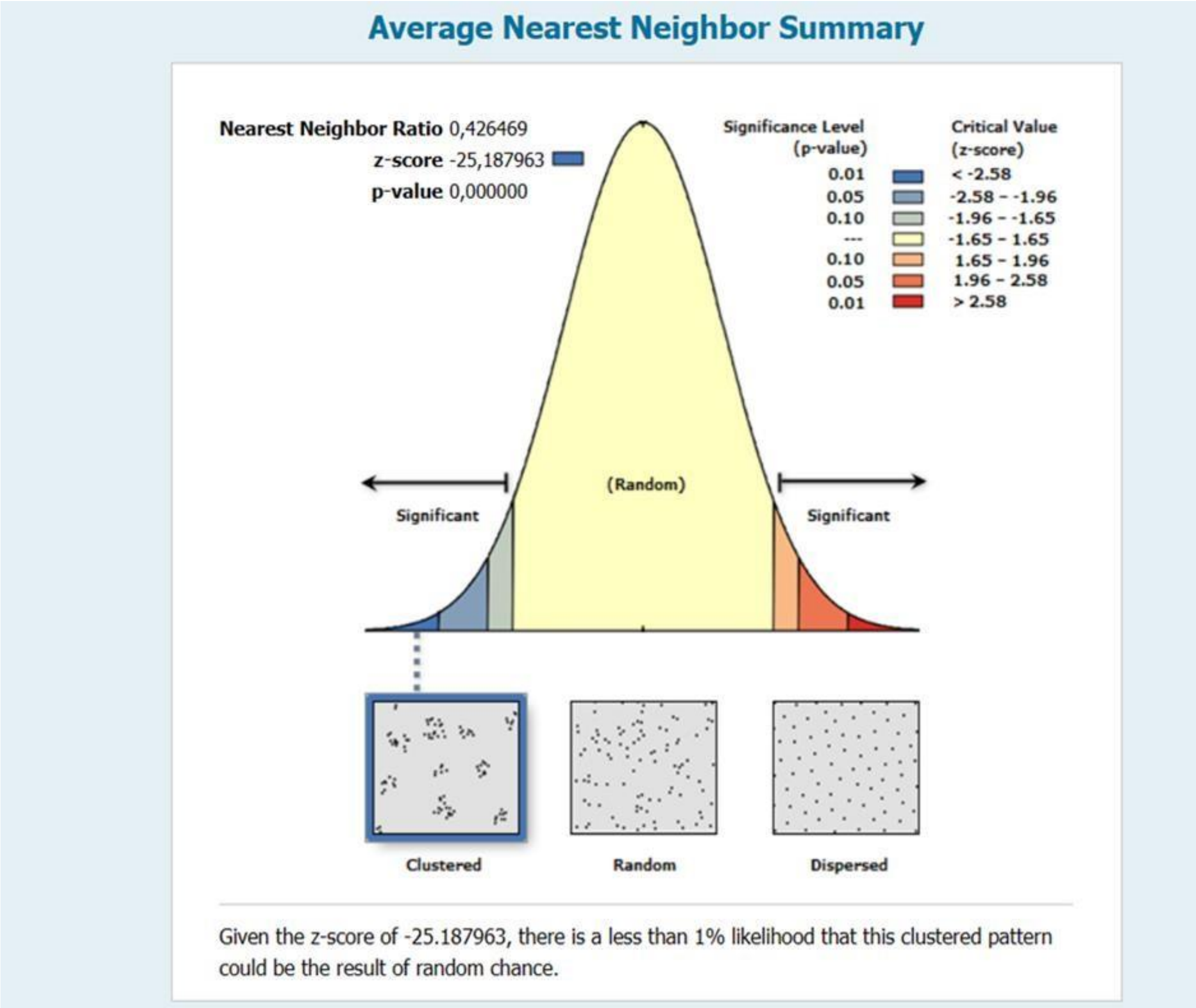

Figure 14: ANN of the schools in the study area.

Table 9: ANN Summary

Observed Mean Distance (M)	Expected Mean Distance (M)	NNR	Z-Score	P-Value
1452.2181	3405.2134	0.426469	-25.187963	0.000000

4.3. Location-Allocation School Accessibility Assessment

The purpose of this section is to present the findings from the location-allocation model that evaluated the schools' accessibility within the BPDM. 4.3.1 presents the distance-based location-allocation results and 4.3.2 presents the results which assess the level of school proximity within the district.

4.3.1. Distance-Based Location-Allocation Modelling

In the network analysis settings, distance is a significant factor that acts as an impedance (Al- Sabbagh, 2022). This research examined the relationship between the local population and the schools within the study area. This research made use of six distance scenarios to examine this relationship. The distances used are 500m, 1500m, 2500m, 3500m, 4500m and 5000m. These distances were chosen based on previous studies that have been done such as Mindahun & Asefa (2019). Additionally, the DBE (2012) states that every school should have a catchment area with a radius of up to 5 kilometres and the total walking distance to and from school may not exceed 10 km. Moreso, the observed results observed in Figure 11 above supported these choices, under the assumption that if the schools are within a 5km buffer zone they are accessible to the local populations that reside within the BPDM.

To better understand school accessibility within the district, the assessment was done at the local municipal level. The local municipal level allowed for a more thorough and nuanced awareness of the local context; this can aid in identifying the unique demands and difficulties faced by the various communities. This can also lead to the formation of effective policies and interventions that are tailored to the local context (LaGarry, 2019). Additionally, this can help to build stronger relationships between schools and the community, which can lead to greater engagement and support for education. The number of schools within each local municipality is presented in Table 10.

Table 10: Numbers of schools located within each local municipality.

Name of Local Municipality	Value
Madibeng	159
Kgetleng	15
Moses Kotane	149
Moretele	63
Rustenburg	141
Total	527

Figure 15 shows the summary of the distance-based location allocation results for the schools located within the local municipalities in the BPDM. Table 11 expands on Figure 15 and puts forth the values associated with school accessibility across the five local municipalities. According to the results presented in Figure 15 and Table 11, the Moses Kotane local municipality has the most accessible schools while the Kgetleng local Municipality has the least accessible schools within the district.

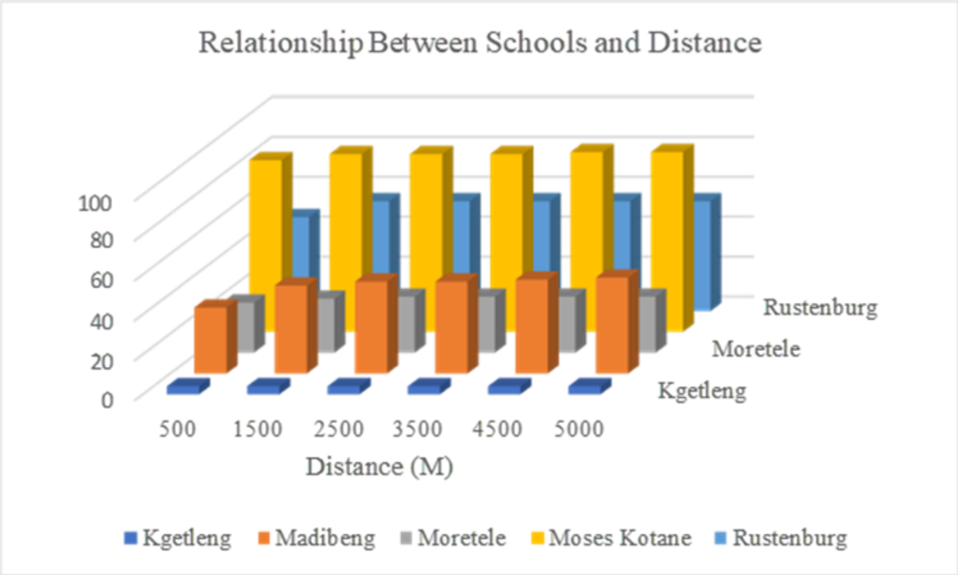

Figure 15: The summary of the location-allocation results for the schools located within the local municipalities in terms of the 6 distance scenarios.

Table 11: Number of accessible schools within each local municipality based on distance.

Distance (M)	Kgetleng	Madibeng	Moretele	Moses Kotane	Rustenburg	BPDM Total	BPDM Total %
500	4	33	25	86	47	195	37
1500	4	44	27	89	55	219	41.56
2500	4	46	28	89	55	222	42.13
3500	4	46	28	89	55	222	42.13
4500	4	47	28	90	55	224	42.5
5000	4	48	28	90	55	225	42.69

In Figure 16, each red line connects a demand node (located) to a school node (chosen). These lines represent the distance between schools and the students attending them. Short lines indicate that students are close to their schools, while longer lines signify greater distance from educational services (Mindahun & Asefa, 2019). Nodes with long lines are concentrated in the central, eastern, and western parts of the BPDM. Nodes with short lines are prevalent in the northwestern areas. Longer lines represent lengthier student commutes along roads to schools within the 5km limit. Students beyond this limit remain unallocated. Shorter lines indicate closer proximity, ensuring students within this range are allocated schools. This analysis highlights disparities in school accessibility, emphasizing the need for equitable allocation and improved educational opportunities for all students.

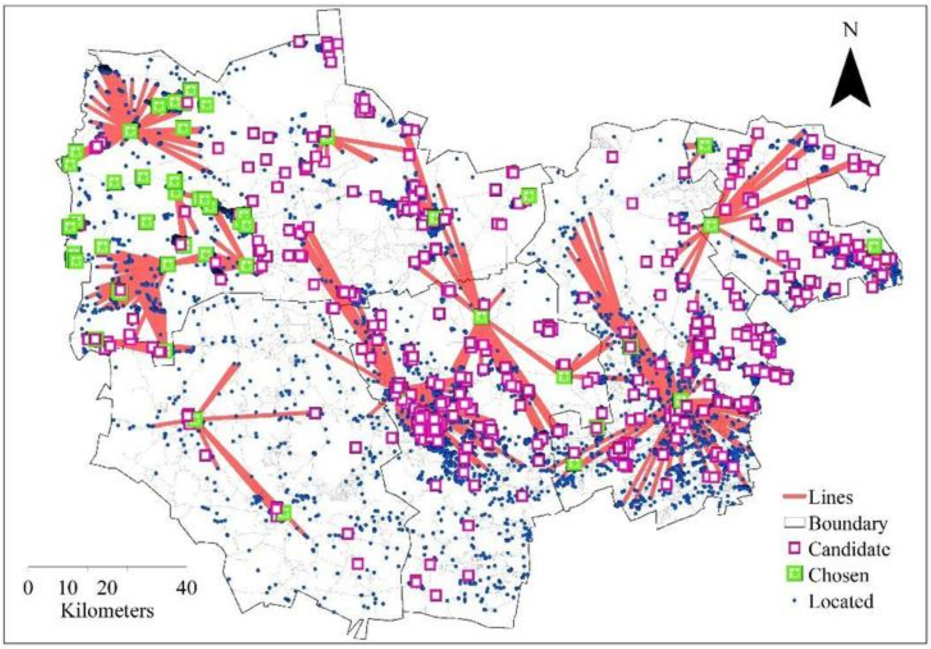

Figure 16: Location-allocation analysis of the chosen 50 schools in the BPDM at 5km impedance cut-off.

4.3.2. Spatial Assessment of School Proximity

The spatial assessment of school proximity is important for ensuring that educational opportunities are accessible to all citizens. Spatial assessment ensures that educational facilities are distributed fairly across neighbourhoods, regardless of socioeconomic factors (Mindahun & Asefa, 2019). The names of the schools that were chosen to be accessible in 4.3.1 within the set distances are presented in Tables 12, 13, 14, 15, and 16 in the Appendix section of this study. These were done to observe which school types (i.e., primary, secondary, private, and intermediate) were the most accessible. This is significant because it can assist administrators and policymakers in making well-informed choices on the distribution of resources and the creation of policies that are suited to the unique requirements of various communities. By identifying which school types are most accessible, policymakers can also prioritize funding and support for those schools, which can help to improve educational outcomes and reduce disparities (LaGarry, 2019). Furthermore, they can work on improving accessibility to unselected schools.

Additionally, parents of school-going children can use these results as a guide when selecting the most appropriate school for their children based on distance.

The observed results show that primary schools are the most accessible across the BPDM (see Tables 12, 13, 14, 15 and 16 in the Appendix). In the Kgetleng local municipality, only one primary school was noted to be accessible within the specified distances. In the Madibeng local municipality, within the distance range of 500m, 23 primary schools were recorded to be accessible; within the distance range of 1500m, 32 primary schools were recorded to be accessible; within the distance ranges of 2500m, 3500m, 4500m and 5000m, 34 primary schools were recorded to be accessible within those distance ranges. In the Moretele local municipality, within the distance range of 500m, 13 primary schools were recorded to be accessible; within the distance ranges of 1500m, 2500m, 3500m, 4500m and 5000m, 16 primary schools were recorded to be accessible at each distance range.

In the local municipality of Moses Kotane, in the distance range of 500m, 58 primary schools were accessible; within the distance range ranges of 1500m, 2500m, 3500m, 4500m and 5000m 61 primary schools were recorded to be accessible at each distance range. In the Rustenburg local municipality, within the distance range of 500m, 29 primary schools were accessible; within the distance ranges of 1500m, 2500m, 3500m, 4500m and 5000m 32 primary schools were recorded to be accessible at each distance range. The accessibility of primary schools in this study suggests that primary school children have better opportunities to access education, and policymakers should also focus on improving access to other school types.

4.4. Optimal Site Selection

The goal was to strategically distribute schools across the study area and create a network of well-placed schools which prioritizes accessibility, suitability, and equity. In Figure 17, the suitable sites symbolized by the green colour represent optimal suitability. These are areas where schools can be built and will provide services to the local population that is not able to access the existing schools. These are the prime candidates for new school sites. The sites that were not suitable were symbolized by a red colour. These are inappropriate locations that could endanger the safety of the staffs and students. For example, they may be near water bodies or steep slopes.

The analysis reveals that the majority of optimal sites are concentrated in the Kgetleng local municipality, aligning with the location-allocation results. Specifically, there are 32 identified sites, highlighting a significant need for new schools within this municipality. However, these findings do not fully address the educational needs in other municipalities. To bridge this gap, the model identified 509 highly suitable sites across the broader study area. While these sites may not meet all the optimal criteria, they still offer favourable conditions for development. With appropriate improvements and modifications, these highly suitable sites can be elevated to better meet the educational needs of the region. This approach ensures a more comprehensive and equitable distribution of educational resources across the entire study area.

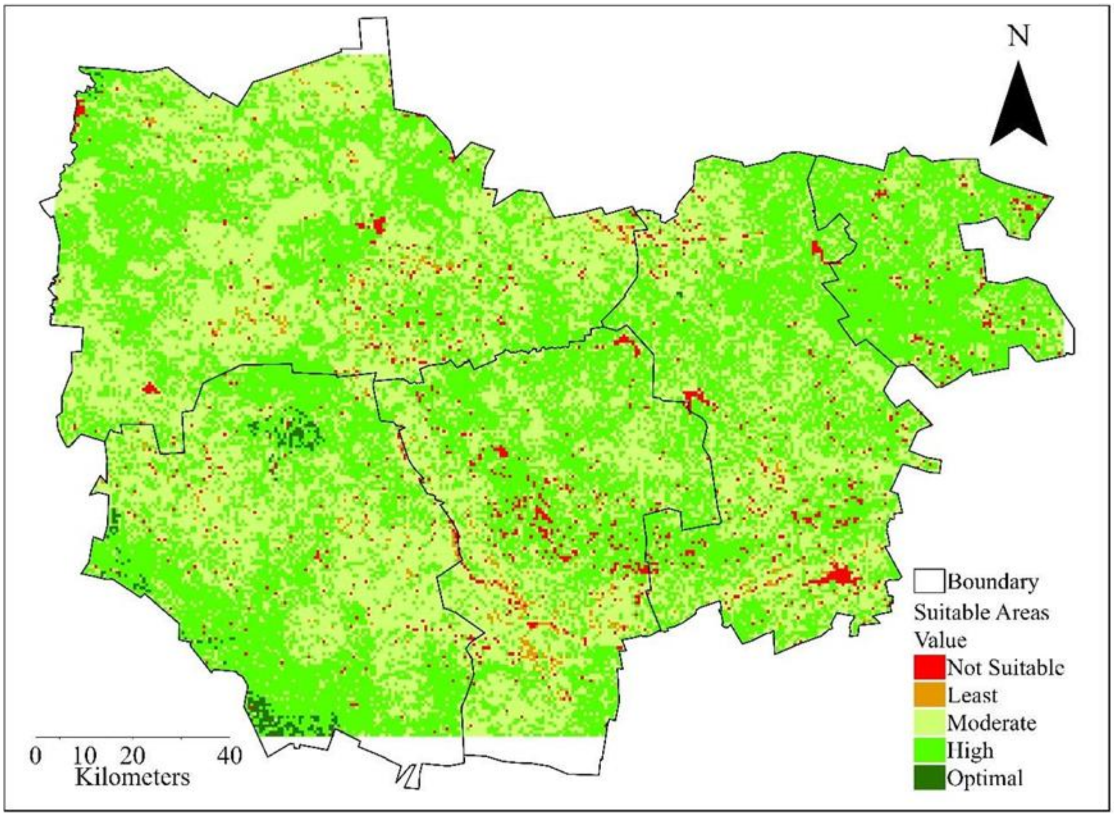

Figure 17: Suitability map for potential new schools.

4.5. Summary of the Chapter

This chapter presents key findings related to school distribution, accessibility and optimal site selection within the BPDM. Most schools within the study area are clustered. Schools in the Moses Kotane Local Municipality are generally more accessible, while those in the Kgetleng Local Municipality face accessibility challenges. The MCDA approach identified 32 optimal sites for potential new schools and all these sites were situated in the Kgetleng Local Municipality. Despite the concentration in Kgetleng, it's essential to consider highly suitable sites across the region. Expanding school coverage to other local municipalities ensures equitable access for all students.

CHAPTER 5

Discussion

5.1. Introduction

The purpose of this study is to use geographic methods to evaluate the school's location and accessibility inside the Bojanala Platinum District Municipality. The results are reviewed, discussed, and further supported by the literature in this chapter. As a result, the discussion begins with the findings regarding the geographical distribution of schools within the district municipality (5.2). Using a GIS-based location-allocation approach, it also highlights school accessibility (5.3) before highlighting the best locations for prospective new schools (5.4). A summary of the chapter is provided in 5.5

5.2. Spatial distribution of schools

The evaluation of school accessibility within communities provides essential insights for educational policymakers and administrators (Al-Sabbagh, 2022). By understanding access patterns, efforts can be targeted toward addressing educational inequalities (Al-Sabbagh, 2022). However, in the BPDM, the issue of school inaccessibility remains unresolved (Bojanala Platinum District Municipality, N.D.). This study aimed to assess school distribution and accessibility in the BPDM using geospatial techniques.

The formation and construction of schools in the BPDM exhibit a clustering pattern. This trend indicates shortcomings in the policies and managerial framework pertaining to the building of schools (Tanveer, Balz, Sumari, Shan, & Tanweer, 2020). Since 2018, a total of 13 new schools have been completed across the four municipal districts in the North West province. Specifically, six schools in the BPDM, four schools in the Ngaka Modiri Molema District, two schools in the Dr Kenneth Kaunda District and one in the Dr Ruth Segomotsi Mompati District (Khechane, 2022). Despite recent construction, the overall distribution of existing schools still reflects historical patterns (South African History Online, N.D.). Addressing this slow progress is crucial for ensuring equitable access to education. The findings of this study, which reveal a clustered pattern in school distribution, align with research conducted in Pakistan by Tanveer, Balz, Sumari, Shan, & Tanweer (2020). In both cases, organic growth and inadequate planning contribute to this clustering phenomenon (Tanveer, Balz, Sumari, Shan, & Tanweer, 2020). These patterns underscore the existence of educational inequalities within the BPDM, emphasizing the need for a policy shift towards more uniform development. Furthermore, This study highlights the concentration of schools in the Rustenburg local municipality compared to other areas within the BPDM. Similar clustering trends have been observed in certain urban areas of the Gauteng province (Makhoali, 2023). These patterns may stem from a lack of policies addressing educational disparities in South Africa's system. To address these challenges, educational policymakers must design and implement effective interventions. Continuous evaluation is essential to achieve the goal of providing equitable and improved educational access for all individuals, regardless of their backgrounds (Du Plessis & Mestry, 2019).

5.3. Accessibility to schools

This study revealed an unexpected finding, accessibility to schools in rural areas surpasses that in urban areas. This contrasts with the results of other studies, including one conducted by Mindahun & Asefa (2019). This means that in certain rural areas, schools are strategically located closer to residential communities. Students in these areas benefit from shorter travel distances, facilitating school attendance. In contrary urban schools are often spread out across larger cities, resulting in longer commutes for some students. Heavy traffic congestion during peak hours can cause delays for urban students using public transportation. Rural settings generally experience less traffic congestion, allowing for smoother travel while urban areas, in contrast, grapple with traffic bottlenecks that impact school accessibility. Research consistently shows that unequal access to education affects overall population prospects (Mindahun & Asefa, 2019). Equitable access is essential for individual and societal well-being (UNESCO, 2023). Education fosters cognitive development, emotional resilience, and adaptability. Without it, individuals miss out on personal growth and fulfilment (University of the People, N.D.).

Previous studies in the BPDM reveal a significant population migration towards Rustenburg. This trend may be attributed to disparities in school access between urban and rural areas, as well as the allure of economic opportunities, particularly in the mining sector. The availability of economic opportunities, especially in mining, attracts individuals seeking employment and improved livelihoods. Rustenburg, as a hub for such opportunities, becomes a magnet for migration (Bojanala Platinum District Municipality, N.D.). This study highlights inadequate access to schools for children attending secondary education. This finding aligns with research by Hall (2023), emphasizing the need for attention to this age group. Students traveling long distances to schools encounter several challenges such as fatigue from long commutes which affects learning during school hours. Busy roads pose risks of accidents, and students become targets for theft or violence. This age group plays a pivotal role in shaping the nation's future. Secondary schooling serves as a bridge to higher education, contributing to South Africa's progress and prosperity. In line with similar studies that addressed school inaccessibility, a viable solution would involve constructing new schools and strategically relocating existing ones (Mindahun & Asefa, 2019).

Educational policymakers in the BPDM and the North West province could adopt a similar approach to mitigate observed inequalities.

The South African government employs a multifaceted approach to ensure school accessibility for local communities. This strategy involves data analysis, community engagement, and targeted interventions. By collaborating with educational stakeholders, policymakers assess accessibility and address existing challenges using this approach (DBE, 2012). This study introduces network analysis, which is a novel approach within the BPDM. Unlike simple analyses, this method evaluates school access through real-world journeys, providing a more accurate representation (Reshadat, Zangeneh, Saeidi, Teimouri, & Yigitcanlar, 2019). Uniquely, this study assesses school access using distance within local municipalities. This incomparable scope and population focus make this approach valuable for other developing countries. The successful implementation of this approach serve as an efficient and appropriate model for similar studies worldwide. By prioritizing school accessibility, a contribution to a brighter educational future for all is made.

Numerous studies highlight the pivotal role of distance in ensuring equitable school access (Mindahun & Asefa, 2019). Proximity directly affects attendance, participation, and overall educational experiences for children. This impact is even more pronounced for younger students or those without reliable transportation. Proximity to school significantly influences attendance rates. When daily travel is feasible, students participate more consistently. Distance analysis helps identify potential barriers, informing strategies to enhance accessibility (Mindahun & Asefa, 2019). This study reveals that 57.31% of schools in the BPDM are beyond a 5 km distance from the local population. Notably, other research considers distances between 1.5 to 2.5 kilometres as a walkable range for various age groups (Van Dyck, De Bourdeaudhuij, Cardon, & Deforche, 2010; Nelson, Foley, O'Gorman, Moyna, & Woods, 2008). Overcoming these disparities is crucial. Sensitivity to this issue is essential for students of all ages.

5.4. Optimal sites for Potential New Schools

Optimal sites for potential new schools are considered better due to their alignment with specific criteria and objectives. Optimal sites meet predefined criteria related to accessibility, safety, proximity to residential areas, and transportation networks. These criteria ensure that schools are strategically located to serve the community effectively. In this study, the concentration of optimal school sites in the Kgetleng Local Municipality which aligned with the location-allocation results. By focusing on Kgetleng, educational planners can strategically address local demand and enhance educational access.

However, it's essential to recognize that other municipalities may not share the same level of need. The results highlight disparities in educational infrastructure requirements across the broader study area. While Kgetleng stands out, neighbouring municipalities may have different priorities. Hence this study further proposes the consideration of highly suitable sites as they span across the district.

The BPDM's strategic location on the platinum belt makes spatial planning critical. Suitability analysis informs decisions about where schools should be situated to support sustainable development. It considers factors such as land ownership, historical context, and demographic trends. Analysing population growth, age distribution, and other demographic factors helps predict future demand for educational facilities. Suitability assessments guide the expansion or relocation of schools based on changing population dynamics. On the other hand, the highly suitable sites and the areas with existing populations have a favourable impact on the search for appropriate places to build schools. A similar result was observed by (Mindahun & Asefa, 2019). This analysis ensures that schools are distributed fairly across the district as it helps identify underserved areas where educational facilities are lacking (Al-Sabbagh, 2022). By addressing these gaps, the BPDM can promote equal access to quality education for all residents.

5.5. Summary of the Chapter

Chapter Five reviewed the results obtained in this research alongside existing literature. It has been recognized that the existing school's distribution has not changed that much as it can be linked to planning that was used by the apartheid government. It has also revealed the inadequacy of the present government to restructure the areas where such planning was implemented.

CHAPTER 6

Conclusion

6.1. Introduction

The purpose of this chapter is to provide a summary of the study and evaluate the results of the set objectives. It contains the summary of the findings (6.2), the conclusion (6.3), and recommendations for future research (6.4).

6.2. Summary

This section summarises findings while reflecting on the goals, objectives, and the research methods used. The aim of this research was to assess the school's distribution and accessibility in the BPDM using geospatial techniques. Below are the research objectives and how they were addressed:

- ✓ To analyse the spatial distribution of schools within the Bojanala Platinum District Municipality.
  The objective of analysing the spatial distribution of schools within the BPDM was to determine how schools are distributed across the region and how accessible they are to the local population. This involved analysing data on the location of schools, and the distance between schools and the local population. The goal was to identify areas where schools are concentrated, dispersed, and randomly distributed. The study revealed that schools within the BPDM are clustered.
- ✓ To assess the school accessibility using a GIS-based location-allocation model.
  The objective of assessing school accessibility using a GIS-based location-allocation model was to determine how accessible schools are to the local population and to identify areas where schools are located far away from them. This involved analysing data on the location of schools and the local population. The goal was to develop strategies to improve the accessibility of schools to the local population. Results indicated that schools in the Moses Kotane Local Municipality exhibit higher accessibility compared to other municipalities.
- ✓ To map the optimal sites for potential new schools using GIS-based Multi-Criteria Decision Analysis (MCDA).
  The objective of mapping the optimal sites for potential new schools using GIS-based MCDA was to identify the most suitable locations for new schools based on a set of criteria. This involved analysing data on the location of existing schools, the LULC, the elevation and road network datasets. The goal was to identify suitable areas where new schools can be placed. The study identified the most optimal sites for potential new schools were concentrated within the Kgetleng Local Municipality.

6.3. Conclusion

GIS serve as a robust platform for municipal planning. In this study, various GIS techniques were employed to provide valuable insights for educational administrators and policymakers. By analysing school distribution patterns, informed decisions can be made regarding educational policies. The geostatistical techniques used in this study revealed that existing school distribution in the BPDM exhibits a clustered pattern. Schools are highly concentrated around a central town, while other areas have fewer schools. This uneven distribution leaves some parts of the population underserved, while others enjoy better access. The location- allocation model highlighted inadequate access to schools for the local population. This revealed a significant planning gap as some areas fall beyond the recommended distance from schools. Hence it is suggested that educational administrators take prompt action to address this issue. Solutions may include establishing new schools or relocating existing ones to ensure complete services and easy accessibility for all. This study has proven that spatial analysis techniques and location-allocation models are powerful tools for recognizing and resolving such disparities. Governments should consider studies like this during development planning to align progress with societal needs and environmental preservation. GIS-driven educational planning ensures equitable access to quality education, benefiting both current and future generations.

6.4. Recommendations

The role of school accessibility modelling is pivotal, but it should not stand alone. Future research can go beyond analysing school distribution and accessibility. This study recommends exploring additional factors influencing educational outcomes such as assessing the quality of education, teacher qualifications, and resource availability. To ensure meaningful impact, active engagement with community members throughout the research process is crucial. Researchers can achieve this by conducting surveys, organizing focus groups, and conducting interviews. By collecting valuable feedback and insights, they can tailor their work to the specific needs of the local population. To maximize research impact, future research can also consider engaging with government officials, educators, and community leaders within the BPDM. Collaboratively developing strategies and solutions will address local challenges effectively and promote sustainable development. Lastly, while this study relied solely on secondary datasets and spatial analysis techniques, this study strongly advises for the adoption of a mixed-methods approach. Given the multifaceted nature of educational research, combining qualitative and quantitative methods will yield richer insights and more robust outcomes.

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APPENDIX

Table 12: Schools that can be accessed by the Kgetleng Local Municipality population located within 500m, 1500m, 2500m, 3500m, 4500m and 5000m.

Distance (M)	Schools
500, 1500, 2500, 3500, 4500, 5000	1. Kgetleng Primary School 2. Koster Intermediate School 3. Koster Skool Gekombineerd 4. Moedwil Secondary School

Table 13: Schools that can be accessed by the Madibeng Local Municipality population located within 500m, 1500m, 2500m, 3500m, 4500m and 5000m.

500	1500	2500 and 3500	4500	5000
1. Academy for Christian Education 2. Bapo Primary School 3. Brits Primary School 4. Die Hoërskool Wagpos 5. EJM Mahlabe Primary School 6. Eletsa Secondary School 7. Ennis Thabong Primary School 8. Goakganya Primary School 9. Hoërskool Brits 10. Ikatisong Secondary School	1. Academy for Christian Education 2. Bapo Primary School 3. Brits Primary School 4. Die Hoërskool Wagpos 5. EJM Mahlabe Primary School 6. Eletsa Secondary School 7. Ennis Thabong Primary School 8. Goakganya Primary School 9. Hoërskool Brits 10. Ikatisong Secondary School	1. Academy for Christian Education 2. Bapo Primary School 3. Brits Primary School 4. Die Hoërskool Wagpos 5. EJM Mahlabe Primary School 6. Eletsa Secondary School 7. Ennis Thabong Primary School 8. Goakganya Primary School 9. Hoërskool Brits 10. Ikatisong Secondary School	1. Academy for Christian Education 2. Bapo Primary School 3. Brits Primary School 4. Die Hoërskool Wagpos 5. EJM Mahlabe Primary School 6. Eletsa Secondary School 7. Ennis Thabong Primary School 8. Goakganya Primary School 9. Hoërskool Brits 10. Ikatisong Secondary School	1. Academy for Christian Education 2. Bapo Primary School 3. Brits Primary School 4. Die Hoërskool Wagpos 5. EJM Mahlabe Primary School 6. Eletsa Secondary School 7. Ennis Thabong Primary School 8. Goakganya Primary School 9. Hoërskool Brits 10. Ikatisong Secondary School

11. Katakane Primary School 12. Kutlwano Primary School 13. Laerskool Elandskraal 14. Lethabong Primary School 15. Lorato Primary School 16. Madiba Utlwa Primary School 17. Malatse Motsepe High School 18. Maruatona Primary School 19. Meriting Primary School 20. Mmanotshe Moduane Secondary School 21. Osaletseng Primary School 22. Oukasi Primary School 23. Rakgatla Secondary School 24. Rekopantswe Secondary School 25. Sanddrift Primary School 26. Segwaelane Primary School 27. Skeerpoort Primary School 28. Tebogo Primary School 29. Tlapa La Thuto Primary School 30. Tlhapi-Moruwe Primary School	11. Katakane Primary School 12. Kgabalatsane Primary School 13. Kutlwano Primary School 14. Laerskool Elandskraal 15. Lesedi Le Legolo Primary School 16. Lethabong Primary School 17. Lorato Primary School 18. Madiba Utlwa Primary School 19. Malatse Motsepe High School 20. Maruatona Primary School 21. Meriting Primary School 22. Mmanotshe Moduane Secondary School 23. Modisakwano Primary School 24. Motlhake Primary School 25. Osaletseng Primary School 26. Oukasi Primary School 27. Pansdrif Primary School 28. Rakgatla Secondary School 29. Rantsou Primary School 30. Rekopantswe Secondary School 31. Sanddrift Primary School	11. Katakane Primary School 12. Kgabalatsane Primary School 13. Khothalo Primary School 14. Klipvoor Primary School 15. Kutlwano Primary School 16. Laerskool Elandskraal 17. Lesedi Le Legolo Primary School 18. Lethabong Primary School 19. Lorato Primary School 20. Madiba Utlwa Primary School 21. Malatse Motsepe High School 22. Maruatona Primary School 23. Meriting Primary School 24. Mmanotshe Moduane Secondary School 25. Modisakwano Primary School 26. Motlhake Primary School 27. Osaletseng Primary School 28. Oukasi Primary School 29. Pansdrif Primary School 30. Rakgatla Secondary School 31. Rantsou Primary School	11. Katakane Primary School 12. Kgabalatsane Primary School 13. Khothalo Primary School 14. Klipvoor Primary School 15. Kutlwano Primary School 16. Laerskool Elandskraal 17. Lesedi Le Legolo Primary School 18. Lethabong Primary School 19. Lorato Primary School 20. Madiba Utlwa Primary School 21. Malatse Motsepe High School 22. Maruatona Primary School 23. Meriting Primary School 24. Mmamogwai Secondary School 25. Mmanotshe Moduane Secondary School 26. Modisakwano Primary School 27. Motlhake Primary School 28. Osaletseng Primary School 29. Oukasi Primary School 30. Pansdrif Primary School 31. Rakgatla Secondary School	11. Katakane Primary School 12. Kgabalatsane Primary School 13. Khothalo Primary School 14. Klipvoor Primary School 15. Kutlwano Primary School 16. Laerskool Elandskraal 17. Laerskool Sonop 18. Lesedi Le Legolo Primary School 19. Lethabong Primary School 20. Lorato Primary School 21. Madiba Utlwa Primary School 22. Malatse Motsepe High School 23. Maruatona Primary School 24. Meriting Primary School 25. Mmamogwai Secondary School 26. Mmanotshe Moduane Secondary School 27. Modisakwano Primary School 28. Motlhake Primary School 29. Osaletseng Primary School 30. Oukasi Primary School 31. Pansdrif Primary School

31. Tlhophane Primary School 32. Tshenolo Primary School 33. Tumo Primary School	32. Sanddrift Primary School 33. Segwaelane Primary School 34. Selamodi Combined School 35. Skeerpoort Primary School 36. Tebogo Primary School 37. Tlapa La Thuto Primary School 38. Tlhapi-Moruwe Primary School 39. Tlhophane Primary School 40. Tshenolo Primary School 41. Tsogo Secondary School 42. Tsogwe Primary School 43. Tumo Primary School 44. Voorwaarts Primary School	32. Rekopantswe Secondary School 33. Sanddrift Primary School 34. Sanddrift Primary School 35. Segwaelane Primary School 36. Selamodi Combined School 37. Skeerpoort Primary School 38. Tebogo Primary School 39. Tlapa La Thuto Primary School 40. Tlhapi-Moruwe Primary School 41. Tlhophane Primary School 42. Tshenolo Primary School 43. Tsogo Secondary School 44. Tsogwe Primary School 45. Tumo Primary School 46. Voorwaarts Primary School	32. Rantsou Primary School 33. Rekopantswe Secondary School 34. Sanddrift Primary School 35. Sanddrift Primary School 36. Segwaelane Primary School 37. Selamodi Combined School 38. Skeerpoort Primary School 39. Tebogo Primary School 40. Tlapa La Thuto Primary School 41. Tlhapi-Moruwe Primary School 42. Tlhophane Primary School 43. Tshenolo Primary School 44. Tsogo Secondary School 45. Tsogwe Primary School 46. Tumo Primary School 47. Voorwaarts Primary School	32. Rakgatla Secondary School 33. Rantsou Primary School 34. Rekopantswe Secondary School 35. Sanddrift Primary School 36. Sanddrift Primary School 37. Segwaelane Primary School 38. Selamodi Combined School 39. Skeerpoort Primary School 40. Tebogo Primary School 41. Tlapa La Thuto Primary School 42. Tlhapi-Moruwe Primary School 43. Tlhophane Primary School 44. Tshenolo Primary School 45. Tsogo Secondary School 46. Tsogwe Primary School 47. Tumo Primary School 48. Voorwaarts Primary School

Table 14: Schools that can be accessed by the Moretele Local Municipality population located within 500m, 1500m, 2500m, 3500m, 4500m and 5000m.

500	1500	2500, 3500, 4500, 5000
1. B Mpoza Christian College	1. B Mpoza Christian College	1. B Mpoza Christian College

2. Matlaisane Secondary School 3. Mmamarumo Primary School 4. Mmankala Technical and Commercial Secondary School 5. Mmatlhame Primary School 6. Mmatsheko Primary School 7. Modimokwane Primary School 8. Mogogelo Primary School 9. Molebatsi Secondary School 10. Moratwe Secondary School 11. Morokwa-Ditlou Primary School 12. Mosetlha Primary School 13. Nchaupe Secondary School 14. Nyakale Primary School 15. Puo-Phaa Secondary School 16. Ramaifala Primary School 17. Ramashita Primary School 18. S. J. Ramutloa Middle School 19. Seboaneng Secondary School 20. Sekitla Secondary School 21. Sempapa Middle School 22. Senteng Primary School 23. Swarisanang Primary School 24. Thipe Primary School 25. Tladistad Primary School	2. Matlaisane Secondary School 3. Mmamarumo Primary School 4. Mmankala Technical and Commercial Secondary School 5. Mmatlhame Primary School 6. Mmatsheko Primary School 7. Modimokwane Primary School 8. Moemise Primary School 9. Mogogelo Primary School 10. Molebatsi Secondary School 11. Moratwe Secondary School 12. Morokwa-Ditlou Primary School 13. Mosetlha Primary School 14. Nchaupe Secondary School 15. Nyakale Primary School 16. Puo-Phaa Secondary School 17. Ramaifala Primary School 18. Ramashita Primary School 19. Resebone Primary School 20. S. J. Ramutloa Middle School 21. Seboaneng Secondary School 22. Sekitla Secondary School 23. Sempapa Middle School 24. Senteng Primary School 25. Swarisanang Primary School 26. Thipe Primary School 27. Tladistad Primary School	2. Matlaisane Secondary School 3. Mmamarumo Primary School 4. Mmankala Technical and Commercial Secondary School 5. Mmatlhame Primary School 6. Mmatsheko Primary School 7. Modimokwane Primary School 8. Moemise Primary School 9. Mogogelo Primary School 10. Molebatsi Secondary School 11. Moratwe Secondary School 12. Morokwa-Ditlou Primary School 13. Mosetlha Primary School 14. Nchaupe Secondary School 15. Nyakale Primary School 16. Puo-Phaa Secondary School 17. Ramaifala Primary School 18. Ramashita Primary School 19. Resebone Primary School 20. S. J. Ramutloa Middle School 21. Seboaneng Secondary School 22. Sekitla Secondary School 23. Sempapa Middle School 24. Senteng Primary School 25. Swarisanang Primary School 26. Thipe Primary School 27. Tladistad Primary School 28. Utsane High School

Table 15: Schools that can be accessed by the Moses Kotane Local Municipality population located within 500m, 1500m, 2500m, 3500m, 4500m and 5000m.

500	1500, 2500, 3500	4500, 5000
1. Agonkitse Primary School 2. Basadi Primary School 3. Batleng Secondary School 4. Bonolo Primary School 5. Comcy Park Primary School 6. Dikgathlong Primary School 7. Dikweipi Primary School 8. Dinkwe Primary School	1. Agonkitse Primary School 2. Basadi Primary School 3. Batleng Secondary School 4. Bonolo Primary School 5. Borite Primary School 6. Comcy Park Primary School 7. Dikgathlong Primary School 8. Dikweipi Primary School	1. Agonkitse Primary School 2. Basadi Primary School 3. Batleng Secondary School 4. Bonolo Primary School 5. Borite Primary School 6. Comcy Park Primary School 7. Dikgathlong Primary School 8. Dikweipi Primary School

9. Dithoteng Primary School	9. Dinkwe Primary School	9. Dinkwe Primary School
10. Gabonewe Secondary School	10. Dithoteng Primary School	10. Dithoteng Primary School
11. Goitsemang Intermediate School	11. Gabonewe Secondary School	11. Gabonewe Secondary School
12. Herman Thebe Secondary School	12. Goitsemang Intermediate School	12. Goitsemang Intermediate School
13. Holy Family Secondary School	13. Herman Thebe Secondary School	13. Herman Thebe Secondary School
14. JM Ntsime Secondary School	14. Holy Family Secondary School	14. Holy Family Secondary School
15. Kalafi Secondary School	15. JM Ntsime Secondary School	15. JM Ntsime Secondary School
16. Keoagile Primary School	16. Kalafi Secondary School	16. Kalafi Secondary School
17. Keorapetse Primary School	17. Keoagile Primary School	17. Keoagile Primary School
18. Kgalatlowe Secondary School	18. Keorapetse Primary School	18. Keorapetse Primary School
19. Kgamanyane Secondary School	19. Kgalatlowe Secondary School	19. Kgalatlowe Secondary School
20. Kgolane Primary School	20. Kgamanyane Secondary School	20. Kgamanyane Secondary School
21. KHAYAKHULU PRIMARY SCHOOL	21. Kgolane Primary School	21. Kgolane Primary School
22. Langa La Sembo Secondary School	22. KHAYAKHULU PRIMARY SCHOOL	22. Kgosibodiba Secondary School
23. Leema Secondary School	23. Langa La Sembo Secondary School	23. KHAYAKHULU PRIMARY SCHOOL
24. Lekgatle II Primary School	24. Leema Secondary School	24. Langa La Sembo Secondary School
25. Lerome Secondary School	25. Lekgatle II Primary School	25. Leema Secondary School
26. Mabeskraal Primary School	26. Lerome Secondary School	26. Lekgatle II Primary School
27. Machama Primary School	27. Mabeskraal Primary School	27. Lerome Secondary School
28. Magong Primary School	28. Machama Primary School	28. Mabeskraal Primary School
29. Maimane Primary School	29. Magong Primary School	29. Machama Primary School
30. Makgophaneng Primary School	30. Maimane Primary School	30. Magong Primary School
31. Makgophe Primary School	31. Makgophaneng Primary School	31. Maimane Primary School
32. Makoba Secondary School	32. Makgophe Primary School	32. Makgophaneng Primary School
33. Makweleng Primary School	33. Makoba Secondary School	33. Makgophe Primary School
34. Mamodimakwana Primary School	34. Makweleng Primary School	34. Makoba Secondary School
35. Mantserre Primary School	35. Mamodimakwana Primary School	35. Makweleng Primary School
36. Maotwe Middle School	36. Mantserre Primary School	36. Mamodimakwana Primary School
37. Maretlwana Primary School	37. Maotwe Middle School	37. Mantserre Primary School
38. Matiki Mooeketsi Primary School	38. Maretlwana Primary School	38. Maotwe Middle School
39. Maudzibi Primary School	39. Matiki Mooeketsi Primary School	39. Maretlwana Primary School
40. Modimong Primary School	40. Maudzibi Primary School	40. Matiki Mooeketsi Primary School
41. Modubyane Primary School	41. Modimong Primary School	41. Maudzibi Primary School
42. Moefi Secondary School	42. Modubyane Primary School	42. Modimong Primary School
43. Moetlo Primary School	43. Moefi Secondary School	43. Modubyane Primary School
44. Mogobe Primary School	44. Moetlo Primary School	44. Moefi Secondary School
45. Mokgaotsi Primary School	45. Mogobe Primary School	45. Moetlo Primary School
46. Mokgatlha Primary School	46. Mokgaotsi Primary School	46. Mogobe Primary School
47. Montana Primary School	47. Mokgatlha Primary School	47. Mokgaotsi Primary School
48. Morare High School	48. Montana Primary School	48. Mokgatlha Primary School
49. Morongwa Primary School	49. Morare High School	49. Montana Primary School
50. Mosome Primary School	50. Morongwa Primary School	50. Morare High School
51. Motlhabe Primary School	51. Mosome Primary School	51. Morongwa Primary School
52. Motlhajoe Primary School	52. Motlhabe Primary School	52. Mosome Primary School
53. Motshabaesi Primary School	53. Motlhajoe Primary School	53. Motlhabe Primary School
54. Motsisi Primary School	54. Motsatsi Primary School	54. Motlhajoe Primary School
55. Moubanamotsei Primary	55. Motshabaesi Primary School	

School 56. Mperebere Primary School 57. Naledi Ya Masa Primary School 58. Nkogolwe Primary School 59. Nonceba Primary School 60. Okomelang Primary School 61. Olefile Secondary School	56. Motsisi Primary School 57. Moubanamotsei Primary School 58. Mperebere Primary School 59. Mphuphuthe Primary School 60. Naledi Ya Masa Primary School 61. Nkogolwe Primary School	55. Motsatsi Primary School 56. Motshabaesi Primary School 57. Motsisi Primary School 58. Moubanamotsei Primary School 59. Mperebere Primary School 60. Mphuphuthe Primary School

62. Poifo Primary School 63. Puso Primary School 64. Rakoko Secondary School 65. Ramokoka Primary School 66. Ramonotwana Primary School 67. Ramoroko Secondary School 68. Rantlaka Middle School 69. Raphurele Secondary School 70. S.G. Ntuane Primary School 71. Sedibelo Secondary School 72. Sedumedi Primary school 73. Sefikile Primary School 74. Sefutswelo Secondary School 75. Sewagodimo Technical And Commercial High School 76. Shadrack F Zibi High School 77. St Annes High School 78. Tapos Primary School 79. THAKADU PRIMARY SCHOOL 80. Thari Primary School 81. Thebe Ya Tlhajwa Secondary School 82. Thebenare Primary School 83. Thoko-ziti Primary School 84. Tholo Primary School 85. Tlhaalapitse Primary School 86. Tshwaraodire Primary School	62. Nonceba Primary School 63. Okomelang Primary School 64. Olefile Secondary School 65. Poifo Primary School 66. Puso Primary School 67. Rakoko Secondary School 68. Ramokoka Primary School 69. Ramonotwana Primary School 70. Ramoroko Secondary School 71. Rantlaka Middle School 72. Raphurele Secondary School 73. S.G. Ntuane Primary School 74. Sedibelo Secondary School 75. Sedumedi Primary School 76. Sefikile Primary School 77. Sefutswelo Secondary School 78. Sewagodimo Technical And Commercial High School 79. Shadrack F Zibi High School 80. St Annes High School 81. Tapos Primary School 82. THAKADU PRIMARY SCHOOL 83. Thari Primary School 84. Thebe Ya Tlhajwa Secondary School 85. Thebenare Primary School 86. Thoko-ziti Primary School 87. Tholo Primary School 88. Tlhaalapitse Primary School 89. Tshwaraodire Primary School	61. Naledi Ya Masa Primary School 62. Nkogolwe Primary School 63. Nonceba Primary School 64. Okomelang Primary School 65. Olefile Secondary School 66. Poifo Primary School 67. Puso Primary School 68. Rakoko Secondary School 69. Ramokoka Primary School 70. Ramonotwana Primary School 71. Ramoroko Secondary School 72. Rantlaka Middle School 73. Raphurele Secondary School 74. S.G. Ntuane Primary School 75. Sedibelo Secondary School 76. Sedumedi Primary School 77. Sefikile Primary School 78. Sefutswelo Secondary School 79. Sewagodimo Technical And Commercial High School 80. Shadrack F Zibi High School 81. St Annes High School 82. Tapos Primary School 83. THAKADU PRIMARY SCHOOL 84. Thari Primary School 85. Thebe Ya Tlhajwa Secondary School 86. Thebenare Primary School 87. Thoko-zibi Primary School 88. Tholo Primary School 89. Tlhaalapitse Primary School 90. Tshwaraodire Primary School

Table 16: Schools that can be accessed by the Rustenburg Local Municipality population located within 500m, 1500m, 2500m, 3500m, 4500m and 5000m.

500	1500, 2500, 3500, 4500,5000
1. Bakubung Intermediate School 2. Bakwena Secondary School 3. Berseba Primary School 4. BF Morake Primary School 5. Bobuantswa Primary School 6. Boons Secondary School 7. Bosabosele Primary School 8. Bothibello Primary School 9. De Hy Primary School 10. Deo Gloria Christian Academy 11. Dimapo Primary School	1. Bafokeng High School 2. Bakubung Intermediate School 3. Bakwena Secondary School 4. Barelwanedi Primary School 5. Berseba Primary School 6. BF Morake Primary School 7. Bobuantswa Primary School 8. Boons Secondary School 9. Bosabosele Primary School 10. Boshoek Laerskool 11. Bothibello Primary School 12. De Hy Primary School

12. Fapha Primary School 13. Fields College 14. Fly Eagle Primary 15. Grenswag Hoërskool 16. HF Tlou High School 17. J.D Mosiah Primary School 18. Kloof View Primary School 19. Laerskool David Brink 20. Laerskool Proteapark 21. Lefaragatlhe Primary School 22. Lekwakwa Primary School 23. Mafenya Primary School 24. Marikana Combined School 25. Marikana Primary School 26. Matlhare Mokautu Secondary School 27. Maumong Primary School 28. Morogong Primary School 29. Nkukise Primary School 30. Nur Ul Iman Muslim School 31. Paardekraal Primary School 32. Ramotse Primary School 33. Rampa Primary School 34. Rasimone Primary School 35. Ruskraal Primary School 36. Rustenburg Educational College Primary 37. Rustenburg Gereformeerde Akademie 38. Selly Park Primary 39. Selly Park Secondary School 40. St Augustine Private Christian School 41. The secondary School 42. Tlapa Primary School 43. Tshirologang Primary School 44. Tshukudu High School 45. Tsitsing Primary School 46. Tsunyane Primary School 47. Tumagole Primary School	13. Deo Gloria Christian Academy 14. Dimapo Primary School 15. Fapha Primary School 16. Fields College 17. Fly Eagle Primary 18. Grenswag Hoërskool 19. HF Tlou High School 20. J.D Mosiah Primary School 21. Kloof View Primary School 22. Laerskool David Brink 23. Laerskool Proteapark 24. Lefaragatlhe Primary School 25. Lekwakwa Primary School 26. Mabitse Primary School 27. Mafenya Primary School 28. Marikana Combined School 29. Marikana Primary School 30. Matlhare Mokautu Secondary School 31. Maumong Primary School 32. Meriti Secondary School 33. Mogono Primary School 34. Mojagedi Secondary School 35. Morogong Primary School 36. Nkukise Primary School 37. Nur Ul Iman Muslim School 38. Paardekraal Primary School 39. Ramotse Primary School 40. Rampa Primary School 41. Rasimone Primary School 42. Ruskraal Primary School 43. Rustenburg Educational College Primary 44. Rustenburg Gereformeerde Akademie 45. Selly Park Primary 46. Selly Park Secondary School 47. St Augustine Private Christian School 48. The secondary School 49. Tlapa Primary School 50. Tlhabane West Primary School 51. Tshirologang Primary School 52. Tshukudu High School 53. Tsitsing Primary School 54. Tsunyane Primary School 55. Tumagole Primary School