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Suitable Abattoir Site Identification for Sustainable Urban Planning and Development: Case of Mekelle City, Tigray, Ethiopia

Thesis

Submitted to the School of Civil and Environmental Engineering Department of Geodesy and Geomatics in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Geodesy and Geomatics Specialization in Geomatics

By

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Approval Sheet

This is to certify that the thesis titled "Suitable Abattoir Site Identification for Sustainable Urban Planning and Development: Case of Mekelle City, Tigray, Ethiopia " submitted in partial fulfill ment of the requirements for the degree of Master of Science in Geodesy and Geomatics Engineering, specialization in Geomatics, has been approved by the thesis committee and accepted by the School of civil and environmental engineering at Addis Ababa University.

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Declaration

I, Tesfay Redae Kiros, hereby declare that this thesis, titled " Suitable Abattoir Site Identification for Sustainable Urban Planning and Development: Case of Mekelle City, Tigray, Ethiopia", submitted to Addis Ababa University, is my original work and has not been presented for a degree in any other university.

To the best of my knowledge, the thesis does not contain any work published or written by another person except where due reference is made in the text. All sources of information have been duly acknowledged.

This work is submitted in fulfillment of the requirements for the degree of Master of Science in Geodesy and Geomatics Engineering, specialization in Geomatics, under the supervision of Tibebu Kassawmar (PhD).

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As Master thesis advisor, I hereby certify that I have read and evaluated this MSc thesis prepared under my supervision.

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Lists of Abbreviations and Acronyms

AHP	Analytical hierarchy processes
COEP	Code of Environmental Practices
CR	Consistency Ratio
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
EPA	Environmental Protection Agency
ESRI	Environmental Studies Research Institute
ETM+	Enhanced Thematic Mapper Plus
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
Ha	Hectare
Km	Kilometers
LU/LC	Land Use/Land Cover
LMA	Livestock Marketing Authority
M	Meters
MCDA	Multi Criteria Decision analysis
MCDM	Multi Criteria Decision Making
MCE	Multi Criteria Evaluation
MLC	Maximum Likelihood Classification
Mm	Millimeter
OLI/TIRS	Operational Land Imager/ Thermal Infrared Sensor
RS	Remote Sensing
UN	United Nation
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WHO	World Health Organizations

Abstract

The fast rate of urbanization presents new difficulties for land management and urban planning, particularly in managing essential services such as abattoirs. In the same fashion, the rapid urbanization of Mekelle city in Tigray, Ethiopia, necessitates sustainable urban planning, particularly in the context of essential infrastructure like abattoirs. In order to reduce negative environmental impacts, optimize land use, and guarantee public health and safety, selecting suitable abattoir site becomes increasingly important as towns and cities grow. Inadequately sited abattoirs can pose significant risks to public health, the environment, and urban developme nt. Hence, this thesis presents a comprehensive study on the use of Geographic Information System (GIS) and Remote Sensing (RS) technologies for identifying suitable abattoir site to ensure sustainable urban planning and development, with a specific focus on Mekelle City, Tigray, Ethiopia. The study integrates a variety of spatial datasets, including land use, topography, surface water, transportation accessibility, and population density, to develop an effective site suitability model. Environmental and socio-economic criteria such as land use land cover, elevation, slope, road, stream, settlements, industrial areas, social services, landfill sites, high tension lines and airport are taken into account to ensure that the locations of established abattoirs hinder the potential of environmental contamination, reduce the possibility of conflicts with nearby residential areas, and adhere to regulations. The study utilizes Analytical Hierarchy Process (AHP), the most popular methods of Multi-Criteria Decision Analysis (MCDA) and weighted overlay techniques within the GIS environment, to evaluate potential abattoir sites and to rank them based on their suitability. Remote sensing data further refines the site selection process by offering critical insights into environmental factors and changes in land cover. According to the findings of the study, the produced final abattoir site suitability map comprises an area of 52.68 km^2 (16.41%) unsuitable, 69.29 km^2 (21.59%) moderately suitable, 193.68 km^2 (60.34%) suitable, and 5.35 km^2 (1.66%) highly suitable. The produced abattoir site suitability map reveals that the north, northwest, west, and southwest parts of the city contain highly suitable sites. Finally, the most suitable abattoir site is selected from the three candidate sites after comparing each other regarding their environmental, socio-economic and regulatory suitability. The study's result suggested that the selected site is situated at the north periphery of Mekelle City, which is most suitable for abattoir development, considering both the current and future urban expansion of Mekelle City. The study's findings underscore the importance of integrating geospatial technologies into urban planning processes to enhance the sustainability, health, and resilience of rapidly growing urban centers like Mekelle.

Key words: *Abattoir, Mekelle, Suitable site selection, Urban planning*

1. INTRODUCTION

1.1. Background of the Study

The fast rate of urbanization presents new difficulties for land management and urban planning. Thus, finding a balance between urban expansion and limited resources has become an important topic of urban development (Ni and Wei, 2024). Urban planning involves the organized development and design of urban spaces to meet the needs of the population while considering economic, social, and environmental factors. In the context of abattoir site selection, urban planning ensures that these facilities are strategically placed to optimize functionality and minimize negative impacts (Van Maarseveen et al., 2019). Since site suitability is the process of understanding current site features and elements that will define the placement for a given activity, site suitability analysis has become essential to meeting the needs of acceptable sites in flexing areas (Kumar and Kumar, 2014). Urban land suitability evaluation, as a scientific approach, can assist decision makers in selecting suitable land use during the land use and urban planning process, enhance land use efficiency, minimize resource waste, and support sustainable urban development (Ni and Wei, 2024).

Finding appropriate locations for urban development is one of the most important planning challenges. Thus, selecting the right location for an abattoir is crucial since it may have an impact on nearby services and cause environmental problems including pollution and the spread of disease (Chandel et al., 2024). The process of identifying an abattoir location is complex and calls for a thorough grasp of a wide range of spatial and non-spatial factors. The conventional techniques frequently utilized for this purpose are occasionally insufficient, given the intricacy and interconnectedness of the constituent elements. The Geographic Information System (GIS) is a potent framework that facilitates the integration, analysis, and visualization of spatial data, offering an organized strategy for decision-making in site selection process. Site selection, according to Misra and Sharma, (2015), is the process of determining which locations are suitable for a project's development based on environmental and socioeconomic considerations. It is standard procedure for people, businesses, and institutions to search for the best location for their planned project, which could be a new airport, school, or bus terminal. Site suitability, according to Kumar and Kumar, (2014), is the process of understanding an existing site's characteristics and the factors that will determine its acceptability for a certain activity. It includes a careful examination of the processes and natural resources that characterize a location. According to Hassen, (2020) and Eldrandaly's, (2013) description, the assessment of site suitability is essentially a multi-criteria analysis problem including multiple competent aspects that appear simultaneously.

The most important environmental concern for abattoirs is selecting an appropriate location. A careful site selection can greatly minimize environmental problems (EPA, 2002). A variety of factors are taken into account while selecting a location for an abattoir, from logistical and regulatory concerns to socioeconomic and environmental problems. Within this framework, Geographic Information Systems (GIS) and Remote Sensing (RS) technologies become indispensable instruments for improving the decision-making process linked to the selection of abattoir sites. In recent years, there has been an increase in the significance of using remote sensing and GIS technology for site suitability evaluations. With the use of these technologies, decision-makers can gather and evaluate geographical data to make well-informed decisions that have the fewest detrimental effects on the environment and local communities. GIS combines several kinds of data to give a thorough grasp of the variables affecting location suitability. Satellite imagery is also one example of a remote sensing technology that helps monitor current circumstances and detect potential issues. Thus, decision-making in the manufacturing industry is increasingly using GIS and remote sensing data to find optimal locations for industries like abattoirs (Chandel et al., 2024).

According to Hamid et al. (2019), these technologies incorporate geographic datasets such as elevation, transportation networks, and satellite imagery. Chandel et al., (2024) have observed that GIS aids in evaluating the feasibility of places based on multiple factors by combining diverse geospatial information, such as satellite images, elevation data, land use or land cover maps, and transportation networks. Furthermore, GIS is a broad term that can refer to various technologies, processes, and methods. The results of these analyses can significantly save time and effort that might otherwise be spent manually searching records, processing data, or field surveying. Although GIS is frequently used for resource inventory and mapping, its potential for planning and decision-making could not be completely realized due to a lack of provision for the incorporation of administrators' opinions, values, justifications, and alternatives. Multi-Criteria Decision Analysis (MCDA), which can handle the examination of several criteria and provide alternative solutions, is helpful in contemplating these constraints (Cheng et al., 2002). One of the most important aspects of strategic and logistical decision-making for manufacturers is selecting a site. Location decisions need to take a variety of factors into account in order to balance environmental sustainability and socioeconomic benefits (Alzamili et al., 2015).

Due to the rapidly changing pattern of urban growth, there are currently more challenges for urban planning and redesign. Parallel to this expansion has been the need for land from urban services like abattoirs and human settlements. Cities' and towns' anticipated physical plans require urgent attention because of the growing complexity involved (Teshome, 2015). In this case, the Geographic Information System (GIS), a computer system that can store and utilize data describing locations on Earth's surface, offers the opportunity to conduct quantitative research, analyze the geographic data, and present the findings on a variety of maps (Wei & Ding, 2015). In most developing countries, cities and towns experience increasing population pressure on limited resources and a deficiency of contemporary economic structures that could potentially alleviate the pressure (Harris, 1990). It is also noted that the need for abattoirs has increased as a result of urbanization and population growth (Tesfaye, 2017). Urban master and land use planning now include municipal abattoir facilities in order to meet social demands. A research by Gadisa et al., (2019) also made clear that the global demand for meat products has witnessed a substantial increase in recent years, driven by population growth, urbanization, and changing dietary habits. As a consequence, the establishment of abattoirs, crucial components of the meat supply chain, is becoming an increasingly complex challenge. Accordingly, the current study was executed to meet the need of the community of Mekelle city for abattoir service by selecting a suitable abattoir site that is environmentally sound, socially acceptable, and economically feasible. The suitable abattoir site selection process was executed by incorporating geographic information systems (GIS) with multi-criteria decision analysis (MCDA) techniques like analytical hierarchy processes (AHP) and remote sensing applications.

1.2. Statement of the problem

Abattoirs are one of the most important services, as they are livestock processing industries located near the population they serve. In the Ethiopian case, abattoirs are usually located within the municipal boundary of the corresponding cities and towns. However, the activities involved in abattoirs pose environmental problems to the neighboring areas. These are shown as fluid wastes, storm water pollution, solid wastes, airborne wastes, diseases, and noise (EPA, 2002; WHO, 1984). In this regard, a study by Adonu et al., (2017) on hygienic conditions of abattoirs in Ghana's Amasaman revealed concerns about health risks for those who live close to abattoirs particularly in developing countries where awareness is low. Furthermore, abattoirs are sometimes found near waste disposal sites and are exposed to pollution. Tesfaye, (2017) presents Teppi town as a typical example. In addition, abattoirs could be affected by certain nearby incompatible industrial activities that emit smoke and dust. This has been found truth in the study area as the main abattoir of Mekelle city is located near Messebo cement factory and plastic factory, which is exposed to harmful dusts emitted from these industries.

Moreover, different research studies that have been performed so far provide a general overview of the varied characteristics of abattoirs, necessitating unique locations that comply with environmental and land use policies. The studies have tried to assess the effect of abattoir to the surrounding environment and its incompatibility with in nearby industries and other land use classes. They have mentioned a number of examples globally as well as in different towns in Ethiopia that portray the existence of serious problems in this regard. The most notable ones include that, in many cases, the sites lack a reasonable time dimension so that they are soon encroached upon by other urban land uses like housing and commercial activities. Ultimately, the abattoirs became subject to relocation earlier than expected. Mekelle city is one of the victims of such problem. For instance, one of Mekelle City's existing abattoirs, located in Quiha Sub-city, which is one of the seven sub-cities of Mekelle City, was built to provide slaughtering services without due consideration of the effects on the neighborhood and with a lack of spatial considerations or the city's potential growth. It is situated quite close to the Desta Alcoholic and Liquor Factory and the recently established "Ederta Brewing Factory". This also indicates a serious problem of incompatibility, representing critical hygienic hazard, and more si milar problems are encountered. It is also observed that not all animals are slaughtered in the abattoir. This in a way has contributed to the poor operations and management in the abattoirs under study. Consequently, this tangible kind of incompatibility problem and poor management of the abattoir is threatening the future sustainability of the city.

Furthermore, Mekelle city is exhibiting tremendous changes in terms of land use and land cover. As the land use and land cover change analysis from 1990 to 2010 and from 2010 to 2023 revealed, the built-up area is increasing significantly as it rises from 19.77 km^2 in 1990 to 20.85

km^2 and 51.95 km^2 in 2010 and 2023, respectively (Appendix). This also shows that Mekelle City is expanding in an unprecedented way. In addition to this, the population growth of the city is increasing from time to time as Mekelle City is the capital city and the economic hub of Tigray Regional State. Thus, due to the high increment in population and the rapid expansion of the city, the existing abattoirs couldn‘t accommodate the interests of users. This also necessitates an abattoir service with efficient supply and with logical standards in all aspects. From this perspective, it demands identifying a suitable abattoir location for the overall sustainability of the city.

Although there have been few studies on the suitability of abattoir sites in Ethiopia, the majority of them fail to incorporate RS approaches with GIS-based multi-criteria decision-making. For instance, Aysheshim, (2002) conducted a study on the application of GIS for urban planning in Ethiopia, specifically focusing on the suitability analysis of abattoir sites in Kulito Town. However, this study fails to consider the integration of geospatial technologies and used the existing urban planning institute data rather than the up-to-dated remote sensing data like satellite images. The study is executed by following the existing urban planning principle only. Due to the current quick updating of information, the manual, traditional planning methods that rely on biophysical data and employ a hierarchical approach are no longer suitable for selecting a location (Wei & Ding, 2015). Manual approaches cannot match the speed and ability to handle spatial data and associated attribute information, as well as integrate several data types in a single analysis (Aronoff, 1989). However, Geographic Information Systems (GIS) and Remote Sensing (RS) play a crucial role in site suitability modeling for abattoirs, contributing to sustainable urban planning and development. By integrating various environmental, social, and economic factors, these technologies facilitate informed decision-making regarding site selection for abattoir (Chandel et al., 2024). In addition, there is no existing study carried out on the site suitability for abattoir establishments in the study area. Thus, the current study considers multi-criteria decision-making techniques with geographic information systems (GIS) and remote sensing (RS) applications to fill the gap. This study intends to overcome the abattoir location problem in Mekelle city and to give information to urban planners to practice the right judgments on providing the best site for the construction of abattoirs that ensures the sustainable development of the city.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this study is to identify suitable abattoir site for sustainable urban planning and development of Mekelle City.

1.3.2. Specific Objectives

In order to achieve the general objective, the study executes the following specific objectives:

- To produce a land use and cover map of Mekelle city for abattoir suitability analysis.
- To develop a GIS-based site suitability model in order to select the most suitable site for abattoir establishment.

1.4. Research Questions

1. What types of areas or LU/LC types are most suitable for abattoir sites?
2. What is the importance of the site suitability model developed using GIS-based MCDA and the application of RS for future LU planning and management in the municipality of Mekelle city?

1.5. Significance of the study

This study was executed to produce a suitable site location map for abattoir service in Mekelle city. The data base created and the procedures and standards followed by this study are believed to provide helpful information to urban planners. It helps to perform the right judgment on the planning of the best site for constructing abattoir facilities that are feasible in all aspects and attains sustainability. In addition, it supports to exercise the ideal judgment on the provision of preferable locations for specific urban facilities and organizations working on environmental issues like sanitation problems related to pollution of air, waste water, and noise.

1.6. Scope and limitations of the study

The scope of this study is limited to Mekelle city, and the study is mainly focused on GIS and remote sensing (RS)-based abattoir suitability modeling for sustainable urban planning and development since modeling suitable sites for abattoirs is a common issue in our country, Ethiopia, generally and in the target study area specifically. By collecting the required data from different sources, the most suitable abattoir service is mapped out for provision of future urban land use allocation for the study area. By analyzing the data and presenting the result in map form, recommendation is given finally for the municipality and urban planners so as to exercise feasible decisions leading to sustainable urban land use management based on the outputs and results of the study. Because of the specific features of the study area, some of the criteria are not incorporated in the abattoir site suitability model. This mainly includes railways.

1.7. Organization of the thesis

The thesis is organized into five chapters. The first chapter introduces the study's background, problem statement, research objectives, questions, significance, and scope and limitations of the study. The second chapter provides a survey of relevant literature that includes theoretical frameworks, previous studies, and a conceptual framework in order to highlight the gaps that the current research attempts to fill. Chapter three provides further information about the materials and methods employed in addition to describing the research concept, study area, sampling strategies, data collection and analysis procedures, and ethical issues. Chapter four discusses and summarizes the findings, examining the implications and comparing them with previous studies. Finally, chapter five brings the thesis to a conclusion by summarizing the main findings, offering recommendations based on the study‘s findings, and outlining potential directions for further research.

2. LITERATURE REVIEW

2.1. Overview of Urban Planning and Sustainable Urban Development

Urban areas are expanding at a rate that is both unprecedented and thrilling, primarily in developing countries. This presents significant issues for urban regions and their neighboring peripheries. In order to overcome obstacles and produce opportunities that, in turn, permit the growth of urban areas, functional specialization, cultural expression, and, most importantly, sustainability, urban areas must be well-planned and effectively governed by these plans (Devas and Rakodi, 1993). Therefore, one of the most essential strategies for guiding urban growth in the direction of opportunity that resists elsewhere is urban planning. Proper urban planning, according to Habitat, (2010), is crucial for bridging the urban gap and is a necessary tool for creating inclusive, environmentally friendly, economically vibrant, culturally significant, and safe communities for citizens. Planning requires regular updates in order to successfully contribute to urban growth. Urban planning must critically evaluate and reinvent itself if it is to contribute positively to urban development. This can be done by carefully examining the new context of urban planning and the solutions it can provide, by studying successful and innovative cases, and by vehemently advocating for better and more appropriate planning for sustainable development (Habitat, 2010).

Ethiopia is experiencing an unprecedented rate of urbanization. It has been growing at a rate of 4.5%, faster than 4% of Sub-Saharan Africa, and is expected to urbanize at rate of 5.4%. The urban population in the 1984-2021 periods grew by 414%, from 4.45 to 22.88 million, according to various sources (World Bank Group, 2015; World Bank Group, 2016; Mezgebo, 2020). This rate will have a major impact on the economy. The economy cannot keep pace with the rate of growth of the urban population. Urban planning is crucial for guiding, directing, and managing urban spatial development trends due to the global accelerating rate of urbanization. Thus, the demand for urban planning professionals in Ethiopia is increasing rapidly due to increased awareness among regional governments and city administrations about the benefits of planned urban development.

Urban planning, traditionally focused on spatial development, often overlooked the promotion of a sustainable urban future. As a result it often fails to incorporate sustainable future promotion, leading to negative environmental effects from development and expansion (Naess, 2001; Neufield et al., 1994). According to Neufield et al., (1994), the urban environmental transition theory suggests that urban development expansion leads to localized, immediate, and health-threatening environmental challenges. Thus, planned urban center development, effective institutional frameworks, and proactive management and governance methods for the issues that are likely to arise in urban areas are necessary for the sustainability of urbanization. There is a direct correlation between population increase and, in some cases, income growth and the increasing need for basic services in urban areas. Therefore, there exists a robust correlation not just between the economy and population growth, but also between the population and its service demand.

2.2. Urban growth pattern of Mekelle City

The urban growth pattern of Mekelle city, Ethiopia, has been extensively studied over the past few decades. Research by Fenta et al., (2017) indicates a significant increase in the built-up area, with annual increments ranging from 8% to 10%. The spatial analysis revealed urban sprawl, characterized by increased heterogeneity and gradual dispersion in the city's outskirts, leading to low-density urban growth (Fenta et al., 2017). Furthermore, in order to accommodate the expanding population, the city's expansion has led to the confiscation of rural properties; this has created problems like the unjust displacement of farmers and insufficient compensation, underscoring the problems with urban sprawl and land administration procedures in Mekelle (Gebregziabher et al., 2014).

The urban growth of Mekelle is influenced by various factors as identified in the research paper by Shimizu Nobuhiro.et al. (2018). This research paper emphasized that the topography of the region plays a crucial role in site selection process, with specific preferred layouts for settlements .Infrastructure have also played a crucial role in Mekelle's urban growth by enabling density, coordinating private investment decisions, and facilitating commercial activities like dairy product commercialization (Cirolia and Rode, 2019; Hagos et al., 2020). The study in Mekelle, Tigrai, Ethiopia, by Arakawa in 2001also highlighted the importance of infrastructure, particularly road infrastructure, in promoting urban growth and concentrating population and economic activities. Additionally, the speculative market and the transformation of land use in the urban outskirts of Mekelle city have contributed to rapid urban growth, with fertile agricultural lands being opened to urbanization (Akhdadache and Zine, 2014).

Understanding and managing urban growth patterns is crucial for sustainable development, impacting transportation efficiency, infrastructure, environmental conservation, social equity, and quality of life. However, poor planning and population pressure have led to urbanization encroachment on agricultural lands, necessitating strategic planning (Aziz et al., 2022). Thus, the use of geospatial technology has been instrumental in assessing urban land use growth in Mekelle, providing valuable insights into the extent and patterns of urban expansion over time (Hagos et al., 2023). Furthermore, urban development and economic progress may be impeded by insufficient infrastructure investment brought on by financial difficulties and a dispersed urban authority. Therefore, investing in infrastructure, including transportation networks and market outlets, is essential for promoting urban growth, attracting investments, and improving the overall economic performance of cities like Mekelle. Moreover, the findings of researches by Fenta et al., (2017) and Gebregziabher et al., (2014) underscore the importance of sustainable urban planning policies to mitigate the socioeconomic and environmental consequences of rapid urbanization in Mekelle city.

2.3. Abattoir as a Fundamental Service

According to certain definitions, abattoirs are facilities that have been authorized and registered by the regulatory body for the purpose of inspecting, sanitizing, and storing meat products intended for human consumption. An abattoir's purpose is to provide hygienically prepared meat by humanely managing the animal and employing hygienic methods for dressing and slaughtering. As a result, their main purpose is to meet the growing, widespread demand for meat in cities (Alonge, 1991; Lawan et al., 2013). According to LMA,(2000) , the major objectives of establishing abattoirs are to: provide more hygienic and clean services for the slaughter of animals; guarantee the appropriate use of animal byproducts, such as blood, hide, skin, hooves, horns, and bones; set and enforce standards; earn revenue for the services provided; and reduce the environmental impact by managing the waste disposal system. Bello and Abubakar, (2023) clarified further that any animal used for slaughter generates income for the government, which is why abattoirs are a source of income.

According to Adonu et al., (2017), slaughterhouses and abattoirs are primarily there to provide a suitable environment for butchering domesticated animals and manage waste spills. The implementation of specific preliminary programs is required in abattoir operations in order to establish the fundamental operating and environmental conditions required for the production of safe food. Among these preliminary programs are great production techniques, standard operating procedures, and appropriate hygiene practices (Lawan et al., 2013). Hence, in considering these prerequisite programmes, certain fundamental factors have to be considered in construction of abattoir and components of an abattoir (Declan et al., 2004; Lawan et al., 2013).

2.3.1. Basic features of an abattoir

According to Gadisa et al., (2019) and Akpabio et al., (2015), a typical abattoir should have trained staff, modern equipment, a lairage, a sufficient and portable water supply, appropriate drainage, and an effective sanitation system. An abattoir is a government-provided or approved facility for slaughtering animals for human consumption, including buildings, lairs, stalls, and spaces within the site (Zerabruk et al., 2019). Depending on their location and the laws of the local government, abattoirs differ in size and sophistication; however, they should provide the following amenities, or have them close by: Lairage, isolation block, office space, lab and restroom, dressing areas with lockers, laundry, and areas for the sale of hides and skins, as well as Slaughter Hall, Cooling Hall, Guttery and Tripery (Gadisa et al., 2019; Manual, 1998).

While most municipal abattoirs have poor handling facilities, commercial abattoirs in developing nations incorporate advanced equipment. According to Gregory, (2005) and Ndou et al., (2011), these discrepancies may have an impact on the behavior of the animals at slaughter as well as the product's quality. (Mummed and Webb, 2015) have noted that, this case is similar in Ethiopia as different abattoirs have different management and facilities, particularly between private and municipality abattoirs. Conversely, the Ethiopian standard prepared under the direction of Agricultural and Food Technology Technical Committee and published by the quality and Standard Authority of Ethiopian (QSAE). Ethiopian standard (ES) 1109:2005: Mutton and Goat Meat Curried and Cancelled - Specification, ES 1110:2005: Chilled and Frozen Mutton and Goat Meat - Specification, ES 1111:2005: Chilled and Frozen Beef - Specification, and ES 1118: 2005: Basic Requirements for Abattoirs are among the various standards and their respective requirements for the meat industries. However, the implementation of the regulation was not very practical, particularly in Ethiopia's municipal slaughterhouses. Private slaughterhou ses were in the vicinity of the application. This demonstrated that many abattoirs had distinct management and operating procedures as a result of infrequent oversight and assessment by higher administrative offices at the federal, regional, and less research was conducted on (Gadisa et al., 2019).

Even though the activity and each of its distinct processes serves as a necessary supply of protein, the way it is handled and any wastes or byproducts it produces, unfavorably have the potential to be hazardous if the right precautions are not taken (Mamhobu-Amadi et al., 2019). Abattoir operations involve various activities such as livestock handling, slaughter, carcass dressing, chilling, packaging, freezing, rendering, drying skins, treating wastewater, and transporting processed materials. The ultimate goal or significance of establishing abattoirs is, therefore, to provide cleaner and hygienic animal slaughtering services; to ensure proper utilization of animal by-products, such as hide, skin, horns, and bones; to establish and control standards and to generate revenue for the services rendered; and to improve the environment by managing the waste disposal system, as stated in (Abubakar and Bello, 2023).

2.3.2. Environmental Impact of Abattoirs

Abattoirs, like many industrial facilities, can pose environmental challenges and contribute to various environmental problems. Urban abattoirs are known throughout the world for a variety of operations that have an impact on the urban environment, either directly or indirectly (Adelegan, 2002). Because of the high need for water for cleaning the environment and washing meat, abattoirs are typically situated near running rivers, particularly in developing nations where water is scarce. As a result, the wastewater from the washing process is released directly into the river. These effluents have a high concentration of organic matter and waste, including blood, lipids, grease, fat, urine, grit, feces, and undigested feeds. When these substances are present in significant quantities, they can harm aquatic life as well as humans (Kosamu et al., 2011). The production of animals and veterinary facilities like slaughterhouses significantly contribute to land degradation, air and water pollution, biodiversity loss, and climate change (Maranan et al., 2009). Livestock waste spills can bring enteric pathogens and extra nutrients into surface waters as well as contaminate ground waters, even while slaughtering animals produces meat and valuable byproducts like leather and skin. Abattoir waste is characterized by high organic matter content and high fat, liquid, and suspended solids levels. Bones, horns, hairs, aborted foetuses, undigested food, and condemned meat are among the solid waste materials (Adeyemo, 2002; Meadows, 1995). Livestock waste spills, containing dissolved solids, blood, gut contents, urine, and water, can pose a significant threat to humans and the environment if not properly managed (WHO, 1981).

According to (EPA, 2019), this issue could be discussed in terms of liquid wastes, solid wastes, airborne wastes, diseases and noise in general as follows:

- **Liquid Wastes:** Among other things, one fundamental characteristic of abattoirs is that they use a lot of water in the process of processing animals, mostly for hygiene reasons. A condition like this generates a lot of effluent that needs to be treated. Generally speaking, storm water characteristics, wastewater, and effluent salinity could be used to illustrate the impact of liquid wastes. For instance, studies conducted in Nigeria (Mamhobu-Amadi, et al., 2019) reported that the densities of chemical and biological oxygen demand (COD and BOD) in blood, wash water, and intestinal fluid ranged from 180 to 218,000 mg/l and 120 to 160,500 mg/l, respectively. Both the wash water and the blood are dumped untreated into the public drain.

In general, the effect of liquid wastes could be explained in terms of effluent salinity and wastewater as well as storm water qualities (EPA, 2019).

- ✓ ***Effluent Salinity***: Effluent generated from dry salting skin preservation method is highly saline and has a very high biochemical oxygen demand. It contains high levels of fluoride. This may lead to salinity problems if the effluent is used for irrigation, and also to fluorosis problems with vegetation.
- ✓ ***Wastewater***: Wastewater produced in animal slaughter areas typically has a high biochemical oxygen demand. In addition, it contains a lot of salt, suspended particles, nutrients, and microbes.
- ✓ ***Storm water***: There is a chance for storm water to get contaminated when it comes in to contact with animals holding pens, sludge, store and treated wastewater irrigation area. This contaminated storm water can have detrimental environmental effects on the surrounding ecosystem.

- **Solid wastes:** The solid waste is mainly; bones, horns, animal dung/faeces/droppings, Paunch or Intestinal content (Mamhobu-Amadi et al., 2019). Solid wastes generated from within an abattoir may have different sources including animal holding areas, slaughterhouse and processing areas, waste treatment plant, unwanted hide or skin and pieces, and unwanted carcasses and carcass parts (EPA, 2002).
- **Airborne wastes**: These are mainly the major gas emission point of the skin roasting operation in the abattoir. As a result, the environment becomes polluted and skin is contaminated. Airborne wastes can encompass various substances such as odors, dusts, and fuel burning emissions.
  - ✓ ***Odors:*** Abattoir operations can cause disagreeable odors from cooking, rendering, water effluent treatment, slaughterhouses, product storage, handling, drying, waste disposal, animal holding pens, carcass holding, and skin handling.
  - ✓ ***Dusts:*** potentials sources of dust emissions at an abattoir include unsealed roads, paddocks, sale yards and holding pens, stockpiled products and materials, and construction activities.
  - ✓ ***Fuel burning emissions***: Fuel burning leads to atmospheric emissions. Materials burned at an abattoir incorporate coal or gas fuel for boilers and steam production, diseased animals, sludge, packaging and unusable skins.
- **Noise*:*** In an abattoir noise can be generated from different sources including animals, processing activity within the slaughterhouse, plant machinery, and service vehicles.

Research has indicated that abattoirs contribute to pollution due to their high levels of fat and highly organic solid and liquid waste (Olawuni et al., 2017; Alonge, 1991; Adeyemo, 2002; Osibanjo and Adie, 2007). Furthermore, studies have demonstrated that livestock waste spills can seriously harm the environment by contaminating air, surface, and ground waters in addition to providing meat supplies and valuable byproducts like leather and skin (Meadows, 1995; World Bank, 1998; Olawuni et al., 2017). (Nwachukwu et al., 2011) also illustrated that erroneous release of animal excrement and blood into streams can lead to eutrophication by over-enriching farmlands and nearby water bodies with nutrients and depleting oxygen. While producing animals for food, significant consideration should be taken on the interactions between animal production and the environment. This realizes environmental conditions and a structure in animal production more secure and further provides to produce safe and healthy animal food as well as avoid environmental pollution and the associated human health risks. The risks to the health of those living close to abattoirs are a growing source of worry, particularly in developing nations where understanding is minimal. People are complaining about the location and management of the abattoirs in their neighborhood (Adonu et al., 2017). In the processing of the animal, waste materials in most cases, are rid of without respect to thorough environmental management practices, thus making them harmful to humans and other terrestrial and aquatic life, thereby making abattoir incompatible to residential land uses (Fearon, 2014; Azi, 2023). Researchers like Bello, (2023) and Oruonye, (2015) studied the effects of abattoirs on surrounding communities in Nigeria and the challenges of waste management in Jalingo Metropolis. These researches used observations and interviews as a qualitative and quantitative research approaches respectively. Their findings show that there is poor waste disposal, which affects the quality of air, water and land. This study aimed to determine the environmental and socio-economic suitability of abattoir location, as most research did not consider the social and economic effects of locating abattoirs to neighboring societies.

2.3.3. Utilities for Abattoirs

The utilities for an abattoir are crucial for ensuring the efficiency, hygiene, and safety of the operations. According to Lawan et al., (2013) and Yemane and Mekelle, (2016), undeveloped, vacant land is typically where new abattoir locations should be located. In these situations, it's critical that an abattoir has the facilities, utilities, and infrastructure it needs to operate properly. According to different literatures, example: Lawan et al., (2013) and LMA, (2000), here are the essential utilities for an abattoir:

- ***Water Supply*:** Water supply is crucial for cleaning equipment, sanitation, and meat processing. Insufficient or absent systems may necessitate boreholes for deep wells (Lawan et al., 2013). Kalio and AliUchechukwu, (2019) also emphasize potable water must be available at appropriate pressure, sterilized equipment in slaughter halls and workrooms, and provided for hand washing. Non-potable water used for fire control must be carried in separate lines, preferably identified by color, and without cross connection or back siphonage.

- ***Electricity Supply:*** Reliable power supply is crucial for machinery, refrigeration, and lighting in abattoirs, including laboratory activities. Meat examination requires 540 lux light intensity, with 220 lux or 110 lux depending on situation.
- ***Road Accessibility***: According to the rural road standard of the Ethiopian Road Authorities, access roads to abattoirs should be at least compacted gravel roads. The provision of such facilities is contingent upon the financial capacity of the corresponding municipality.
- ***Waste disposal and Drainage Systems***: Efficient waste disposal systems are necessary to handle both solid and liquid waste produced during the slaughtering and processing of animals. It should be on an elevated plane to facilitate better natural drainage and prevent water stagnation.
- ***Cooling and refrigeration:*** Refrigeration units are required to maintain the freshness and quality of meat products. Cold storage is crucial in preventing bacterial growth and spoilage.
- ***Slaughter equipment:*** Specialized equipment for stunning, bleeding, evisceration, and processing of animals is necessary for efficient and humane slaughter.
- ***Safety systems:*** Fire detection and suppression systems, emergency exits, and other safety measures are crucial to ensure the well-being of workers and prevent accidents.

2.4. Site Selection for Abattoir

The primary environmental concern for abattoirs is site selection. Basically, Careful site selection can greatly reduce the environmental nuisance (EPA, 2019; Yemane and Mekelle, 2016). According to Standard, (2005), the location of abattoir shall be suitable i.e. distant from temple, religious ceremony area, education area, hospital, clinic, dormitory and community that will cause danger, annoyance and damage to the person and one‘s property. As can be noted like most spatial decision making issues, the land allocation issue connected with abattoirs is multi-criteria in nature, including financial, social, environmental and, political measurements (Yemane and Mekelle, 2016).According to EPA, (2019);LMA,(2000); Standard, (2005); Rahman, (2004), the site to be selected for abattoir should be:

- Situated outside a town or city, in an area that won't soon be inhabited. Generally speaking, the rural site is preferable to the other locations, thus when feasible, choose a rural area.

- Be on a raised surface to promote improved natural drainage and avoid water stagnation . Surrounding the abattoir with a stock-proof fence will keep other animals out and slaughter stock in.
- Compliance with the free corridor regulation for civil aviation,
- Avoid facing either the leeward or windward side of the town and instead face the direction in which the wind exits from residential areas. East or west of the town is where the abattoir should be located if north or south winds are the predominant wind direction. If not for the purpose of making the building look better, the area may be landscaped and covered with trees to offer windbreaks, shade, and cover.
- Easily reachable from any location inside the town or city,
- Make sure to have ample space for future expansion.
- Have ample water supply for washing, etc., at an estimated requirement of 150 gallons per animal slaughtered or 10,000 litters/ton of dressed carcass weight,
- Choose permeable soil for foundations and piling, avoid agrarian farmland as it may be a waste of productive land and subject to chemical drift.
- Good availability of stock nearby,
- Proximity to supply of varied labour,
- Be considering the provision of rail tracks for animal receipt by railways.

Rahman, (2004) has generalized that, ―urban sites should be avoided; rural and nominated sites are preferred‖. According to Yemane and Mekelle, (2016) and Standard, (2005), the site characteristics for an abattoir is evaluated based on various suitability aspects including: The planning suitability of a site which depends on factors such as land use, physical characteristics, infrastructure, location, and financial consequences; Physical suitability involves the site's capacity, current land use, zoning, ownership, and environmental impact; Infrastructural suitability refers to existing and supplementary infrastructures and Location suitability refers to the site's proximity to specific features.

2.5. Abattoir Site Selection Criteria

When selecting a site for a specific land use, it is necessary to weigh a variety of criteria and determine whether the area is suitable for the intended use. Selecting an appropriate site for an abattoir (slaughterhouse) involves considering various factors to ensure efficiency, safety, and compliance with regulatory standards. According to Estoque, (2011), criteria are a set of standards or requirements that serve as the foundation for the decision to make. Site selection is the process of locating sites that meet the standards established by the selection criteria. According to Collins et al., (2001), the selection of abattoir site involves a complex array of critical factors from physical, economic, policies, and environmental disciplines.

According to Estoque, (2011), there are two types of criteria: factor and constraint. The former is a criterion that either highlights or detracts from an alternative's acceptability, while the latter is the component or attribute that stands for limitations. For instance, Wei, (2015) identified two key factors to consider when planning residential sites. According their illustration, showstopper criteria are those that may prevent development completely. Existing or proposed biodiversity/geo-diversity sites, geological hazard zones and protected drinking water sources zone are good examples. Assessment criteria, such as accessibility to entertainment sites and distance to public facilities, can influence the suitability, design, layout, and housing capacity of a site. Careful consideration must go into choosing the right criteria for MCE. To get the intended outcomes, the number of criteria should not be either too small or too large. While too few criteria might not be sufficient to offer all the important information required, too many criteria for a single objective tends to mislead decision-makers (Pourebrahim et al., 2010; Morales and de Vries, 2021). The criteria discussed below are based on different literatures which are relevant to this study (example: Yasin et al., 2023, Hassen, 2020, Tesfaye, 2017 and Standard, 2005).

2.5.1. Land use/Land cover (LU/LC)

Land use and land cover are two related but distinct concepts that are commonly used in the fields of geography, environmental science, and land management. Land use refers to the activities and uses performed by individuals on a specific area of land. It describes how people utilize the land for residential, commercial, industrial, agricultural, recreational, or other purposes. In contrast, land cover refers to the natural and manmade characteristics found on the surface of the Earth. It includes the various types of vegetation, water bodies, bare soil, artificial surfaces, and other natural or man-made elements that cover the land. The proper definition of these two concepts, despite their common interchangeability or confusion, distinguishes them from each other (Vali et al., 2020). According to Vali et al., (2020), Land cover is the observed (bio) physical cover on the Earth's surface, while Land use is characterized by the arrangements, activities and inputs by people to produce, change or maintains a certain land cover type. Remote sensing technologies, such as satellite imagery, are frequently employed to study and monitor land use and land cover patterns at regional and global scales. Land-use suitability analysis is a method used to determine the most suitable spatial pattern for future land use based on specific requirements, preferences, or activity predictors (Collins et al., 2001).

The selection of suitable site for abattoir must be based on a set of local criteria to ensure that the maximum cost-benefit ratio for a community is attained. Rahman, (2004) underlined that arable farmland shouldn't be selected because it could be a waste of productive land for crop cultivation and could be vulnerable to chemical drift from crop spraying. It is essential to locate the abattoir as close to animal farms as possible, while keeping it as far away as possible from residential areas, schools, hospitals, and other sensitive locations to reduce any potential environmental impact, particularly with regard to stench and respiratory issues. Every attempt should be made to locate the abattoir site and related roads on government land that is not currently leased nor inhabited, whether legally or illegally, in order to minimize the impact on the local population, avoid the need for land acquisition, and eradicate the need to resettle residents (COEP, 2011). Yemane and Mekelle, (2016) have observed that formerly undeveloped, vacant land is typically the location of newly constructed abattoir facilities.

2.5.2. Topography

Topography is the physical characteristics of a specific land area. It refers to various landforms (physical features) which represent the external shape of the earth. Usually, the features consist of natural landforms like valleys, rivers, lakes, and mountains. Cities, highways, dams, and other man-made structures may also include. It determines the shapes and patterns of several other landform and land cover characteristics. A relatively flat and well-drained location may be preferable for construction and operational purposes. Tesfaye, (2017) suggests that the site selection for an abattoir building project should consider both elevation and slope.

- ***Elevation*:** In order to stop contamination from spreading, abattoirs could be built in a location below city level (Fard and Zahraei, 2012). The evaluation of elevation classes is based on the landscape's suitability for urban land use distribution.

- ***Slope*:** Slope is crucial for urban development sites in hilly terrain, affecting building cost and surface drainage. According to (LMA, 2000), a desirable slope ranges from 2 to 10%, with values below 2% not suitable for safe drainage.

2.5.3. Surface water

Surface water is the water found on Earth's surface in natural sources such as rivers, lakes, ponds, streams, and oceans. The distribution and quality of surface water can be influenced by factors like pollution, deforestation, urbanization, and climate change. The direct release of wastewater from abattoirs to surrounding water bodies such as lakes, streams, Rivers (tributaries and meanders), seas, and oceans contributes a lot to water pollution (Ndukwe et al., 2023). Waste water from abattoir is one of the major sources of pollution in river. Water usage in abattoir operations is high. If discharged to controlled waters it will have an environmental impact by virtue of volume and quality water run-off Pollution and consequent damage of watercourses (EPA, 2019). Similarly, byproducts such as blood and stomach contents pose a risk to surface waters if not properly contained. According to Sumamo, (2015), Abattoir site must not be situated in close proximity to surface water (streams, rivers, lakes, sea). So as to avoid possible contamination of the river/ stream and to prevent the abattoir from being flooded, the site should not lie within 100 meters of rivers/streams (LMA, 2000). The criterion is crucial for environmental and economic reasons as it may lead to pollution issues and necessitate a costly efficient drainage system. Gemitzi et al., (2007) considered a minimum of 100 meters buffer distance as the minimum distance for site selection for abattoirs.

2.5.4. Accessibility

- **Transportation:** It is recommended that the abattoir should be in close proximity to major transportation routes, including roads, highways, and possibly rail, to facilitate the movement of livestock to the abattoir and the distribution of meat products to markets. An abattoir is essentially a processing plant where the processed product is carcass meat and the raw materials are animals. Like in any other industry, raw materials must arrive at the processing location and completed products must be removed from the premises on time.
- ✓ **Roads:** Roads include all forms of public transportation facility, including municipal and interstate roadways. It is a crucial element in the examination of site suitability as well.

Roads and railroads must connect the location in order to facilitate the easy transportation of both raw and processed materials. For the abattoir to operate efficiently, transportation by road or rail should be available year-round (Yasin et al., 2023). Access roads to abattoirs should be at least compacted grovel rood as per the Ethiopian Rood Authority's Rural Road Standard (RR10) (Yemane and Mekelle, 2016). According to Yemane and Mekelle, (2016), the premises' roadways must be thoroughly graded, compacted, dust-proofed, and drained. Paved or tarred sections are required for the building verge, major internal access road, loading bays, and all other places used for vehicle traffic. According to LMA, (2000) and Yasin et al. (2023), in order to find out better accessibility to the existing road and considering urban expansion buffer zones have been created by taking distances between 50 and 400 meter distance from the existing major roads to generate accessibility map.

2.5.5. Environmental Constraints

Constraints are limitations or restrictions that can hinder the planning, development, or operation of a specific project, system, or activity. In various contexts, constraints may refer to different types of limitations. Here, the constraints are the criteria that constrain, or limit the areas for abattoir site. Estoque, (2011) explains a constraint as an area that is not desired in any form or deemed inappropriate, as well as an aspect or feature that symbolizes constraints or restrictions. Constraints serve to limit the choices that are being examined. These include water bodies and protected areas (typically represented by a Boolean mask). As a result, buffer zones are crucial for keeping competing land uses apart and reducing the negative consequences of new construction in environmentally sensitive areas. The most effective measure against these issues is to maintain appropriate buffer distances from neighboring land users (Tesfaye, 2017). There are many more criteria/constraints that can be included in the assessment of suitable site for the location of abattoir. The constraints mentioned here are based on relevant literatures (Chandel et al., 2024; Yasin et al., 2023; Teshome, 2015).

- ***Industrial areas:*** To minimize the effect of neighborhood activities upon the abattoir, polluting industries are considered especially, dust and smoke emitting industries can create chemical and other type of pollution. Abattoir should be situated at least 300 meters from dust emitting industries.

- ***Waste dump sites (landfill):*** A waste dump site, often referred to as a landfill or dump, is an area designated for the disposal of waste materials generated by human activities. These sites are carefully managed to control the impact of waste on the environment and public health. Waste dump is considered mainly from hygienic point of view. Abattoir should be located at least 500 meters from waste dump site and 300 meters from dust emitting industries.
- ***Social services:*** In order to avoid the disturbance of sounds generated from the abattoir and the odor that can significantly affect the society, the site should be located at least 300 meters from social services (health services, schools, worship places and recreational areas).
- ***Airport:*** Abattoir practices produce a lot of wastes such as, bone and flesh which attract a number of birds (Scavengers); therefore, an abattoir must be away from airports to prevent bird menace to aircrafts. Hence, an abattoir must not be located within 6 kilo meters of an airport.
- ***High- tension power line:*** In order to alleviate or avoid possible accidents that could be encountered because of big flying birds (e.g. scavengers) hovering over the abattoir, the site should be at least 500 meters from high-tension power lines.

There are no set criteria for choosing a slaughterhouse's location, but for the majority of the factors in a given study, credible explanations such as environmental restrictions and the potential of each location make it imperative to revisit the criteria (Fard and Zahraei, 2012). According to Fard and Zahraei, (2012), the following articles could be reviewed in order to find a suitable location as preliminary action and instruction:

- **Location relative to the city:** The site location should be place out of the city limits. Moreover site selecting must not be on the way of the city development.
- **Distance to the city:** The legal distance from a large slaughterhouse to a town border is around 6 km, for a middle size one is 3km and for small ones is considered 2 Km.
- **The position in relation to communication roads:** The site could be located near to one of the arterial roads or a broad link to the arterial road. In cities that are located on the railway track, it is more accurate to choose a place for slaughterhouse near the railway and if it possible create a branch line to be observed.

- **Slope:** The best place to build abattoir would be somewhere below city level to reduce contamination from spreading.
- **Prevailing winds:** It must not situate on the way of prevailing wind. This may reduce the diffusion of bad smell into the city. The main concern is to relieve possible negative impacts that the abattoir can pose on the surrounding environment and vice versa.
- **Required water:** Abattoir Construction should take place in a location where access to the necessary water is possible. Tap water is not advised because of the excessive water intake. Drilling deep or semi-deep wells is ideal for this purpose.
- **Waste water treatment:** The location should be such that wastewater treatment and disposal are prepared. To that end, the following ideas are suggested in order to accomplish this goal: A city with a sewage system should choose a location such that the effluent from the slaughterhouse does not enter the system. After the slaughterhouse's wastewater is treated, the waste water may be dumped into a river if the city does not have a sewage system and the slaughterhouse is located close to river. If there is not a river, the effluent from the slaughterhouse should be purified after making sure that the leftover water is used for agriculture on nearby areas.
- **Location of polluting industries:** Dust, smoke, ash, and other pollutants from industrial processes should not be seen in slaughterhouses.
- **Access to electricity network:** When it comes to a slaughterhouse's need for energy, the location of the facility must be someplace where using the power system is allowable by law. Although using a generator rather than a power network to provide the necessary energy in big slaughterhouses is possible, it is not advised unless absolutely necessary.
- **Future land use:** The final factor considered in determining a candidate site's viability for an abattoir is the area's intended future land use. To reduce the site acquisition costs, it is ideal for the slaughterhouse location to be on agricultural or unoccupied property.
- **Site Capacity:** Nearly one hectare of land should be found to accommodate all the necessary components of the abattoirs (LMA, 2000).

2.6. Geographic Information System (GIS) in Suitable Site Selection

The assessment of site suitability is a multi-criteria issue that involves the simultaneous presence of various competent factors. Geographic Information System (GIS) facilitates decision makers' work by offering tools for spatial analysis that are especially well-suited for overlay analyses of several relevant factors (Yasin et al., 2023). Geographic Information Systems (GIS) have become indispensable tools in spatial decision-making processes. Several studies have successfully applied GIS techniques to various aspects of site selection, emphasizing the importance of spatial analysis, data integration, and visualization. According to studies by Kao et al., (1996) and Oyinloye, (2013), GIS is an effective tool for site selection because it can handle huge amounts of spatial data from several sources. They concluded from their study that GIS can handle a lot of geographic data, potentially saving time that might be needed for selecting a suitable location.

A research by Imtiaz and Abd Nasir, (2011) noted that the Geographic Information System has shown to be useful and efficient when used to identify appropriate land for a certain service allocation on a global scale. According to a study by Kabite et al., (2012), GIS is helpful in choosing landfill sites because of its special ability to conduct an integrated analysis of spatial and attribute data to automatically produce maps that when further analyzed and/or investigated in the field, yield a number of candidate sites, thus reducing out on the process's time and expense. A study titled "GIS Based Multi-Criteria Analysis for Industrial Site Selection" was carried out by Rikalovic et al., (2014). The study highlighted the importance of Geographic Information Systems (GIS) as a tool for geographical analysis, offering the capacity to acquire, archive, query, examine, present, and generate geographic data. They thus have a significant impact on the process of making spatial decisions. Chukwuma et al., (2021) employed Geographic Information System (GIS) to analyze the location of a biogas plant. According to their research, the use of GIS as a suitable tool for site suitability studies is a positive indicator that the tool can address location-related problems.

Globally, geographic information systems (GIS) are used to carry out the process of selecting sites for various purposes, including management and precisely locating urban infrastructure, such as industrial slaughterhouses or abattoirs. For abattoir site selection, GIS facilitates the identification and assessment of relevant criteria such as proximity to markets, transportation infrastructure, environmental constraints, and socio-economic factors. In a study by Chandel et al., (2024), GIS was employed to develop a spatial model for abattoir site selection in Adola Woyu town, Ethiopia, demonstrating the significance of considering both spatial and non-spatial factors. The study highlighted the ability of GIS to streamline the decision-making process and optimize resource allocation. Furthermore, in a study by Fard and Zahraei, (2012), the use of GIS was substantial in evaluating the existing abattoir of the study area and in identifying a new location for future development by considering economic, social and environmental factors. Moreover, GIS have the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. It has also the ability to integrate variety of geographic technologies like GPS, Remote Sensing etc. Thus, GIS is considered as a kind of decision support system in which spatially referenced data are integrated in a problem solving environment. Urban living generally faces several difficulties on a daily basis, including traffic and pollution, limited access to public services, and other issues that are addressed by the planning process, which is facilitated by GIS technology and is quicker, more effective, and of higher quality.

2.7. Multi-Criteria Decision Analysis (MCDA/MCDM)

Multi Criteria Decision Making (MCDM) is one of the most important fields of operations research and deals with the problems that involve multiple and conflicting objectives. It is obvious that when more than objective exists in the problem, making a decision becomes more complex. MCDM is both an approach and a set of techniques, with the aim of providing an overall ordering of options, from the most preferred to the least preferred option (Oguztimur, 2011). MCDM approaches provide a systematic procedure to help decision makers choose the most desirable and satisfactory alternative under uncertain situation (Cheng, 2001).In order to get information for decision making, MCDA is a procedure that integrates and transforms spatial data with the preferences of the decision maker. According to Saarikoski et al., (2016), Multi-Criteria Decision Analysis (MCDA) is a general framework for supporting complex decision-making situations with multiple and often conflicting objectives that stakeholders groups and/or decision-makers value differently. GIS-based MCDA is a method that merges and converts spatial and non-spatial data into a final decision (Malczewski, 2006). The integration of MCDA principles with GIS enhances the decision-making process by systematically considering multiple criteria and their respective weights.

MCDA methods like Analytical Hierarchy Process (AHP) and Weighted Overlay Analysis have been utilized in site selection studies across various domains. In a notable study by Chandel et al., (2024), AHP was utilized to prioritize criteria for abattoir site selection, taking into account environmental, economic, and social factors. The study emphasized the importance of stakeholder engagement in determining the relative importance of criteria, showcasing the flexibility of MCDA in accommodating diverse perspective. Land suitability primarily focuses on analyzing a vast amount of multifactor data. Berry, (2004) has carried out a study to determine Least Cost Path (LCP) procedure. 20 criteria were used to calibrate weights by the AHP procedure. Hill et al., (2005) also used a spatial implementation of the Analytic Hierarchy Process (AHP) extensively for MCDA in assessment of catchment condition for the intensive land use zone of Australia. The conventional land suitability analysis method known as the Analytic Hierarchy Process (AHP) provides a systematic approach to choose a suitable location. For site selection, it also recommends incorporating the GIS-based land suitability model (Mendoza, 2000; Chandio et al., 2012). By breaking down, dividing, and comparing numerous attributes, the AHP reduces cognitive errors. It can specifically compare both quantitative and qualitative indices. Selection, assessment, resource allocation, conflict resolution, prioritization and ranking, and optimization are just a few of the many domains in which it finds widespread use (Song and Kang, 2016). According to Mendoza, (2000), comparing AHP to traditional site suitability analysis methods reveals the following benefits. First, it offers a structured approach to quantify suitability by breaking down the suitability analysis problem into levels and hierarchical components. Secondly, AHP is more dependent on the observations or a view of ―experts‖ regarding the many factors and their apparent impacts on site appropriateness than it is on the completeness of the data set. Thirdly, the technique is more transparent, which increases the likelihood of acceptance, particularly in cases where the suitability study is the final foundation for land distribution. Fourth, AHP enables experts and stakeholders to contribute to the determination of a site's suitability for a proposed land use. Hence, analytic hierarchy process (AHP) was used for weight derivation of the criteria for this study analysis and all the factor maps were combined using weighted over lay analysis tool in ArcGIS to produce the final abattoir suitability map.

2.8. Remote Sensing (RS) Application in Suitable Site Selection

Remote Sensing technologies, including satellite imagery and aerial photography, provide valuable spatial information for site selection processes. These technologies offer real-time and historical data for land cover, land use, and environmental conditions, contributing to a more accurate assessment of potential sites. Remote sensing technology is capable of providing up-to-date geographic information on land-use/ land-cover patterns useful as input data in the task of site selection (Abbas and Ukoje, 2009). Remote sensing data can provide detailed topographic information, including slope, aspect, and elevation. This is important for selecting sites with suitable terrain to ensure proper drainage and prevent environmental issues. Remote sensing is used for assessing environmental impacts; it plays a significance role in assessing the environmental impact of abattoir activities. By analyzing vegetation indices and land cover changes, potential impacts on ecosystems and water bodies can be evaluated.

The process of using satellite imagery to extract criteria for abattoirs, such as land use and land cover identification, is one of the applications of remote sensing for slaughterhouse site suitability analysis. Distinct research papers have employed remote sensing in various ways to identify abattoir sites. A study by Yasin et al., (2023) exemplifies the integration of Remote Sensing in abattoir site selection by incorporating land cover data to identify suitable areas and assess environmental impacts. The research highlighted the capability of Remote Sensing to provide timely and cost-effective data for decision-making. A study named "GIS and remote sensing-based site suitability analysis for a new abattoir" was conducted by Chandel et al., (2024). They have described from their research how remote sensing technologies, including satellite imaging, help with monitoring current circumstances and spotting possible problems.

2.9. Integration of Geo-spatial technology for Site Suitability Analysis

Geo-spatial technologies are central to achieving a successful transition from traditional environmental and resource management practices to sustainable development because of their integrative quality of social, economic and environmental data and their addressing quality in relationship among places at local, national, regional and global levels (Fikadu, 2011).While individual applications of GIS, MCDA, and Remote Sensing have proven beneficial, recent research advocates for integrated approaches that capitalize on the strengths of each technology. Dong et al., (2008), for example, conducted an integrated assessment of urban development suitability using remote sensing and GIS techniques. In places where ground data are not readily available, GIS and remote sensing can offer a vast amount of relevant data in spatial and temporal resolutions (Abushandi and Alatawi, 2015). Forzieri et al., (2008) evaluated the suitability of sites for the construction of small dams with the intention of storing water in arid regions using GIS and remote sensing techniques.

Furthermore, GIS and Remote Sensing are widely recognized as essential tools for managing, analyzing, and displaying vast amounts of data in local and regional planning activities (Pareta, K. 2013). Using GIS and multi-criteria decision analysis for various objectives from various perspectives has resulted in the achievement of numerous researches. For example, Wei and Ding, (2015) conducted a study in China to choose housing development locations using GIS-based multi-criteria decision analysis (GIS-MCDA). Multi-criteria decision making with in the GIS environment by integrating various thematic layers is found to be helpful in determining appropriate sites suitable for industrial development like abattoir (Reta and Deresso, 2021). For instance, the study by Yasin et al., (2023) demonstrated the synergy of GIS-based MCDA and Remote Sensing in a comprehensive site selection model, emphasizing the need for a holistic approach to address the complexity of abattoir site selection. According to a study by Chandel et al., (2024), decision-makers will have access to precise and current information about the suitability of possible abattoir sites by using remote sensing and GIS-based MCDA approaches.

Despite the advancements in GIS, MCDA, and Remote Sensing applications in abattoir site selection, there remains a notable gap in the literature regarding the simultaneous integration of these technologies. Few studies have systematically combined GIS-based MCDA with Remote Sensing to develop a comprehensive decision-making framework for abattoir site selection. While individual studies have contributed valuable insights, a comprehensive integration of these technologies is essential to address the complexity of decision-making in this domain. The present study aims to fill this gap by developing a GIS-based MCDA model that incorporates Remote Sensing data for a more robust and informed abattoir site selection process.

3. Materials and Methods

3.1. Descriptions of the Study Area

3.1.1. Location

Mekelle is the capital city and commercial center of the Tigray National Regional State in the northern Ethiopia (Figure 3.1). Mekelle is one of the fastest growing and the second largest city next to the capital, Addis Ababa. The city is located at about 783 km north of Addis Ababa between 13° 25‘ 24‖ and 13° 33′ 44‖ N and 39° 25′ 26‖ and 39° 33′ 14‖ E. The City Mekelle was established as a national capital during Emperor Atse Yohannes the 4th era in 1864 E.C and got its urban structure during his region. It is situated in the extension of the northern highlands of Ethiopia. The area of the city under study covered about 321.32 square kilometers (32132 ha). The city has seven sub-cities, which are divided into about 33 Kebeles (Figure 3.1). Mekelle is a rapidly growing city with a substantial workforce, serves as the commercial hub for northern Ethiopia. Mekelle boasts a vast commercial market and excellent connectivity to Eritrea and Djibouti's Red Sea port. Ethiopia's pro-business policies and numerous manufacturers as well as educational centers have already made Mekelle their home due to its numerous advantages.

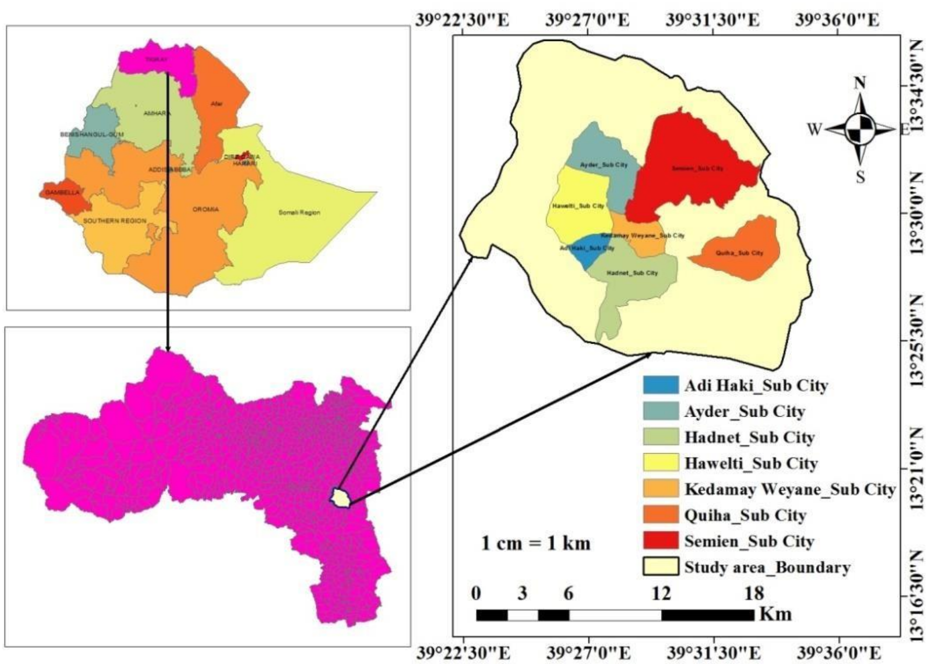

Figure 3.1: Location map of the study area

3.1.2. Population

With a population of approximately 611,574 in 2024 (UN World Urbanization Prospects), Mekelle is the second-largest city in Ethiopia and the economic, cultural, and political center of the Tigray region. Like many other urban areas across East Africa, Mekelle has grown rapidly in recent decades, with an average growth rate exceeding 4.11 % annually (UN World Urbanization Prospects). Mekelle City has experienced significant population growth and urban expansion in recent decades. The rapid population growth of the city has prompted the construction of haphazard settlements and urban expansion, which has resulted in the eviction of farmer households and the provision of inadequate compensation. These developments emphasize the necessity for better land administration and management strategies in Mekelle. The United Nations World urbanization Prospects predict that Mekelle is expected to have a population of 611,574 in 2024 and will rise to 952,550 by 2035. From the historical growth rate, Mekelle had 14,107 residents in 1950; over the past year, the population has increased by 24,167, or 4.11% annually. The most recent edition of the UN World Urbanization Prospects provides the population estimates and projections. These figures refer to Mekelle's urban agglomeration, which normally consists of the city's population as well as surrounding suburban areas.

3.1.3. Topography

Mekelle City is bordered by hills to the north and east, and relatively flat terrain to the south and west (Figure 3.1). Mekelle is situated at the base of the Choemea and Bubu Hills, which form a triple watershed between the Tekeze and Danakil rivers. The Choemea Ridge to the east is the highest point in the city. The catchment of city drains into the Tekeze River basin. The altitude varies from 2458 meter at eastern side to 1793 meter above sea level in the North Western side of the city (lower reach of Elala River). The city has an overall tilt from Eastern to Western and North Western side. Most streams and tributaries are controlled by this tilt while others are controlled by geological structures and underlying geology.

3.1.4. Climate and Hydrology

The northern star, Mekelle City, has an effective temperature between 14°C and 20°C that can be classified as "Woyna Dega" (temperate) region (Ethiopian Mapping Agency, EMA, 1981). Thus, the average temperature feels comfortable for most of the time. The city experiences a long dry season and summer-rain season. May is the hottest month while December is the coldest month. The rainy season is characterized by erratic, unreliable, and uneven distribution. The average annual rainfall ranges from 400mm to 800mm and greater than 80% of the rainfall is received in the Monsoon season (June-August). The temperature of Mekelle varies from place to place and as elevation increases the temperature decreases. It has a moisture index (P/ET) ranging in between 0.25 and 0.5, which indicates moderately dry area. The city is also characterized as windy where the wind has two major directions, west-east during spring and east-west during the winter season.

The hydrological/catchment setup is characterized by spares flow downstream, from places of high elevation towards the area with flat topography where the tributaries join Geba River then to Tekeze River. Elala and Aynalem Rivers are the perennial streams and major tributaries of the Giba River. The Elala River drains the central plain whereas the Aynalem River drains the south of the potential zone. The two rivers facilitate the surface drainage system of the city that contributes to irrigation and it is also good for wastewater collection by gravity.

3.1.5. Transportation

Mekelle has a developing transportation infrastructure that plays a crucial role in its accessibility. The city is well-connected by a network of major highways, notably linking it to Addis Ababa, which supports both regional and national travel. Mekelle's road network includes various local roads that facilitate movement within the city, although road conditions can vary, with some areas needing maintenance. Public transportation in Mekelle includes buses operated by both private and government entities, providing affordable options for residents and visitors. Shared taxis and minivans are common for shorter trips, offering flexible travel within the city. Although rideshare services are limited, local transportation options are available to meet the needs of the population. Mekelle Airport serves as the primary air travel hub, connecting the city with Addis Ababa and other regional destinations, which is crucial for both business and personal travel. Historically, rail transport also played a role, but current services are limited. Efforts to improve transportation infrastructure, including road expansions and better public transit options, are ongoing to address the challenges of congestion and varying road conditions, enhancing the city's accessibility and supporting its growth.

3.1.6. Economy

Mekelle serves as the regional state of Tigray's economic center. Fertile farmlands to the south, substantial mineral deposits to the east and west, and a variety of tourist attractions are all located within a 100-kilometer radius of the city. The biggest cattle and salt markets in Ethiopia are reportedly found in Mekelle. The city is home to several animal-related businesses and is well-known for the excellent leather made from sheep and goats raised nearby. Additionally, it hosts one of Ethiopia's biggest cement plants. Spices and premium honey are some examples of potential export goods that utilize regional resources. There is land accessible nearby for horticul ture and floriculture, which are becoming more and more important as sources of foreign exchange. The city also has a well served industrial zone, primarily for export oriented enterprise s or those pursuing import substitutions. Micro and small businesses play a major role in the city' s economic activity. Most of the population is dependent on informal businesses.

3.2. Research Methodology

3.2.1. Data Acquisition

In this study, both the primary and secondary data were gathered from different sources. The data used and their source is illustrated in the table below (Table3.1):

Table 3.1: The data used in the study and their source

Data	Source of Data	Purpose
Satellite image of 2023 (Landsat 8-OLI/TIRS) (30m)	https://earthexplorer.usgs.gov/	LU/LC classification
SRTM DEM (30m)	https://earthexplorer.usgs.gov/	To generate elevation, slope and streams
Base map of Mekelle the city	Municipality	For extraction of criteria maps like roads, social services, industrial areas, high tension lines, airport, landfill sites etc.
Boundary map	Municipality	To delineate the study area
Handheld GPS Data	Field survey	To identify location of targeted existing urban facilities and to collect ground control points

3.2.1.1. Primary Data

Primary data includes the field data collection using different instruments like Global positioning system (GPS) and interviews of experts and local residents. The spatial data were collected using handheld GPS instrument in field. These include the locations of existing abattoir, waste dump site, airport and the ground control points (GCPs) collected for accuracy assessment. Direct and indirect, unstructured interviews were conducted with the experts and stakeholders during the field survey to gather more information. Using the data from this study, priority criteria and other considerations for choosing an abattoir site were determined and developed. Additionally, it served to rank the possible abattoir locations in the study area and to identify issues within it. In addition to this, the experts provided valuable insights on the current infrastructure and land use patterns in Mekelle city. This information was crucial in determining the feasibility of establishing abattoir service and ensuring its compatibility with the existing urban fabric. Furthermore, the interviews clarified the social and environmental effects that must be taken into account when choosing a location for an abattoir, assisting in the development of a more thorough decision-making process.

3.2.1.2. Secondary Data

The main sources of secondary data were unpublished or published publications, legal document s, a strategic plan, and satellite images of the study area. Different secondary data types were collected from different sources. The city municipality contributed by providing the secondary data, which included boundary maps and a structural plan or base map. The land use and cover information from the satellite image of 2023 at 30 meters resolution and census-based demographic information are among the secondary data used in this study analysis. The secondary data also includes studies and reports from other research organizations and institutions that addressed related urban planning and development as well as abattoir challenges or topics. These sources enhanced the primary data gathered for the study with insightful observations and analyses. For the purpose of getting digital elevation models (DEM) and satellite imagery from the US Geological Survey's Landsat program, the web searches proved especially beneficial. These data sources improved the research of urban planning and development patterns and abattoir site suitability modeling by offering crucial spatial and visual data. Furthermore, the review of previous research contributed to the development of the study's theoretical framework and offered a more comprehensive explanation of the results.

3.2.2. Software and instruments used for the Study’s Analysis

ArcGIS 10.7 software from ESRI was used to create, update, overlay, and visualize the thematic maps based on the site suitability assessment for the abattoir. Using GIS to overlay thematic layers and generate land databases requires first converting each layer map into a common coordinate system. The advanced spatial analyst extension in Arc Map 10.7 was utilized for proximity analysis, reclassification, and map and visual production. It was also used for report creation and statistical manipulation. Arc Map 10.7's spatial analyst update also made it possible to calculate proximity and distance measurements, which helped find suitable sites for the abattoir. In addition, Google earth Pro was used for the execution and validation of the accuracy assessment of the classified LU/LC map which portrays different LU/LC classes. The resulting maps and graphics gave the site suitability analysis a clear visual representation, which helped project stakeholders make well-informed decisions. Microsoft Word, Excel, and PowerPoint were among the additional software programs utilized in this study. These software applications served as tools for organizing, analyses, and presenting data. The research report was written and formatted using Microsoft word and data manipulation and statistical computations were performed using Excel. In order to properly communicate the study's findings, PowerPoint helped create visually appealing presentations. Global Positioning System (GPS), digital camera, and compass were the instruments used to collect field data and navigate site direction. Handheld GPS was utilized to accurately collect the coordinates of each data point, ensuring precise location information. The field site was visually documented using the digital camera, which captured photos that could be referred for additional verification of the research. The compass was also essential in determining the direction and orientation of the field site, aiding in mapping and navigation.

3.3. Methods

3.3.1. Geo-data base creation

All the data layers used for the analysis like urban land use, elevation, slope, road, streams, land fill sites, social services, industrial area, airport and high tension lines were stored in the geo-database in order to store the collected data and the analysis results in a logical arrangement. The factors involved were evaluated according to their relative importance towards designating areas of high suitability classes and assigned weights. The classes in each factor layers also compared one another and ranked by their contribution to the output. The collected data were automated (digitized, and clipped by the study area boundary) and organized into logical groupings of the factors in the data base. Land use and land cover data were collected using a supervised classification algorithm with satellite images. The supervised classification method yielded significant insights into the geographical distribution of various land use and land cover categories in the studied area. Using this data in addition will help us spot patterns and trends that can assist us for planning and land manage more efficiently. This study categorized the factor layers into five groups:

- **Land use land cover (LU/LC):** Built-up area, agriculture, forest, shrub, vegetation, water bodies and bare land.
- **Topography:** elevation, slope
- **Accessibility:** proximity to major roads
- **Surface water:** distance to streams
- **Constraints:** Locations in terms of distance to industrial areas, social services, land fill sites, high tension lines and airport.

3.3.2. Spatial data processing and analysis

In order to choose appropriate abattoir sites, this section describes the processing and analysis of satellite images for land use/ land cover classes and the Digital Elevation Model (DEM) for generating slope and streams. This is a crucial component in abattoir site suitability modeling which involves handling and examining of geospatial data to identify the best location for abattoir facility.

3.3.3. Spatial Multi-criteria Decision Analysis (MCDA)

Decision-makers and/or stakeholder groups may have conflicting objectives that they value differently, and Multi-Criteria Decision Analysis (MCDA) provides a broad framework for enabling these circumstances (Saarikoski et al., 2016). According to Belton and Stewart, (2002), the term MCDA refers to a broad category of formal methods that aim to explicitly consider a variety of aspects when assisting individuals or groups in making important decisions. Chandel et al., (2024) also explained that, with the use of multi-criteria analysis, decision-makers can make well-informed and logical choices by considering the significance and weight of each criterion. It offers a thorough assessment that aids in determining the best option by taking into account several variables simultaneously. To put it plainly, GIS-MCDA is a process that blends and modifies geographic data with the decision-maker's preferences, or value judgments, to produce information for decision-making (Malczewski, 2006). By combining MCDM with GIS data, decision makers can consider a variety of factors when determining the ideal location for an abattoir, such as land use, proximity to residential areas, access to transportation, and environme ntal effect (Chandel et al., 2024). Determining the ideal location for an abattoir site, which has a range of economic, environmental, and social ramifications, is a typical example of a decision-making scenario supported by MCDA methodologies. The prime objective of this study was to locate a suitable abattoir site by combining geographic information system (GIS) and remote sensing applications with a multi-criteria decision-making (MCDM) technique. In order to determine the best location for an abattoir, this study utilizes multi-criteria evaluation methodologies to take into account a number of issues relating to social effects, economic viability, and environmental impact.

3.3.4. Analytic Hierarchy Process (AHP)

Analytical hierarchy process (AHP), which was first developed by Saaty in 1970‘s, integrates experts‟ opinions and evaluation scores into a simple elementary hierarchy system by decomposing complicated problems from higher hierarchies to lower ones. The AHP approach is effective at breaking down complicated issues and enables the decision-maker to incorporate both subjective and objective considerations as well as uncertainty in their decision-making processes (Saaty, 1980). This study used the analytical hierarchy process (AHP), which is typical in abattoir site selection, to determine the weights of the factors. Based on the decision maker's pairwise evaluations of the assessment criteria, AHP assigns a weight to each criterion. By using the pairwise comparison matrix, the decision-maker compares each criterion with others and determines the level of preferences for each pair of such criteria. In the method of Analytical Hierarchy process (AHP), the use of ordinal scale (1 - 9) is adopted to help in determining the preference value of one criterion against the other. Comparing the row and column criteria reveals whether the row criterion is more, less, or equal to the column criterion. The larger the weight, the more significant the related criterion is. Determining the criteria weights based on AHP pairwise comparisons method has three main steps as follows.

- The first step is to develop a matrix by comparing the criteria
- The second step is to calculate the criteria weight
- The third step is to estimate the consistency for sensitivity analysis known as consistency ratio (CR).

If the paired comparisons exhibit a consistency ratio of less than 0.1, it suggests a respectable degree of consistency, but once the CR is greater than 0.1, it shows that the pairwise comparison s are inconsistent in judgment and further analysis may be needed.

Table 3.2: The 9- point scale for pairwise comparison of the criteria

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgments strongly favor one activity over another.
7	Very strong importance	An activity is strongly favored, and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6 &8	Intermediate values	Intermediate values between the two adjacent judgments are needed when the above number requires compromise.
1/2,1/3,1/4,1/5,1/6,1/7,1/8 & 1/9	Reciprocal values	The reciprocal values have been used when the row criterion is less important than the column criterion.

Source: Adapted from Saaty, 1977

3.3.5. Buffering

Buffering refers to the creation of zones around specific features on a map within a geographic information system (GIS). These zones, or buffers, are used to analyze the spatial relationships and influence areas of these features concerning the suitability of locations for an abattoir. In this study Proximity Analysis was used to buffer social services, industrial areas, landfill sites, airport, streams/river and high tension lines to ensure the abattoir is located at a sufficient distance so as to avoid potential conflicts or nuisances (such as odor or noise). In addition, roads were buffered to enable identifying areas that are well-connected and accessible for transporting livestock and meat products. This ensures logistical efficiency and reduces transportation costs.

3.3.6. Weighted Overlay

In the context of this study, weighted overlay is a GIS-based analytical method used to combine multiple spatial data layers, each representing different factors influencing the suitability of a location for an abattoir. A final suitability map was created by overlaying these weighted layers, which were each given a weight determined by its relative importance. With the consideration of multiple factors and their relative importance, this method offers an objective and methodical approach to decision-making. Weighted overlay allows the incorporation of various spatial data layers that are relevant to abattoir suitability. These include: land use, proximity to roads, Topography (elevation and slope) and Environmental constraints. Each of the factors has been assigned a weight based on its relative importance according to different literatures which are relevant to this study as well as based on experts and stakeholders' opinion. This ensures that the most critical criteria have a greater influence on the final suitability assessment. By standardizing the data layers to a common scale, weighted overlay was used for the comparison of factors that were originally in different units and the final suitability map was produced to provide a visual representation of the most and least suitable areas for an abattoir. In this study, the weighted layers were overlaid using a simple arithmetic operation. Each cell value in the resulting raster was calculated as the sum of the products of the standardized layer values and their respective weights as bellow:

$$\text{Suitability Score} = \sum (\text{Weight}_i \times \text{Standardized Value}_i)$$

Where, Weight_i is the weight of criteria i and standardize value_i is the reclassified raster of criteria i

3.4. Conceptual Framework and Flowchart of the Study

To achieve the main goal of the study, six fundamental steps were accomplished. These include:

1) **Criteria Identification and Data Collection:** identifying site selection criteria is a critical step. This mainly focuses on identifying the key factors that influence abattoir site

suitability. These criteria can vary depending on the specific project or objective, but they generally include factors such as accessibility, land use compatibility, environmental impact, and infrastructure availability.

2) **Spatial Data Layer Preparation:** Each factor was prepared as separate spatial data to represent its corresponding layer in a GIS geo-database
3) **Standardize the Layers:** This involves reclassifying the data into a consistent range of a common scale.
4) **Assign Weights to Factors:** Each factor was assigned a weight based on its relative importance to abattoir suitability.
5) **Overlay the Layers:** The weighted layers were then overlaid using GIS software. This involves multiplying each layer by its assigned weight and summing the results to produce a composite suitability score for each location.
6) **Generate Suitability Map:** The result is a suitability map where each location has a composite score indicating its overall suitability for an abattoir. Locations with higher scores are more suitable based on the combined influence of all factors.

Generally, the detail work flow of the study is depicted in the diagram below:

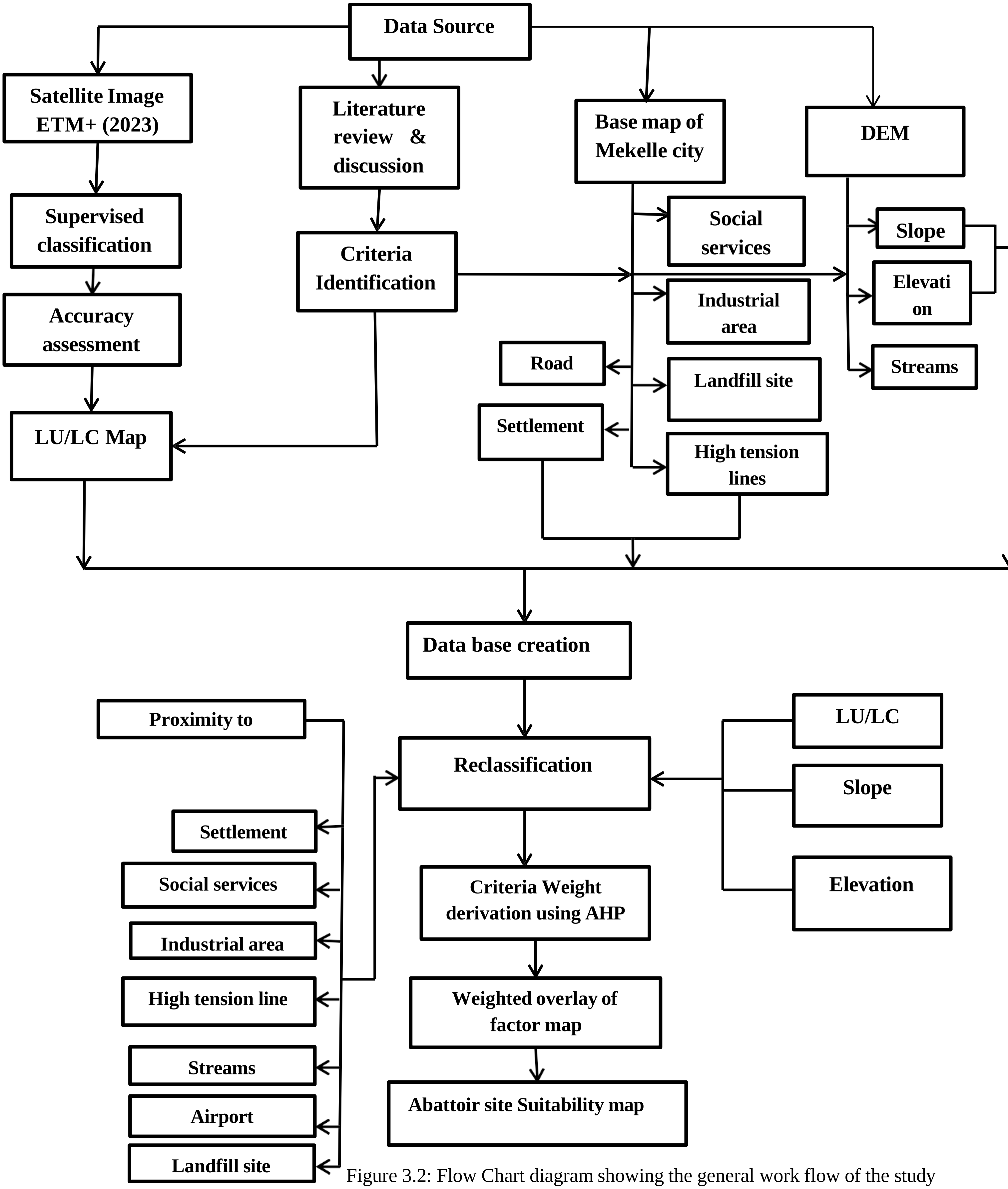

Figure 3.2: Flow Chart diagram showing the general work flow of the study

4. Results and Discussion

4.1. Criteria Identification and Description

The fundamental step in abattoir site suitability modeling is identifying and defining the criteria and constraints that will guide the analysis. This step involves a comprehensive understanding of all factors that impact the suitability of a site, which are then used to create a detailed and structured framework for evaluation. Selecting a suitable site for an abattoir involves considering various criteria to ensure operational efficiency, environmental protection, public health, and community welfare. In addition to the relevant spatial data, non-spatial data such as economic reports, demographic statistics, legal documents, and environmental impact assessments were considered while identifying the critical criteria. The criteria identified for this study are categorized as factors and constraints. The factor is a criterion which enhances or distracts from the suitability of an alternative, while the constraint is the element or feature that represents limitations. The factors considered in this study are land use land cover (LU/LC), topography (elevation and slope), accessibility (road), surface water (stream/river), whereas the constraint includes industrial areas, social services, landfill sites, high-tension lines, airport etc. A comprehensive review of literature was made to identify relevant criteria (factors and constraints) for abattoir site suitability modeling. With a common spatial reference system of WGS_1984 UTM, Zone 37 North, a map was created for each criterion based on a predefined spatial data layer. The criteria were selected based on synthesized literatures as well as experts and stakeholders‘ opinions. The criteria identified for this study are summarized and tabulated in (Table 4.1) as below.

Table 4.1: Abattoir site selection criteria

No	Spatial Data	Criteria
1	Land use	Select bare land or agricultural land.
2	Settlement	250 meters away from settlements
3	Elevation	Lower level of the city
4	Slope	Between 2-10 percent slope
5	Road network	Between 20 and 400 meters from the existing road
6	Social Service	300 meters away from social services
7	Industrial area	300 meters away from Industry
8	Landfill site	500m away from Landfill site/Waste Dump

9	River/stream	100 meters away from the rivers or streams
10	High-tension power line	500 meters away from the High Tension Line
11	Airport	It must not be located within 6 kilo meters of an air port
12	Wind direction	It must not situate on the way of prevailing wind
13	Boundary	Within municipal boundary
14	Site Capacity	Greater than or equal to one hectare
15	Future Land use	Prioritize

Source: Fard and Zahraei, (2012); LMA, (2000); EPA, (2002); Standard, (2005)

4.1.1. Land Use/Land Cover (LU/LC) Map preparation

- **Satellite image processing**

LU/LC classes were classified and analyzed using Landsat satellite images of the Landsat 8 OLI/TIRS with path and row numbers 169 and 51, respectively, acquired on October 17, 2023. The Landsat images were downloaded from United States Geological (USGS) Earth Explorer (https://earthexplorer.usgs.gov/), which is an essential tool for researchers, planners, and professionals who need access to a wide range of geospatial data for various analytical and decision-making purposes. The Landsat satellite image quality, particularly for those with little or no cloud cover, was taken into consideration while choosing the dates for the images. The Landsat image was geo-referenced to the WGS_84 datum and projected to Universal Transverse Mercator Zone 37 North coordinate system. The image was then processed in ArcGIS 10.7 software and finally it was clipped by the study area shape file using ArcGIS spatial analyst tool (extraction by mask).

- **Image classification**

Image classification can be defined as the task of categorizing images into one of several predetermined classes (Rawat and Wang, 2017). One of the most popular analyses of remotely sensed data is image classification. The primary goal of an image classification task is to create a thematic map that depicts classes of interest, like land cover, using the information the image has about the spectral response of the Earth's surface (Foody, 2008). According to Foody, (2002), there are two different kinds of image classifications: supervised which assigns cells based on how well they fit a predetermined set of spectrally specified classes, and unsupervised, which categorizes cells based on their relative spectral similarity. The classified image that results from each scenario can be used to create a thematic map that shows the region's land cover.

✓ Supervised image classification

According to (Rwanga and Ndambuki, 2017), supervised classification is where ―the user develops the spectral signatures of known categories, such as urban and forest, and then the software assigns each pixel in the image to the cover type to which its signature is most comparable‖. For this study, only supervised classification was performed. The supervised classification was accomplished after preparing training area for each land cover classes. The training sites were selected for each land cover class by using the on-screen digitizing of features. More than one training area was used to represent a particular class throughout the image. Google Earth pro was used as reference source to classify the selected points. Finally, Maximum Likelihood Classification (MLC) algorithm was used to classify the entire image based on the predetermined training sites. The land use and land cover map of the study area was categorized into seven groups with their description based on Anderson, (1976) and Rwanga and Ndambuki, (2017) as shown in the table below (Table 4.1).

Table 4.2: Land use/land covers classes of the study area and their description

No	Land use/land cover class	Description of land use/land cover classes
1	Built-up Land	Urban or built-up land is comprised of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, and villages, strip developments along highways, transportation, power, and communications facilities.
2	Agricultural Land	Agricultural land may be defined broadly as land used primarily for production of food and fiber. This includes cropland and pasture.
3	Forest Land	Forest lands have a tree-crown areal density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products.
4	Water Bodies	These are areas covered by water bodies including, lakes, reservoirs, stream, rivers, swamps
5	Barren Land	Barren land is land of limited ability to support life. In general, it is an area of thin soil, sand, or rocks.
6	Shrub Land	Lands with woody vegetation less than 2 meters tall, which is covered by small trees, bushes, shrubs, in some cases mixed with grasses less dense than forests. The shrub foliage can be

		either evergreen or deciduous
7	Vegetation Land	Vegetation land includes highly green grass lands, plants and trees collectively, typically those in a specific region.

The land use land cover map was then produced which comprises the seven land use land cover categories (Figure 4.1). According the classified image, Agriculture is the dominant land cover class which comprises the highest area coverage of 192.4 km^2 which is 59.89 percent of the study area map. Whereas, Water bodies represent the least area coverage of 0.15 km^2 which covers 0.05 percent of the study area map. The result of the classified LU/LC map (Figure 4.1) provides a visual representation of each land cover type and their percentage of area coverage throughout the map is tabulated below (Table 4.2).

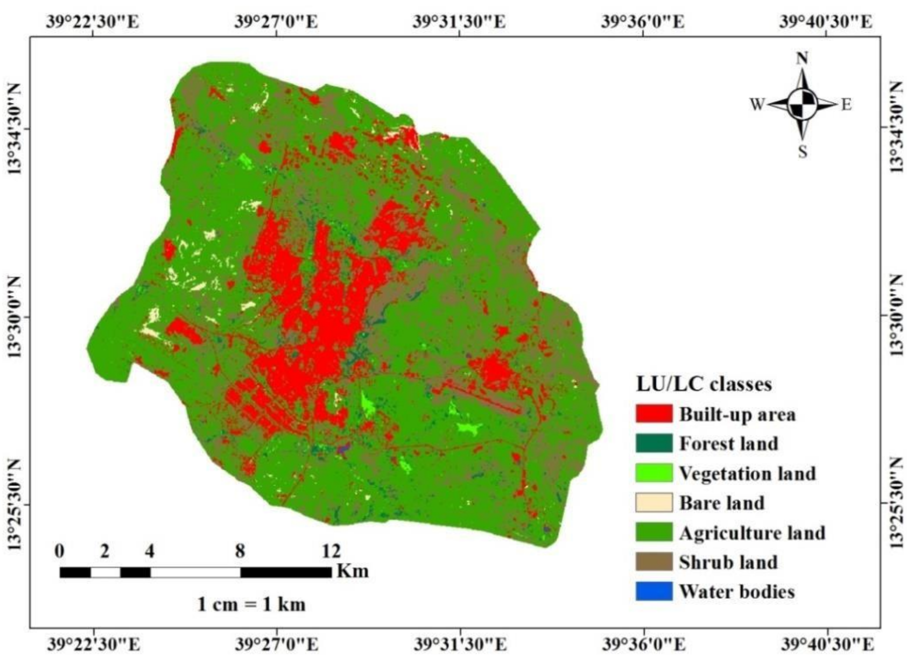

Figure 4.1: Land use/land cover map of the study area

Table 4.3: Land use/ land cover classes and their area coverage

N<u>o</u>	**Land use/land cover classes**	**Area (Km^2)**	**Area (%)**
1	Agriculture land	192.4	59.89
2	Bare land	3.26	1.01

3	Built-up area	51.95	16.17
4	Forest land	6.09	1.90
5	Shrub land	65.74	20.45
6	Vegetation land	1.73	0.53
7	Water bodies	0.15	0.05
Total		**321.32**	**100**

➢ Accuracy Assessment

Accuracy assessment is the most important stage of image classification process. Accuracy refers to the degree to which a map or classification is "corrected" in the context of thematic mapping from remotely sensed data. If a thematic map produced by classification presents an objective depiction of the land cover of the area it depicts, it could be deemed accurate (Foody, G.M., 2002). Essentially, the purpose of accuracy assessment in remote sensing analysis is to give an unbiased framework for assessing the overall quality of the thematic map that the classification output represents (Foody, 2009). Classification accuracy is, thus, generally understood to indicate how closely the resultant image classification matches reality or adheres to the "truth"(Oppenheimer, 1997; Foody, 2002). In this study accuracy assessment was carried out in order to evaluate the accuracy of the pixel sampling into the appropriate land cover classes quantitatively. The accuracy assessment technique was made through a confusion or error matrix. The pixel that has been categorized from the image was compared to the same site in the field that could be clearly identified on both the high resolution Landsat image and Google earth pro. A total of 175 reference points (appendix-2) were collected in field using handheld GPS. As indicated in the table below (Table 4.4), the result of an accuracy assessment typically yields for this study the map's overall accuracy as well as the accuracy of each class on the map.

Table 4.4: Confusion matrix of the LULC classification

LU/LC class	Built-up	Forest	Vegetation	Bare land	Agriculture	Shrub	Water bodies	
Built-up	20	0	0	1	0	2	0	
Forest	0	7	1	0	2	0	0	
Vegetation	0	0	7	0	2	1	0	
Bare land	0	0	0	10	0	0	0	
Agriculture	1	0	0	1	78	2	0	
Shrub	1	0	0	0	6	23	0	**30**
Water bodies	0	0	0	0	1	1	8	**10**
Total producer	**22**	**7**	**8**	**12**	**89**	**29**	**8**	**175**

Table 4.5: Users and producers accuracy

LU/LC class	**Users Accuracy**	**Producers Accuracy**	**Over all Accuracy**	**Kappa coefficient**
Built-up	87%	90%		
Forest	70%	100%		
Vegetation	70%	88%		
Bare land	100%	83%	87%	82%
Agriculture	95%	88%		
Shrub	76%	79%		
Water bodies	80%	100%		

According to Rwanga and Ndambuki, (2017), Kappa coefficient ranging from 0.81 - 1.00 is almost perfect. Hence, the classified image is found to be fit for further research as the kappa coefficient gained for this study is 82%.

4.1.2. Digital Elevation Model (DEM) processing

A lot of terrain features can be accessed from the DEM data including slope, aspect, contour, watershed, etc. Among all of them, terrain slope seems to be the most important features for abattoir site suitability analysis. According to LMA, (2000), places with slope greater than 10% are not suitable for abattoir site and the flatter the better. The elevation map of the study area is depicted in (Figure 4.2) and the terrain slope map was calculated using ArcGIS raster surface analysis tool (Figure 4.3).

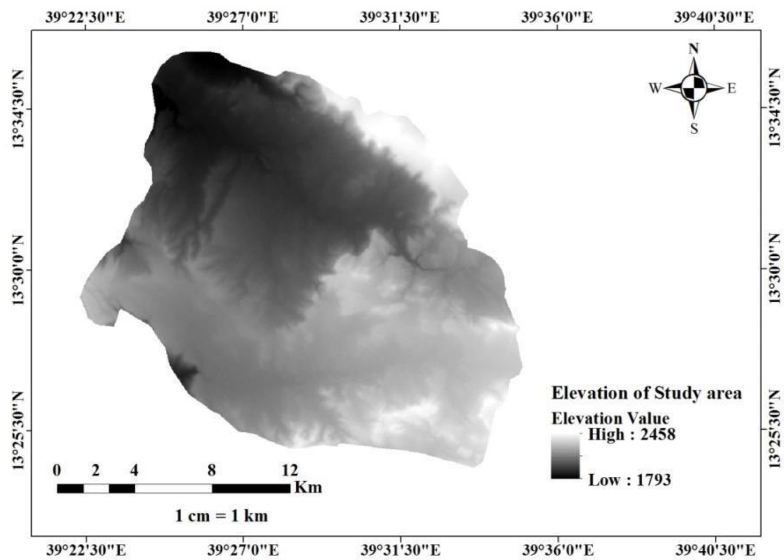

Figure 4.2: Elevation map of the study area

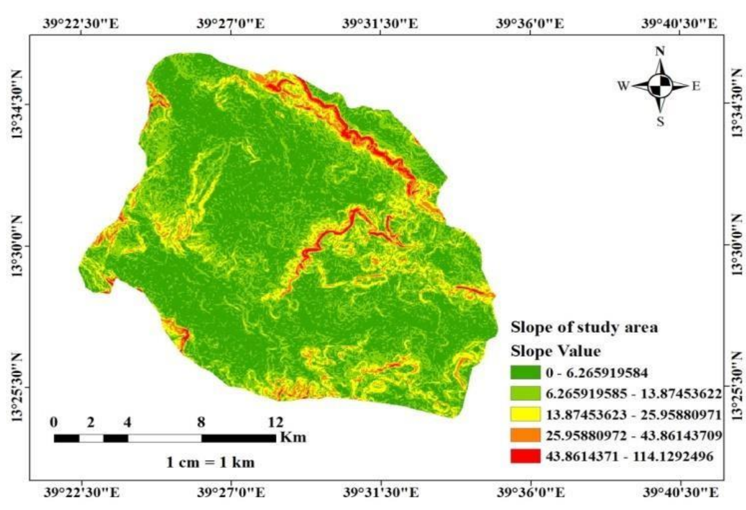

Figure 4.3: Slope map of the study area

4.2. Standardization of criteria Maps

The main focus of criteria standardization is converting various criteria or factors, which might be measured on different scales or units, into a common scale to allow for meaningful comparison and combination. This is an essential step in multi-criteria decision analysis (MCDA) used to determine the suitability of different locations for abattoirs (slaughterhouses). It is not possible to compare the factors and constraints based just on their raw scores because they have distinct measuring scales. Thus, the factor maps were standardized to enable comparability. Standardization makes it possible to compare criteria scores within a single alternative. Therefore, the raster features of all the factors and constraints were reclassified into a common scale range. This common scale range ensures that the values of all the factors are consistent and comparable. Reclassifying the raster features into the same scale range makes data analysis and interpretation easier and allows for more precise decision-making. Accordingly, all the factors and constraints were reclassified in to four common scales which represent the level of suitability of the corresponding factor or constraint as unsuitable for scale 1, moderately suitable for scale 2, suitable for scale 3 and highly suitable for scale 4.

4.2.1. Land Use/Land Cover (LU/LC)

Primarily, the land use and land cover map of the study area was developed using a satellite image of Landsat 8 ETM+ acquired on October 17, 2023, which comprises seven categories, namely: built-up area, agriculture land, forest land, vegetation land, shrub land, bare land, and water bodies. Then each of the land use and cover types was reclassified into four classes based on their importance to evaluate the suitability of abattoir site. According to Yemane and Mekelle, (2016), formerly undeveloped, vacant land is typically the ideal location of newly constructed abattoir facilities. It is necessary to select the abattoirs location in an area that is close to animal farms and as far from residential areas, schools, hospitals, and other sensitive areas as possible to minimize potential environmental impact, mainly odour and potential respiratory problems. The ―Code of Environmental Practices for Slaughterhouse Development‖, COEP, (2011) also emphasized that, to minimize impact on inhabitants and to prevent the need for land acquisition and the need for resettlement of inhabitants, every effort should be made to locate the proposed site and associated roads on government land that is not currently leased nor inhabited whether legally or illegally.

Table 4.6: Reclassified land use and their suitability level

Land use class	**Value**	**Level of suitability**
Built-up area and water bodies	1	Unsuitable
Forest and shrub land	2	Moderately suitable
Agricultural and vegetation land	3	Suitable
Bare land	4	Highly suitable

Thus, bare land was classified as highly suitable followed by agricultural and vegetation land as suitable, forest and shrub land as moderately suitable and finally built-up area and water bodies as unsuitable as we couldn‘t construct an abattoir facility on water bodies. In addition, the high preference of bare land over built-up area ensures minimizing the impact of abattoirs on the surrounding environment including social services, industrial areas and residential areas more importantly. Furthermore, since there is plenty of demand for infrastructural development, the designation of "bare land" permits the growth of abattoirs in the future, ought to the need arise. This makes sure that the abattoirs can adjust to the growing needs of the meat industry without altering the status or intruding into already-existing urban areas. The result of the reclassified land use/cover map is depicted in Figure 4.4.

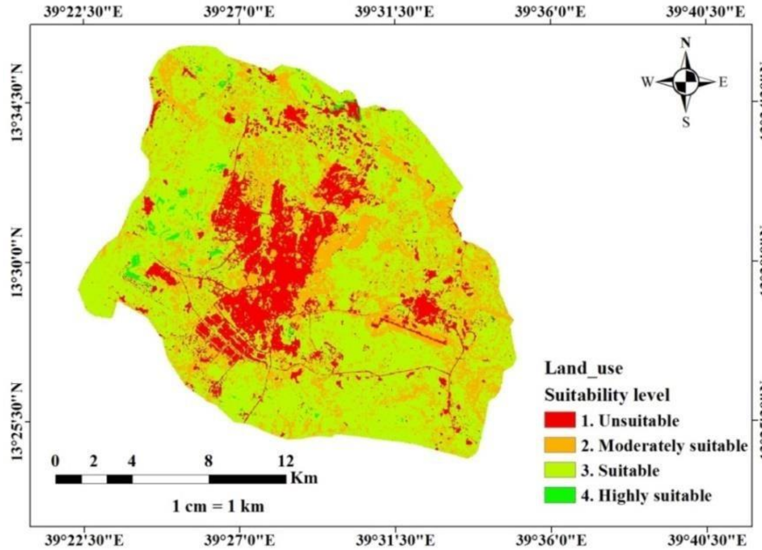

Figure 4.4: Reclassified land use map

4.2.2. Settlement

The abattoir should be located at a reasonable distance from residential areas to reduce the impac t of noise, odors, and potential pollution. A minimum of 250 meters distance should be considere d to separate the abattoir from residential and administrative areas, and commercial places (EPA, 2002). A minimum of 250 meters distance was thus considered to buffer the settlements.

Table 4.7: Reclassified distance from settlement and their suitability level

Buffer distance of Settlement (m)	Value	Level of suitability
<250	1	Unsuitable
250-500	2	Moderately suitable
500-750	3	Suitable
750-2600	4	Highly suitable

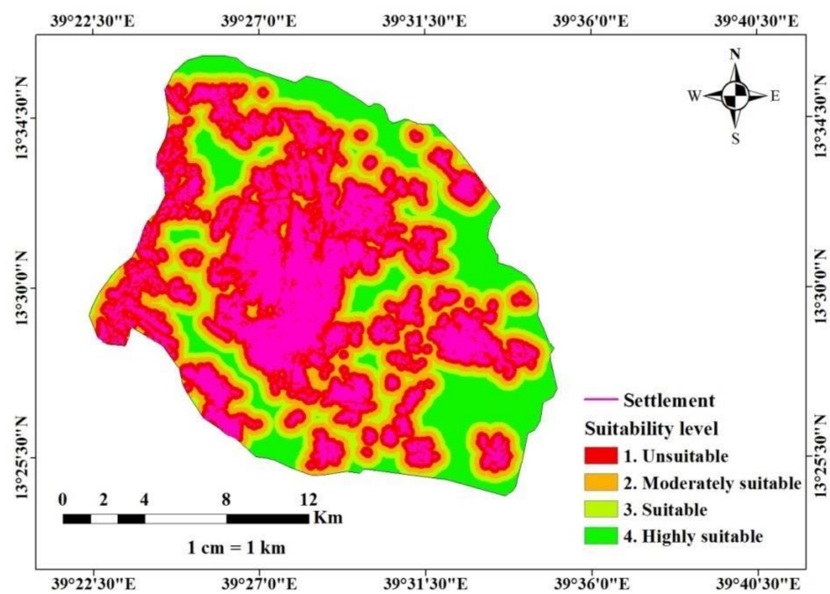

Figure 4.5: Reclassified settlement map

4.2.3. Elevation

Primarily, the elevation factor was generated from Aster digital elevation model (SRTM DEM). It was processed in Arc GIS 10.7 and classified using ArcGIS spatial analyst extension of surface module based on the elevation level of the study area. The elevation raster was then reclassified in to four classes by examining the value and the frequency of elevation in the study area.

Table 4.8: Reclassified elevation and their suitability level

Elevation (m)	Value	Level of suitability
2036-2458	1	Unsuitable
2024-2036	2	Moderately suitable
2014-2024	3	Suitable
1793-2014	4	Highly suitable

According to Fard and Zahraei, (2012), the best place to build abattoir would be somewhere below city level to reduce contamination from spreading. Accordingly, areas with high altitude were classified as unsuitable, whereas areas with low altitude were classified as highly suitable. The highest elevation of the study area was 2458m and the lowest elevation was 1793m. For abattoir facility it is recommended to construct in the lowest level of the city. Hence, the regions of higher elevation were classified as unsuitable whereas regions of lower elevation were classified as suitable as shown in (Table 4.8). The resulted reclassified elevation map is depicted in the figure below (Figure 4.6).

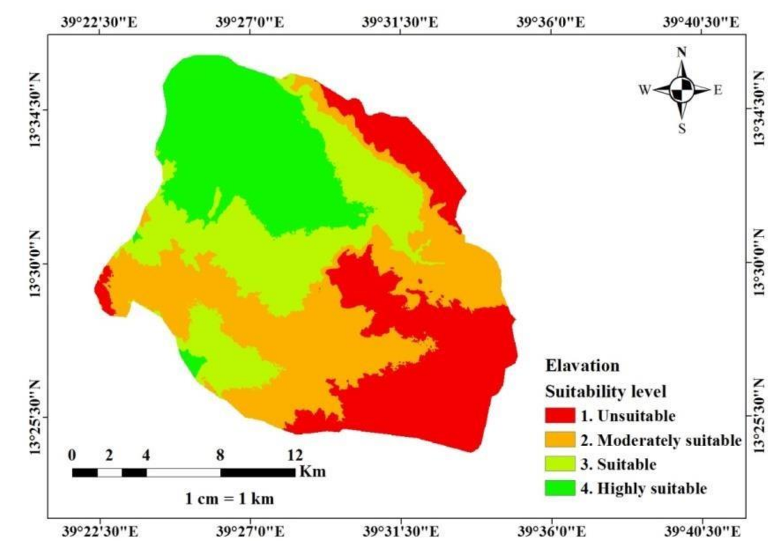

Figure 4.6: Reclassified elevation map

4.2.4. Slope

For abattoir suitability modeling, the slope of the land is an important factor to consider. In this study, a slope factor was generated from the digital elevation model (DEM) using the ArcGIS spatial analyst extension of the surface module, enabling us to classify the region according to how level and steep the landscape is. The slope should be neither too steep nor too flat in order to provide adequate drainage of wastewater and rainwater, preventing water from pooling around the facility. According to LMA, (2000), the recommended ideal slope for an abattoir site is a gently sloping region with a range of 2 to 10%. This range ensures proper drainage without causing erosion or runoff problems. A slope that is too steep can lead to excessive runoff and potential contamination of nearby water sources. As a result, the study area's slope was reclassified in to four classes (1 up to 4) based on their slope percent value, and its suitability level was assigned. As shown in the table below, if the slope percent value is high, the suitability level will be unsuitable, and vice versa. The highest slope of the study area was 111 percent, which represents the steep slope of the region and was then classified as unsuitable locations for an abattoir facility. The slope value below 10 percent was classified as suitable area for abattoir location.

Table 4.9: Reclassified slope and their suitability level

Slope (%)	**Value**	**Level of suitability**
>30	1	Unsuitable
20-30	2	Moderately suitable
10-20	3	Suitable
2-10	4	Highly suitable

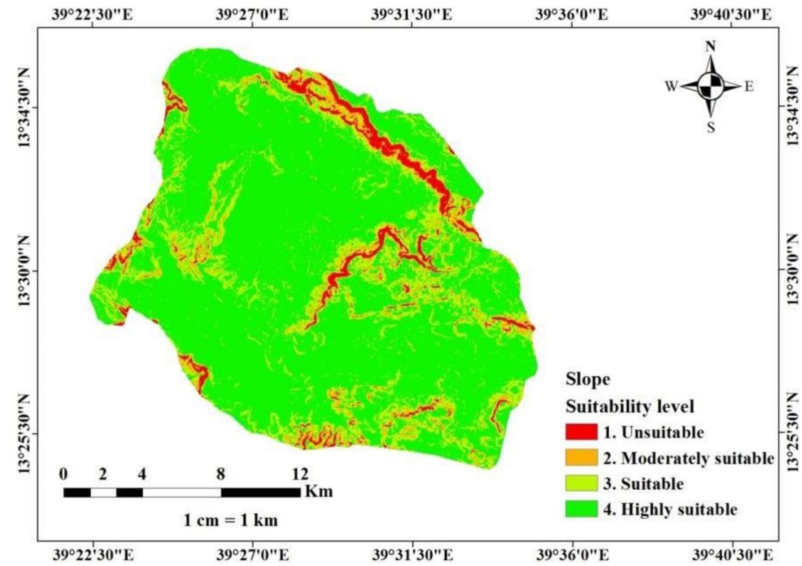

Figure 4.7: Reclassified slope map

4.2.5. Road

The selection of an abattoir site is a critical decision that involves various factors, with road access being one of the most important. Efficient road access allows for the timely distribution of meat and meat products to markets, retailers, and customers. Sites with existing road infrastructure offer better potential for future expansion and increased production capacity. Efficient road access plays a pivotal role in the overall success and sustainability of an abattoir operation. In this study, buffer zones have been created by taking distances between 20 to 400 meters from the existing major roads in order to find out better accessibility to the existing road and suitable accessibility map was generated. This accessibility map might assist in locating possible locations for animal slaughterhouses and meat processing plants that are handy to main roads. The buffer distance zones have been reclassified into four levels according to the degree of closeness to the abattoir location. As a result, the shorter buffer distances were considered highly suitable, whereas the longer buffer distances were considered unsuitable. Thus, road buffers that were deemed extremely suitable were assigned a rank value of four, while those that were deemed unsuitable were assigned a rank value of one (Table 4.10).

Table 4.10: Reclassified distance from roads and their suitability level

Buffer distance of Roads (m)	Value	Level of suitability
>1200	1	Unsuitable
800-1200	2	Moderately suitable
400-800	3	Suitable
<400	4	Highly suitable

Planning and resource allocation can be achieved more efficiently by classifying buffer distance zones according to how close they are to the abattoir site. This reduces the possibility of contamination or spoiling by ensuring quick and safe transportation of meat products. Furthermore, the overall quality of the supply chain can be further improved by successfully mitigating potential transportation-related risks and issues by classifying longer buffer distances as unsuitable and shorter buffer distances as highly suitable.

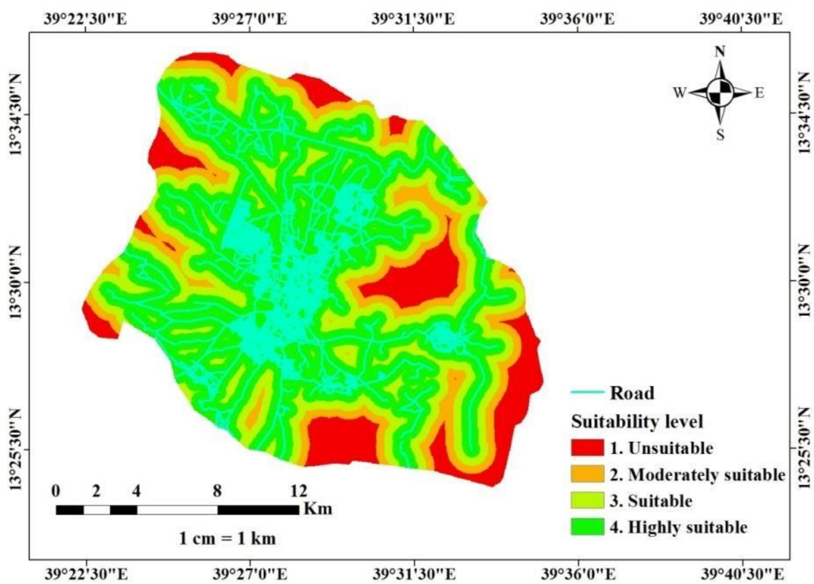

Figure 4.8: Reclassified road map

4.2.6. Stream

Proximity to a stream or other water bodies is another significant consideration when selecting an abattoir site. While access to water is essential, it comes with both benefits and challenges.

Abattoirs require a significant amount of water for cleaning, processing, and maintaining hygiene standards. Therefore, proximity to a stream can provide a reliable and ample water supply. In contrary, proximity to a stream increases the risk of water pollution from abattoir waste if not properly managed. Contaminants from processing activities can enter the waterway, harming aquatic life and downstream water users. In addition, sites near streams are often more vulnerable to flooding, which can disrupt operations and cause significant damage to infrastructure. Therefore, balancing the benefits and challenges of stream proximity requires careful planning, adherence to regulations, and the implementation of best practices to ensure that the abattoir operates sustainably and responsibly. In this study, the streams/river factor was generated from the digital elevation model (DEM) using the ArcGIS spatial analyst extension of hydrology module. Then it was buffered based on the 100m distance standard criteria set by EPA, (2002), to locate abattoirs from critical environmental resources such as streams or rivers. Thus, four buffer zones have been drawn around streams by reclassifying the buffered stream, and a relative suitability rank was assigned to each buffer distance categories. Accordingly, buffers far from streams were ranked as highly suitable, while buffers near streams were ranked as unsuitable as shown in the table below, (Table 4.11).

Table 4.11: Reclassified distance from stream and their suitability level

Buffer distance of Streams (m)	**Value**	**Level of suitability**
<100	1	Unsuitable
100-200	2	Moderately suitable
200-300	3	Suitable
>300	4	Highly suitable

Choosing an abattoir location inside the most appropriate and highly suited places may help to improve water resource management and minimize any potential negative effects on neighboring streams. This also further ensures that water pollution controlled is critical for maintaining public health, especially if the stream is used by nearby communities for drinking, irrigation, or recreation.

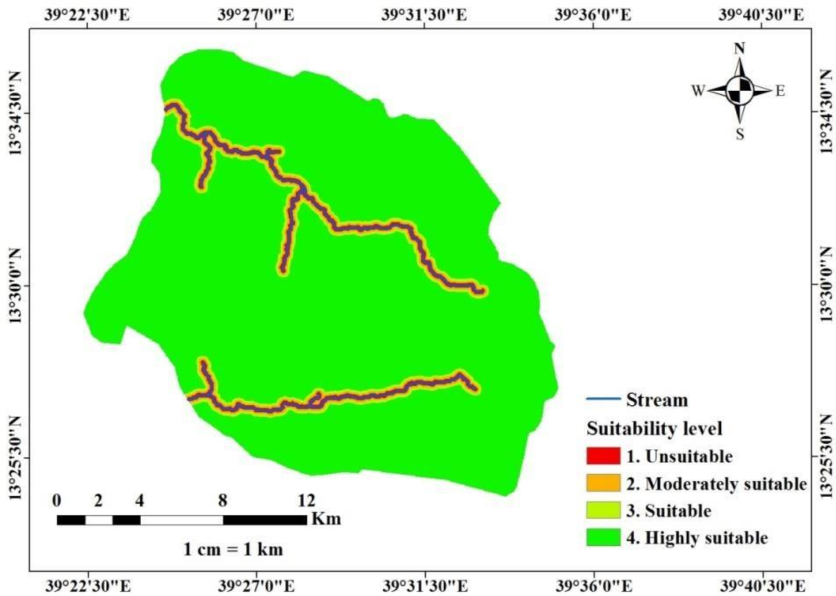

Figure 4.9: Reclassified stream map

4.2.7. Constraints

Selecting an abattoir site involves multiple constraints that ensure the location is suitable for operations, compliant with regulations, and minimizes negative impacts on the environment and community. In this study, social services, industrial areas, landfill sites/waste dump sites, airports and high tension lines were considered as constraints. To reduce the potential harm that an abattoir may cause to the environment and vice versa, it should be located a considerable distance away from these locations. These constraints ensure the selected site for an abattoir is suitable, sustainable, and compliant with all necessary regulations and standards. Addressing these constraints comprehensively helps in making an informed decision that balances operational needs with environmental protection and community well-being. Thus, certain measures of distance should be set aside as a buffer zone surrounding the urban facilities listed above. Accordingly, each of these constraints were classified based on the standard criteria using spatial analyst buffer zone Euclidian distance and the reclassified optimum buffer zone of each factor was taken as suitable site for abattoir facility. The constraints taken in this study were buffered and reclassified based on the standard buffer distance set by EPA, (2002) and LMA, (2000).

➢ Industrial areas

Buffering industrial areas for abattoir site selection involves creating buffer zones around industrial areas to assess the suitability of potential abattoir sites. To minimize the impact of neighborhood activities upon the abattoir, particularly dust and smoke emitting industries that can produce chemical and other form of pollution, abattoir should be located at least 300 meters away from dust emitting industries. The constraints of industrial areas were taken from the city municipality structural plan and their coordinate system was transformed in to WGS_1984_UTM _Zone_37N so as to make comparable with the other factors. Therefore, buffer zones of 300 meters were made around industrial sites based on the standard criteria using spatial analyst buffer Euclidean distance. The buffered distance of the industrial area was then reclassified in to four ranks as the locations farthest from the industrial area were ranked as highly suitable and locations nearest to industrial area were ranked as unsuitable (Table 4.12).

Table 4.12: Reclassified distance from industrial areas and their suitability level

Buffer distance of industrial area (m)	**Value**	**Level of suitability**
<300	1	Unsuitable
300-600	2	Moderately suitable
600-900	3	Suitable
>900	4	Highly suitable

Buffering industrial areas is a crucial step in abattoir site selection, helping to identify suitable sites while considering regulatory, environmental, infrastructural, and community factors. This process helps to ensure that the abattoir is appropriately located concerning other industrial activities, residential areas, and environmental features. By systematically creating and analyzing buffer zones, stakeholders can make informed decisions that balance operational efficiency with environmental protection and community well-being.

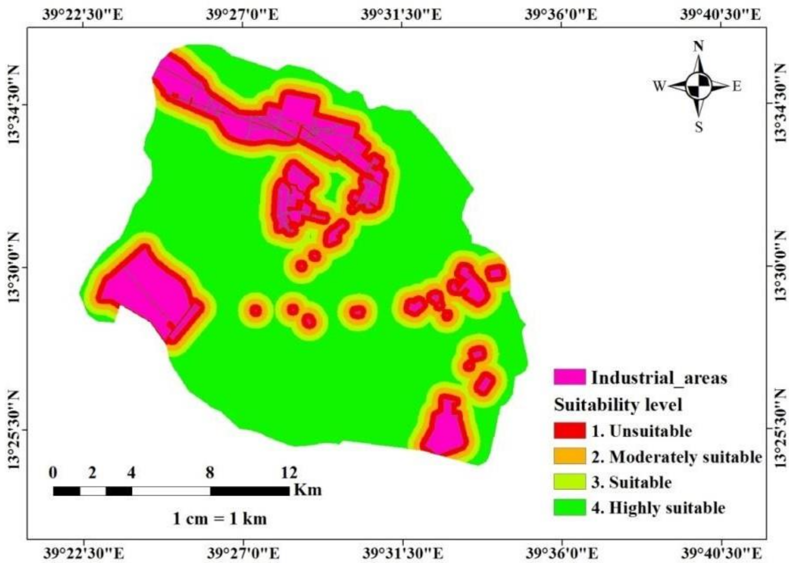

Figure 4.10: Reclassified industrial area map

- **Social services**

When determining the location of an abattoir (slaughterhouse) facility in relation to social services, several key factors must be considered to ensure safety, health, and minimal disruption to the community. Abattoirs should be located at a sufficient distance from social services and residential areas to minimize noise, odor, and potential health risks. Abattoirs must comply with local, state, and national regulations regarding their distance from schools, hospitals, and other sensitive areas. Accordingly, social services were considered in this study to determine the suitability of abattoir site. The social services constraints were generated from the structural plan of the city and like the other factors their coordinate system was transformed in to WGS_1984_UTM_Zone_37N to make fit with the other factors and constraints. A buffer distance of 300 was reserved around these facilities based on the standard criteria using spatial analyst buffer Euclidean distance to mitigate the negative impact of the abattoir over the surrounding social services. The buffer distance of the social services was later reclassified in to four classes and their suitability levels were assigned based on the farthest and nearest distance to these facilities. Thus, areas that have shortest distance to the social service were classified as unsuitable and assigned value one, whereas areas with the longest distance were classified as highly suitable and assigned value four, (Table 4.13).

Table 4.13: Reclassified distance from social services and their suitability level

Buffer distance of social services (m)	**Value**	**Level of suitability**
<300	1	Unsuitable
300-600	2	Moderately suitable
600-900	3	Suitable
>900	4	Highly suitable

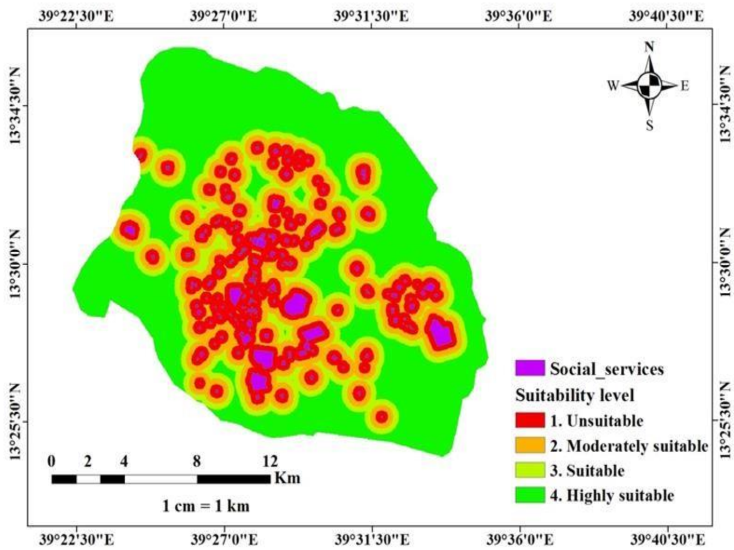

Figure 4.11: Reclassified social service map

➢ Landfill/waste dump sites

When locating an abattoir in relation to a landfill or waste dump site, several important considerations should be taken into account to ensure environmental safety, operational efficiency, and compliance with regulations. Maintaining a significant distance between the abattoir and landfill helps to prevent potential contamination of water, air, and soil. The landfill site constraints were generated from the structural plan of the city. To make the analysis possible, their coordinate system was transformed in to WGS_1984_UTM_Zone_37N same as the other factors and constraints. The abattoir should be situated at a significant distance from the landfill to avoid contamination. It is also important to consider the direction of the prevailing winds to prevent odors and airborne contaminants from the landfill from reaching the abattoir. Thus, buffer distance of 500 meter was considered around the landfill sites based on the standard criteria using spatial analyst buffer Euclidean distance to prevent odors, pests, and contamination from reaching the abattoir. The buffer distance from the landfill sites was later reclassified in to four classes and their suitability levels were assigned based on their buffered distance proximity. Thus, areas that have shortest distance to the landfill site were classified as unsuitable and assigned value one, whereas areas with the longest distance were classified as highly suitable and assigned value four, (Table 4.14).

Table 4.14: Reclassified distance from landfill sites and their suitability level

Buffer distance of landfill sites (m)	Value	Level of suitability
<500	1	Unsuitable
500-1000	2	Moderately suitable
1000-1500	3	Suitable
>1500	4	Highly suitable

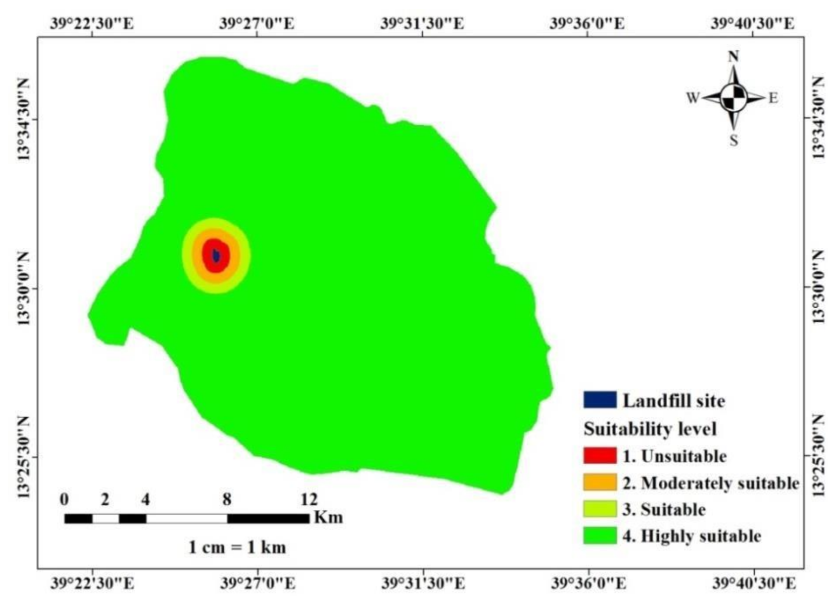

Figure 4.12: Reclassified landfill site map

➢ Airport

Airports often have strict regulations regarding the placement of facilities like abattoir that can attract birds or wildlife, which pose a risk to aircraft. Abattoirs can attract birds due to waste and offal, so it's crucial to check local and national regulations regarding the minimum distance required between an abattoir and an airport. An abattoir should be located far enough from the airport to minimize the risk of bird strikes. According to EPA, (2002), an abattoir must not be located within 6 kilo meters of an airport. Thus, buffer distance of 6 kilo meter was considered around the airport based on the standard criteria using spatial analyst buffer Euclidean distance to minimize the risk that can encountered due to the scavengers menance to aircrafts.

Airport zone was clipped from the structural plan of the city and projected into WGS_1984_UTM_Zone_37N, the same spatial reference system as the other factors. The buffer distance from the airport zone was later reclassified in to four classes and their suitability levels were assigned based on their buffered distance proximity. Thus, regions that have shortest distance to the airport zone were classified as unsuitable and assigned value one, whereas regions with the longest distance were classified as highly suitable and assigned value four (Table 4.15).

Table 4.15: Reclassified distance from airport zone and their suitability level

Buffer distance of Airport (Km)	**Value**	**Level of suitability**
<6	1	Unsuitable
6-8	2	Moderately suitable
8-10	3	Suitable
>10	4	Highly suitable

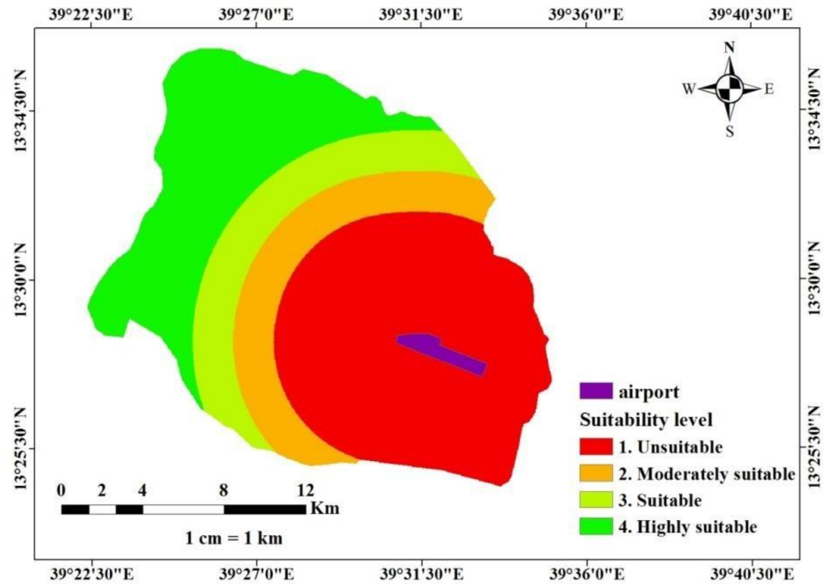

Figure 4.13: Reclassified Airport map

➢ High-tension power lines

High-tension power lines carry high-voltage electricity, which poses significant safety risks. Therefore, it is important to locate the abattoir at a safe distance to prevent any risk of electrical accidents. Moreover, high-tension lines can create electromagnetic interference, which might affect sensitive electronic equipment used in the abattoir. Thus, a sufficient distance should be considered to mitigate any potential interference. According to EPA, (2002), the abattoir site should be at least 500 meters away from high-tension lines in order to avoid possible accidents that could be encountered because of big flying birds (e.g. scavengers) hovering over the abattoir. Accordingly, buffer distance of 500 meter was considered around the high-tension power lines based on the standard criteria using spatial analyst buffer Euclidean distance in order to alleviate possible accidents that could be faced because of big flying birds. In this study high-tension power lines were clipped from the structural plan of the city and projected into WGS_1984_UTM_Zone_37N, the same spatial reference system as the other factors and constraints. The buffer distance from High-tension lines was then reclassified based on their proximity and their suitability level was designated as unsuitable if it is nearest to the high-tension power line and suitable if it is far enough from the high-tension power lines as shown in table below, (Table 4.16).

Table 4.16: Reclassified distance from high-tension lines and their suitability level

Buffer distance of High-tension lines (m)	Value	Level of suitability
<500	1	Unsuitable
500-1000	2	Moderately suitable
1000-1500	3	Suitable
>1500	4	Highly suitable

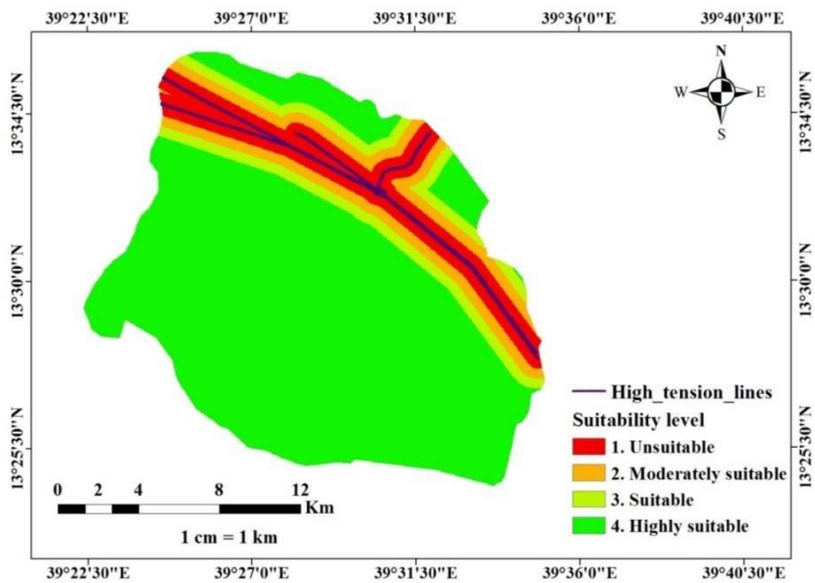

Figure 4.14: Reclassified high-tension lines map

4.3. Criteria Weight Calculation

In this study, various criteria were considered and weighted to assess the suitability of a location for an abattoir. Accordingly, land use land cover, elevation, slope, roads, streams, settlements, industrial areas, social services, landfill sites, airport and high-tension power lines were used as input data sets to produce the abattoir suitability map. Satellite images, Digital Elevation model (DEM) and base map or structural plan of Mekelle city were the main source the maps for each input data sets. Analytic Hierarchy Process (AHP) was used to compare each pair of criteria to establish their relative importance. According to Saaty, (1980), this method uses a scale (usually

1-9) to rate the importance of one criterion over another. The results were then used to create a comparison matrix, from which the weights or priority values were derived. A pair-wise comparison matrix was developed (Table 4.17) to compare all the criteria and weight or the principal eigenvector for each criterion was calculated by summing the values in each column, dividing each element by the column total, and dividing the sum of the normalized scores for each row by the number of criteria as shown in (Table 4.18). The weights assigned to each criterion reflect their relative importance in the decision-making process. The larger the weight is, the more important the factor in overall suitability.

Table 4.17: Pairwise comparison matrix for the criteria

Criteria	LU	EL	SL	R	STR	SET	IN	SS	LF	AP	HTL
LU	1	2	3	2	2	3	3	3	3	3	3
EL	0.5	1	2	3	3	3	3	3	3	3	2
SL	0.33	0.5	1	2	2	3	3	3	3	2	2
R	0.5	0.33	0.5	1	2	3	3	3	3	2	2
STR	0.5	0.33	0.5	0.5	1	3	3	3	3	2	2
SET	0.33	0.33	0.33	0.33	0.33	1	2	2	2	0.5	0.5
IN	0.33	0.33	0.33	0.33	0.33	0.33	1	2	2	0.33	0.5
SS	0.33	0.33	0.33	0.33	0.33	0.5	0.5	1	2	0.5	0.33
LF	0.33	0.33	0.33	0.33	0.33	0.5	0.5	0.5	1	0.5	0.33
AP	0.33	0.33	0.5	0.5	0.5	2	3	2	2	1	0.5
HTL	0.33	0.5	0.5	0.5	0.5	2	2	3	3	2	1
Sum	**4.81**	**6.31**	**9.32**	**10.82**	**12.32**	**21.33**	**24**	**25.5**	**27**	**16.83**	**14.16**

Where: LU= Land use land cover R =Road IN = Industrial areas AP = Airport
EL =Elevation STR =Stream SS = Social services HTL = High-tension lines
SL =Slope SET =Settlement LF = Landfill sites

Table 4.18: Normalized pair-wise comparison matrix of the criteria

Criteria	LU	EL	SL	R	STR	SET	IN	SS	LF	AP	HTL	Sum	Weight
LU	0.208	0.317	0.322	0.185	0.162	0.141	0.125	0.118	0.111	0.178	0.212	**2.079**	0.189
EL	0.104	0.158	0.215	0.277	0.244	0.141	0.125	0.118	0.111	0.178	0.141	**1.812**	0.165
SL	0.069	0.079	0.107	0.185	0.162	0.141	0.125	0.118	0.111	0.119	0.141	**1.357**	0.123
R	0.104	0.052	0.054	0.092	0.162	0.141	0.125	0.118	0.111	0.119	0.141	**1.219**	0.111
STR	0.104	0.052	0.054	0.046	0.081	0.141	0.125	0.118	0.111	0.119	0.141	**1.092**	0.099
SET	0.069	0.052	0.035	0.030	0.027	0.047	0.083	0.078	0.074	0.030	0.035	**0.561**	0.051
IN	0.069	0.052	0.035	0.030	0.027	0.015	0.042	0.078	0.074	0.020	0.035	**0.478**	0.043
SS	0.069	0.052	0.035	0.030	0.027	0.023	0.021	0.039	0.074	0.030	0.023	**0.424**	0.039
LF	0.069	0.052	0.035	0.030	0.027	0.023	0.021	0.020	0.037	0.030	0.023	**0.367**	0.033
AP	0.069	0.052	0.054	0.046	0.041	0.094	0.125	0.078	0.074	0.059	0.035	**0.728**	0.067
HTL	0.069	0.079	0.054	0.046	0.041	0.094	0.083	0.118	0.111	0.119	0.071	**0.884**	0.080

To evaluate the rationality of AHP, the consistency for sensitivity analysis, known as the consistency ratio (CR), was computed to determine the degree of consistency that has been used in developing the judgments. According to Odu, (2019), if the consistency ratio is less than 0.1, then the ratio indicates a reasonable level of consistency in the pairwise comparisons. Whereas if the CR is greater than 0.1, it shows that the pairwise comparisons are inconsistent in judgment. The consistency ratio was calculated using the formula provided by Odu, (2019) as below.

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}}$$

Where: **CR** stands for consistency ratio, **CI** stands for consistency index and **RI** stands for random index. The random index value is 1.51 from (Table 4.19) which was derived from Saaty‘s book.

Table 4.19: Random Index Value

Order	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

Source: Saaty, 1980

$$CI = \frac{\boldsymbol{\lambda}\text{max} - \text{n}}{\text{n} - 1}$$

Where: **λmax** is the principal Eigen value of the matrix and **n** is the order of the matrix or number of criteria. λmax is calculated and found to be 11.668 and the number of criteria considered for this study are 11.

Therefore,

$$CI = \frac{11.668 - 11}{11 - 1}$$

CI= 0.0668

Thus,

$$CR = \frac{0.0668}{1.51}$$

CR = 0.044, which is acceptable

In this study, the consistency ratio was found to be 0.044. According to the above-given threshold, the pairwise comparisons were consistent, and the result is acceptable to be used in the site suitability modeling for the abattoir.

Assigning weights to criteria in abattoir suitability modeling is a crucial step to ensure that the most important factors are appropriately prioritized in the decision-making process. In this process, consulting experts in various fields related to abattoir operations, including environmental science, logistics, economics, and public health, can provide insights into the relative importance of each criterion. Accordingly, experts‘ opinions were gathered and relevant literature was consulted to calculate the relative importance of the factors involved in this study.

The computed priority value was used as a coefficient for the respective factor maps to be combined in the weighted overlay analysis in the ArcGIS environment. Finally, the overall suitability score was determined by multiplying the weights by the standardized values of each factor after they had been assigned, and then their products were summed up to produce a final suitability map.

4.4. Criteria maps Integration and suitability map generation

As stated in the first chapter of the study, one of the specific objectives of this study was to develop a GIS based model for assessing the suitability of potential sites for abattoir establishme nt, which is its ultimate goal. In this stage, all the factor maps were combined to produce the final suitability composite map that shows the potential locations for abattoir establishments. The weighted overlay analysis was used to combine all the factor maps using the ArcGIS model builder (Figure 4.15). In the weighted overlay analysis, the weights were considered as influences on the suitability map to be produced. That means a factor with a higher weight will have a greater influence on the suitability of a location for an abattoir. The result that has been produced is the abattoir site suitability map (Figure 4.16).

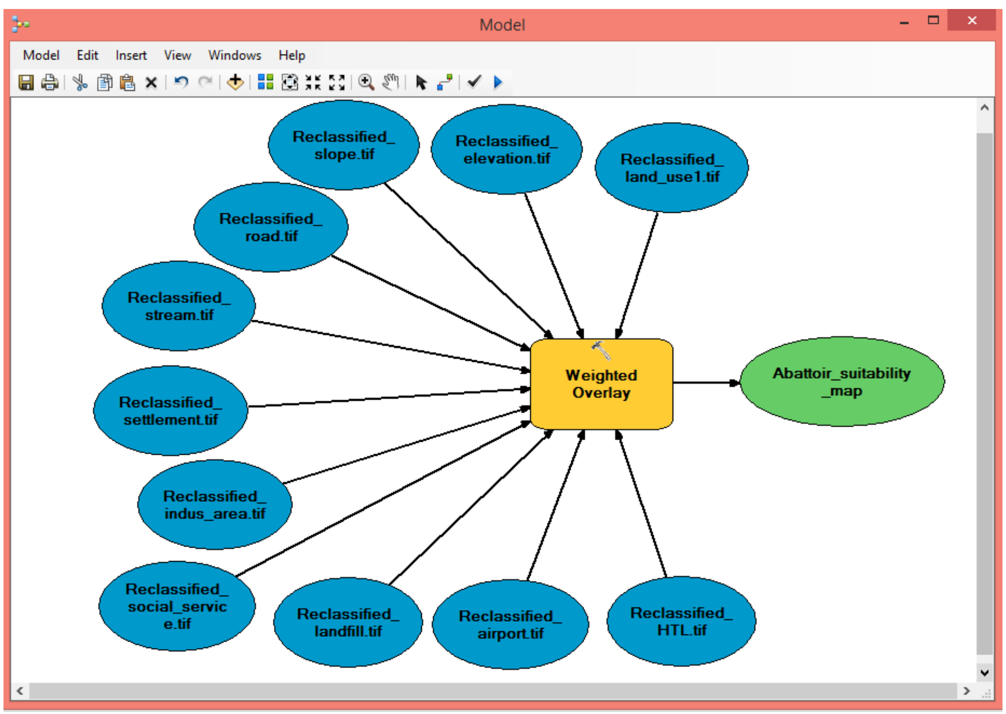

Figure 4.15: Abattoir site suitability Model builder

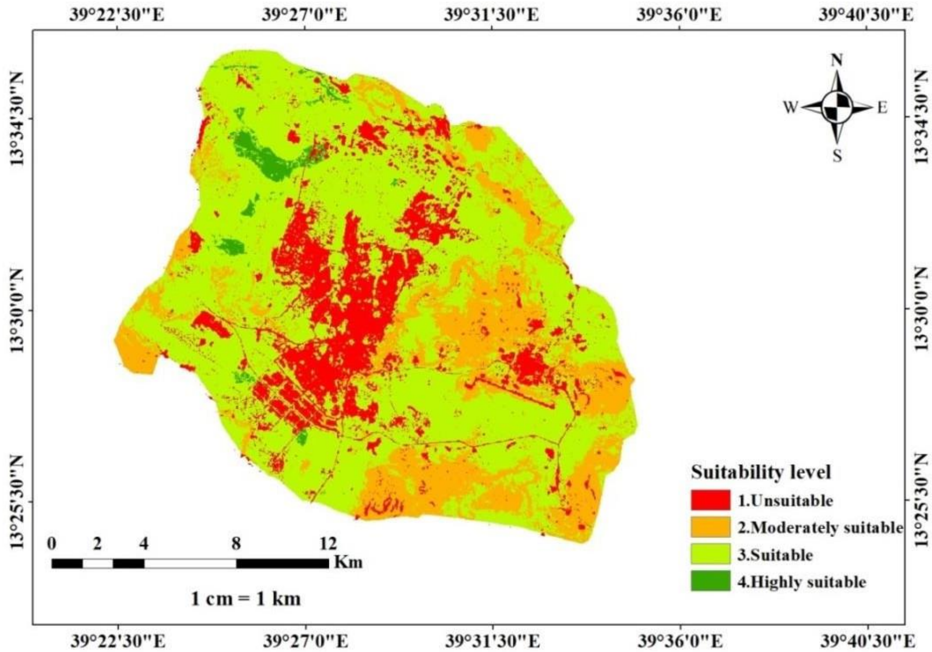

Figure 4.16: Abattoir site suitability map

Table 4.20: Statistical analysis of the abattoir site suitability map

Suitability level	**Value**	**Count**	**Area (Km^2)**	**Area (%)**
Unsuitable	1	58,536	52.68	16.41
Moderately suitable	2	76,984	69.29	21.59
Suitable	3	215,202	193.68	60.34
Highly suitable	4	5,946	5.35	1.66
Total		**356,668**	**321**	**100**

The produced abattoir site suitability map has four suitability level classes: unsuitable (52.68 Km^2), moderately suitable (69.29 Km^2), suitable (193.68 Km^2) and highly suitable (5.35 Km^2) (Table 4.20). The produced abattoir site suitability map (Figure 4.16) reveals that the north, northwest, west, and southwest parts of the city contain the highly suitable site. This highly suitable area mainly falls over the bare land of the city. Whereas the unsuitable area covers the developed part of the city, like settlements and other social and infrastructural land uses. The remaining area of the city is covered by moderately suitable and suitable classes, which cover the forest/shrub land and vegetation/agriculture areas of the city, respectively. The unsuitable area is the developed area of the city and water bodies which are restricted areas for abattoir establishment. Therefore, it is excluded from the choice for abattoir site. The moderately suitable and suitable areas have a relatively good suitability level for abattoir site than the unsuitable areas. But these areas are not the ideal sites for an abattoir facility. Because, when we locate the abattoir on this area it can be encroached by residential and other urban facilities very soon and the city‘s municipality will enforce to relocate the abattoir site before the expected time. The highly suitable area, which covers the bare land on the other hand, is the appropriate site for an abattoir service. Selecting highly suitable area for locating abattoir site helps to minimize cost of land for the accommodation of abattoir facility, to reduce the impact of the abattoir over the living environment and ensures the compatibility of the abattoir facility with other surrounding land uses. Hence, the highly suitable area (bare land) is preferred as the best area for the establishment of the abattoir. This area is located near the periphery of the city and is also located in the north, northwest, west, and southwest of the city. Thus, it is undeniable that the abattoir will have a prolonged life before it can be relocated because it is situated in this location. Ultimately, selecting this extremely appropriate location guarantees the abattoir's long-term existence and viability under the city's urban planning framework.

4.4.1. Final Abattoir Site Location Map preparation

The final abattoir site was selected from the different highly suitable sites on the abattoir suitability map. From these highly suitable sites, it is important to identify the most suitable site that fulfills environmental sustainability, economic feasibility, and social acceptance. To identify the most suitable abattoir site, three candidate sites were selected from the highly suitable map. The candidate sites were nominated as site one, site two, and site three. The final suitable site selection process was done by evaluating factors such as proximity to transportation routes, availability of utilities, and compliance with zoning regulations. Hence, all the constraint maps were added to the highly suitable map (Figure 4.17), and the candidate sites were compared with respect to these constraints. In addition to the classified land use and land cover map of the study area and the structural plan of the city, Google Earth Pro was used to cross-check the actual land use and land cove type of the candidate sites that were selected from the highly suitable sites. Accordingly, the final abattoir site was evaluated and validated using Google Earth Pro and future land use planning in the study area. Site visits were also conducted to validate the abattoir site suitability map against the real-world conditions of the study area. The three candidate sites were compared to each other (Table 4.21) regarding their proximity to transportation routes, availability of utilities, and compliance with zoning regulations, as well as wind directions and future expansion of the city so as to identify the most suitable final abattoir site (Figure 4.18).

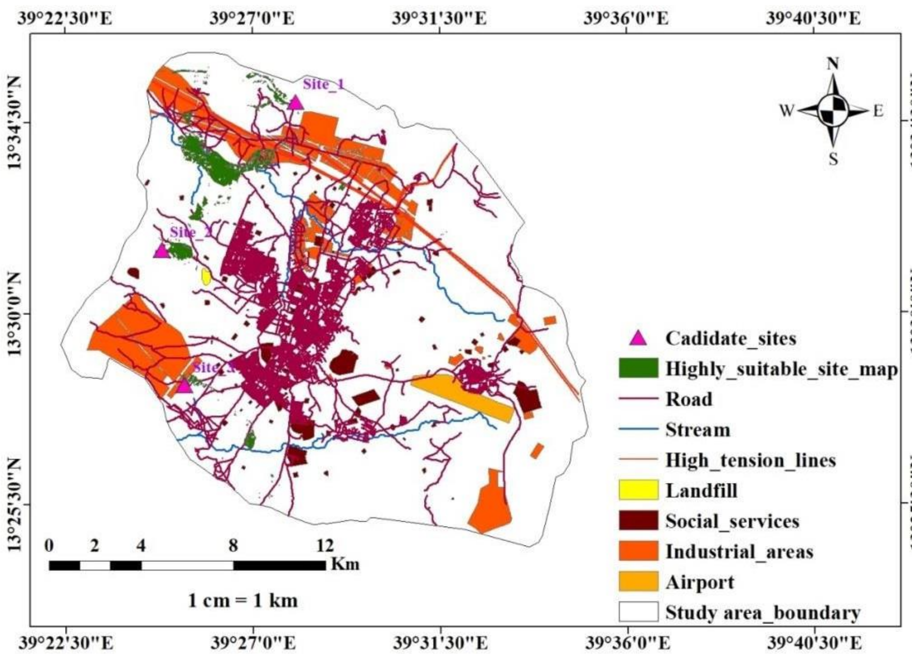

Figure 4.17: Candidate sites and constraints map

Table 4.21: Comparison of Candidate sites suitability

Criteria	**Site-1**	**Site-2**	**Site-3**
Land use	Bare land (H. suitable)	Bare land (H. suitable)	Bare land (H. suitable)
Distance from SET	755.29 m (H. suitable)	497.69 m (M. suitable)	734.46 m (Suitable)
Elevation	1970 m (H. suitable)	2008 m (H. suitable)	2121 m (Suitable)
Distance from road	307.48 m (H. suitable)	487.73 m (Suitable)	156.76 m (H. suitable)
Distance from stream	2798.66 m (H. suitable)	2091.96 m (H. suitable)	626.98 m (H. suitable)
Distance from SS	2976.45 m (H. suitable)	1510.88 m (H. suitable)	1488.11 m (H. suitable)
Distance from IN	492.69 m (M. suitable)	2242.82 m (H. suitable)	48.93 m (Unsuitable)
Distance from landfill	8210.10 m (H. suitable)	1426.06 m (suitable)	4427.23 m (H. suitable)
Distance from Airport	12927.43 m (H.suitable)	12158.95 m (H.suitable)	9740 m (Suitable)
Distance from HTL	1814.54 m (H. suitable)	5290.69 m (H. suitable)	10824.71 m (H.suitable)
Wind direction	H. suitable	Unsuitable	Unsuitable

Future land use	Suitable	Unsuitable	Unsuitable
Area in hectare	1.62 Ha (H. suitable)	0.91 Ha (Unsuitable)	0.62 Ha (Unsuitable)

Where, SET= Settlement, SS= Social Services, IN= Industrial areas, HTL= High tension lines, H. suitable= highly suitable and M. suitable = moderately suitable

The comparison table (Table 4.21) revealed that the three candidate sites have a good suitability potential for the abattoir site. But site one is the most suitable site due to its proximity to access to transportation (distance from roads of 307.48 meters), being sufficiently distant from constraints, attaining sufficient site area,1.6 ha needed for abattoir operations, and being situated at the north periphery of the study area, which is not in the direction of the wind blows. In the study area, winds predominantly blow from the east to the west. According to Fard and Zahraei, (2012) and expert opinions, it is not recommended to locate an abattoir site in the direction of the wind blows. Therefore, selecting this site for abattoir location ensures alleviating possible negative impacts that the abattoir can pose on the surrounding environment and vice versa. According to Fenta et al., (2017), Mekelle City‘s expansion took place mainly in three directions: towards the northeast along the highway to Wukro town in Semien sub-city, to the northwest in Ayder sub-city, and to the southwest in Adi Haqi and Hadinet sub-cities. Since this site is located towards the north, it is convenient regarding the city‘s future expansion area and situated in a place that will not soon become an abode of habitation. This also guarantees the abattoir's extended lifespan, free from encroachment by other land-use activities.

However, the two remaining candidate sites: site two and three have certain defects and limitations. For instance, site two is situated nearest to the landfill site of the study area. It is also located in the western periphery of the study area, in the direction of the wind blows. As a result, odors from the landfill could reach the abattoir, which could potentially harm the abattoir activity. Moreover, this site is located in the area that is needed for future expansion. Fard and Zahraei, (2012) emphasized that site selection for abattoirs must not be in the way of city development. Therefore, this site shouldn‘t be recommended since it can be encroached upon by other activities earlier than expected. According to Standard, (2005), the selected abattoir site shall have enough spaces for lairage, road, parking, office, waste water treatment, and other necessary areas. The selected site should have an area greater than or equal to one hectare (LMA, 2000). However, this site has an area of 0.91 hectares, which is less than the recommended standard. The third candidate site is site three, which is located in the south west corner of the study area. This site is primarily situated at a high proximity of 48.93 meters to the Mekelle industrial park. According to Fard and Zahraei, (2012), abattoirs or slaughterhouses should not be exposed to pollution from industrial operations, dust, smoke, ash, etc. Therefore, selecting this candidate site may expose the abattoirs to contamination due to the smoke and dust that are emitted from the industries. It also has a minimum area of 0.62 hectares, which couldn't accommodate the spaces needed for lairage, roads, parking, offices, waste water treatment, and other necessary areas. Furthermore, this site is situated in the direction of the prevailing wind and in the way of the city's future expansion, similar to the second site (site 2). Due to these limitations, the two remaining candidate sites (site two and site three) were excluded from the options, and site one was selected as the best site for an abattoir location.

4.4.2. Description of the final Selected Abattoir site

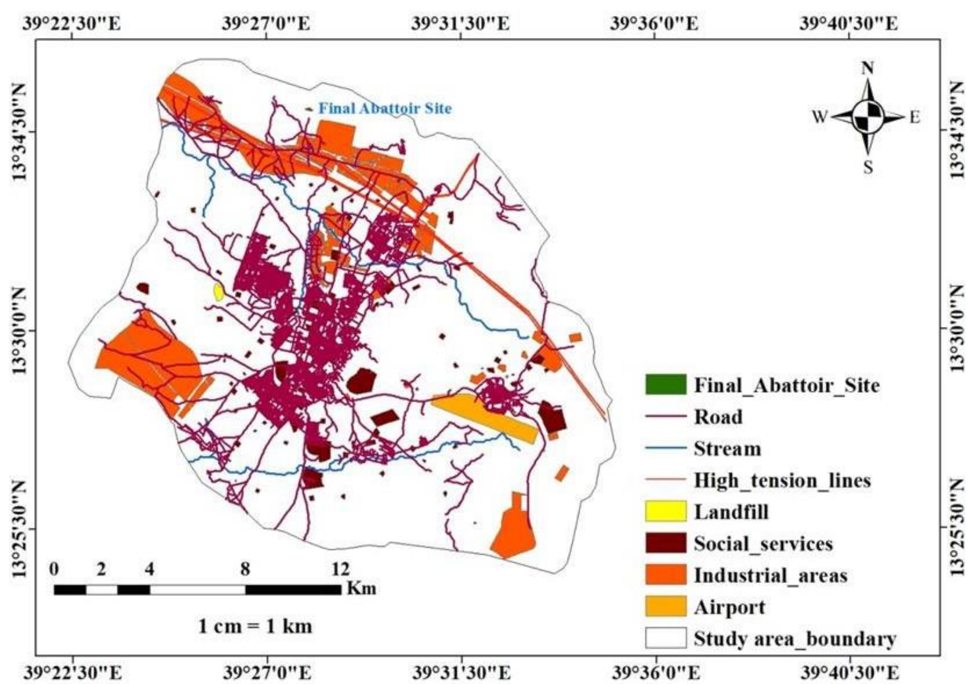

Figure 4.18: Final abattoir site location map

- **Location:** This site is located in the north corner of the study area with a geographic location of 13°35'01''and 39°27'59''latitude and longitude respectively. According to Fard and Zahraei, (2012), the site location for abattoir should be placed within the city limits and the selected abattoir site must not be on the way of the city development. The current selected site is thus situated within the study area boundary near the periphery of the _‘Felege Mayat‘‘ rural area. The rural site generally outweigh those of the other sites, hence it is recommended that a rural location be chosen where possible. Being situated the abattoir site in this area provides this site a natural buffer and ensures that there will be no future development that could potentially obstruct the project.

- **Topography:** The elevation and slope of the selected site is 1970 meters and 2.8 percent respectively. According to Fard and Zahraei, (2012), a location beneath the city level should be chosen for abattoirs in order to prevent pollution from spreading. It is also justified that, the desirable slope for abattoir site is suggested to be gently sloping area (LMA, 2000), which ranges from 2 to 10 per cent. The highest elevation of the study area is 2458 meter and the lowest elevation is 1793 meter. Therefore, the selected site is found in the lower level of the study area with elevation of 1970 meters and with a recommended slope range of 2.8 percent.
- **Land use land cover:** As stated above, the land cover type on which the most suitable site is laid is bare land. This site is currently available as vacant land use. According to Yemane and Mekelle, (2016), formerly undeveloped, vacant land is typically the ideal location of newly constructed abattoir facilities. As a result, choosing this site for the abattoir construction helps reduce site acquisition costs. This also further ensures environmental sustainability, economic feasibility, regulatory compliance, and community welfare.
- **Transportation and utilities:** This site is conveniently located near the major highway of Mekelle-Abyi-Adi and has existing water utilities like the Geba River, which has good proximity to this site. For the abattoir to operate consistently, access to rail or road transportation should be available year-round (Yasin et al., 2023). Thus, having convenient transportation accessibility and sufficient water utilities makes this site the ideal choice for the abattoir‘s future growth and sustainable development.
- **Site capacity:** According to the analysis, there was sufficient high potential site area coverage available to secure adequate land parcels for an abattoir service. According to LMA, (2000), the selected site for abattoir should have an area greater than or equal to

one hectare. The chosen site is 1.62 hectares in size, which is acceptable according the standard and could potentially be sufficient to accommodate the infrastructure and amenities required for the abattoir's growth.

5. Conclusions and Recommendations

5.1. Conclusions

The current study was aimed to develop abattoir site suitability modeling using GIS and remote sensing for sustainable urban planning and development in the case of Mekelle city, northern Ethiopia. This study demonstrates the critical role that advanced geospatial technologies can play in optimizing urban infrastructure, particularly in the context of abattoir location. By integrating GIS and RS, this research provides a robust framework for assessing the suitability of potential abattoir sites, considering a variety of environmental, social, and economic factors. The results indicate that careful site selection, guided by spatial data analysis, can significantly reduce environmental impacts, enhance public health, and promote more sustainable urban growth.

Furthermore, the study underscores the importance of incorporating modern geospatial tools in urban planning processes to ensure that infrastructure development aligns with broader sustainability goals. However, any GIS model is only as good as the data at hand. In the broader scope of urban development, parameters like terrain features, elevation, land use/cover, and proximity to roads are vital in identifying potential abattoir sites for urban expansion through site suitability analysis techniques. Therefore, eleven parameters from the environmental, social, and economic domains were taken into account for the current study. Moreover, the research's methodology and available data led to the selection of the three candidate sites. From these candidate sites, the most suitable site was identified by incorporating sustainable practices in site selection and facility design that ensures the abattoirs contribution to the overall goals of sustainable urban development. In addition, this study assures that the selected most suitable site is the ideal location for the abattoir site, as it is situated at the north periphery of the study area, which is not in the direction of the wind blows and the city‘s future expansion. Furthermore, the study concludes selecting the most suitable location for abattoir establishment ensures environmental sustainability, economic feasibility, regulatory compliance, and community welfare. This selection process directly benefits from and contributes to urban planning and sustainable development goals. Therefore, the best site was selected by considering the urban planning guidelines and zoning regulations, ensuring the abattoir fits within the broader urban framework.

5.2. Recommendations

The results of this thesis suggest that while selecting suitable sites for abattoirs, urban planners and policymakers should incorporate Geographic Information System (GIS) and Remote Sensing (RS) technology. The effective use of these spatial technologies enables an in-depth review of environmental, social, and economic aspects, resulting in better decisions that support the ultimate goal of sustainable urban development. The study also demonstrated that, in order to ensure sustainable urban planning and development in the study area, GIS and RS were both pertinent and required for land suitability assessments generally and specifically in abattoir suitability modeling. The findings of this study showed how effectively GIS can identify potential sites for the construction of an abattoir based on a variety of factors, such as population density, infrastructural accessibility, land use and land cover characteristics, and environmental impact assessments. The study also underlined how crucial it is to include community involvement and stakeholder‘s consulting in the decision-making process in order to guarantee balanced and sustainable urban growth and developments. This also helps to obtain public support and reduces future opposition in the process of choosing the location of the abattoir. Lastly, the following further implementations are recommended by this study:

- The model does not include some important factors (such railway) because of the unique peculiarities of the study area. When such features are readily available, the analysis ought to take them into account.
- The main focus of this study was to resolve the location problems related to municipal abattoirs. Depending on their complexity and type, export abattoirs which are expected to be important to the nation's future prosperity may require additional considerations.
- Any extra data such as land cost, thorough soil data, and other social and economic variables can improve the GIS model's outputs and produce more reliable findings.
- To systematically assess possible abattoir locations, urban planning authorities should use the multi-criteria decision analysis framework, which integrates GIS and RS data, as described in this paper. This approach will ensure the inclusion of all relevant factors, such as the environment impact, the compatibility of land use, and public health concerns.

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Appendices

Appendix 1: LULC Change of Mekelle City between 1990 and 2023

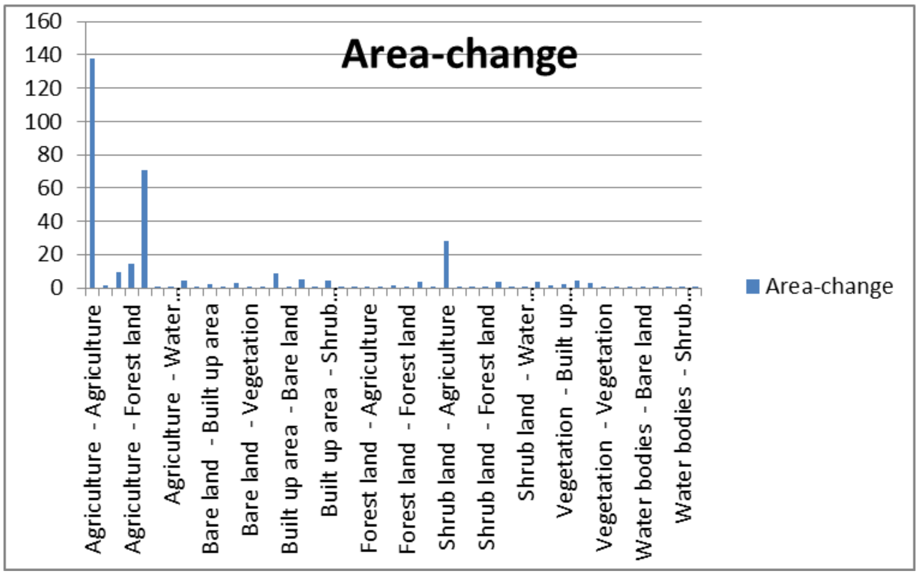

Fig 1: LULC change between 1990 and 2010

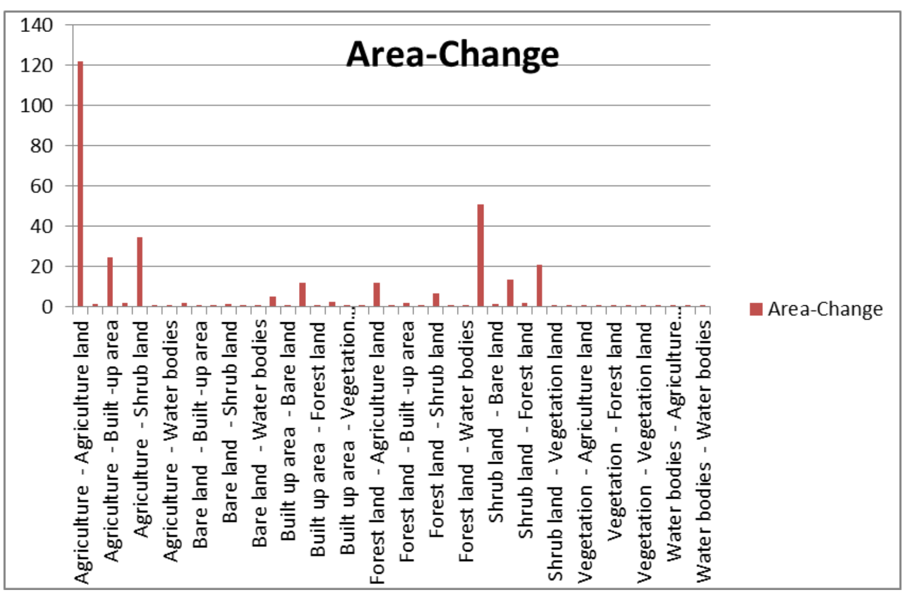

Fig 2: LULC change between 2010 and 2023

Appendix 2: Ground Control Points (GCPs) for Accuracy Assessment

SN	**Shape** *	**X_**Coordinate	**Y_**Coordinate	**Elevation**	**LULC class**
1	Point	547709.988	1503330.01	1867.6	Agriculture land
2	Point	546749.9769	1503180.021	1871	Bare land
3	Point	544679.9817	1502940.016	1921.8	Shrub land
4	Point	546779.767	1502520.231	1895	Agriculture land
5	Point	549209.99	1502400.013	1903.4	Water bodies
6	Point	549629.9789	1501980.026	1924.6	Agriculture land
7	Point	549929.9837	1501740.018	1930.3	Agricultre land
8	Point	551639.769	1501440.234	2030.4	Agricultre land
9	Point	549749.994	1501200.006	1986.5	Agricultre land
10	Point	545099.9819	1500720.02	1838.8	Shrub land
11	Point	545549.9877	1500630.012	1896.1	Forest land
12	Point	550499.771	1500480.22	1980.2	Shrub land
13	Point	554939.992	1500479.999	2378.8	Bare land
14	Point	554459.9809	1500360.01	2298.9	Built-up area
15	Point	555599.9857	1500090.005	2396.1	Agricultre land
16	Point	544199.771	1500030.22	1909.9	Built-up area
17	Point	553589.992	1499939.999	2097.7	Agricultre land
18	Point	546329.9809	1499910.01	1895.7	Shrub land
19	Point	553259.9857	1499910.005	2073.5	Agricultre land

20	Point	545639.771	1499850.22	1896.9	Agricultre land
21	Point	551429.992	1499159.999	1978.9	Agricultre land
22	Point	544949.9809	1499130.01	1930.7	Agricultre land
23	Point	546239.9857	1499010.005	1914.8	Vegetation land
24	Point	547109.771	1498950.22	1911.6	Agricultre land
25	Point	544409.992	1498799.999	1979	Agricultre land
26	Point	549089.9809	1498710.01	1921.7	Shrub land
27	Point	549509.9857	1498560.005	1931.4	Agricultre land
28	Point	555599.771	1498560.22	2246	Built-up area
29	Point	545369.992	1498409.999	1946	Agricultre land
30	Point	558839.9809	1498140.01	2407	Agricultre land
31	Point	545639.9857	1498020.005	1937.4	Agricultre land
32	Point	550199.771	1497960.22	1956.5	Shrub land
33	Point	547499.992	1497449.999	1973.7	Bare land
34	Point	553289.9809	1497360.01	2014.3	Shrub land
35	Point	550469.9857	1497270.005	1960.6	Vegetation land
36	Point	558809.771	1497030.22	2353	Agricultre land
37	Point	545519.992	1496819.999	1959.4	Agricultre land
38	Point	558869.9809	1496760.01	2334.2	Agricultre land
39	Point	545609.9857	1496670.005	1957.1	Shrub land
40	Point	557489.771	1496580.22	2087.2	Agricultre land
41	Point	551579.992	1496549.999	1969	Forest land
42	Point	549239.9809	1496310.01	1986	Built-up area
43	Point	545549.9857	1496190.005	1977.6	Bare land

44	Point	545249.771	1495920.22	1984.3	Shrub land
45	Point	551219.992	1495739.999	1977.9	Shrub land
46	Point	555359.9809	1495410.01	2012.5	Agricultre land
47	Point	545609.9857	1495020.005	1997.7	Agricultre land
48	Point	550859.771	1495020.22	1992.9	Built-up area
49	Point	546869.992	1494959.999	2001	Agricultre land
50	Point	546599.9809	1494900.01	2012.8	Agricultre land
51	Point	546539.9857	1494840.005	2011.1	Bare land
52	Point	554399.771	1494750.22	2004.3	Vegetation land
53	Point	547859.992	1494449.999	2050.9	Built-up area
54	Point	543959.9809	1494270.01	2101.6	Bare land
55	Point	551729.9857	1494240.005	2011.5	Agricultre land
56	Point	552359.771	1494210.22	2017.8	Built-up area
57	Point	542819.992	1493939.999	2015.8	Forest land
58	Point	545219.9809	1493760.01	2079.1	Bare land
59	Point	552299.9857	1493700.005	2033.7	Built-up area
60	Point	554279.771	1493430.22	2124.9	Agricultre land
61	Point	544829.992	1493399.999	2121.4	Agricultre land
62	Point	549689.9809	1493340.01	2029.9	Built-up area
63	Point	547739.9857	1493280.005	2064.9	Agricultre land
64	Point	560459.771	1493040.22	2184.2	Agricultre land
65	Point	561089.992	1492829.999	2170.2	Shrub land
66	Point	550349.9809	1492800.01	2039.5	Shrub land
67	Point	552119.9857	1492680.005	2061.6	Built-up area

68	Point	558389.771	1492680.22	2130.4	Agricultre land
69	Point	543569.992	1492619.999	2099.9	Agricultre land
70	Point	552929.9809	1492620.01	2104.9	Shrub land
71	Point	560909.9857	1492440.005	2161.2	Shrub land
72	Point	560789.771	1492380.244	2148.3	Shrub land
73	Point	553409.992	1492439.993	2184.8	Forest land
74	Point	545909.9809	1492380.208	2121.3	Bare land
75	Point	556439.9857	1492349.987	2225.8	Agricultre land
76	Point	545819.771	1492319.998	2109.5	Agricultre land
77	Point	550079.992	1492319.993	2050.1	Built-up area
78	Point	546299.9809	1492290.208	2158.8	Agricultre land
79	Point	545519.9857	1492259.987	2141.6	Shrub land
80	Point	545309.771	1492229.998	2144.1	Agricultre land
81	Point	562019.992	1492049.993	2193.4	Agricultre land
82	Point	542399.9809	1491900.208	2186.1	Agricultre land
83	Point	556019.9857	1491809.987	2269.3	Shrub land
84	Point	555929.771	1491779.998	2267.2	Agricultre land
85	Point	554249.992	1491659.993	2282.9	Agricultre land
86	Point	557159.9809	1491630.208	2184.6	Agricultre land
87	Point	544859.9857	1491599.987	2148.8	Agricultre land
88	Point	544319.771	1491539.998	2148	Shrub land
89	Point	550649.992	1491449.993	2073	Built-up area
90	Point	558029.9809	1491270.208	2206.2	Agricultre land
91	Point	548159.9857	1491239.987	2125	Agricultre land

92	Point	541319.771	1491179.998	2229.8	Agricultre land
93	Point	559709.992	1491089.993	2192.9	Shrub land
94	Point	552599.9809	1491030.208	2211.4	Forest land
95	Point	548099.9857	1491029.987	2118.1	Vegetation land
96	Point	558449.771	1490999.998	2240.9	Built-up area
97	Point	548399.992	1490969.993	2113.9	Built-up area
98	Point	557219.9809	1490970.208	2222.4	Water bodies
99	Point	553679.9857	1490789.987	2239.1	Shrub land
100	Point	555239.771	1490729.998	2262.3	Built-up area
101	Point	543119.992	1490699.993	2170.7	Agricultre land
102	Point	546149.9809	1490700.208	2125.6	Agricultre land
103	Point	550229.9857	1490459.987	2095.8	Forest land
104	Point	542219.771	1490399.998	2136.5	Shrub land
105	Point	554609.992	1490399.993	2238.7	Built-up area
106	Point	542009.9809	1490250.208	2187.7	Agricultre land
107	Point	557879.9857	1490219.987	2267	Built-up area
108	Point	557609.771	1489949.998	2248.4	Shrub land
109	Point	554129.992	1489889.993	2209.2	Agricultre land
110	Point	555089.9809	1489680.208	2224	Agricultre land
111	Point	549479.9857	1489380.016	2144.9	Built-up area
112	Point	554429.771	1489200.231	2216.9	Agricultre land
113	Point	545789.992	1488960.01	2114	Built-up area
114	Point	561869.9809	1488810.021	2308.5	Agricultre land
115	Point	556679.9857	1488780.037	2244	Agricultre land

116	Point	548729.771	1488510.252	2127.2	Built-up area
117	Point	551699.992	1488510.031	2170.7	Agricultre land
118	Point	556379.9809	1488420.042	2219.5	Vegetation land
119	Point	555719.9857	1488300.037	2223.3	Agricultre land
120	Point	552989.771	1488270.252	2188.6	Vegetation land
121	Point	559499.992	1488240.031	2251	Built-up area
122	Point	545519.9809	1488060.042	2074.4	Agricultre land
123	Point	551429.9857	1487880.037	2161.8	Bare land
124	Point	561209.771	1487730.252	2273.9	Agricultre land
125	Point	546989.992	1487640.031	2103.1	Agricultre land
126	Point	549149.9809	1487640.042	2122.8	Built-up area
127	Point	547079.9857	1487610.037	2103	Shrub land
128	Point	554429.771	1487610.252	2201.6	Agricultre land
129	Point	550049.992	1487580.031	2135.3	Shrub land
130	Point	557429.9809	1487430.042	2232.7	Vegetation land
131	Point	560909.9857	1487280.037	2270.5	Agricultre land
132	Point	557159.771	1487130.252	2238.9	Agricultre land
133	Point	550979.992	1487070.031	2141.9	Agricultre land
134	Point	548999.9809	1487010.042	2115.4	Shrub land
135	Point	547829.9857	1486830.037	2104.2	Shrub land
136	Point	550139.771	1486770.252	2121.2	Vegetation land
137	Point	551789.992	1486680.031	2143.3	Water bodies
138	Point	552299.9809	1486680.042	2156.8	Shrub land
139	Point	550019.9857	1486590.037	2117.2	Vegetation land

140	Point	551579.771	1486590.252	2137.1	Water bodies
141	Point	558569.992	1486590.031	2277.3	Agricultre land
142	Point	549929.9809	1486470.042	2118.9	Forest land
143	Point	560939.9857	1486470.037	2287.4	Agricultre land
144	Point	551399.771	1486440.252	2143.9	Water bodies
145	Point	546329.992	1486410.031	2118.7	Agricultre land
146	Point	550379.9809	1486380.042	2123.3	Forest land
147	Point	549179.9857	1486320.037	2114	Agricultre land
148	Point	552119.771	1486320.252	2160.9	Agricultre land
149	Point	551729.992	1486200.031	2147.1	Water bodies
150	Point	553859.9809	1486200.042	2229.8	Water bodies
151	Point	557639.9857	1486140.037	2274	Shrub land
152	Point	559409.771	1486140.252	2260.6	Water bodies
153	Point	550859.992	1486110.031	2144	Agricultre land
154	Point	554189.9809	1486110.042	2228.1	Forest land
155	Point	548309.9857	1485960.037	2115.3	Agricultre land
156	Point	554579.771	1485870.252	2239.3	Vegetation land
157	Point	548219.992	1485660.031	2125.1	Agricultre land
158	Point	550229.9809	1485450.042	2139.9	Bare land
159	Point	558239.9857	1485420.037	2393.1	Shrub land
160	Point	550529.771	1485360.252	2144.4	Agricultre land
161	Point	549899.992	1485270.031	2137	Built-up area
162	Point	557879.9809	1485240.042	2394.4	Agricultre land
163	Point	549599.9857	1484580.016	2166.4	Agricultre land

164	Point	554039.771	1484490.231	2283.9	Agricultre land
165	Point	557429.992	1484340.045	2310.4	Agricultre land
166	Point	551669.9809	1484190.056	2307	Agricultre land
167	Point	557339.9857	1484010.051	2308	Agricultre land
168	Point	557129.771	1483920.266	2305	Agricultre land
169	Point	549929.992	1483890.045	2213.8	Shrub land
170	Point	560789.9809	1483710.056	2348.5	Agricultre land
171	Point	555749.9857	1483290.051	2276	Agricultre land
172	Point	558389.771	1483080.266	2262.6	Agricultre land
173	Point	560579.992	1483019.986	2318.8	Water bodies
174	Point	560669.9809	1483019.997	2321.9	Water bodies
175	Point	560819.9857	1482809.992	2340.8	Forest land

Appendix 3: Incompatibility of the existing abattoir with other land uses

(Photographs taken during field inspection)

Fig 3: Existing abattoir (A) exposed to harmful dust emitted from Messebo cement factory (B).

Fig 4: Exiting abattoir (A) situated nearest to plastic factory (B) affected by air borne wastes.

Fig 5: A church wich (A) is affected by by the odour from the existing abattoir (B) in Quiha subcity.

Fig 6: Incompatibility of the existing abattoir(C) with Enderta Brewing Factory (A) and Desta Alcohol & Liquor Factory (B).