Evaluation of Land Use Suitability for Selection of Industrial Sites by Using Geospatial Technology. A Case of Adama Town, Oromia, Ethiopia.

Redwan Awol Said

A Thesis Submitted to

The Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's of Science in Geoinformatics Engineering

Office of Graduate Studies

Adama Science and Technology University

JULY, 2021

ADAMA, ETHIOPIA

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By: Redwan Awol Said ID: PGR/19375/12

Advisor: Getachew B/ Meskel (PhD)

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APPROVAL SHEET

I, the advisor of the thesis entitled "Evaluation of Land Use Suitability for Selection of Industrial Sites by Using Geospatial Technology. A Case of Adama Town, Oromia, Ethiopia" and developed by Redwan Awol Said, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Getachew B/ Meskel (PhD)	_______________	_______________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Redwan Awol Said have read and evaluated the thesis entitled "Evaluation of Land Use Suitability for Selection of Industrial Sites by Using Geospatial Technology. A Case of Adama Town, Oromia, Ethiopia" and examined the candidate during open defense. This is, therefore to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master's of Science in Geoinformatics Engineering.

Tilahun Erduno (PhD)	_______________	_______________
Chairperson	Signature	Date
Roba Gemechu (PhD)	_______________	_______________
Internal Examiner	Signature	Date
Asfaw Mohamed (PhD)	_______________	_______________
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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DECLARATION

I hereby declare that this Master Thesis entitled "Evaluation of Land Use Suitability for Selection of Industrial Sites by Using Geospatial Technology. A Case of Adama Town, Oromia, Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Redwan Awol Said	______________	____________________
Name of the student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Evaluation of Land Use Suitability for Selection of Industrial Sites by Using Geospatial Technology. A Case of Adama Town, Oromia, Ethiopia" prepared under my guidance by Redwan Awol Said submitted in partial fulfillment of the requirements for the degree of Master's of Science in Geonformatics Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Getachew B/ Meskel (PhD)	______________	______________
Name of major Advisor	Signature	Date

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TABLE OF CONTENTS

LIST OF TABLES

Table Number and Title **Page**

LIST OF FIGURES

Figure Number and Title **Page**

LIST OF ACRONYMS

ACMO ....Adama City Municipality Office

AHP ....Analytical Hierarchy Process

AP ....Additive Reflectance Factor

CSA ....Central Statistics Agency

DEM ....Digital Elevation Model

EIA ....Existing Industrial Areas

ERDAS ....Earth Resource Data Analysis System

FAHP ....Fuzzy Analytical Hierarchy Process

GDP ....Gross Domestic Product

GIS.................Geographic Information System

GPS ....Global Positioning System

GST…............Geospatial Technology

IPDC ....Industrial Park Development Corporation

LULC.............Land Use Land Cover

MADM ....Multi Attribute Decision Making

MCDM ....Multi Criteria Decision Making

MODM ....Multi Objective Decision Making

MP ....Multiplicative Reflectance Factor

NAVSTAR ....Navigation System with Timing and Ranging

PLC................Private Limited Company

RS…...... ....Remote Sensing

SRTM ....Shuttle Radar Topographic Mission

SSDS..............Site Selection Decision System

TFNS ....Triangular Fuzzy Numbers

UNID ....United Nation Industrial Development

USGS ....United State Geological Survey

WHO..............World Health Organization

WLC ....Weighted Linear Combination

ABSTRACT

Preliminary observations indicate that industrial area development can significantly boost Ethiopians attractiveness for investment and business. However, as several reports indicate, industrial areas are the second foremost factor that caused to increase the toxic pollution problems in worldwide. There are a huge number of industries developing in Awash basin , all of which have an impact on the basin's water. Most of industries in Adama Town are situated in the periphery of strong streams that flow to Awash River. Therefore, the main objective of this research is to evaluate land use suitability for selection of industrial site in Adama Town by using geospatial technology. In this study, fourteen sub-criteria coined under economic, environmental, geological and population major criteria were used for the evaluation. Fuzzy Analytical Hierarchy Process (FAHP) was implemented to overcome the limitation of AHP. Consequently, weights were elicited for the criteria based on the FAHP method. Accordingly, economic major criteria and Land Use Land Cover sub-criteria were taken the highest weight influence for the decision with their respective value of 45% and 26%. Weighted linear combination (WLC) algorithm in Idrisi selva software was utilized to superimpose the weighted criteria. Thus, the suitability map result indicated that the study area can be categorized into restricted, unsuitable, less suitable, moderately suitable and suitable zones. A surprisingly highly suitable zone was not detected in the study area. Thus, the second alternative, which is a suitable zone accounts for 41.8km^2 of the study area while about 180.9km^2 of the area was restricted for any industrial activity. The other unsuitable, less and moderately suitable class index covers 92.41km^2 of the study area collectively. Assessment map statistics confirmed that around 24.8% of the existing industrial areas are clustered in a restricted class index. Scientific-based industrial site selection is important in maintaining a clean environment and sustainable economic development. For selecting a suitable industrial site geospatial technology are effective and efficient than the usual approach. Therefore, the final output of this study could be helpful in the management of industrial site selection by providing additional insight to the decision-makers to consider the negative and positive aspects of industrial sites in the other regions of the country as well. Finally, to mitigate issues related to industrial sites impact on the environment, investors, and residence numerous stakeholders from the various field ought to work collaboratively.

KEYWORDS: *FAHP, Geospatial Technology, Industrial sites, Multi-criteria, WLC*

CHAPTER 1: INTRODUCTION

1.1. Background of the Study

Few countries in the world have achieved a high degree of economic and social development without developing an advanced industrial sector, which helps to alleviate poverty by creating jobs and income (United Nations Industrial Development Organization [UNIDO], 2018b). Economic development is fundamentally a transformation from traditional agriculture to modern agriculture, industries, and services. Industrial development has been a foundation of each countries economy, particularly since the industrial revolution (Fernando et al., 2015). Ethiopia has had a phenomenal economic growth rate of 11% per year for the past 12 years, with the agriculture and service sectors providing the foundation. But, the contribution of industry to Gross Domestic Product (GDP), on the other hand, has stayed below 14%, which is less than half of the low-income country average in Sub-Saharan Africa (UNIDO, 2018a). Therefore, it is important to delineate and evaluate land use suitability for industrial sites development to enhance the contribution of industry to the GDP.

Land evaluation is a process for matching the characteristics of land resources uses using a scientifically standardized technique. Land suitability is the degree of appropriateness of land for a certain use (Ritung et al., 2007). According to the Ethiopian Industrial Parks Proclamation (No.886/2015), industrial areas can be defined as an area with distinct boundaries designated by the appropriate organ to develop comprehensive, integrated, multiple or selected functions of industries.

Identifying the optimum suitable site for the firm is one of the most significant considerations in starting a process and expanding or reallocating all types of industries. The success or failure of the establishment of an industrial system depends on the site selection acts, the main objective in industrial site selection is to find the most suitable site with all the desired conditions satisfied and defined by the selection criteria (Abushnaf et al., 2015). Site selection of a capital project is a critical decision made by owners/investors that significantly affects their profit and loss. Decisions regarding the locations of industrial facilities influence where people work, live and determine the lifestyle of a community (Ramcharan & Dey, 2005). According to Sarath et al., (2018), the establishment of industries is in the very interest of societal development but not for individual or political gains. However, traditionally industrial zones have been chosen nearly entirely on the basis of economic and technological grounds. Currently, a higher level of sophistication is desired in order to meet a number of social and environmental standards that may be imposed through laws and government regulations (Rikalovic et al., 2015). According to various reports, industrial areas are the second most important factor contributing to the global increase in toxic pollution problems. As a result, it is critical to plan and select appropriate sites (Fernando et al., 2015). Selecting an industrial area is one of the most important decisions in the process of establishing, expanding, or moving an industry (Rikalovic et al., 2015). This is mostly governed by factors such as availability of resources (raw materials, utilities, labor forces, and so on), construction suitability, further expansion possibility, logistics, availability of market, social and environmental factors, and physical planning considerations (Ramcharan & Dey, 2005).

The significant impact of industrial area development in the national economy, environment and the effectiveness of geospatial technology in site suitability analysis were the motivation of the present study. Preliminary observations indicate that industrial area development can considerably boost Ethiopia's attractiveness for investment and business, as demonstrated by intense interest to take up space in one of the parks that are under construction (UNIDO, 2018a). As stated by Balist et al., (2019), the location of industrial areas is a critical factor in regional planning due to the socio-economic and environmental impacts which this kind of decision has on any territory. A proper location must attend to a wide range of factors to coordinate socio-economic benefits and environmental sustainability.

According to Beyene (2019), industrial areas can be selected by considering Land Use Land Cover, waterbody, road networks, elevation, slope, geological fault lines and residential area influential factors. In fact, industrial sites are not only impacted by these factors. As stated by Rikalovic et al., (2015), industrial site selection is a complex problem it requires diversified factors from different fields such as environmental, economic and social. Further, due to incapability of the Analytical Hierarchical Process (AHP) to overcome the existence of vagueness in the decision-making process was criticized by different scholars for instance (Balist et al., 2019, Dinade, 2016, Nyimbili & Erden, 2020, Maddahi et al., 2017, Hatta et al., 2014 and Tesfay, 2016). However, Beyene (2019) was utilized AHP method for the elicitation of weighing for the identified factors.

Successful formulation of policies for land usage requires analysis of land usage details to make sure the site selected for a certain purpose is appropriate. Land use planning consists of identification, suitability analysis, conflicting judgments in comparative analysis. Many problems associated with the real world have spatial factors involved in them. MCDM and GIS can be able to solve them efficiently with their computational capabilities, which implicitly became a platform to the majority of the problems that are required for better planning (Sarath et al., 2018). The AHP has been widely used to solve MADM problems. However, due to the existence of vagueness and uncertainty in judgments, a crisp, pairwise comparison with a classical AHP may be unable to accurately represent the decision-makers ideas. Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with the mapping of one's perception to a number (Hatta et al., 2014).

The process of industrial site selection begins with the recognition of an existing or projected need to meet new or growing markets. This recognition triggers the series of actions starting with searching out and screening geographic areas and specific locations. The good geographical location nearest to the capital city Addis Ababa and favorable climatic situations of Adama have contributed to the rapid expansion of the City as a commercial, industrial, residential and recreational center since its establishment in 1916 (Tesema & Sori, 2017). According to the Ministry of Industry (2015), study report Adama Town is one of the most appropriate places for sub-sector industrial planting.

Conclusively, the main objective of this research is to evaluate land use suitability for selection of industrial sites in Adama Town. Economic, environmental, geological, and population important aspects were combined into the current study by considering the positive and negative effects of the industry on the surrounding environment and the investor. Many geospatial data layers and related variables are used to select the optimum location for an industrial site (Fernando et al., 2015). However, Site selection with minimum impacts is very difficult to achieve considering criteria one by one, because of the big list of criteria including very important spatial factors (Fernando et al., 2015). Additionally, to fill the gap of AHP a Fuzzy Analytical Hierarchy Process (FAHP) based multi-criteria evaluation decision (MCE) system was utilized to weigh fourteen identified parameters for selecting an industrial location in Adama Town.

1.2. Statement of the Problem

The rapid development of the industrial field resulted in equally rapid diffusion of industries. However, most investors confront high transaction costs due to a lack of infrastructure and weak institutions on the one hand, and industrial pollution affects people and the environment in a variety of ways on the other. Furthermore, according to various reports, industrial areas are the second most important factor contributing to the global increase in toxic pollution problems. As a result, it is critical to plan and select appropriate sites in order to minimize the negative effects on people, investors, and the environment. Unfortunately, in many low and middle-income countries, industrial zones have little attention to be paid on the environmental and social impacts because their industries are often located in very populated areas (Fernando et al., 2015).

At the international level, some scholars are attempting to employ geospatial technologies to find optimal places for the industry. In contrast to other land use suitability analysis, in our country, little attention has been dedicated to finding a suitable location for the industry using those technologies.

Adama Town is one of the selected Towns for sub-sector industrial planting, according to the Ministry of Industry (2015). The study, on the other hand, views the selection criteria as primarily economic factors. As a result, they overlooked environmental, geological, and population requirements as additional elements to consider when deciding where to locate a good industrial Town. Furthermore, the scope of this feasibility study was limited to identifying Towns for a sub-sector; it did not include selecting sites inside a Town, and the selection process was manual, with no use of geospatial technology to integrate selected economic criteria to support a decision.

According to Adama Town's newly developed master plan, the majority of the earlier established industries are clustered around the residential area and on the periphery of strong streams that flow to the Awash rivers and Koka lake. As a result, the firm may be able to discharge waste into streams, harming the environment. Most industries release polluted effluents into the natural environment, including streams and rivers, without treatment, resulting in substantial environmental contamination and negative health and social consequences for people who are exposed (Ethiopian Electric Power Corporation [EEPCo], 2018). According to World Health Organization [WHO] (2017), there are a huge number of industries developing in the Awash Basin, all of which have an impact on the basin's water quality. Further, the majority of industrial sites in the basin do not treat their wastewater before dumping it into open areas or bodies of water. Along with the river flow, there are industrial areas in the basin, one of which is Adama. Therefore, Selecting industrial site based on scientifically standardized technique reduce the adverse impact of industrial site by providing alternative optimal sites for decision makers for industry expansion.

Lastly, in this study based on the indicated drawbacks, economic, environmental, geological and population parameters were deemed and the Fuzzy Analytical Hierarchy Process (FAHP) was applied to weigh the criteria as a technique to overcome the limitations of the Analytical Hierarchy Process (AHP). Additionally, GIS, RS and Google Earth technologies were integrated to help the industrial site selection decision system.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this thesis research is to evaluate land use suitability for selection of industrial sites for the development of industry in Adama Town by integrating geospatial technologies.

1.3.2. Specific Objective

In addition to the main objective, this study also has specific objectives that to be accomplished necessarily to hit the target of the main goal set these are;- To

- Identify criteria that affect the location of industrial sites.
- Allocate weights for the criteria map based on the Fuzzy Analytical Hierarchy Process (FAHP) method.
- Evaluate the existing industrial areas based on the produced assessment suitability map.
- Show the overall suitability of the study area for industrial site development by overlaying criteria thematic map.

1.4. Research Questions

- What are the criteria that affect the location of industrial sites selection?
- How are weight assigned for criteria based on the Fuzzy Analytical Hierarchy Process (FAHP)?
- How can be the existing industrial areas are evaluated?
- Is the study area suitable for industrial zone development with selected criteria?

1.5. Significance of the Study

The primary aim of this thesis research is to evaluate land use suitability in order to determine a suitable site for the industry in Adama Town. As a result, the study output and findings will benefit a distinct group of people, either directly or indirectly. The study will primarily illustrate the effectiveness of geospatial technology such as GIS, RS, Google Earth, and the Fuzzy Analytical Process (FAHP) method for evaluating land use suitability for industrial site selection. Secondly, the study's ultimate product is a map that depicts the suitability of land for an industrial zone. As a result, urban planners and decision-makers in Adama Town could use this map as a starting point for deciding on which areas industries to be developed and expanded. Thirdly, if the decision-makers use the result of this study then the investor and community will be benefited. Because, this study was considered environmental, economic, geological and population factors for industry location. The community will be benefited by getting employment opportunities and maintaining a sustainable clean environment with minimum industrial pollution and the investor will be profited by the location of industry near to infrastructure by reducing the cost spent on transportation of raw materials and finished output. Finally, different researchers may benefit from this research output by using it as a reference for further land suitability studies for industrial sites.

1.6. Scope of the Study

The geographic scope of this study is delimited to the Adama Town municipality boundary for the evaluation of land use suitability for industrial site selection. Industrial site selection is a complex process it requires analysis of different economic, environmental, geological soil, and social factors. Therefore, the thematic scope considered fourteen criteria for selecting a site for industrial area development such as distance from (major road, railway, highway, the existing industrial areas, landfill site, heavy power line, waterbody (stream &

river), geological fault lines and settlement areas) topographic elevation, slope, soil type, population density and LULC. Weight was developed for criteria based on the Fuzzy Analytical Process (FAHP). Finally, factors were combined with a weighted linear combination algorithm in Idrisi selva software.

1.7. Limitation of the Study

As stated earlier in the statement of the problem section little study had conducted in this country regarding industrial site selection using geospatial techniques. Thus, the standard distance for factors proximity analysis is not yet available at the national level. Consequently, international proximity distance standards were used to reclassify the suitability of factors for a decision system.

1.8. Organization of the Thesis

This thesis study was compiled into five chapters. The first chapter deals with the introduction which gives background information about the study, statement of the problems, objective of the study it comprises general and specific objectives, research questions raised, the significance of the study, the scope of the study, limitations of the study and organization of the thesis. The second chapter deals with a review of related literature which includes introduction, industrial location theory, industrial environment, the concept of geospatial technology, decision support with GIS, GIS and multi-criteria decision making, method of determining a weight for a decision, analytical hierarchy process, fuzzy analytical hierarchy processes, empirical review of related study and lastly conceptual framework of industrial site selection. The third chapter deals with the materials and methods employed for this thesis research. This embraces; description of the study area, data and software used, the methodology implemented, technical flow chart of the methods and industrial site selection criteria and process. The fourth chapter deals with data analysis, result and discussion, which encompasses suitability of economic, environmental, geological and population parameters for industrial site selection, standardizing factors, calculating weight for main and sub-criteria, weighted linear combination, assessment of the existing industrial area, and discussion about the finding and result obtained. Lastly, chapter five, which is about the conclusion and recommendation made for the study.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Industrialization began in the 19th century around the central Europe and was gradually spread towards Asia and other regions of the world. The rapid development of the industrial field caused to rapid distribution of the industries as well (Fernando et al., 2015). Identifying an optimal site for industrial areas is an extremely difficult and complicated process because it requires data from diverse social and environmental fields and a number of conflicting qualitative and quantitative criteria existed for evaluation/selection (Mehdi et al., 2015). The principles of liberalization, globalization, and privatization and the relative changes at the global economy have been very important for the industrial zones development. Most of the countries use this tool for the development of industrial field with minimizing its negative impacts on people and the environment. This has been very important as a better environmental management tool, which can be used for sustainable development of the industrial sector. The best location for the industrial zone is the key factor of the accomplishment of its main objectives which are the requirement of all facilities and the minimum of social and environmental negative impacts (Fernando et al., 2015).

2.2. Industrial Location Theory

Location theory has a long and rich historical tradition, its early development is associated with authors such as Weber (1929), Hoover (1948), Lösch (1954), among others. The traditional economic theory views the business firm as an optimizing agent that selects a location to maximize profits. The historical legacy of viewing the location process as a search for the least–cost location is still present in the work of most industrial recruiters, as most early work on industrial location focused primarily on the minimizing of transportation costs. Any aspect that could affect production costs at a specific area might be factored into a firm's location decision (Salvesen & Renski, 2003). According to Rikalovic et al., (2015), traditionally industrial zones have been chosen nearly entirely based on commercial and technological grounds. Currently, a higher level of complexity is desired in order to meet a variety of social and environmental requirements set by legislation and government regulations. Because of the socioeconomic and environmental consequences of such decisions on any territory, the location of industrial areas is a crucial component in regional planning. To coordinate socio-economic benefits and environmental sustainability, a suitable location must consider a wide range of issues (Berube, 2014).

2.2.1. Weber's Theory of Industrial Location

Alfred Weber formulated a theory of industrial location in which an industry is located where the transportation costs of raw materials and final product is a minimum. Weber's theory of industrial location is very comprehensive and known as 'Least Cost theory'. He was the first one to analyze the general regional factors of transport and labor costs as primary factors, and the agglomeration costs as secondary factors, influencing the optimal location of the manufacturing industries. He singled out two special cases. In one the weight of the final product is less than the weight of the raw material going into making the product. This is the weight losing case. In the other the final product is heavier than the raw material that require transport. Usually this is a case of some ubiquitous (everywhere available) raw material such as water being incorporated into the product. This is called the weight-gaining case (Djwa, 1960).

2.2.2. Hoover's Theory of Industrial Location

One of the most outstanding American contributors to location theory of is Edgar Hoover, who combine Weber's theory with the partial equilibrium analysis of the general economic theory. Hoover state that the theory of location may take only three things for granted: (a) the distribution of natural resource, (b) desires and tastes of human beings and (c) economic technique. Hoover also tried to propound a least cost theory of location, in which he tried to overcome some of the weaknesses of Weber's theory. Hoover starts with the assumption of perfect competition between producers or sellers at any one location. Secondly, he assumes perfect mobility of factors of production and takes transportation costs and production or extraction costs as the determinants of location. Hoover's analysis differs from weber's in the sense that he , unlike weber, consider all possible locating factors, and not only the general one with influence every plant location, regardless of economic system (Djwa, 1960).

2.2.3. Lösch's Theory of Industrial Location

August Losch contends that in free economy the correct location of the individual enterprise lies where the most profit is greatest. He criticize Weber for taking gross revenue as constant by assuming a given demand and price. In reality demand not only varies with price and the size of the market but also with the chosen site of production. In fact, says Losach the optimum location would shift with each change in price. Losach recognize the complexity of determining the point maximum profit. He conclude that the solution can only be obtained by means of trial and error. In others words, for every prospective location one has to determine the total attainable demand with the aid of market analysis and also the optimum output through cost analysis. Losch admits that this method does not exclude the possibility that other points, which are not considered may yield a higher profit (Djwa, 1960).

2.3. Industrial Environment

The proper utilization of natural resources is now an important component of economic development. Although land is one of the most valuable natural resources, it also contains several resources (Efe et al., 2015). Industrial manufacture is important for economic development and employment opportunities. However, it can also cause health problems and long-term environmental impact. A considerable number of people live too close to industrial plants and are directly affected by the pollutants emitted. They are also more at risk for accidental releases and fires. Industry in the developing countries can differ in size and technology from a one man roadside workshop to huge industrial enterprises, such as oil refineries. Sometimes certain industries are concentrated in a specific area of a city by tradition (Sida, 2016). Most industries release their effluents containing pollutants into the natural environment including streams and rivers without any treatment, causing serious environmental pollution with serious health and social effects on those exposed to it (EEPCo, 2018). Ethiopia has comprehensive legislation to safeguard environmental protection, notably the 2002 Environmental Pollution Control Proclamation and the 2008 Prevention of Industrial Pollution Regulation, but the federal ministry of Environmental, Forestry, Climate Change and Regional Environmental Protection Agencies have limited capacity to manage and regulate the environmental threats posed by the fast growing industrial sector, and there is little systematic monitoring and inspection. Coordination between the industrial, water and other sectors is currently too weak to manage the impacts of the envisaged developments. The capacity of city-level Environmental Protection Offices is even more constrained. They are tasked with enforcing standards, but need appropriate guidelines, standards, and enforcement measures. Town and City leaders currently give very little attention to managing and mitigating potential pollution impacts of existing and new industries (Heymans et al., 2017).

2.4. Overview of Industry in Ethiopia

Industrialization is the driving force behind a country's socio-economic change. It is chosen for producing economic dynamism, creating job opportunities, and creating a competitive advantage. Ethiopia, like all other countries, has been working to change the structure of its economy since the late nineteenth century. Modern manufacturing plants first appeared in the country in the 1920s (about 25 were established by 1927, primarily by foreigners), but it was not until the 1950s that a concentrated attempt was made to develop a modern industrial sector. In addition, since then, the industry has gained momentum, and a comprehensive plan to promote industrialization and economic development has been implemented (Mulu, 2013 as cited in Fenta, 2014). According to UNIDO (2018a), as stated in the introductory part Ethiopia's economy has grown at a phenomenal rate of 11% per year during the last 12 years, with agriculture and service industries expanding. The contribution of industry to GDP, on the other hand, has remained below 14 percent, which is less than half of the sub-Saharan. Therefore, the phrase industrial park is now a very commonly used term under Ethiopian Economic Policies that it is vital to concentrate multiple resources into one single location to see a good impact on effective resource usage, infrastructures, and boost employment rate and productivity (Gebeyehu, 2014). As presented in (Table 2.1) about 12 export processing industrial parks have been established across the country based on accessibility to market outlets, infrastructure, economic potential, and regional development balance. Almost all industrial parks are established along corridors of railway networks that are either completed or under construction and are on schedule (Ohno, 2017).

Table 2.1 List of industrial parks located in Ethiopia

No	Name of park	Site location from Addis Ababa	Area in (hectare)	Status of operation
1	Addis industry village	Addis Ababa	8.7	Operational
2	Bole Lemi I	Addis Ababa	156	Operational
3	Bole Lemi II	Addis Ababa	186	Operational
4	Kilinto	Addis Ababa	337	Operational
5	Hawassa	South	300	Operational
6	Dire Dawa	East	1500	Operational
7	Kombolcha	North east	700	Operational
8	Mekelle	North	1000	Operational
9	Adama	South east	2000	Operational
10	Bahir Dar	North west	1000	Operational
11	Jimma	South west	500	Operational
12	Debre Birhan	North west	1000	Operational

Source: (Industrial Park Development Corporation [IPDC], 2015)

2.5. Geospatial Technology (GST)

Geographical Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), Google Earth, and other new technologies that aid the user in the collecting, processing, and interpretation of spatial data are all examples of geospatial technology (U.S. Department of Labor, 2005 as cited in Jaglan et al., 2018).

2.5.1. Geographic Information System (GIS)

GIS is computerized information storage, processing and retrieval systems that have hardware and software specially designed to cope with geographically referenced data and corresponding attribute information (tables, charts and statistics). It is evident that numerous elements must be considered during the decision-making process, making the task of selecting appropriate tools to enable the concentration of data, information, and expertise difficult. New trends in information technologies put Geo-information systems (GIS) in the center of events in industrial locations science. The siting and placement of a major facility means to satisfy a number of competing objectives and criteria. To accomplish task such as industrial site selection, we need to prepare number of maps, each with a different theme (Rikalovic et al., 2014).

2.5.2. Remote Sensing (RS)

Remote sensing is the technology of gathering information about objects or phenomena without being in physical contact with them. For this, different wavelength regions of the electromagnetic spectrum are utilized. Electromagnetic radiation is comprised of a large spectrum of wavelengths right from very short wavelength cosmic rays to long radio waves. In remote sensing, the most useful regions are the visible (0.4-0.7 μ), reflective infrared (0.7-3.0 μ), thermal infrared (3.0 to 5.0 μ and 8.0 to 14.0 μ) and the microwaves (1 mm to 1 m). All remote sensing systems, capture radiation in different wavelengths reflected/emitted by the earth surface features and record it either directly on the film as in the case of aerial photography or on a digital medium like tape; latter is used for generating the image (Kushwaha, 2005).

2.5.3. Global Positioning System (GPS)

A GPS is the device, which provides information on the geographic coordinates, altitude, time, direction of movement, the distance covered. Global Positioning System is also called Navigational System with Time and Ranging (NAVSTAR). A GPS consists of a constellation of radio-navigational satellites, a ground control segment, which manages satellite operation and users, who use specialized GPS receivers to receive a wide range of data. The system was established by the Department of Defense (DoD) of United States of America primarily to fulfill defense needs and as a byproduct to serve the civilian community. The satellite constellation consists of 21 satellites and three spare satellites positioned 20,000 km (about three times the earth’s radius) above the earth. Each satellite receives and stores information from the control segment, maintains very accurate time through onboard precise atomic clocks and transmits signals to the earth (Kushwaha, 2005).

2.5.4. Google Earth

Is a virtual globe, map and geographical information program that was originally called Earth Viewer 3D, and was created by Keyhole, Inc, a Central Intelligence Agency (CIA) funded company acquired by Google in 2004. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe. Google Earth uses digital elevation model (DEM) data collected by NASA's Shuttle Radar Topography Mission (SRTM). The internal coordinate system of Google Earth is geographic coordinates (latitude/longitude) on the World Geodetic System of 1984 (WGS84) datum i.e., the same datum that used by GPS. Google Earth shows the earth as it looks from an elevated platform such as an airplane or orbiting satellite. Most of the high resolution imagery in Google Earth Maps is the Digital Globe Quickbird which is roughly 65cm pansharpened (65 cm panchromatic at nadir and 2.62 m multispectral at nadir). Google is actively replacing this base imagery with 2.5 m SPOT Image imagery and several higher resolution datasets (Mohammed et al., 2013).

Due to the rising demand for spatial data, major advancements in the integration of remote sensing data and GIS are now taking place. Remote sensing and Geographic Information Systems (GIS) technologies complement one other in three ways: i) Remote sensing may be utilized to collect data sets for usage in GIS; ii) GIS datasets can be used as auxiliary information to improve remote sensing products; and iii) RS and GIS data can be combined in resource analysis and modeling (Abushnaf et al., 2015). With its synoptic view, repeating coverage, and reliability, remote sensing data has opened up a world of possibilities for industrial area mapping and change detection. Spatial data stored in digital database of GIS, such as Digital Elevation Model (DEM) and capability of GIS to integrate different datasets can be effectively used to evaluate the suitability of land for industrialization. Within the GIS, satellite images and other topography information can be used to give important data for industrial planners and developers (Johar et al., 2013).

Lastly, three main forms of geospatial technology, such as Geographic Information System (GIS), Remote Sensing (RS), and Google Earth, were used to assist the site selection decision system (SSDS) in this thesis for evaluating land use suitability for selection of industrial sites in Adama Town.

2.6. Decision Support with GIS

Geographical information systems can help to aid in decision-making in a variety of ways. The production of suitability maps is one method. They reveal which places or locales are particularly well suited for a particular use, or which are particularly vulnerable to a hazard. In most decision-making scenarios, many decision criteria are considered (Flitter et al., 2013).

2.7. GIS & Multi-Criteria Decision Making (MCDM)

Identification, appropriateness analysis, and contradictory judgments in comparison analysis are all part of land use planning. Many problems associated with the real world have spatial factors involved in them. With their computational capabilities, MCDM and GIS can address them quickly, implying that they have become a platform for the majority of the problems that are necessary for improved planning. Multi-criteria evaluation which area Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM) are two types of decision making (MODM). The term MCDM is used to refer to both attribute and objective management. The objective of Multi Attribute Decision Making (MADM) analysis is to select the most preferable alternative. To solve MADM challenges, a variety of decision-making procedures can be applied. Additive decision methods are widely accepted to solve the MADM problems along with ideal point methods. Analytical Hierarchy Process (AHP) is one of the additive decision methods, which is used in a lot of real world problems as well as non-spatial problems. Breaking down complex problems into basic forms using a hierarchy or levels system, and then incorporating mathematical calculation for pairwise comparison and normalization to produce priority vectors, also known as criteria weights(Sarath et al., 2018).

2.8. Method of Determining a Weight for Decision

2.8.1. Weighting by Ranking

The simplest method is to rank the criteria in ascending or decreasing order. Ascending means that the most important criterion receives rank 1, the second criterion receives rank 2, and so on until the total number of criteria is reached. The least important criterion receives rank 1 when ranking in descending order, and so on. The numerical weights corresponding to the ranks are derived in a variety of ways once the ranks have been allocated. a) Rank sum: With n criteria, rank r receives the weight n-r+1. b) Reciprocal rank: With n criteria, rank r receives the weight 1/r, its reciprocal value. c) Rank exponent: With n criteria, rank r receives the weight $(n-r+1)^p$. The exponent p is a parameter to control the distribution of the weights (Flitter et al., 2013).

2.8.2. Weighting by Rating

Another popular method is rating. The ranked criteria are assigned a score based on their respective importance. a) Point allocation: the overall score is to be distributed within the chosen criteria. For example, with a total score of 100, criteria could receive the weights 35, 30, 20, 10, and 5 points with decreasing importance. b) Ratio estimation: each criterion is provided with an arbitrary score from a defined range of values. The most important criterion receives the highest score (e.g. 100) and the insignificant criteria receive a score of 0 (Flitter et al., 2013).

2.8.3. Weighting by Pairwise Comparison

According to Flitter et al., (2013), a pairwise comparison is another method for weighing many factors. It is based on the Analytic Hierarchy Process (AHP), a well-known decision-making framework created by an American mathematics professor in the 1960s (1980). This strategy allows you to focus on simply comparing two criteria at a time. As a result, when dealing with a large number of classes, the effort required to compare each criterion with each other grows rapidly (to be exact: with n criteria, there are n(n-1)/2 comparisons).

To summarize, many ways of allocating weight to criteria have been presented and discussed earlier. However, as a method, their accuracy and dependability are also very diverse. Furthermore, the three techniques have different underlying scales. They range from ordinal (weighting by ranking) to interval (weighting by rating), to ratio scale (pairwise comparison). While the first two methods lack a theoretical foundation, the last one can be quantitatively validated. Wrong weights lead to incorrect suitability analysis conclusions and, as a result, incorrect judgments (Flitter et al., 2013).

As a result, the focus of this thesis is to evaluate land use suitability in order to make the best possible industrial sites decision. Based on the above-mentioned strength toward weighting, weight by pairwise comparison was used to assess the relative importance of the criterion.

2.9. Analytical Hierarchy Process

Multiple criteria decision making (MCDM) is a generic term for all methods that exist for helping people making decisions according to their preferences, in cases where there is more than one conflicting criterion. Multi-Criteria Decision Analysis (MCDA) is a set of analytical approaches that aid decision-makers in solving complicated problems by utilizing information provided by the decision-makers. There are several techniques to multi-criteria decision-making that can be successful based on the many concerns. The Analytic Hierarchy Process (AHP) is a decision-making technique for determining the relative relevance of criteria in a given decision-making situation (Hashemi et al., 2017). AHP provides an effective tool to deal with complex decision-making and unstructured problems (Soltani & Marandi, 2011).

The AHP is an iterative technique, which consists of a number of stages that can be modified to suit a particular problem (Tsiko & Haile, 2011). It is a tool for evaluating many issues in numerous areas of human requirements, such as political, financial, and several other diverse interests, in order to solve difficult decision problems (Singh Thakur et al., 2018).

2.10. Fuzzy Analytical Hierarchy Process

Both FAHP and AHP methods are extremely useful for prioritizing multiple-choice criteria and sorting them into a hierarchical structure. FAHP assesses the relative importance of each criterion and also generates an overall rank of alternatives or weight of factors. In the classic AHP method, the numerical values of linguistic variables are directly used for the evaluation of the criteria. If the environment where the decision-making process takes place is fuzzy, then fuzzy numbers will be used for the evaluation concerning some deviations of the decision-makers (Wijitkosum & Sriburi, 2019).

The AHP has been widely used to solve MADM problems. Due to the ambiguity and uncertainty in judgments, a crisp, pairwise comparison with a conventional AHP may not be able to effectively portray the decision-makers views. Even while the AHP discrete scale offers the advantages of simplicity and convenience of use, it does not account for the uncertainty associated with mapping one's perception to a number. FAHP is an effective approach for dealing with the fuzziness of data used to determine the preferences of various decision factors (Hatta et al., 2014).

2.11. Empirical Review

2.11.1. Global Experience in Industrial Site Selection

Balist et al., (2019) had attempted to evaluate the potentiality of land for industrial sites development by combining spatial and decision making techniques. For their study, they had used different parameters that affect the potentiality of land for industrial sites development these were slope, elevation, and distance from road, landslide, geology, land use, erosion, and distance to river, fault and groundwater. Similarly, they used Fuzzy Analytical Hierarchy Process for elicitation of attribute weight, while WLC was used to combine the criteria. To summarize, the finding of their study, reveals that the maximum weight was elicited to geological fault lines while the least weight was given to topographic elevation factor and its degree of influence was 0.251 and 0.027 respectively.

According to Ahmadipari et al., (2018), study entitled "an integrated environmental management approach to industrial site selection by genetic algorithm and fuzzy analytical hierarchy process in Geographic Information System". Suitable areas for the industry can be selected by eight parameters measured as independent variables such as distance from rivers, distance from protected areas, land use land cover, distance from fault lines, distance from urban area, distance from industrial areas, slope elevation, and distance from main roads. In order to overcome the uncertainty and flow that originate from Analytical Hierarchy Process (AHP) during the decision-making process Fuzzy Analytical Hierarchy Process (AHP) was employed as a technique for distributing weights. The final result obtained from the analysis depicts that the study area fell under five categories such as exclusively suitable, less suitable, suitable, moderately suitable, highly suitable and extremely suitable and its corresponding study area coverage in percentage was 25.0, 13.5, 15.9, 22.4, 18.0, and 5.2.

Sarath et al., (2018) had presented the combination of a Geographic information system (GIS) and multi criteria decision-making (MCDM) to identify distinctly the suitable zone for industries. Six criteria that were used by the researchers for analysis of land suitability for industrial sites are LULC, flood, geology, road, DEM and slope. To develop the importance level of criteria for industry location they implemented AHP based pairwise comparison. The high and lower weight were assigned to geology and road respectively. For criteria standardization, they used simple linear transformation by allocating a score value of 1,2,3,4, and 5 for the consecutive influence from unsuitable to highly suitable. Finally, for aggregation of these criteria, they used weighted linear combination methods.

Fernando et al., (2015) had produced a GIS-based model to screen the most suitable location for industrial zone in Kesbewa Divisional Secretarial Division of Colombia District Srilanka. As a methodology, initially they used seven sets of site selection criteria that were identified through literature review and consultation of experts. Land use, water, soil type, wildlife, archeological site, roads and power line were the selection criteria. For deriving the weight for the criteria, they used AHP methods. The set minimum requirement for the industrial zone was 25 acres and they developed a 100m buffer zone (green belt) for the final suitable zone to minimize the pollution of industry. Lastly, they classified the finding into excellent, very good, good, fair and not suitable. Besides to criteria selection limitation of this study also had a strength and the main strength of this study was the inclusiveness of green belt assessment in a final suitability map to minimize the pollution of industry. The overall global empirical study related to industrial site selection reviewed under the present study was summarized in (Table 2.2).

Table 2.2 Summarization of international experience in industrial site selection

No	Author	Criteria	Methods	Country
1	(Johar et al., 2013)	Railway, road, river, urban area & LULC	AHP, GIS, WLC	India
2	(Sarath et al., 2018)	LULC, flood, geology, road, settlement area, DEM & slope	GIS, AHP, WLC	India
3	(Fernando et al., 2015)	Power line, road, archeologic site, soil, wildlife, water &LULC	GIS, AHP, WLC	Srilanka
4	(Ahmadipari et al., 2018)	River, LULC, protected area, fault line, urban area, rural area, industrial area, slope, elevation &main road	GIS, FAHP, GA, WLC	Iran
5	(Alzamili et al., 2015)	Urban area, landfill site, heritage site, airport, river, rural area, industrial area, slope, natural resource, railway, LULC, oil pipe& highway	GIS, AHP, WLC	Iraq
6	(Balist et al., 2019)	Slope, elevation, road, river, LULC, geological fault line, ground water, geology, land slide & erosion	GIS, FAHP, WLC, fuzzy logic	Iran
7	(Jiang, 2007)	Build up area, street, main road, highway, railway, factories, and slope	GIS, AHP, WLC	China

8	(Roy et al., 2019)	Land price, transport, resource, LULC, environmental attribute, availability of wasteland, slope and river	GIS, AHP,WLC	India
9	(Abushnaf et al., 2015)	Geomorphology, land cover, ground water, main road and river	GIS, AHP, WLC	India
10	(Naghdi et al., 2017)	Erosion, soil depth, soil texture, main road, climate, attitude, slope, aspect, highway, vegetation, protected area, land use, population, urban area, village, waterline, power line, existing industrial area and airport	GIS,SAW, AHP, WLC	Iran
11	(Fataei et al., 2015)	Slope, geological fault, surface water, land use, urban area, and pathway	GIS, AHP, WLC	Iran
12	(Reisi & Soffianian, 2013)	Waterbody, groundwater depth, urban area, land use, water supplies, road, slope and industry	GIS, AHP, Boolean logic,	Australia
13	(Ohri & Singh, 2010)	Highway, settlement area, waterbodies, water table, railway, river, forest area, flood plain and slope	GIS, WLC,AHP	India

Finally, as shown in (Table 2.2) many studies and researches were undertaken at the worldwide level to identify ideal places for the industry. However, the methods for analyzing independent parameters for final conclusions differ from one researcher to another. There is no universal buffer distance standard for pre-analysis of criteria for decision-making, such as proximity to a road, river, urban area, railway, power line, degree of slope, and existing industry. Each researcher utilized a different distance. This property makes an industrial site selection is subjective for instance (Roy et al., 2019, Ahmadipari et al., 2018, Sarath et al., 2018, Abushnaf et al., 2015, Alzamili et al., 2015, Fataei et al., 2015, Ohri & Singh, 2010 and Jiang, 2007) used different buffer distance reclassifications intervals. To overcome the subjectivity of industrial sites selection distance analysis, a new methodology was adopted in this study, which involved taking the average proximity distance of criteria utilized by various researchers as described above. Furthermore, the empirical research shows that road networks, waterbody, topographic slope and elevation, LULC, geology factor and AHP method are the most commonly employed criteria for industrial site selection.

2.11.2. National Experience in Industrial Site Selection

Beyene (2019) had integrated Geographic Information System (GIS) and remote sensing technology for industrial site selection in Hawassa Town. The researcher used an aggregate of nine criteria such as slope, soil, Land Use Land Cover, proximity to water bodies (lake, swamp and river), distance from roads, distance from residential areas and geological fault. To calculate the weight for each determined criteria the researcher applied Analytical Hierarchy Process (AHP). The result obtained from the analysis demonstrates that about half (50.7%) of the Hawassa Town was suitable for the industrial location. Additionally, it depicts GIS and RS are valuable tools that can support the decision-makers to find the best possible industrial sites. To summarize, industrial site selection is a complex multi-criteria problem it requires diversified criteria includes environmental, economic, geologic and population factors. However, factors like the existing industrial areas, landfill site, population density and heavy power lines were not taken into account by the researcher.

Ministry of Industry (2015) conducted feasibility studies for selected sub-sector such as coffee processing, corn processing, garment accessories manufacturing, glass packaging, label manufacturing, leather accessories, metal packaging, paper packaging manufacture, plastic and flexible manufacturing, and sesame manufacturing. A suitable location for these plants were selected across the country based on a two-stage location and site selection procedure. The first stage involved identifying potential project locations and prioritizing and selecting the appropriate one. The project location determining factors considered in the study were the supply of raw material and input, access to market, availability of skilled and unskilled labor, infrastructure such as road, electricity, and telephone line, availability of social amenity hospital, school, training center residence housing. The second stage of the project location and site selection procedure involved identifying alternative project locations within the selected project location and selecting of optimum project location from the proposed site.

From this feasibility study finding, Adama Town is amongst one of the nominated Towns for sub-sector industry planting. However, the study emphasizes the selection criteria almost mainly depend on economic criteria. Thus, neglected to consider environmental, geological, soil type and population criteria as the main factors for locating a suitable industrial site. Moreover, the feasibility study was only delineated to identifying Towns for sub-sector. Additionally, the selection process was based on a manual method that was not used any kind of geospatial technology for integrating selected economic factors to support a decision.

According to Alvima PLC (2012), a study report on environmental impact assessment of pasta and macaroni project located in Adama Town, Kebele 09. The land adjacent to the project site and the neighboring environment are the most impacted area directly or indirectly by the project. Primarily, soils are the natural ecosystem to be impacted by the project. Secondly, there is a landscape form in the project site, which is impacted. Employees are other key elements influenced by the plant establishment and its processing and production of the pasta and macaroni factory. To mitigate the listed impact the organization used baseline environmental conditions for the project such as physical environment, biological environment, and socio-economic environment. However, the environmental impact assessment study was conducted after the land for the project was obtained from the Oromia investment board based on a lease. This shows that before the allotment of land for pasta and macaroni project, suitability analysis of land for the industry was not assessed in GIS and RS based method.

Finally, in the present study, the above-described limitations were used as an input to select a sustainable suitable site for the industry by harmonizing environmental, geological, population, and economic main criteria factors to find an optimal location for sitting of industry. To compensate the vagueness and uncertainty that arise from the decision-making process Fuzzy Analytical Process was applied. Furthermore, geospatial technology mainly GIS, RS, and Google Earth was used to fill the above indicated manual based selection of land for industry.

2.12. Conceptual Framework of the Study

Conceptual framework is summarized how all reviewed literature under this chapter is contextualized to the present study in order to formulate the framework for demarcating land for industrial site development. Demarcating optimal sites for industrial development is a complicated process it needs data from the diversified economic, environmental and geological fields. As indicated in the empirical review part, Several studies have been conducted in the field of industrial site selection and the most common frequently used independent variable which affects the suitability of land for industrial development by all scholars are road network, topographic slope, elevation, Land Use Land Cove (LULC) and geological factors. So depending upon the literature, suitability type and study area, major road, railway, highway, elevation slope, existing industrial area, LULC, waterbody, landfill site, heavy power line, geological fault line, population density, and soil type independent variable were identified for the current study to enhance the suitability of industrial sites (dependent variable) by harmonizing these factors based on geospatial technology.

Geospatial technology essentially Geographic Information System (GIS) and remote sensing have a considerable role in industrial site selection because it manages a large number of data and integrates different source data. Therefore, it has been applying in various filed of suitability for instance in the field of industrial site selection the different researchers applied this technology.

Suitable industrial site selection is not only dependent on independent thematic map criteria but also it is dependent on different moderator variable, which includes spatial analysis, classification, bufferization, geospatial technology and weight allocation. Suitable site selection for the industrial site is sensitive to the weight influence assigned for factors. Flaw and ambiguity are common characteristics of decision-makers in suitability analysis that affect the weight influence factors for final decision. Thus, in order to avoid vagueness in the decision-making process, the weight was critical and necessary established based on Fuzzy Analytical Hierarchy Process (AHP). According to empirical review, there is no common standard distance of buffering criteria different researchers used different standard distance, therefore, in order to overcome this limitation average of buffer distance used by some researchers were used for the current study.

Finally, the weighted factors were integrated in a weighted linear algorithm to produce the expected result of the present study, which is a suitability map for industrial sites development. The overall summarized conceptual framework of all reviewed literature under this chapter is contextualized in the current study for selecting suitable land for industrial site development was shown in below (Figure 2.1).

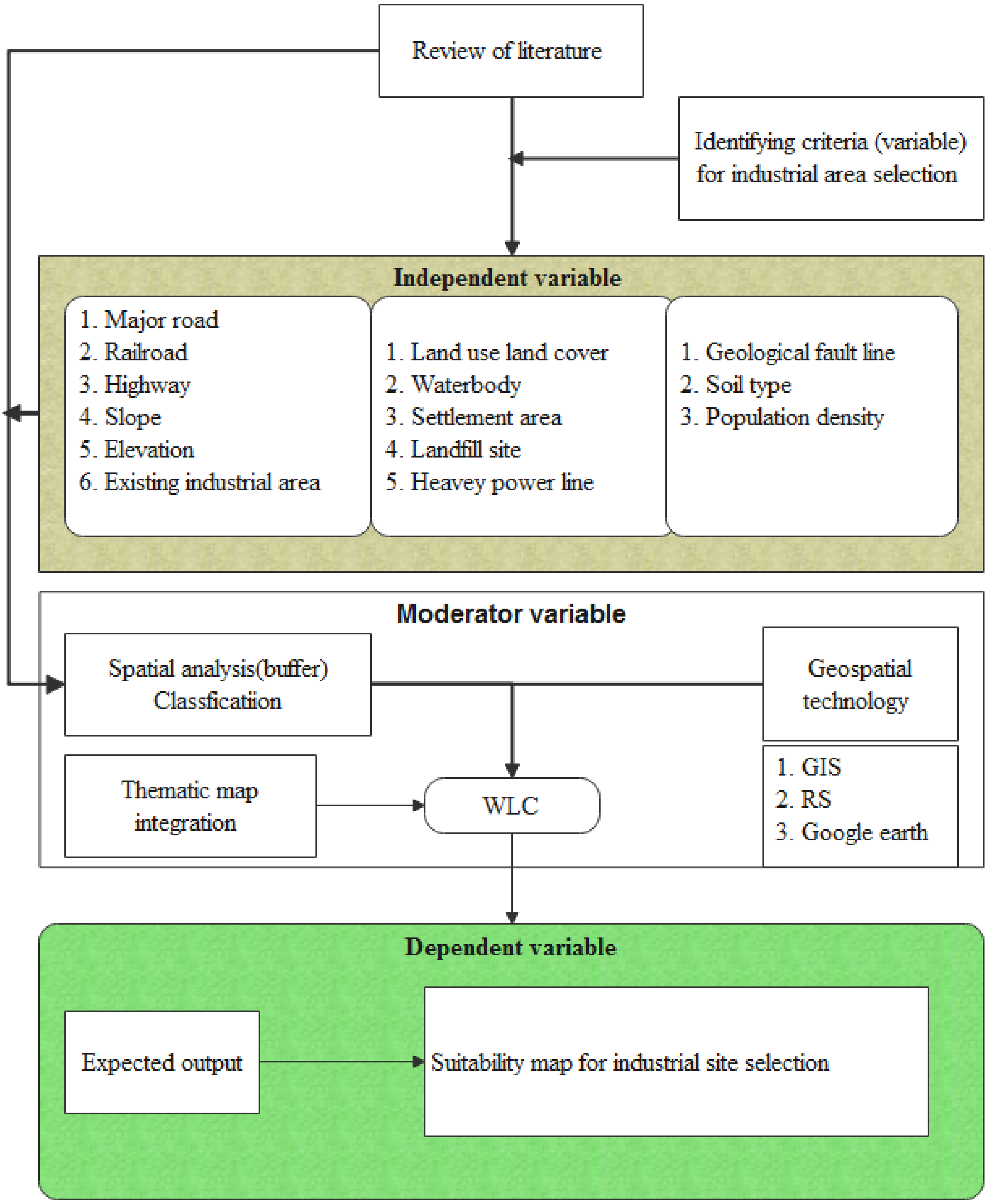

Figure 2.1 Conceptual framework of suitable site selection for industry

CHAPTER 3: MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographic Location

Adama is a Town in central Oromia Region, Ethiopia. Adama Town is located at nodal point along the railway line that stretched from Port of Djibouti to Finfinne/ Addis Ababa in the heart of Rift Valley with incomparable opportunities for tourism, conference, industrial and trade of development in the region. It is located at 8.54°N 39.27°E at an elevation of 1712 meters, 99 km southeast of Addis Ababa. The Town sits between the base of an escarpment to the west, and the Great Rift Valley to the east. Adama Town is a busy transportation centers. Adama district fully enclaves and demarcates Adama Town in four corners of its margins. The Town is also situated north of prominent Awash River that has been the most utilized river for irrigation in the country and the source of city's potable water (Adama City Municipality Office [ACMO], 2018).

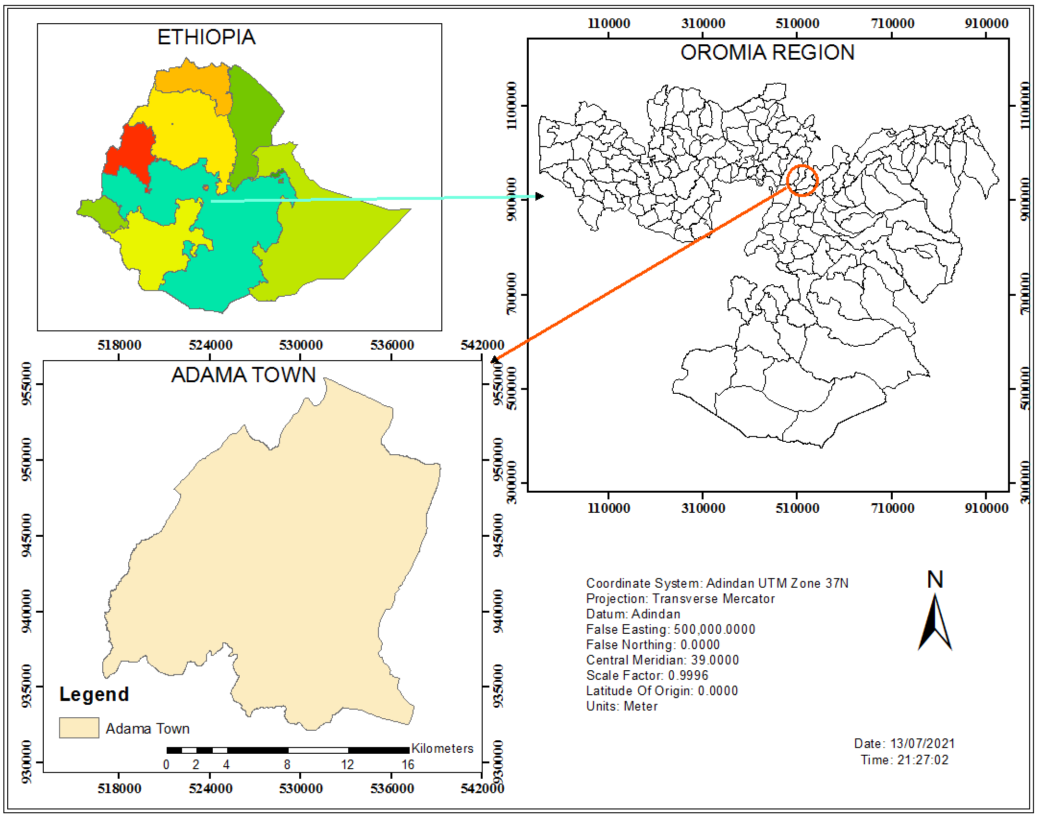

Figure 3.1 Location map of the study area

3.1.2. Demography /population

The size of population of any place is affected by birth rates, death rates and migration. Demographically, Adama is the most rapidly growing city both in terms of population and physical areas in the region starting from the outset of its establishment due to ongoing urban spread out, natural growth of population and high level of rural urban migrations. According to the last three consecutive censuses conducted in the country showed large increase of population in the city. So that the first Ethiopian population and housing census, which was held in May 1984, Adama had a population of 77,237. The second population and housing census conducted in 1994 reported that Adama had a total population of 127,842 of whom 61,965 were males and 65,877 were females. According to the third Ethiopian population and housing census which was conducted in 2007 (the most recent year for which data are available), 220,212 people of whom 108,872 males and 111,341 females that distributed over land areas 133.6 km^2 were inhabited in Adama. Based on this the projected population of Adama city including four sub urban Genda's under the city administration in 2016 (2009 E.C) was 391,597 of whom male 193,992 and female 197,605 (ACMO, 2018).

3.1.3. Geological Characteristics

Adama is situated within the Wonji Fault Belt, in the main structural systems of the Ethiopian Rift Valley. Geological studies indicate that the present physiography of the area is the result of volcano-tectonic activities occurred in the past and thus deposition of sediment largely of fluvial and lacustraine origin (ACMO, 2018).

3.1.4. Soil Type

Adama Town is covered by four kind of major soil type which are mollic andosols, eutric fluvisols, haphlic phaeozomes and haplic luvisosls. According to Food and Agricultural organization [FAO] (2001), the physical and hydrological characteristics of these soil are defined as follow:-

Mollic andosols: - Andosols are a zonal soils found in all climates and at all altitudes. Consequently, they occur together with almost any other Reference Soil Group. Most Andosols have excellent internal drainage because of their high porosity and their occurrence in predominantly high terrain positions. The good aggregate stability of Andosols and their high permeability to water make these soils (relatively) resistant to water erosion.

Eutric fluvisols:- Most Fluvisols are wet in all or part of the profile due to stagnating groundwater and/or flood water from rivers or tides. Their texture can vary from coarse sand in levee soils to heavy clays in basin areas.

Haphlic phaeozomes:- Phaeozems are porous, well-aerated soils with moderate to strong, very stable, crumb to blocky structures. Phaeozems with clay accumulation have even better water storage properties than other Phaeozems but may still be short of water in the dry season.

Haplic luvisols:- Luvisols have favorable physical properties; they have granular or crumb surface soils that are porous and well aerated. They have a higher clay content in the sub soil than in the top soil, as a result of pedogenetic processes (especially clay migration) leading to an argic sub soil horizon.

3.1.5. Industrial Development

The Ethiopian government has been designing various policies to uplift the agricultural based economy gradually and build an industrial base in the country through providing various incentives for investors. These developmental policies and strategies have made the private sector slowly flourish in the city and enabled the city to enter into new era and grow in better direction. In Adama’s existence, the city currently experiences the expansion of industrial development and private investors, which are the major actors in industrial development. The predominant types of industries found in the city are labor intensive, non-high technology, non-pollutant agro-industries and light industries that produce non-durable consumer goods and process agricultural product to the finished goods (ACMO, 2018).

3.2. Data and Software

3.2.1. Data and Data source

The availability of data is the most important thing to perform any kind of analysis. Therefore, in this research, spatial and non-spatial data were used to extract fourteen parameter maps for the analysis of land for industrial area. These spatial and non spatial data are Adama Town base map, master plan, topographic map, satellite imagery, population data, soil and geological map data. Additionally, the details of the data used, their source and data type was presented in (Table 3.1).

Table 3.1 List of data and data source used for the study

Data	Type	Sources
Topographic map	Spatial	Ethiopia Geospatial Information Institute
Adama Town base map & master plan	Spatial	Adama city municipality office
Population data	Non-spatial	Adama city municipality office
Satellite image Landsat image	Spatial	Google Earth USGS
Soil data	Spatial	Ministry of Agriculture (MoA)
Geological data	spatial	Ministry of Agriculture (MoA)
DEM	Spatial	Google Earth USGS

3.2.2. Software and Materials Used

As presented their list, version, and purpose in (Table 3.2), in order to complete, the study effectively different software packages were operated to help a decision such as ERDAS imagine, ARC GIS, Idrisi selva and Microsoft word. A number of tools have been used to determine the proper site for capital-intensive infrastructure development facilities. These tools include Expert Systems (ES), Geographic Information Systems (GIS), and Multi-Criteria Decision Analysis (MCDA) techniques (Ohri & Singh, 2010). Environmental Resource Data Analysis System (ERDAS) imagine software was applied to preprocess the satellite image for applying the geometric, radiometric and atmospheric correction, layer stacking of corrected satellite image and finally, for the classification of existing land use land cover (LULC) map of Adama Town by supervised classification technique and accuracy assessment. ARC GIS was used for preparing criteria to perform spatial analysis like proximity, buffer, rasterization, and digitization. Many GIS analysis tools were used in the study such as buffer zoning, euclidean distance, reclassification, and overlay analysis (Alzamili et al., 2015). A reclassification is an effective tool used in GIS for creating categorical attributes in a dataset by classifying various features based on existing attributes

(Roy et al., 2019). Google earth was exploited to conduct an accuracy assessment for land use land cover classification map by incorporating with Erdas Imagine software.

Table 3.2: List of Software used in the study

No	Software	version	Purpose
1	ERDAS IMAGINE	2015	Geometric correction Radiometric and atmospheric correction For classification of land use land cover (LULC) from land sat image. Accuracy assessment for LULC
2	ARC GIS	10.8	Creating geo-database Spatial tool analysis Preparing of selected criteria into a thematic map An attribute analysis of the criteria and result find.
3	Google Earth	7.3	For Random point collection and accuracy assessment
3	Microsoft word	2016	For report preparation.
4	Idirisi Selva	17	For overlaying a criterion thematic map

3.3. Methodology

In the present thesis research, the methodology designed in order to achieve the general and specific objective set for the study was presented in five steps as follow. *First*, after problem identification various source data layers that affect the location of the industry were collected from the minister of agriculture, Adama city municipality office, Ethiopian geospatial information institute and USGS earth explorer website. The suitable site selection for an industrial zone involves many geospatial data layers and related attributes. Since the site selection process is highly dependent on several criteria and factors (Fernando et al., 2015). *Second*, thematic criteria such as distance from (major road, high way, railway, heavy power line, settlement areas, geological fault lines, waterbody (rivers and streams, landfill site and existing industrial areas), population density, soil type, elevation, slope and Land Use Land Cover (LULC) were extracted from the collected data layer. The criteria used for the site selection process for industrial area were designated based on various literature and prior knowledge of the study area for instance (Balist et al., 2019, Beyene, 2019, Sarath et al., 2018, Rikalovic et al., 2015, Mehdi et al., 2015, Fataei et al., 2015 and Alzamili et al., 2015). In order to extract a thematic map different spatial analysis tool was utilized such as classification, bufferization, and accuracy assessment. *Third*, According to Saaty (2003) as cited in (Gawlik, 2008) says that his model accepts an unlimited number of entries at the Criteria and Sub –criteria levels. But, he states clearly that only a limited number of analyzed criteria and alternatives can assure an appropriate precision of obtained results. Therefore. as illustrated in (Figure 3.2) the hierarchical relationship between main and sub-criteria was generated and criteria were categorized into the following major criteria such as economic criteria (Major road, High way, Railway, elevation, Slope and existing industrial areas), environmental criteria (Land Use Land cover, Landfill site, Settlement, Waterbody and Heavy power lines), geological criteria (Soil type and Geological fault lines) and population criteria (Population density) for systematic determination of overall weight. When the criteria are more than nine developing a hierarchical structure is the most important stage for locating a suitable site for land use planning. A hierarchical structure is the graphical representation of a complex problem the general purpose of the issue is placed on top and the next levels include criteria, sub-criteria and alternatives (Hashemi et al., 2017). *Fourth*, the selected criteria for the analysis were standardized through the linear scale transformation method to make the scale of measurement uniform for all factors. For criterion standardization in the current study, by using the Spatial Analyst tool in ArcMap the proximity maps were categorized into five classes with the values that range from 1 to 5, where the value of 5 was taken as highly suitable while that of 1 was unsuitable for all factors considered (Gelan, 2018). For suitability analysis, it is necessary to give some score to each category as per its importance for industrial development since each category will not have the same weight or usefulness for industrial development (Johar et al., 2013). Therefore, to compare the criteria literature reviews and opinions of experts were engaged. *Fifth*, a Fuzzy Analytical Hierarchy Process (AHP) based pairwise comparison matrix was utilized to weigh the selected criteria. The FAHP method and Chang's (1996) method, which is a very simple method for generalizing the hierarchical analysis process to the fuzzy space, was used in order to assign weight to the criteria (Maddahi et al., 2017). *Finally*, the weighted criteria were superimposed by a weighted linear combination algorithm. The weighted linear combination technique was applied to aggregate the standardized layers in this study (Gelan, 2018). The obtained suitability map was statistically analyzed and presented to evaluate the suitability of the study area for industrial site selection. Further, in order to assess the existing industrial area assessment map was overlaid with the EIA. The overall methodology that was used in this study was demonstrated in (Figure 3.3).

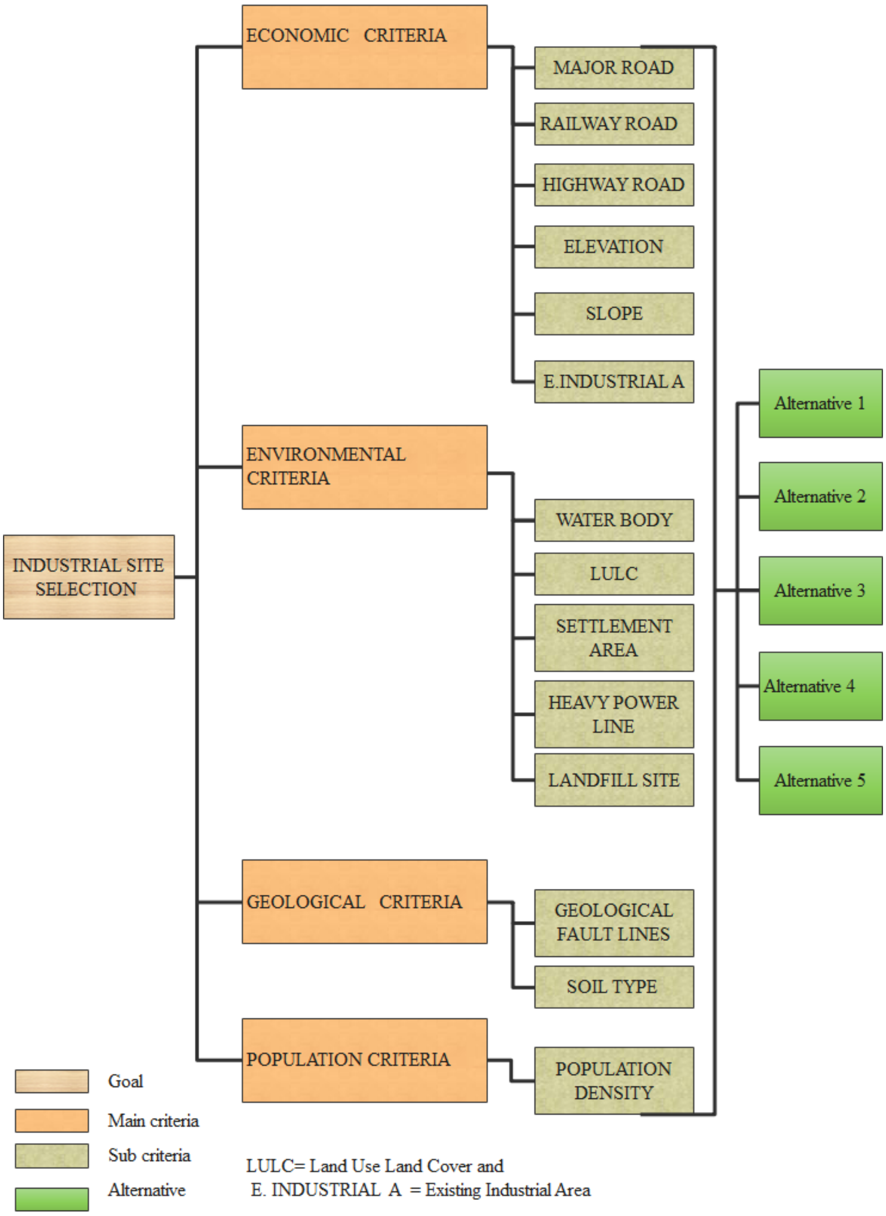

Figure 3.2 Hierarchical structure of the criteria

3.4. Technical Flow Chart of the Methods

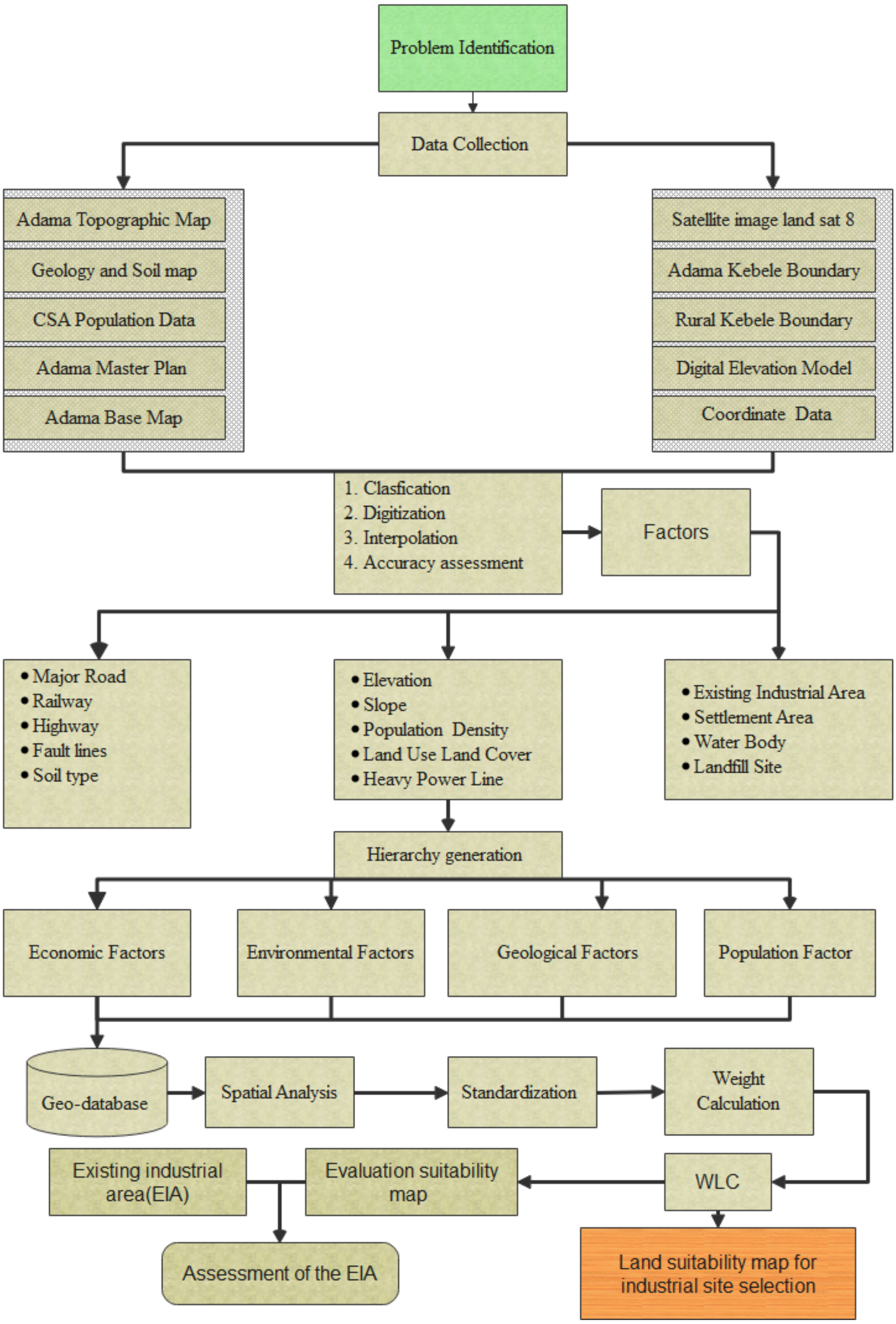

Figure 3.3 Schematic flowchart of the methodology used

3.5. Industrial Site Selection Criteria and Process

Industrial site selection study is a huge business, whether measured in terms of money spent, decision-makers involved, employees impacted, or the local economy impacted. A huge variety of variables influences the selection process. To determine the best location for capital improvement facilities, a variety of approaches can be employed. Geographic information systems (GIS), image processing systems, and remote sensing techniques are among the mapping tools (Johar et al., 2013). The process of selecting an industrial site involves a multi-criteria analysis that takes into account a wide range of elements such as economic, social, technological, environmental, and political difficulties that may conflict with one another (Rikalovic et al., 2014). The first phase of each site selection study is defining important criteria for specific selection. There are many criteria which should be considered in locating industrial establishments (Reisi & Soffianian, 2013). According to FDRE Industrial Parks Regulation (2019), site shall be selected for industrial park designation based on the following criteria: Industrial economics and dynamics, such as the presence of business activity and private-sector support for designation in the area; Accessibility and connectivity, such as major transportation links, labor markets, and distribution hubs in the area. Infrastructure and environmental criteria, such as roads, freshwater or water distribution networks in the area, wastewater treatment facilities, and flood risk. Social infrastructure, such as schools, hospitals, hotels, places of worship, and retail businesses in the area; and Land availability and suitability for development.

3.5.1. Topographic Factors

Topographical features are key factors in construction and output flows (Fataei et al., 2015). Topographic features encompass topographic slope and elevation above mean sea level. Slope gradient is usually expressed as percent slope or degree slope is used to represent the degree of variability in elevation. While elevation ranges are expressed in meters above mean sea level. Sea level of an area is a very important factor during the identification of potential industrial sites. Slope map provides us the information such as the slope of the area which is also very crucial for ease of construction and stability at later stages (Sarath et al., 2018). Always, the flat terrain is better to build up plant than sharp terrain (Jiang, 2007).

3.5.2. Land Use Land Cover Factors

Land use situation with regard to different environmental effects and the condition of industrial area is very important (Fataei et al., 2015). Any sort of imbalance in land utilization can have very serious impact on the land use system. It is a known fact that land is exploited in many ways and utilizing it judiciously is an achievement of a decision-maker (Sarath et al., 2018). Some land uses such as cities, water bodies, agricultural lands, gardens, and forests are not suitable for industrial construction (Reisi et al., 2011).

(a) *Road Networks:*

Transportation network bears the greatest importance in the industrial site selection process. Not only that, the mode of transportation is also important. Therefore, the transportation criterion is divided into three categories: Highways proximity, major roads proximity and railways proximity (Ohri & Singh, 2010). Access roads such as highways, major road and railroads are some important factors in industrial area development in borderlines (Fataei et al., 2015). The areas close to the road networks have good traffic conditions. The products can be delivered to any place of the urban area and region by the roads. Therefore, areas close to the roads have higher suitability than other places (Jiang, 2007). Areas far away from transportation infrastructures are unsuitable for the industry due to the economic feasibility aspect of industry locations. Based on this justification major road, highway, and railway road network criterion was considered for the current study.

(b) *Settlement areas:*

The main requirement for any kind of development is the availability of wasteland or suitable site for construction. Moreover, for the development of industrial area, mainly due to industrial hazards, the main requirement is to have such sites away from the settlements (Johar et al., 2013). These areas are barriers to industry development. Industrial areas should not be in the vicinity of populated urban areas (Reisi et al., 2011). The more distance from industrial areas the higher suitability and consistency will be (Fataei et al., 2015).

(c) *Water bodies:*

Waste water from industry is one of the major sources of pollution in rivers. Industry must be located at some safe distance from rivers and other water bodies (Ohri & Singh, 2010). To mitigate the capacity of industrial area waste on nearby water bodies (streams and rivers) pollution waterbody factor should be critically measured in terms of buffer distance suitability for final site selection decisions.

(d) *Existing industrial areas:*

The centralization effect is an important factor to the construction of plants. The close and centralized factories have more effect on each other than the distant and dispersed ones. So if the new sites of plants are adjacent to the old factories, they have more suitability (Jiang, 2007). Additionally, having a group of firms that produce complementary products and services close to one another can enhance the ability of the firms to make cluster wide changes in their product offerings. Close geographical proximity also allows for more frequent and rich communication between the firms (Jote et al., 2010).

(e) *Landfill Site:*

Environmental factors play an important role in today's industrial scenario. To make an industry sustainable to various changes in the industrial working, the environment plays an important role (Singh Thakur et al., 2018). According to Alzamili et al. (2015), the industrial site may include industries that cannot tolerate any contamination rate distance of at least should be kept between 2-5 km. To avoid this sensitivity existing landfill waste disposal site was used as an input spatial information parameter.

(f) *Heavy Power Lines:*

As industries are meant to be generally with medium to high investment, care should be taken in such a manner that investment is not at stake with hasty decisions (Sarath et al., 2018). According to the Ethiopian Electricity Agency directive, (2005, as cited in EEP, 2021) the minimum horizontal distance between any structure and overhead electric line clearance of 30 meters wide is required from any heavy power line transmission.

3.5.3. Geological Factors

(a) *Geological fault:*

Seismology and faults are very important in the development planning. The fracture resulted from geological faults will affect neighborhood sediments and rocks. Regarding legal buffer from fault lines and avoiding industrial developments in such areas are considerable factors in the industrial area site selection (Fataei et al., 2015). Geology was considered as it plays an important in the suitability decision of sites for industries. Strength of the rock and absence of fault zones will make the site suitable at the first place (Sarath et al., 2018) .

(b) *Soil type:*

Drainability is used to describe the relative rapidity and extent of removal of water in the soil, which is dependent upon the soil permeability. The soil has a significant impact on the amount of recharge, which can infiltrate into the groundwater and hence, influences the ability of contaminants to move vertically into the vadose zone (Ohri & Singh, 2010). Based on infiltration rate soil type play a great role in the movement of liquid waste into the ground. In this study, soil type was measured to minimize the capacity of industrial waste on ground water contamination.

3.5.4. Population Factor

Densely populated urban areas particularly in low and middle-income countries are particularly vulnerable to the effects of environmental and climate change. Where there are dense concentrations of households and economic activities, the effects of climate change can affect large numbers of people and have a major impact on urban economies even if they affect only relatively small land areas (Dodman, 2009). Population density is measured by dividing a given population by a given area. According to various reports, industrial areas are the second most important factor contributing to the global increase in toxic pollution problems (Fernando et al., 2015). Therefore, it is important to consider the population density of a given area in order to select a sustainable industrial area. Areas with low population density are the ideal planning location for industrial development

CHAPTER 4: DATA ANALYSIS, RESULT AND DISCUSSION

4.1. Economic Criteria for Industrial Site Selection

In this major economic criteria distance from major road, distance from railway, distance from highway, slope, topographic elevation and distance from the existing industrial area sub-factors were considered to optimize the selected suitable site for industry development economically.

4.1.1. Major Road Networks Factor

Transportation facility is a major concern if the economic aspect is raised for any industrial and manufacturing areas. According to Ohri & Singh (2010), cost of raw material transportation, finished goods transportation etc. is dependent on the proximity to transportation facility. Transportation network bears the greatest importance in the site selection process. Therefore, the existing major road networks of Adama Town was one of the transportation facility that was considered for this study. The suitability decreased as the distance from road network increased. This results in longer distances to be less suitable as transportation costs increase (Reisi et al., 2011). The digitized and Produced major roads proximity distance from the Adama Town base map and the topographic map was graded into five classes as unsuitable, less suitable, moderately suitable, suitable and highly suitable. As presented in (Table 4.1) break values used for the classification of major road proximity distance into five classes were based on the suggestions of previous researchers' for major road categorization (Ahmadipari et al., 2018, Jiang, 2007, Roy et al., 2019 and Abushnaf et al., 2015).

Table 4.1 Suitability index of the reclassified major road proximity distance in (m)

(Ahmadipari et al., 2018)	(Jiang, 2007)	(Roy et al., 2019)	(Abushnaf et al., 2015)	In this study	Score	Area in km^2	%
0-500	0-100	0-500	0-200	0-300	S5	56.34	18
500-1500	100-200	500-600	200-400	300-700	S4	46.83	14.96
1500-3000	200-300	600-700	400-600	700-1200	S3	45.36	14.49
3000-4500	300-400	700-800	600-800	1200-1600	S2	31.52	10.07
>4500	400-500	900-1000	800-1000	>1600	S1	132.99	42.48

In (Table 4.1): S5= highly suitable, S4=suitable, S3=moderately suitable, S2=less suitable, and S1= unsuitable

The following is a reclassified map of the study area road networks based on the appropriateness index for industrial site selection (Figure 4.1). According to the reclassified main roads vicinity distance highly suitable, suitable, moderately suitable, less suitable and unsuitable ranks were graded for the classes of 0 to 300, 300 to 700, 700 to 1200, 1200 to 1600 and > 1600. As presented in (Table 4.1) the coverage of each index in terms of area and percentage was 132.99 km^2 (42.48%), 31.52 km^2 (10.07%), 45.36 km^2 (14.49 %), 46.82 km^2 (14.96 %) and 56.34 km^2 (18%) as its order from unsuitable to highly suitable. As seen from the reclassified result of the major road network map, places near major roads were graded highly suitable for industrial site selection, with a score of five, but areas too remote from road networks were deemed unsuitable from an economic standpoint.

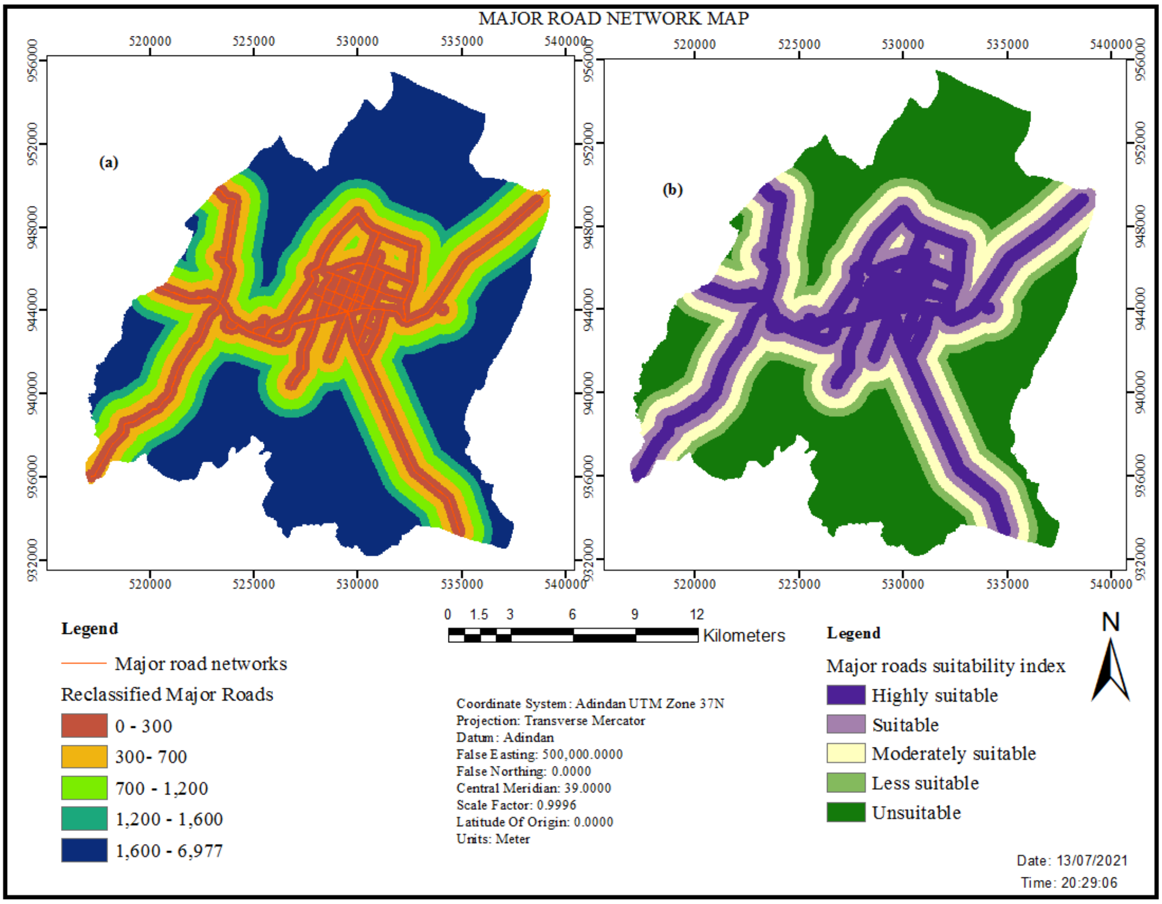

Figure 4.1 Major road factor map (a) reclassified distance from major road and (b) suitability index

4.1.2. Railway Road Network Factor

The railway is an important and cost-effective means of transporting industrial products (Jiang, 2007). As a result, areas near the railway may be more suitable than other locations. Because of the economic impact on business establishment, the railway spatial information component was used in this study. The railway road network was digitized from the study area base map, and their buffer was generated using ArcGIS software's euclidean distance analysis tool. The euclidean closeness railway distance was graded into five class indices, as shown in (Figure 4.2), as unsuitable, less suitable, moderately suitable, suitable, and highly suitable based on classes from >8000, 4400 to 8000, 2400 to 4400, 1000 to 2400, and 0 to 1000 respectively. As it can be seen from (Table 4.4) to derive a suitability interval distance, the suggestion of prior researchers' study mean values were taken for the current study for instance (Johar et al., 2013, Jiang, 2007 and Abushnaf et al., 2015).

Table 4.2 Suitability index of the reclassified railway proximity distance in (m)

(Johar et al., 2013)	(Jiang, 2007)	(Abushnaf et al., 2015)	In this study	Score	Area in km^2	%
0-2000	0-100	0-1000	0-1000	S5	57.87	18.49
2000-5000	100-200	1000-2000	1000-2400	S4	73.14	23.36
5000-10000	200-300	2000-3000	2400-4400	S3	82.84	26.46
10000-20000	300-400	3000-4000	4400-8000	S2	86.49	27.63
>20000	400-500	>4000	>8000	S1	12.7	4.06

In (Table 4.2): S5= highly suitable, S4=suitable, S3=moderately suitable, S2=less suitable, and S1= unsuitable

Here, in (Figure 4.2) the reclassified railway road in terms of industrial site selection was portrayed into five suitability class indexes. As seen in (Table 4.2) the area and percentage of analysis of reclassified railway factor map show that 12.7 km^2 (4.06%), 86.49 km^2 (27.63%), 82.84 km^2 (26.46%), 73.14 km^2 (23.36%) and 57.87 km^2 (18.49%) was unsuitable, less suitable, moderately suitable, suitable and highly suitably correspondingly. For this study objective, the areas proximity to the railroad factor were allotted as highly suitable while areas remote to the railroad were assigned as unsuitable. This implies that most of the areas were less suitable for the evaluation of land suitability for the industry in terms of railway proximity, whereas the least of areas were unsuitable for industrial site selection.

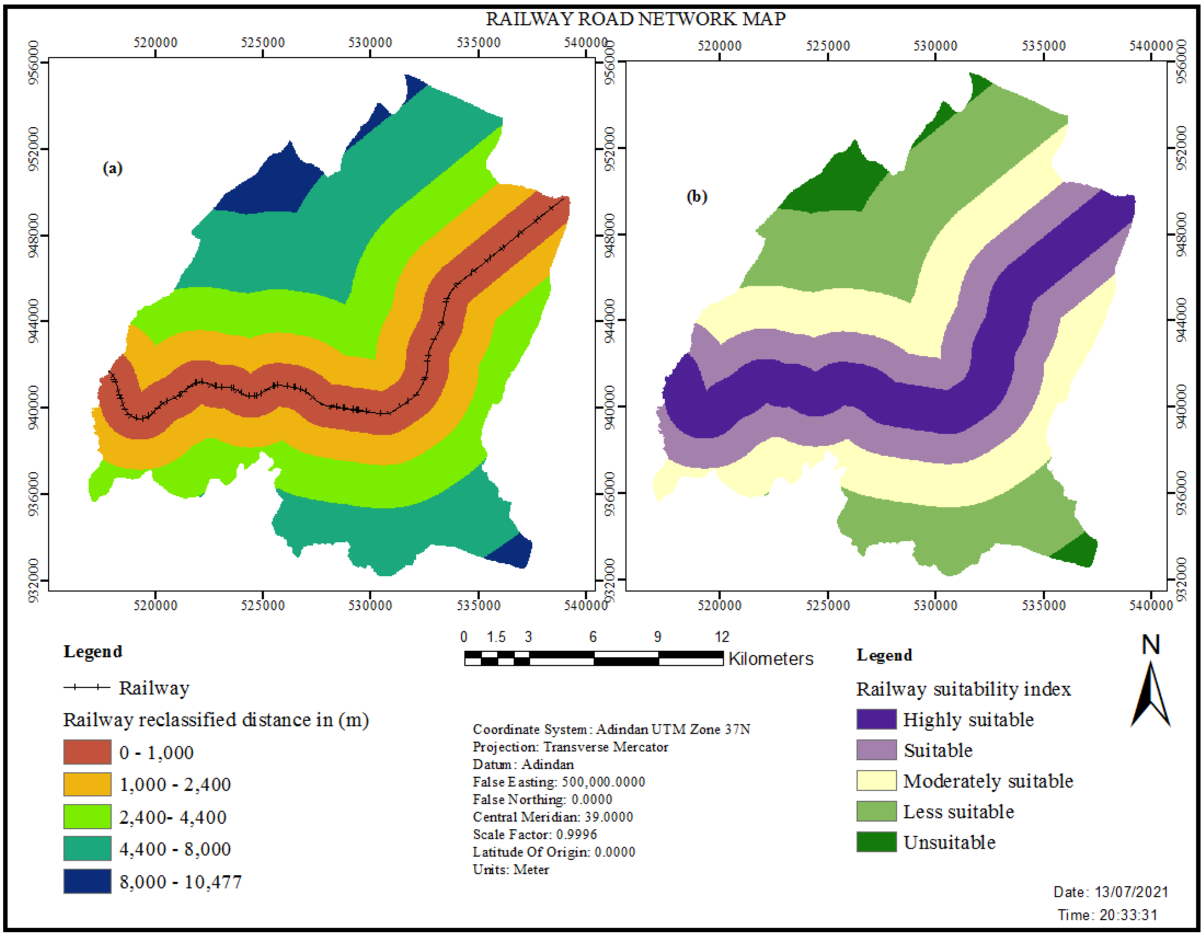

Figure 4.2 Railway factor map (a) reclassified distance from railway and (b) suitability index

4.1.3. Highway Road Network Factor

Industrial land serves as manufacturing, warehousing, and distribution centers, which require priority locations necessary for receiving, storing, and distributing goods. The location of these establishments is becoming increasingly important as firms compete to deliver their products efficiently as possible (Berube, 2014). Highway roads are one of the transportation infrastructures that support and facility being industrialization. According to Alzamili et al., (2015), highways are used 75% of the time for industrial purposes. This statement shows that highways are a fundamental factor in the establishment of an industrial area. Therefore, as demonstrated in (Figure 4.3) the high way road network was digitized and reclassified into five groups that range from unsuitable, less suitable, moderately suitable, suitable and highly suitable based on produced proximity distance through euclidean spatial analysis tool and respective scores assigned were 1, 2, 3, 4 and 5. In this study, the areas near highway roads were considered highly suitable for the demarcation of industrial sites, which accounts for about 5.7 km^2 out of the total area coverage. The statistical analysis of the reclassified highway map and respective value of the suitability index was showed in below (Table 4.3).

Table 4.3 Suitability index of the reclassified highway proximity distance in (m)

(Jiang, 2007)	In this study	Score	Area in km^2	%
0-100	0-100	S5	5.7	1.82
100-200	100-200	S4	3.98	1.27
200-300	200-300	S3	4.41	1.41
300-400	300-400	S2	3.88	1.24
>400	>400	S1	295.07	94.26

In (Table 4.3): S5= highly suitable, S4=suitable, S3=moderately suitable, S2=less suitable, and S1= unsuitable

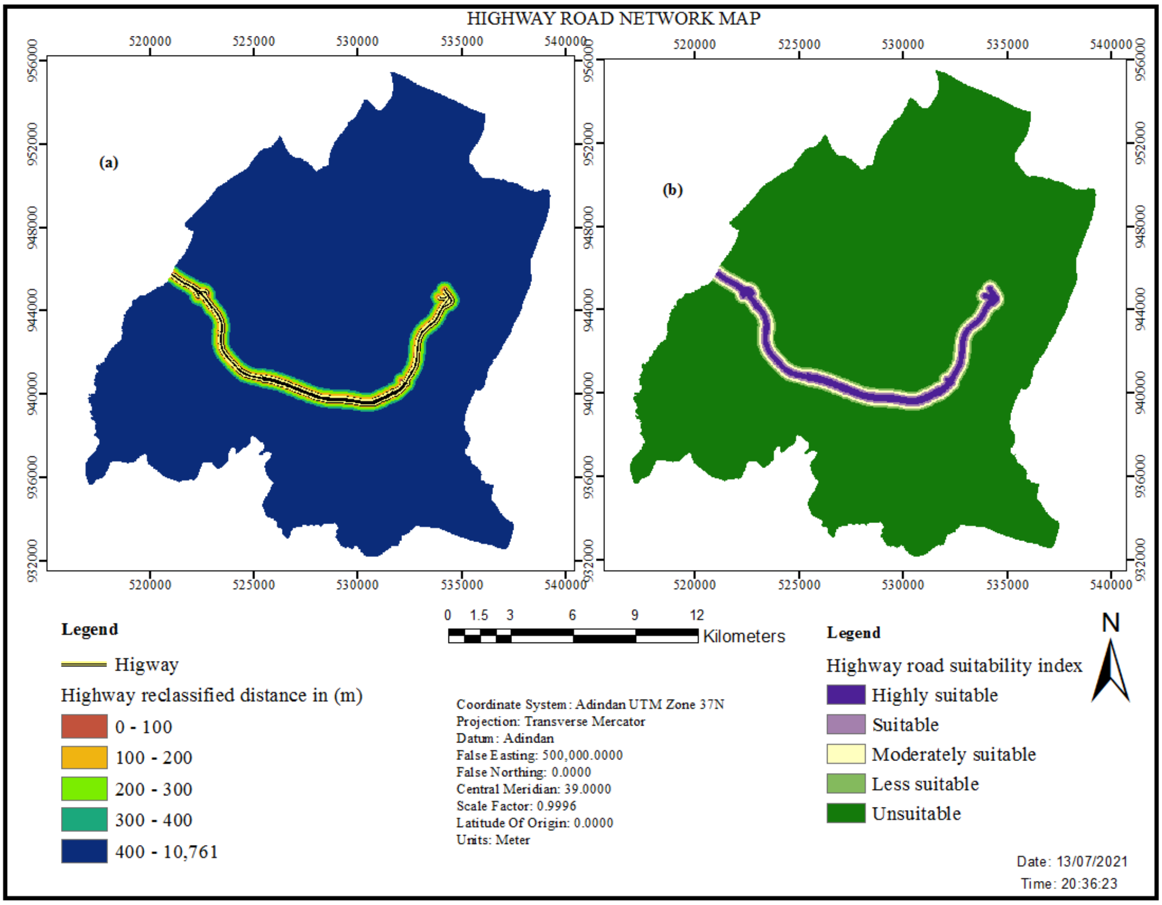

Figure 4.3 Highway road factor map (a) reclassified distance from highway and (b) suitability index

4.1.4. Topographic Elevation Factor

The sea level of an area is a very important factor during the identification of potential sites. Sites far above the sea level increase the transportation cost are considered unsuitable (Sarath et al., 2018). Elevation of the area where potential locations for industries is sited is to be known for better decision to be taken. Shuttle Radar Topographic Mission (SRTM) DEM was downloaded from the website www. Earth explorer.com with a spatial resolution of 30 m according to the study area and classified based on elevation present at that location. From the digital elevation model map, the maximum and minimum elevations of the study area are 1452 m and 2058 m respectively above mean sea level. The maximum elevations are located at the Northwest, west edge and southeast direction of the Town. This means areas with higher elevations are not suitable for optimal location of industrial site due to economic disadvantages. Based on this fact topographic elevation of the Town was categorized under major economic criteria.

According to (Table 4.4), the study area's digital elevation model was reclassified into five categories: unsuitable, less suitable, moderately suitable, suitable, and highly suitable, with elevation ranges of 1452-1600, 1600-1700, 1700-1800, 1800-1900, and 1900-2058 meters above sea level. From the reclassified map result statistics majority of the study area was highly suitable and suitable for zoning of an industrial site, which covers 25.5 % and 41.49 % of the study area respectively while least of the area was moderately suitable, less suitable and unsuitable which cover 33.01 % the study area collectively. For the current study aim, the areas with a low elevation value were ranked as highly suitable for industrial site.

Table 4.4 Suitability index of the reclassified digital elevation above mean sea level

DEM(above mean sea level)	Score	Suitability range	Area in km^2	Percentage (%)
1452-1600	S5	Highly suitable	79.82	25.50
1600-1700	S4	Suitable	129.88	41.49
1700-1800	S3	Moderate suitable	55.66	17.78
1800-1900	S2	Less suitable	30.61	9.78
1900-2058	S1	Unsuitable	17.07	5.45

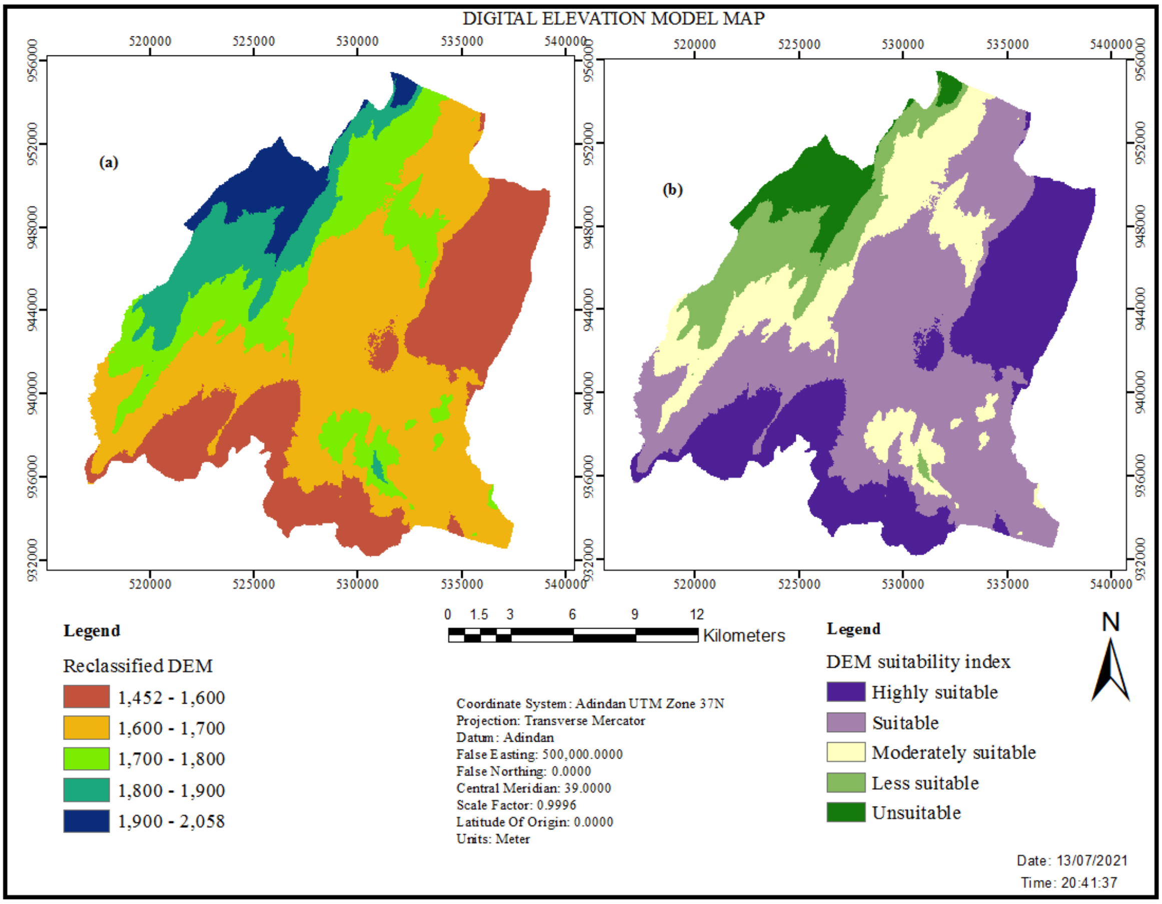

Figure 4.4 Digital Elevation Model factor map (a) reclassified DEM and (b) suitability index

4.1.5. Topographic Slope Factor

Topographical features are key factors in construction and output flows (Fataei et al., 2015). Slope gradient is usually expressed as percent slope or degree slope is used to represent the degree of variability in elevation. The sea level of an area is a very important factor during the identification of potential industrial sites. Areas with a gentle slope were taken as more suitable for the construction of large structures. Moreover, stability issues during the construction phase. To lessen the risk of instability during construction, steeper slope locations are often avoided (Sarath et al., 2018). Additionally, as stated by Jiang (2007), always the flat terrain is better to build up plant than sharp terrain. A slope map of the study area was generated from SRTM DEM downloaded from the www. Earth explorer.com website. The spatial resolution of the slope was 30 m depends on DEM resolution. ArcGIS 10.8 software was applied to generate a slope from the DEM raster and an extension of spatial analysis and surface toolbox was used to portray the reclassified slope distribution of the study area.

Based on their significant impact on the formation of industrial sites, the slope map created from the digital elevation model was grouped into five clusters. As a result, the classes interval used for the reclassifications were based on the mean value of earlier researcher's experiences as tabulated in (Table 4.5).

Table 4.5 Suitability index of the reclassified slope values in degree

(Fataei et al., 2015)	(Ahmadipari et al., 2018)	(Jiang, 2007)	(Roy et al., 2019)	In this study	Score value	Area in km^2	(%)
0-6	0-5	0-15	0-4	0-7	S5	254.17	81.19
6-10	5-15	15-30	4-6	7-15	S4	43.20	13.8
10-15	15-30	30-45	6-8	15-25	S3	12.61	4.03
15-20	30-45	45-60	8-10	25-35	S2	2.85	0.91
>20	>45	>60	10-12	>35	S1	0.21	0.07

In (Table 4.5): S5= highly suitable, S4=suitable, S3=moderately suitable, S2=less suitable, and S1= unsuitable

As depicted in (Figure 4.5) the reclassified topographic slope distributions, the suitability indexes used for slope factor were unsuitable, less suitable, moderately suitable, suitable and highly suitable. When we see the overall share of these suitability indexes in area and percentage for industrial delineation it accounts about 0.21 km^2 (0.07 %), 2.85 km^2 (0.91 %), 12.61 km^2 (4.03 %), 43.20 km^2 (13.8 %) and 254.17 km^2 (81.19 %) respectively. These results show that the study area was primarily highly suitable for industry establishment, with a slope ranging from 0 to 7 degrees. The maximum slope of the Town, according to the reclassified portray, ranges from 35 to 44 degrees, while the minimum slope ranges from 0 to 7. Areas with higher slope values are not suitable for industry, whereas areas with a lower topographic slope rise are the right alternative for industrial sites. The less the slope amount the more suitable will be (Fataei et al., 2015).

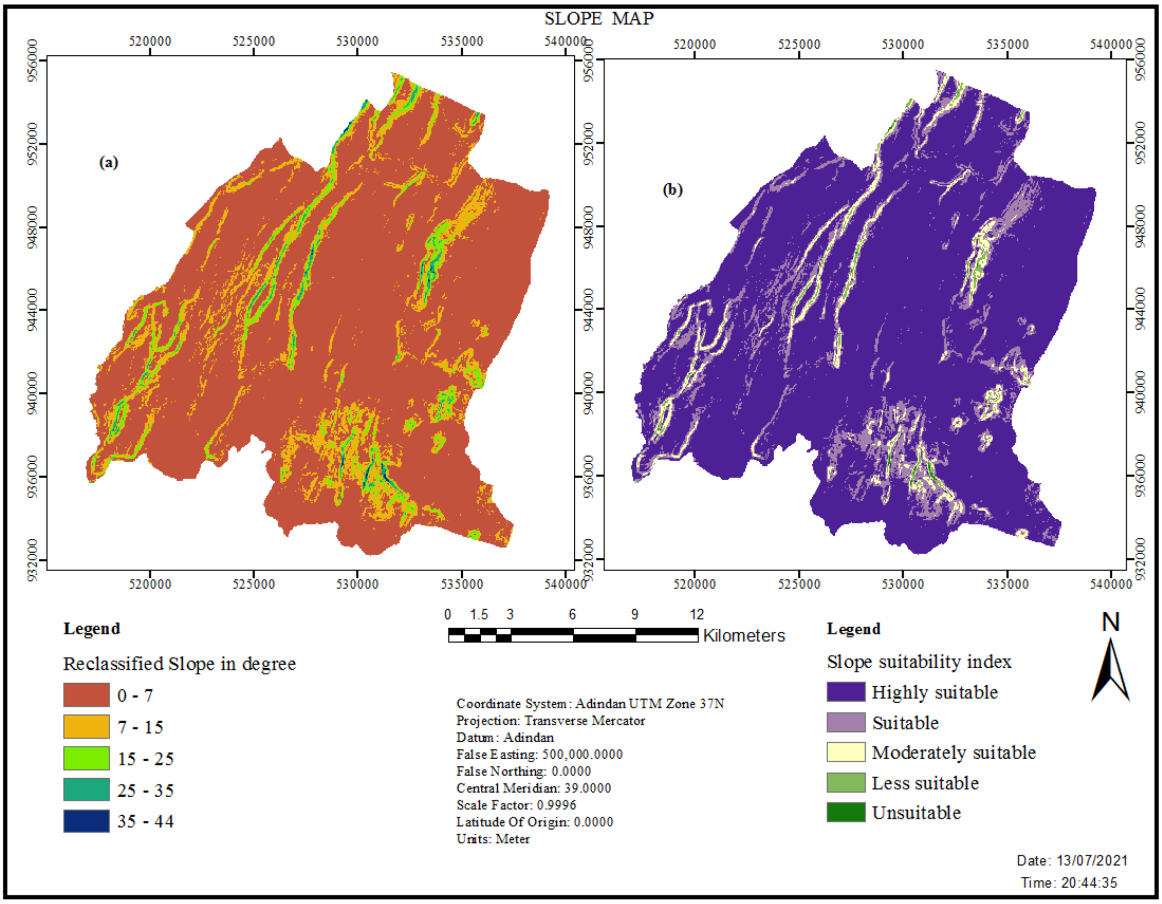

Figure 4.5 Slope factor map (a) reclassified slope and (b) suitability index

4.1.6. Existing Industrial and Manufacturing Site Factor

When developing new optimally suitable industrial zones, proximity to other businesses, availability of utilities, and lending institutions (such as banks, etc.) were all elements to consider (Negi & Jain, 2008). The centralization effect, according to Jiang (2007), is a significant feature in plant design. Close, centralized factories have a greater impact on each other than the far, dispersed factories. Therefore, if the new sites of plants are adjacent to the old factories they have more suitability. The proximity of industrial sites makes it easier for on-site work to be performed. Additionally, having a group of firms that produce complementary products and services close to one another can enhance the ability of the firms to make cluster wide changes in their product offerings. Close geographical proximity also allows for more frequent and rich communication between the firms (Jote et al., 2010). The existing industrial areas digitalized from the master plan of the study area were bufferized and reclassified. As summarized in (Table 4.6) the existing industrial and manufacturing sites proximity distance was graded into five suitability classes based on the suggestions of (Ahmadipari et al., 2018) and (Jiang, 2007).

Table 4.6 Suitability index of the reclassified proximity distance in (m) used for the EIA

(Ahmadipari et al., 2018)	(Jiang, 2007)	In this study	Score	Area in km^2	%
0-1000	0-200	0-600	S5	88.67	28.33
1000-5000	200-400	600-2700	S4	130.64	41.73
5000-10000	400-600	2700-5000	S3	79.73	25.47
10000-30000	600-800	5000-6000	S2	1l.91	3.80
>30000	>800	>6000	S1	2.09	0.67

In (Table 4.6): S5= highly suitable, S4 = Suitable, S3 = moderately suitable, S2=less suitable, and S1= unsuitable

The suitability index utilized for the reclassified existing industrial zones was unsuitable, less suitable, moderately suitable, suitable, and highly suitable, as shown in (Figure 4.6). Thus, the buffer distance interval used for the indexes in meters was 0-600, 600-2700, 2700-5000, 5000-6000 and >6000 respectively. The statistical analysis result of the area and percentage for new industrial site selection based on the used EIA suitability factor were Unsuitable 2.09 km^2 (0.67%), Less suitable 11.91 km^2 (3.80%), moderate suitable 79.73 km^2 (25.47%), suitable 130.64 km^2 (41.73%) and highly suitable 88.67 km^2 (28.33%). These show that the majority of the study area was suitable for industrial sites, whereas the least amount of the study area was unsuitable.

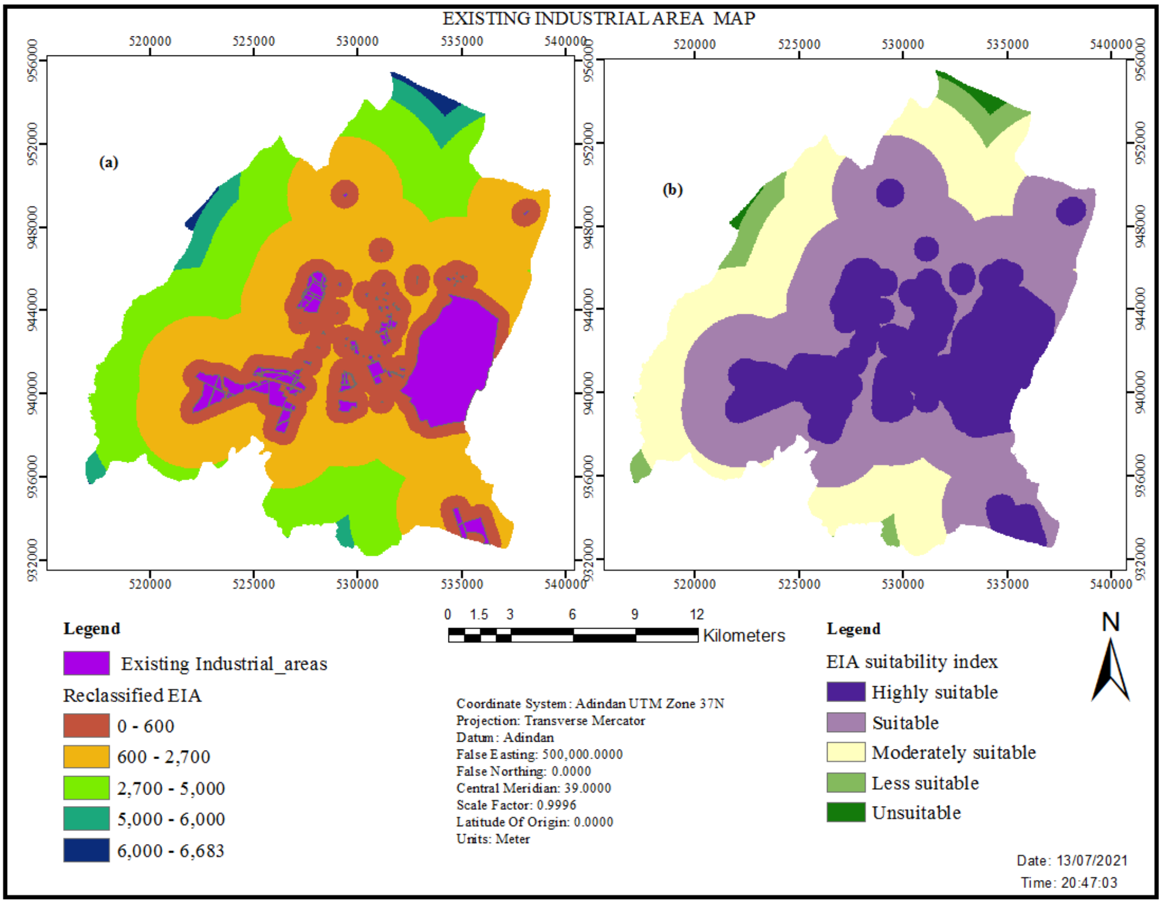

Figure 4.6 Existing industrial areas factor map (a) reclassified distance from EIA and (b) suitability index

4.2. Environmental Criteria for Industrial Site Selection

Under this environmental major criteria, the impact of environment activity on the industry, the impact of industrial sites on the environment and the impact industrial site on the human beings, were taken into account using the following sub-factors: Land Use Land Cover, distance from waterbody, distance from heavy power lines, distance from settlement areas and distance from landfill site.

4.2.1. Land use land cover (LULC) Factor

In order to extract Land Use land Cover factor for the current study several activities were performed such as preprocessing, classification and accuracy assessment. Land use classification is the process of categorizing the data based on their data file values. If pixels fulfill a certain set of criteria then the pixel is assigned to the class that corresponds to that criterion. There are two ways to classify the pixel in different categories that are supervised and unsupervised (Johar et al., 2013). Preprocessing before evaluation of criteria for further analysis is necessary to achieve the required quality output. According to the below algorithm described in Equation (4.1) preprocessing was conducted. After downloading land sate 8 satellite image for the year (2021) from (www. Earth explorer. Com) website both radiometric and atmospheric corrections were applied to make the image more visible to a classification of land use land cover. Finally, the corrected and georeferenced bands were layer stacked using ERDAS imagine software.

In the case of, Landsat 8 satellite image correction is done directly by converting row digital number (satellite image) to reflectance directly. Thus, in this study both radiometric and atmospheric corrections was applied to the row images at once.

$$\mathrm{P\lambda} = (\mathrm{mp} * \mathrm{Qcal}) + \mathrm{Ap} \qquad \text{Eq. (4.1)}$$

Where:

Mp = multiplicative reflectance factor

Ap = additive reflectance factor

Qcal = band no/image

Both of these input parameters were acquired from the image metadata file attached to the compressed satellite image. A supervised classification technique was employed to classify the existing land cover class into waterbody, vegetation, settlement, farmland and bare land. A total of 100 points were added to the classified image by stratified sampling technique in Erdas imagine software for accuracy assessment. As shown in (appendices) the accuracy assessment was calculated by integrating these sample points with google earth pro software. The overall classification accuracy obtained was 87.00 % that is acceptable for further analysis.

Due to the significant impact of these land cover classes on ecosystem balancing, delineating industrial sites on vegetation and water bodies is not suggested. Water bodies, wetlands, forest covering, and residential regions, according to Johar et al. (2013) are not ideal for industrial establishment. Open spaces, unoccupied lands, and rangelands are all good places to put an industrial site. Both water bodies and vegetative land cover were categorized as restricted for this study, as shown in (Table 4.7) and (Figure 4.7), whilst settlements, farmland, and bare land were allocated as unsuitable, suitable, and highly suitable, respectively. The overall contribution of each land cover class for industrial site selection in terms of area coverages was water body (0.7 km^2), vegetation (68.0.4 km^2), settlement (66.16 km^2), farmland (84.16 km^2) and bare land (93.98 km^2).

Table 4.7 Land use land cover class suitability for industrial site selection

LULC class	Score	Suitability range	Area in km^2	%
Bare land	S5	Highly suitable	93.98	30.03
Farmland	S4	Suitable	84.16	26.88
Settlement	S1	Unsuitable	66.16	21.13
Water body	0	Restricted	0.7	0.22
Vegetation	0	Restricted	68.04	21.74

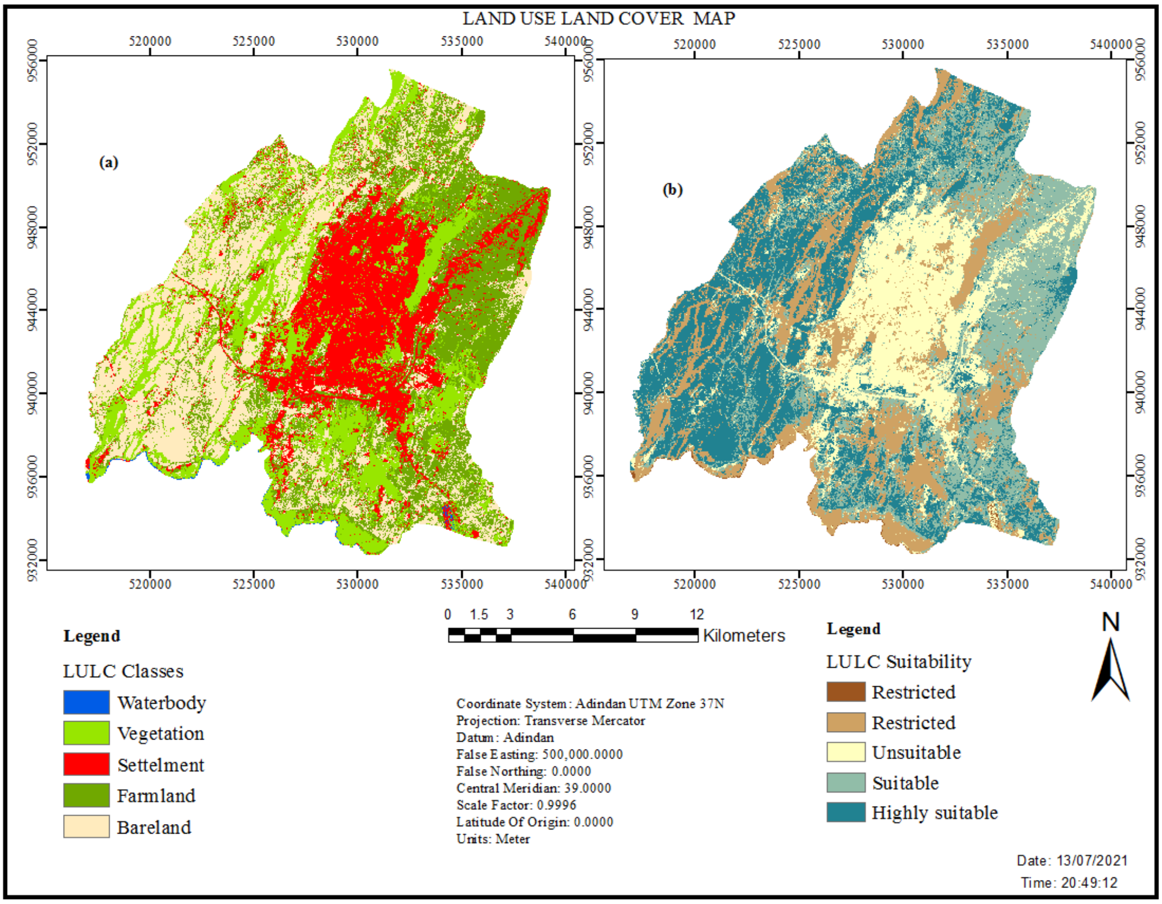

Figure 4.7 Land Use Land Cover Factor map (a) LULC classes (b) LULC suitability index

4.2.2. Rivers and Streams (water body) Factor

One of the most significant sources of contamination in rivers is industrial wastewater. Industry must be kept at a safe distance from rivers and water bodies (Ohri & Singh, 2010). Most industries discharge polluted effluents into the natural environment, including streams and rivers, without treatment, resulting in substantial environmental contamination and negative health and social consequences for people who are exposed (EEPCo, 2018). Therefore, Industrial sites should not be in the vicinity of water bodies. According to Gemeda (2018), many parts of the study area coupled with the nature of topography are exposed to erosion, gully formation and flood problem for its loosely held soil. Large numbers of gullies that dissect the various parts of the City are emerging. They have been obstacles to integrating the different parts of the City. The streams in the City neither are used for recreation nor are inputs for production. The economic cost of allocating land on riverbanks is pollution caused by open dumping. This condition has its negative impact on the quality of the land or suitability of the land for different urban development. As previously, mentioned, industrial sites should not be built near rivers or powerful streams in order to reduce pollution caused by industrial waste. Thus, the spatial analysis tool was used to calculate the proximity euclidean distance for the rivers and streams that were extracted from the base map.

Table 4.8 Suitability index of the reclassified rivers and streams proximity distance in (m)

(Fataei et al., 2015)	(Johar et al., 2013)	(Ahmadipari et al., 2018)	(Roy et al., 2019)	(Abushnaf et al., 2015)	In this study	S
0-200	0-2000	0-400	0-200	0-200	0-600	1
200-500	2000-5000	400-600	200-400	200-400	600-1400	2
500-1000	5000-10000	600-800	400-600	400-600	1400-2600	3
1000-10000	10000-20000	800-1000	600-800	600-800	2600-5000	4
>10000	>20000	>1000	800-1000	800-1000	>5000	5

In (Table 4.8): S1= unsuitable, S2=less suitable, S3= moderately suitable, S4=suitable and S5= highly suitable

Stream and river networks were buffered and classed into five classifications, as seen in (Figure 4.8), ranging from unsuitable to highly suitable. For buffer distance determination, the average value was taken after five related literature were reviewed as indicated above in

(Table 4.8). For this study, areas that were more than 5 kilometers away from rivers and streams were deemed highly suitable for industrial zone development, while areas that were close to rivers and streams were considered unsuitable. When we look at the area covered by each suitability index in square kilometers, it depicts that unsuitable was (102.96), less suitable was (60.09), moderately suitable was (52.15), suitable is (63.04), and highly suitable was (34.8).

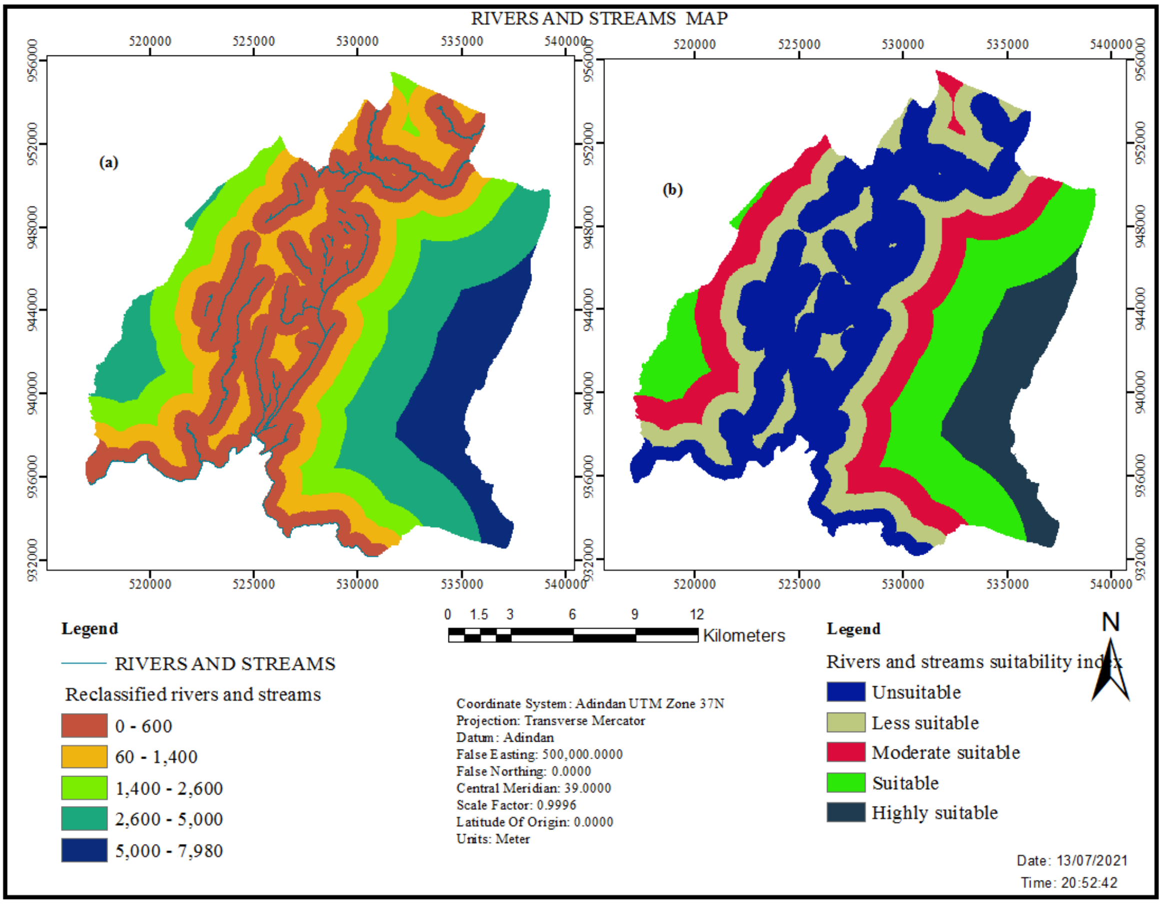

Figure 4.8 Water body factor map (a) reclassified distance from waterbody (b) suitability index

4.2.3. Settlement Areas Factor

According to Johar et al. (2013), the availability of wasteland or a suitable construction site is the most important condition for any type of development. Furthermore, the main need for the development of industrial sites, primarily due to industrial dangers, is that such sites be located distant from communities. This will not have much impact on the health of the people residing around the industrial sites. The main traditional methods of bringing industry closer to settlement and agglomeration were implemented with the goal of enhancing economic growth by increasing job opportunities in the area (Roy et al., 2019). However, this practice would have an impact on those who live near to industry, either directly or indirectly. To reduce the negative impact of industrial site noise, dust particles, and liquid waste released into the surrounding neighborhood, a safe distance should be maintained. Settlement areas factor was extracted from the classified Land Use Land Cover map of the year (2021). A logical distance should be selected between residential areas and industrial sites (Fataei et al., 2015). As a result, the residential/ settlement areas were buffered and reclassified into five groups as shown in (Table 4.9) using the buffer distance suggested by (Fataei et al., 2015, Johar et al., 2013, Ahmadipari et al., 2018 and Jiang, 2007).

Table 4.9 Suitability index of the reclassified settlement areas proximity distance in (m)

(Fataei et al., 2015)	(Johar et al., 2013)	(Ahmadipari et al., 2018)	(Jiang, 2007)	In this study	Score	Area in km^2
0-1500	0-100	0-2000	0-200	0-1000	S1	170.15
1500-3000	100-200	2000-4000	200-400	1000-2000	S2	69.71
3000-6000	200-300	4000-5500	400-600	2000-3000	S5	3.75
6000-12000	300-500	5500-75000	600-800	3000-5000	S4	28.32
>12000	>500	>7500	800-1000	>5000	S3	41.12

In (Table 4.9): S5= highly suitable, S4=suitable, S3=moderately suitable, S2=less suitable, and S1= unsuitable

For the current study, settlement areas were categorized as unsuitable, less suitable, moderately suitable, suitable, and highly suitable based on the reclassification distance. The locations between 0 and 1000 meters were deemed unsuitable, whereas those between 2000 and 3000 meters were considered highly suitable. The more distance from industrial sites the higher suitability and consistency will be (Fataei et al., 2015). But, because of the transportation costs for employees to go to the industrial site, sites that are too far away from residential regions are not highly suitable. As demonstrated in (Figure 4.9) to maintain two objectives (health and economic issues), the medium value was chosen as the most preferable for industrial land demarcation. From the reclassified map statistics presented in (Table 4.9), the area share of each suitability range was 170.15 km^2, 69.71 km^2, 3.75 km^2, 28.32 km^2, and 41.12 km^2 in order from unsuitable to highly suitable. These findings show that the majority of the study area was not suitable for optimal industrial site selection, although a moderate area was highly suitable for industrial site development from a settlement aspect.

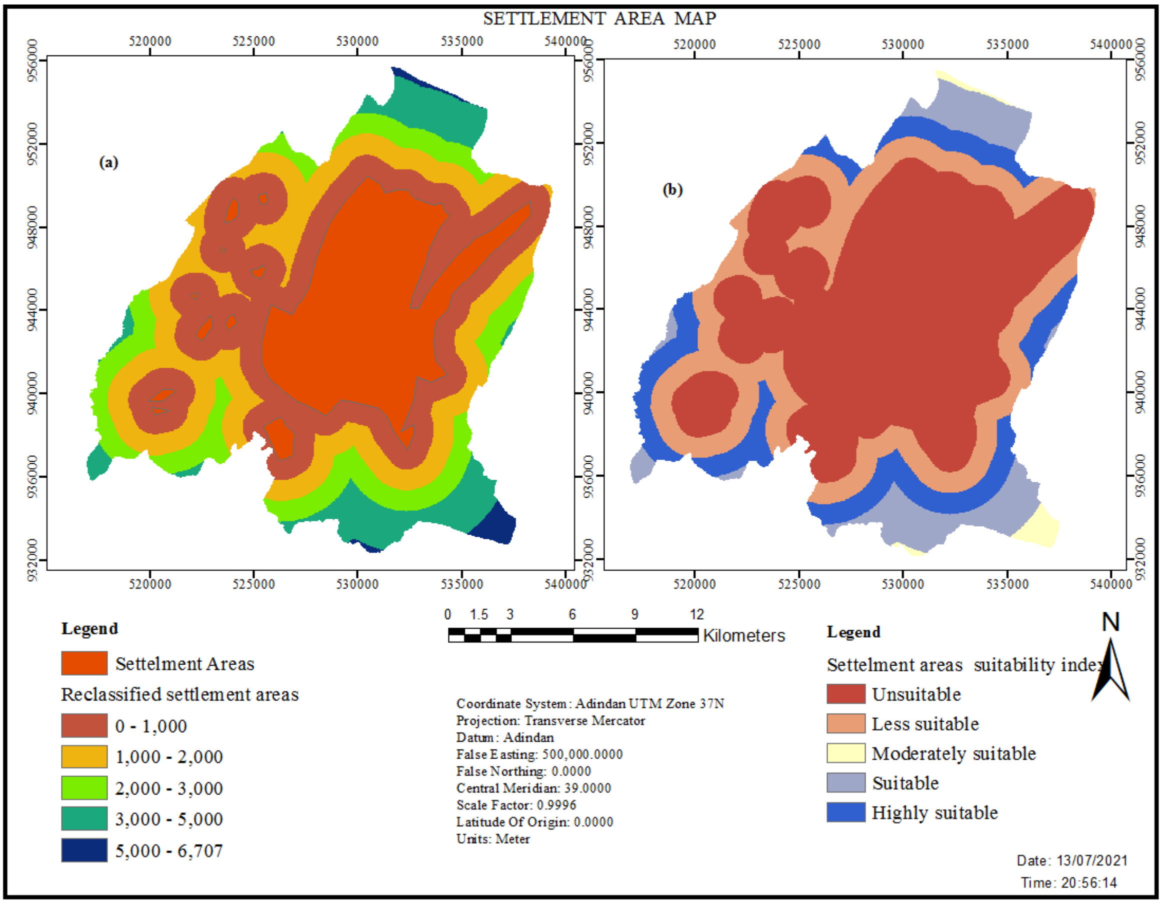

Figure 4.9 Settlement areas factor map (a) reclassified distance from settlement areas and (b) suitability index

4.2.4. Heavy Electric Power Lines Factor

From the perspective view of the safety of constructed industrial facilities, humans and the environment industrial site must be located at some safe distance from heavy electric power lines. Unfortunately, if an accident occurs on a power line, the consequences for industry, humans, and the environment may be unanticipated. As industries are meant to be generally with medium to high investment, care should be taken in such a manner that investment is not at stake with hasty decisions (Sarath et al., 2018). As a result, considering heavy electric power lines as one criterion for industrial site selection is a critical and important decision. The heavy electric power line was one of the criteria that influenced the placement of a feasible industrial site in the current study. Heavy electric power line was digitized and exported from Adama Town base map. According to the Ethiopian Electricity Agency directive, (2005, as cited in EEP, 2021) the minimum horizontal distance between any structure and overhead electric line clearance of 30 meters wide is required from any heavy power line transmission, which carries 66KV to 230KV.

To reclassify the heavy electric power line based on this standard, their euclidean distance was computed using the spatial analysis extension toolbox in ArcGIS 10.8 map and then reclassified with distance ranges of 0-30m, 30m-60m, 60m-90m, 90m-120m, 120m-150m, and > 150m based on the above statement. In the linguistic variable, their suitability indexes were restricted, unsuitable, less suitable, moderately suitable, suitable, and highly suitable, respectively. Below (Table 4.10 and Figure 4.10) are a description demonstrating its distance range and suitability index for heavy electric power lines.

Table 4.10 Suitability index of reclassified heavy power line proximity distance in (m)

Distance in meter (m)	Score	Suitability	Area in km^2	Percentage (%)
0-30	0	Restricted	9.12	2.91
30-60	S1	Unsuitable	4.55	1.45
60-90	S2	Less suitable	6.01	1.92
90-120	S3	moderately Suitable	4.38	1.40
120-150	S4	Suitable	6.38	2.04
>150	S5	Highly Suitable	282.6	90.28

From the reclassified map, as it can be seen from (Figure 4.10) the overall contribution of each suitability index for optimal industrial site selection in terms of heavy electric power line suitability, 9.12 km^2 was restricted, 4.55 km^2 was unsuitable, 6.01 km^2 was less suitable, 4.38 km^2 was moderately suitable, 6.38 km^2 was suitable, and 282.6 km^2 was highly suitable. To generalize, in terms of heavy electric power line factor the majority of the study area was highly suitable whereas the least of the area was moderately suitable for industry establishment.

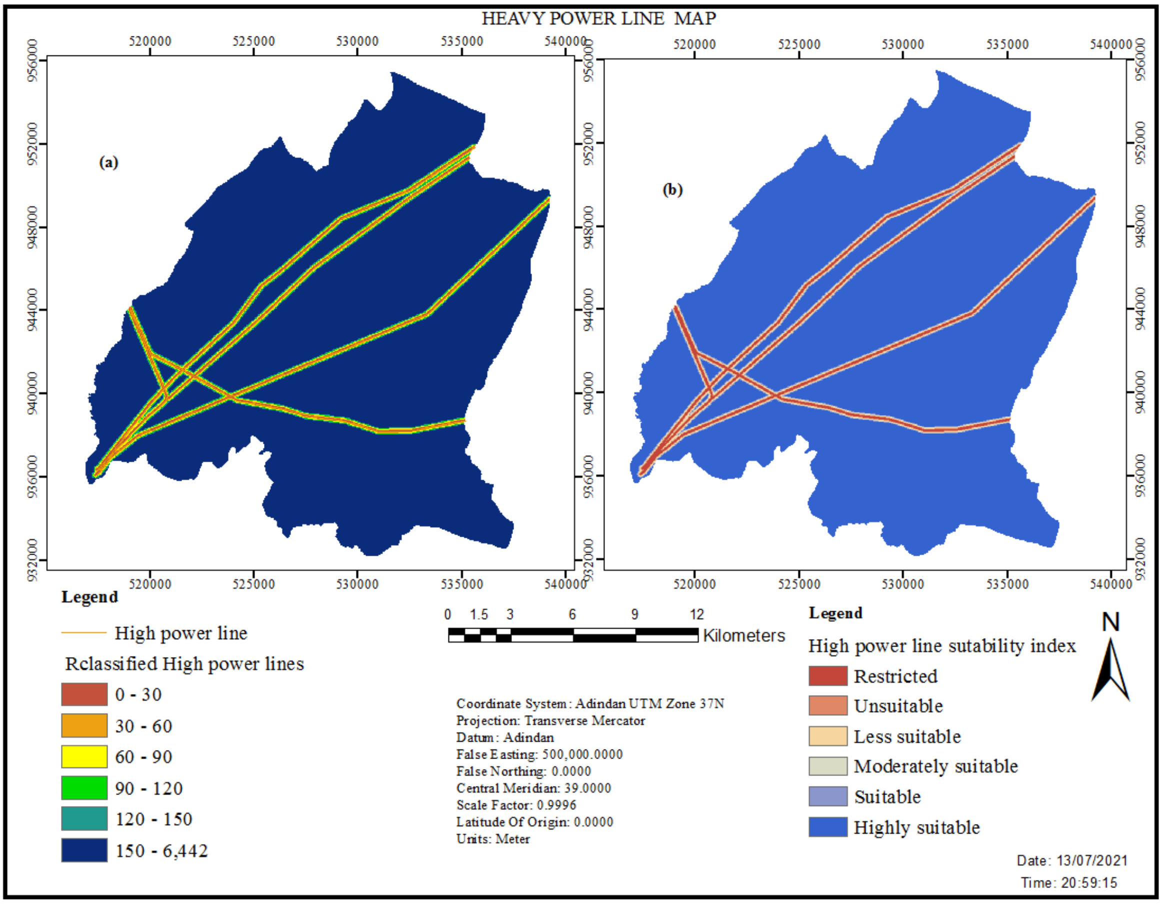

Figure 4.10 Power line factor map (a) reclassified distance from power line and (b) suitability index

4.2.5. Landfill Site Factor

Environmental factors play an important role in today's industrial scenario. To make an industry sustainable to various changes in the industrial working, environment plays an important role. With the proper control of the effects of these environmental factors, the Sustainability of an industry can be further increased (Singh Thakur et al., 2018). The quality of human health has been impacted by the growth of urban populations, municipal operations, and the ongoing discharge of garbage into the environment. One of the most significant sources of risks to human health and the environment is waste production (Hashemi et al., 2017). When landfill sites are close to industrial locations, they may dump discarded garbage straight into the industry during wet seasons, posing a major threat to both industry productivity and the environment. Different types of industry and production, such as food and beverage, materials, and chemical factories, might be found in the industrial zones. Some of these industries are sensitive to contamination from any source, which lowers the quality of the product provided by the facility, either directly or indirectly. According to Alzamili et al. (2015), the industrial site may include industries that cannot tolerate any contamination rate distance of at least should be kept between 2-5 km. To avoid this sensitivity existing landfill waste disposal site was used as an input spatial information parameter. The existing waste disposal area was extracted from the base map of Adama Town by utilizing ArcGIS 10.8 software. Because of the lower risk of contamination, areas further away from landfills are more suitable for industrial plants. However, places that are too far away from landfills are not cost-effective since industries must travel long distances to dispose of their trash. unsuitable, less suitable, moderately suitable, highly suitable, and suitable were the score ranges used for landfill sites categorization into five classes with intervals of 0-4000, 4,000-6,000, 6,000-8,000, 8,000-10,000, and >10,000.

Table 4.11 Suitability index of the reclassified landfill site proximity distance in (m)

Distance in meter (m)	Score	Suitability	Area in km^2	%
0-4,000	S1	Unsuitable	52.38	16.74
4,000-6,000	S2	Less suitable	57.56	18.39
6,000-8,000	S3	moderate Suitable	59.68	19.06
8,000-10,000	S5	Highly Suitable	52.22	16.68
>10,000	S4	Suitable	91.2	29.13

The overall contribution of each suitability class for industrial site demarcation in terms of areas was 52.38 km^2, 57.56 km^2, 59.68 km^2, 52.22 km^2, and 91.20 km^2 based on the reclassified and indexed map of landfill site factor depicted in (Figure 4.11). Unsuitable, less suitable, moderately suitable, highly suitable, and suitable are the suitability ranks that was assigned in linguistic variables for landfill factor. To compensate the environmental impact and economic benefit in the current study, locations located at a medium distance from the landfill site were considered highly suitable, while sites located too distant from the dumpsite were reclassified as suitable for achieving the study's goal. From this perspective, the study area was dominantly suitable for industrial zoning in regards to landfill suitability factor.

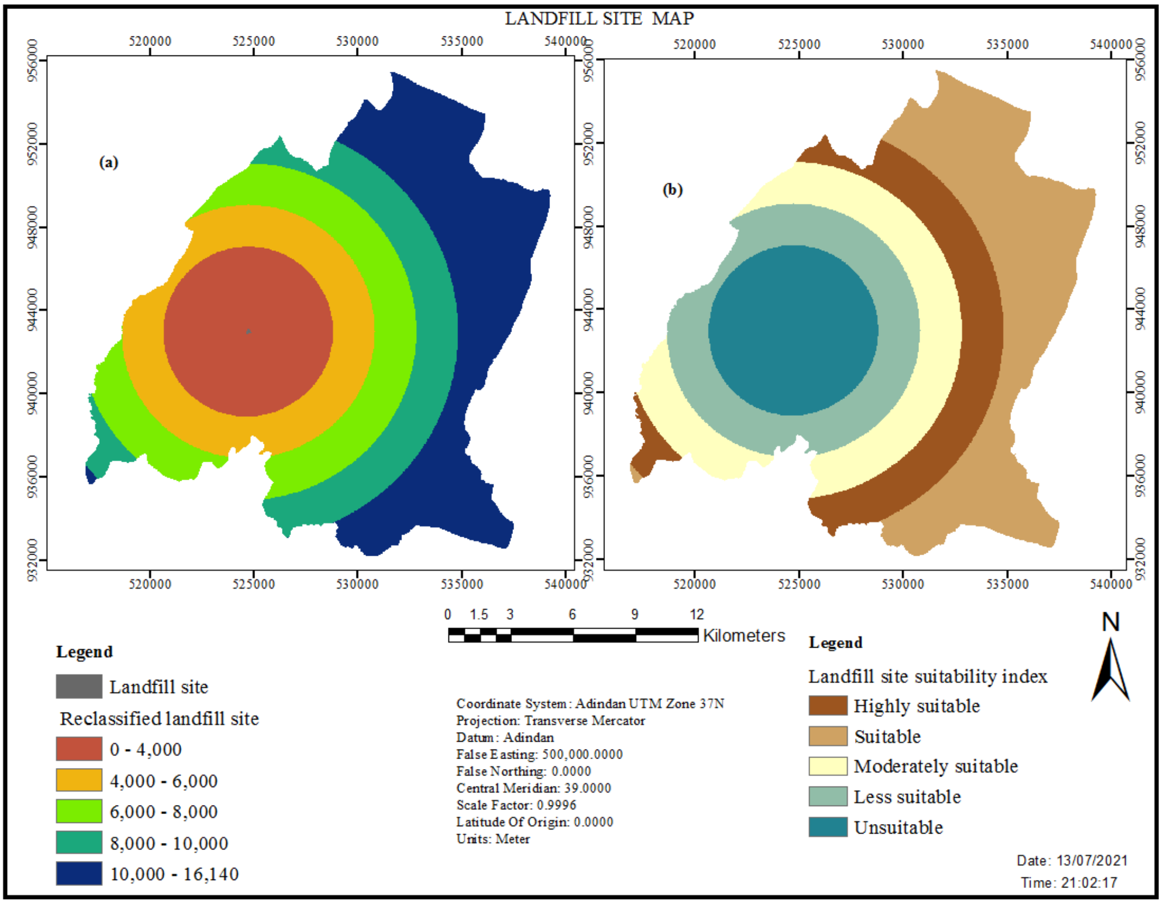

Figure 4.11 Landfill site factor map (a) reclassified distance from landfill site and (b) suitability index

4.3. Geological Criteria for Industrial Site Selection

4.3.1. Geological Fault Factor

Geology was considered as it plays an important in the suitability decision of sites for industries absence of fault zones would make the site suitable at the first place. Without this consideration, we cannot go forward in the process of site selection at any cost (Sarath et al., 2018). Geological Faults are one of the geological phenomena that cause problems for industrial construction, so they should be avoided in industrial sites (Reisi et al., 2013). Regarding legal buffer from fault lines and avoiding industrial developments in such areas are considerable factors in the industrial site selection (Fataei et al., 2015). As a result, one of the parameters in the current study was the geological fault line. According to Sarath et al., (2018), industrial site selection should be done carefully by watching out the fault lines and avoid areas nearer to them to ensure stable rock to build a structure. To determine the best land location for an industrial site, geological fault lines digitized from Ethiopian geological map were reclassified by comparing and analyzing the fault distance categorization of other researchers as shown in (Figure 4.12).

Table 4.12 Suitability index of the reclassified Fault lines proximity distance (m)

(Fataei et al., 2015)	(Ahmadipari et al., 2018)	In this study	Score value	Area in km^2	%
0-2000	0-3000	0-2500	S1	186.11	59.45
2000-4000	3000-5000	2500-4500	S2	91.23	29.14
40000-10000	5000-7000	4500-8000	S3	30.83	9.85
10000-20000	7000-9000	8000-9000	S4	2.67	0.86
>20000	>9000	9000-10564	S5	2.2	0.7

In (Table 4.12): S1= highly suitable, S2=suitable, S3=moderately suitable, S4=less suitable, and S5= unsuitable

According to the reclassified geological fault lines factor map shown in (Figure 4.12). Highly suitable, suitable, moderately suitable, less suitable, and unsuitable ranks were graded to the class intervals of 9000 to 10564, 8000 to 9000, 4500 to 8000, 2500 to 4500, and 0 to 2500, respectively. The statistical summaries of the reclassified fault lines factor map presented in (Table 4.12), illustrate that 186.11 km^2 (59.45 %) of the study area was unsuitable, 91.23 km^2 (29.14 %) of the study area was less suitable, 30.84 km^2 (9.85 %) of the study area was moderately suitable, 2.68 km^2 (0.86 %) of the study area was suitable and 2.2 km^2 (0.7 %) of the study area was highly suitable. For the present thesis research according to the suggestion of different scholars, the areas near to geological fault lines were assigned as unsuitable whereas the area remote to fault lines were reclassified into highly suitable for delineation of industrial site. In terms of fault lines suitability, the study area was dominantly unsuitable for industrial site selection.

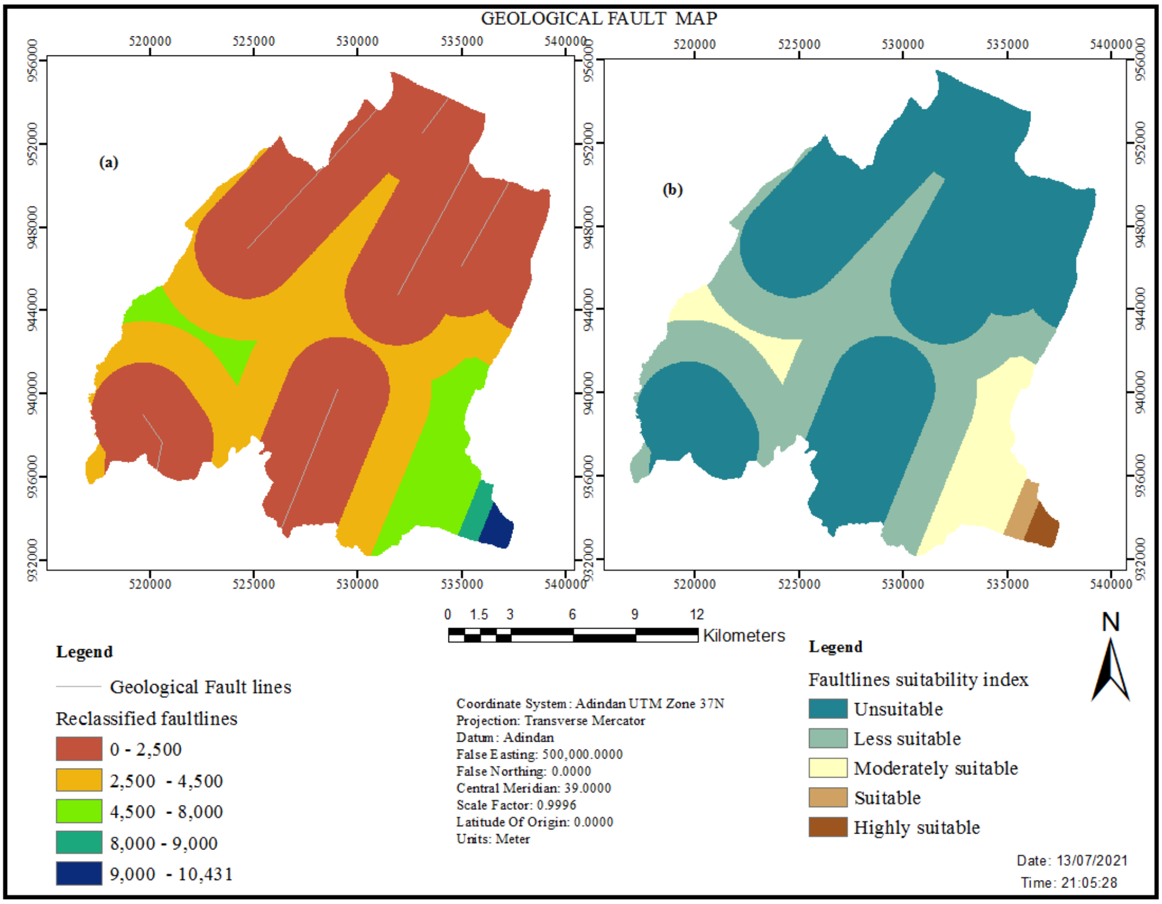

Figure 4.12 Fault lines factor map (a) reclassified distance from fault lines and (b) suitability index

4.3.2. Soil Type Factor

The achievement of sustainable development requires a balanced integration of environment, economic, geological and social objectives, taking into account the needs and concerns of both present and future generations (Singh Thakur et al., 2018). In this study, soil type was measured to minimize the capacity of industrial waste on ground water contamination. Based on infiltration rate soil type play a great role in the movement of liquid waste into the ground. The soils with a high percentage of silt and clay particles have a higher water-holding capacity. Moreover, the size and spacing of soil particles determine how much water can flow in. Wide pore spacing at the soil surface increases the rate of water infiltration, thus coarse soils have a higher infiltration rate than fine soils (Ball, 2001 as cited in H/Gebriel, 2017).

Table 4.13 Soil type, texture and infiltration rate (source FAO, 2001)

Soil type	texture	Silt content	Clay content	Sand content	Infiltration rate(mm/h)
Mollic andosols	loam	39	22	39	10-20
haplic luvisols	loam	37	22	41	10-20
Haplic phaeozems	loam	39	21	40	10-20
Eutric fluvisols	Loam sand	12	8	80	20-30

For this study purpose, the existing soil type of the study area digitized from soil map of Ethiopia was reclassified into highly suitable, suitable, moderately suitable and unsuitable based on the amount of silt and clay content and infiltration rate as presented in (Table 4.13). Mollic andosols have high percentages of silt and clay content jointly and less amount of infiltration rate. Therefore, it was grouped under highly suitable classes. The soil with a high percentage of silt and clay particle has high water holding capacity less susceptible for erosion. The infiltration rate of haplic luvisols is similar to mollic andosols however their silt and clay amount are less. Thus, haplic luvisols was ranked as suitable. haplic phaeozems and eutric fluvisols soil type were reclassified under moderate suitable and unsuitable classes accordingly based on infiltration rate.

Table 4.14 Suitability index of soil type for industrial site selection

Soil type	Score	Suitability index	Area in km^2	%
Mollic andosols	S5	Highly suitable	278.1	88.84
Haplic luvisols	S4	Suitable	0.17	0.05
Haplic phaeozems	S3	Moderate suitable	24.83	7.93
Eutric fluvisols	S1	Unsuitable	9.94	3.18

As shown in (Table 4.14) above, the bulk of the study area was highly suitable for industrial site delineation in terms of soil type spatial information layer, covering 278.1 square kilometers, while the smallest portion of the study area was suitable, accounting for 0.17 square kilometer. The remaining sections, with an area coverage of 24.83 and 9.94 square kilometers, were moderately suitable and unsuitable for zoning out of the overall study area.

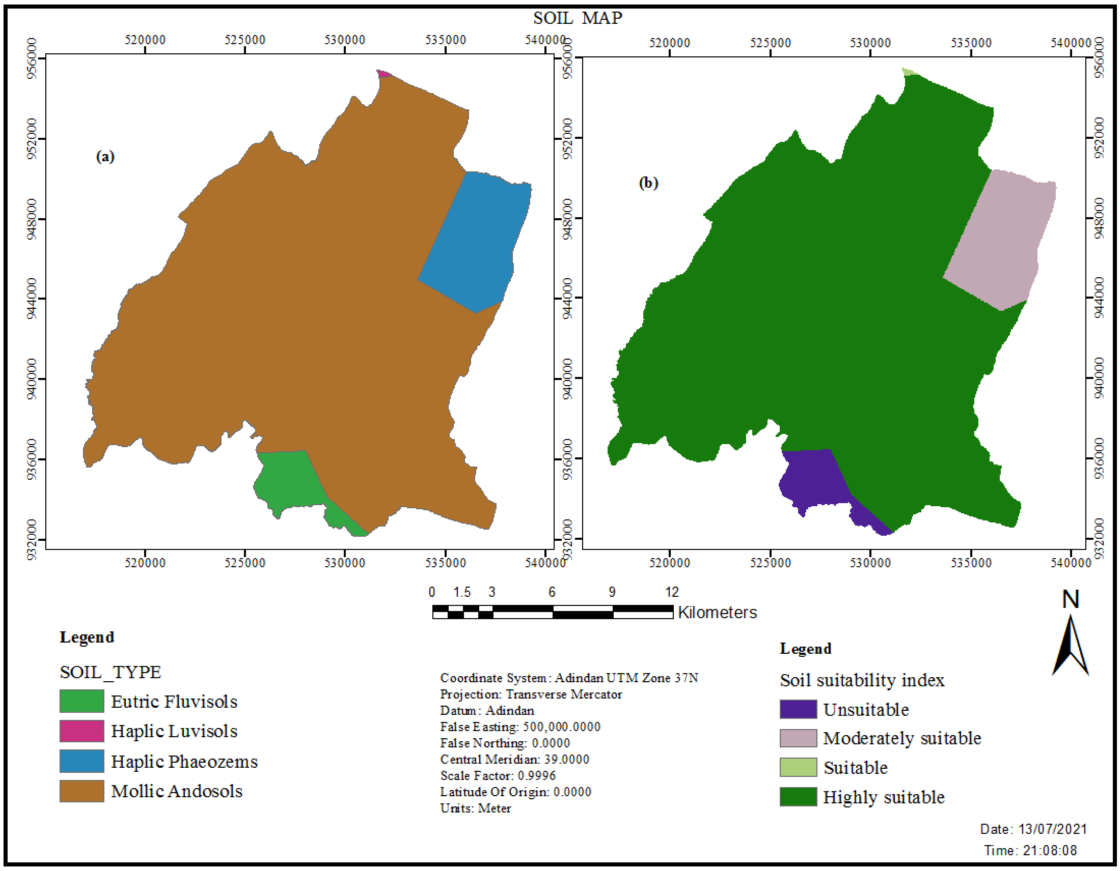

Figure 4.13 Soil type factor map (a) soil type and (b) suitability index

4.4. Population Criteria for Industrial Site Selection

4.4.1. Population Density Factor

Urban density is a term used in urban planning and urban design to refer to the number of people inhabiting a given urbanized area per given building. Urban density was considered an important factor in understanding how cities function. It was believed that as the number of building increased the built area will increase and the neighborhood becomes denser. From the ground reality, it was known that most municipal service delivery is related to the population density (Gemeda, 2018). The density of population varies from area to area. According to analysis result, the central parts of the city have high population density in comparison with the urban expansion areas. The urban Ganda with the biggest population is irreecha(09), whereas, the urban Genda with the least population is Gurmu(06). But, ganda Gurmu (06) is the second dense, whereas Badhatu (07) is the first densiest. Densely populated urban areas particularly in low and middle-income countries are vulnerable to the effects of environmental and climate change (Dodman, 2009). Lower population density was considered as more suitable than higher population density for optimal industrial site selection since the cost of land, property and effects on population decreases with decreasing density. In addition to this, Industrial waste are the main source of pollution in the worldwide therefore highly dense population are easily exposed to pollution. For this study population density of the study area was reclassified into five grades as depicted in below (Table 4.15).

Table 4.15 Suitability index of the reclassified population density per km^2

Population density per km^2	Score value	Suitability index	Area in km^2	%
132.65-1004.30	S5	Highly suitable	247.6	79.1
1004.30-3300.51	S4	Suitable	40.82	13.04
3300.51-9480.68	S3	Moderate suitable	15.04	4.80
9480.68-20112.98	S2	Less Suitable	8.23	2.63
20112.98-37581.91	S1	Unsuitable	1.35	0.43

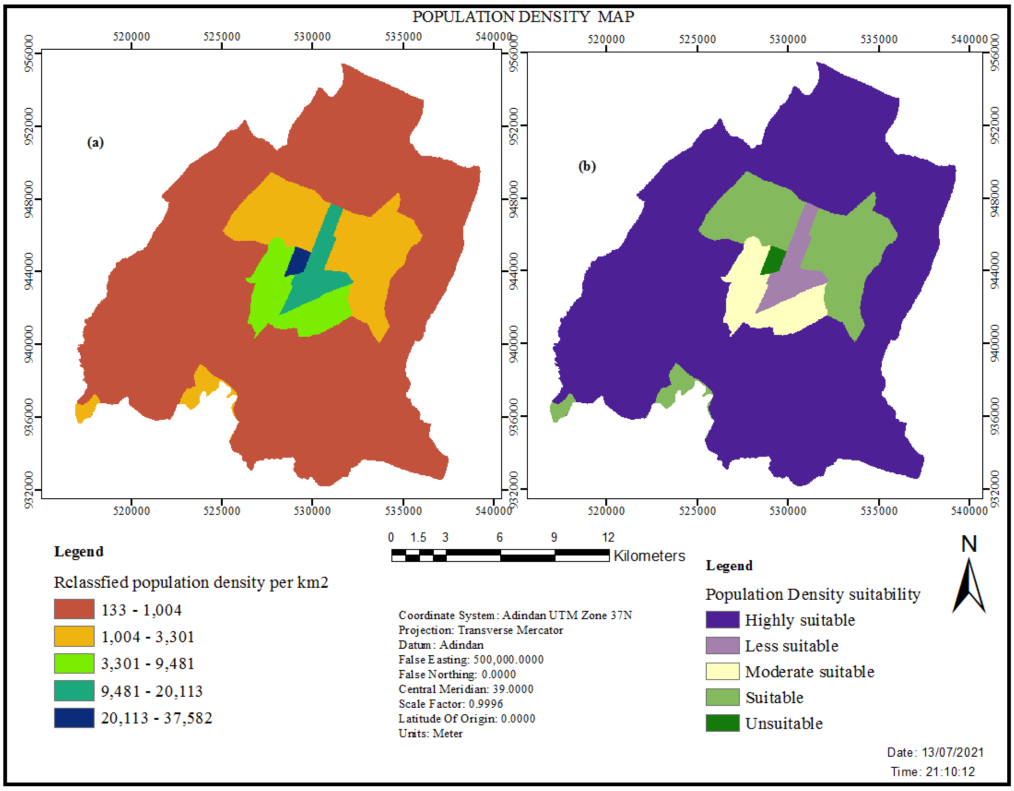

Figure 4.14 Population factor map (a) reclassified population density and (b) suitability index

4.5. Standardizing Factors

After preparation, the factor maps had to be standardized. The values in different input maps may have different meanings and they may include different measurement units (e.g. the slope map in terms of degree, roads in terms of distance, etc.). In order to make the values mutually comparable, it is necessary to standardize them by turning into similar measurement units (Maddahi et al., 2017). Even though different methods can be used to standardize criteria maps, linear scale transformation is the most frequently used technique (Malczewski, 2003, as cited in Gelan, 2018). Therefore, in this study for criteria standardization linear scale transformation was implemented to transform heterogeneous factors into uniform measurement scales. To assign scale for the criteria reclassification was done based on different researcher's suggestion then new value was assigned as 5, 4, 3, 2 and 1 for highly suitable, suitable, moderately suitable, less suitable and unsuitable respectively.

4.6. Calculating Weightage for Main and Sub criteria

4.6.1. Fuzzy Analytical Hierarchy Process (FAHP)

The FAHP is an AHP format, which assesses different factors using fuzzy numbers. While AHP is based on using the crisp numbers, FAHP has overcome the imperfections of AHP. Since vagueness is a common characteristic of many decision-making problems, the FAHP technique has been developed to compensate for that limitation (Maddahi et al., 2017). Therefore, the priority weights of each criterion were computed by utilizing the Fuzzy-AHP based methodology in the current study after reclassifying and standardizing the criteria. The comparison of one criterion over another was computed based on previous related research studies and the opinion of different experts. To capture the experience and knowledge of expert's questionnaires were developed in the form of pairwise comparison see (appendix 4). Then the collected comparisons through linguistic variables were transformed into fuzzy numbers one by one.

4.6.2. Triangular Fuzzy Numbers (TFNs)

Fuzzy numbers are natural generalizations of ordinary numbers. Triangular fuzzy numbers are frequently used to capture the ambiguity of the parameters which are related to selecting the alternatives (Lee *et al*, 2013, as cited in Dinade, 2016). In this research study, a triangular fuzzy number was used to rank the suitability of land for industry based on the reclassified value of the map. Triangular fuzzy numbers are expressed with boundaries instead of crisp numbers for reflecting the fuzziness as decision-makers select the alternatives or pairwise comparisons matrix. This property makes FAHP is advantageous over the AHP method for site selection problems.

Table 4.16 Triangular fuzzy number of a linguistic variable used in the study

Linguistic variable	Crisp pairwise number	Triangular fuzzy number	Reciprocal triangular fuzzy number
Extremely important	9	(9, 9, 9)	(1/9, 1/9, 1/9)
Very strong important	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Strong important	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Moderate important	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Equally important	1	(1, 1, 1)	(1, 1, 1)
Intermediate important	2, 4, 6, 8	(7, 8, 9), (5, 6, 7), (3, 4, 5),(1, 2, 3)	(1/9,1/8,1/7), (1/7,1/6, 1/5), (1/5, 1/3, 1/3), (1/3, 1/2, 1)

Source: (Maddahi et al., 2017) and (Nyimbili & Erden, 2020)

According to Chang (1996), a fuzzy number M or R is called a triangular fuzzy number (TFN), as it is membership function is given by

$$\mu\ddot{a}(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l} & x \in [l, m] \\ \frac{x}{m-u} - \frac{u}{m-u} & x \in [m, u] \\ 0 & otherwise \end{cases} \qquad \text{Eq. (4.2)}$$

Where l is the lowest possible value, m is the middle possible value and u is the highest possible value in judgment interval of decision making.

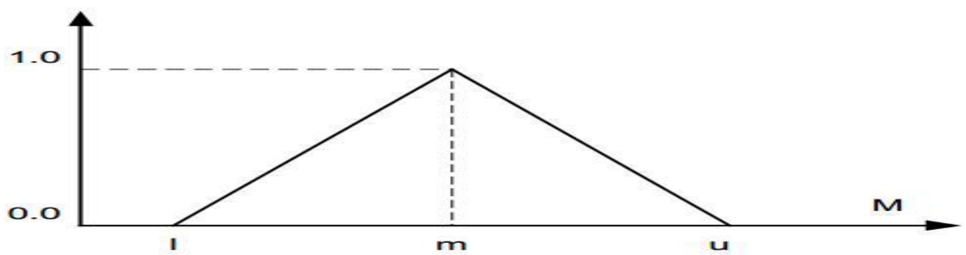

Figure 4.15 Fuzzy membership function

Consider two triangular fuzzy number (TFNs) M_1 and M_2 $M_1 = (x_1, y_1, z_1)$ and $M_2 = (x_2, y_2, z_2)$, their addition and multiplication operational laws are presented in (Equation 4.3 and 4.4) as follows:

$$M_1 + M_2 = (x_1, y_1, z_1) + (x_2, y_2, z_2) \quad \text{Eq. (4.3)}$$

$$= (x_1 + x_2,\ y_1 + y_2,\ z_1 + z_1)$$

$$M_1 * M_2 = (x_1, y_1, z_1) * (x_2, y_2, z_2) \quad \text{Eq. (4.4)}$$

$$= (x_1 * x_2,\ y_1 * y_2,\ z_1 * z_2)$$

In this thesis study, to determine the weight of the criteria fuzzy analytical hierarchy process (AHP) based fuzzy extent analysis method was used.

$$\tilde{A} = (\ddot{a}_{\mathrm{ij}})_{n*n} \begin{bmatrix} (1,1,1) & (l_1, m_1, u_1) & . & . & (l_{1n}, m_{1n}, u_{1n}) \\ l_{21}, m_{21}, u_{21} & (1,1,1) & . & . & (l_{2n}, m_{2n}, u_{2n}) \\ . & . & . & . & . \\ . & . & . & . & . \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & . & . & (1,1,1) \end{bmatrix} \quad \text{Eq. (4.5)}$$

Where;

$$\ddot{a}_{\mathrm{ij}} = \left(l_{ij}, m_{ij}, u_{ij}\right), \ddot{a}_{ij}^{-1} = \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}},$$

The step of chang's fuzzy extent analysis was presented as follow

Step 1: normalize the value of row sum, also known as the value of fuzzy synthetic extent where by making use of fuzzy arithmetic operation of the equation.

$$\tilde{S} = \sum_{i=1}^{n} \tilde{a}_{ij} * \left[\sum_{k=1}^{n} \sum_{j=1}^{N} \tilde{a}_{ij}\right]^{-1} \quad \text{Eq. (4.6)}$$

Where *denotes the extended multiplication of two fuzzy numbers. To obtain $\sum_{i=1}^{n}$ äij the fuzzy addition operation has been applied to the fuzzy numbers in the fuzzy judgment matrices, such that,

$$\sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_j,\ \sum_{j=1}^{n} m_j,\ \sum_{j=1}^{n} u_j\right) \quad \text{Eq. (4.7)}$$

To obtain $\left[\sum_{k=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}\mathrm{j}\right]^{-1}$ the fuzzy addition operation was applied to column values in the matrix obtained from, followed by computation of the inverse of the resulting vector such that,

$$\left[\sum_{k=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}\mathrm{j}\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{n} u_j,}, \frac{1}{\sum_{j=1}^{n} m_j,}, \frac{1}{\sum_{j=1}^{n} l_j,}\right) \quad \text{Eq. (4.8)}$$

Step 2: This step involved taking two criteria at a time and then using their normalized TFN's obtained from Equation (4.6), to determine the degree of possibility of one criterion fuzzy number's being greater than or equal to the other criteria fuzzy number's ($\tilde{S}_i \geq \tilde{S}_j$). This can be represented by Equation (4.9) as follows.

$$V(\tilde{s}_i \geq \tilde{s}_j) = \sup_{y \geq x}\left[\min\left(\tilde{s}_i(x), \tilde{s}_j(y)\right)\right] \qquad \text{Eq. (4.9)}$$

This can be equivalently expressed as

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1 & if\ m_i \geq m_j \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & if\ l_j \geq u_i \\ 0 & other\ wise \end{cases}$$

Where; $\tilde{S}_i = (l_i, m_i, u_i)$ and $\tilde{S}_j = (l_j, m_j, u_j)$

In order to compare, $\tilde{S}_i$ and $\tilde{S}_j$, both the values of $V(\tilde{S}_i \geq \tilde{S}_j)$ and $V(\tilde{S}_j \geq \tilde{S}_i)$ has been computed. The degree of possibility for a fuzzy number to be greater than n fuzzy number

$\tilde{S}_i = (i = 1,2 \ldots j)$ can be defined by:

$$V(s \geq \tilde{S}_1), \tilde{S}_2 \ldots \tilde{S}_j) = V[(s \geq \tilde{S}_1) \text{ and } (s \geq \tilde{S}_2) \text{and} \ldots (s \geq \tilde{S}_3)] \qquad \text{Eq. (4.10)}$$
$$= min \vee ((s \geq \tilde{S}_i), i = 1,2, .. j)$$

Assume that $d(\tilde{A}_i) = min V(\tilde{S}_i \geq \tilde{S}_j), j = 1, 2 \ldots n; j \neq i$

Then the weight vector given by:

$$W' = (d(A'1), d(A'2), d(A'3) \ldots .. d(A'n)) \qquad \text{Eq. (4.11)}$$

Where $d(\tilde{A}_i)$ are n element

Via normalizing, the normalized weight vector are

$$W = (d(\tilde{A}_1), d(\tilde{A}_2), d(\tilde{A}_3), \ldots d(\tilde{A}_n)) \qquad \text{Eq. (4.12)}$$

Where W is non fuzzy number

Step 3: The normalized weight vectors for each fuzzy comparison matrix,$\widetilde{A}$, at each level of the hierarchy was determined by normalizing the weight vector, w. In other literature's this process is known as defuzzification and involves dividing each value in the weight vector, W by their total sum as follows:

$$W_i = \frac{V(\tilde{S}_i \geq \tilde{S}_j) \quad j=1....n; j \neq i}{\sum_{k=1}^{n} V(\tilde{S}_k \geq \tilde{S}_j) \quad j=1...n; j \neq k} \qquad \text{Eq. (4.13)}$$

Human beings have diverse ways of thinking and making decisions, especially when it comes to determining the suitability of land for various purposes. For example, different degrees of priority are assigned by experts and publications for the identical pairwise comparison of slope and elevation criteria. As indicated in the previous section of this research document weight was determined based on the comparison of one criterion over the other based on literature and expert's suggestion using a fuzzy linguistic variable. Then these linguistic variables were converted into triangular fuzzy numbers. Therefore to overcome the subjectivity limitation of decision making in suitability analysis geometric mean value of different experts and literature suggestions were computed through the below Equation (4.14) then the computed value has been used for final pairwise comparison and weight derivations. Buckley’s geometric mean method was used to determine the criterion’s fuzzy geometric mean (Mallick, 2021).

$$\tilde{r_i} = (\tilde{a}_{i1} * \tilde{a}_{i2} * \tilde{a}_{i3} \ldots \tilde{a}_{in})^{1/n} \qquad \text{Eq. (4.14)}$$

Where $\tilde{a}_{in}$ is fuzzy comparison value of criterion i to criterion n, therefore, $\tilde{r_i}$ is geometric mean of fuzzy comparison value of criterion i to each criterion, n is the number of involved experts decision-makers and literature suggestion in comparison. Finally, the weights obtained in each hierarchy were combined by multiplying the top major criteria by the lower sub-criteria that were directly related. This was done by multiplying the weight of a factor in the lower level by that of the element/s in the upper level as long as they were directly related as in the hierarchical structure (Dinade, 2016).

According to Equations (4.5 and 4.14), the pairwise comparison for major criteria such as economic, environmental, geological and population was matriculated as it can be seen in (Table 4.17).

Table 4.17 Pairwise comparison of main criteria

C	C1	C2	C3	C4	W
C1	1,1,1	0.719, 1.041, 1.614	1.835, 2.731, 3.557	1.741, 2.581, 3.383	0.453
C2	0.620, 0.960, 1.390	1,1,1	1.856, 2.564, 3.200	1.712, 2.595, 3.415	0.439
C3	0.281, 0.366, 0.545	0.313, 0.390, 0.539	1,1,1	0.780, 1.182, 1.616	0.069
C4	0.296, 0.387, 0.574	0.293, 0.385, 0.584	0.619, 0.846, 1.282	1,1,1	0.039
		λ_{max} = 4.0048 , N = 4 ,	**CI = 0.0016,**	**CR = 0.0018**	

In (Table 4.17): C= Criteria, C1=Economic criteria, C2= Environmental criteria, C3= Geological criteria, C4= population criteria and W=Normalized weight

According to Equation (4.6), row sum was normalized, also known as the value of fuzzy synthetic extent were conducted for economic, environmental, geological and population major factors based on transformed triangular pairwise comparison matrix.

$\tilde{S}_{c1}$ = (5.295, 7.353, 9.554) * (1/25.700, 1/20.029, 1/15.063) = 0.206, 0.367, 0.634

$\tilde{S}_{c2}$ = (5.188, 7.119, 9.006) * (1/25.700, 1/20.029, 1/15.063) = 0.202, 0.355, 0.598

$\tilde{S}_{c3}$ = (2.374, 2.938, 3.700) * (1/25.700, 1/20.029, 1/15.063) = 0.092, 0.147, 0.246

$\tilde{S}_{c4}$ = (2.207, 2.619, 3.441) * (1/25.700, 1/20.029, 1/15.063) = 0.086, 0.131, 0.228

To determine the degree of possibility of one criterion fuzzy number‘s being greater than or equal to the other criteria fuzzy number‘s ($\tilde{S}_i \geq \tilde{S}_j$)

Equation (4.9) was applied as follows.

$\min V(\tilde{S}_{c1} \geq \tilde{S}_{c2}, \tilde{S}_{c3}, \tilde{S}_{c4})$ = min (1.000, 1.000, 1.000) = 1

$\min V(\tilde{S}_{c2} \geq \tilde{S}_{c1}, \tilde{S}_{c3}, \tilde{S}_{c4})$ = min (0.971, 1.000, 1.000) = 0.971

$\min V(\tilde{S}_{c3} \geq \tilde{S}_{c1}, \tilde{S}_{c2}, \tilde{S}_{c4})$ = min (0.152, 0.173, 1.000) = 0.152

$\min V(\tilde{S}_{c4} \geq \tilde{S}_{c1}, \tilde{S}_{c2}, \tilde{S}_{c3})$ = min (0.087, 0.106, 0.895) = 0.087

Finally, the crisp weight 0.453, 0.439, 0.069 and 0.039 were elicited for economic, environmental, geological and population criteria respectively based on normalized results obtained in Equation (4.9) through Equation (4.13). Similarly, as major criteria based on Equation (4.5 and 4.14), the pairwise comparison for economic criteria which embraces (Major road, Highway, Railway, Elevation, Slope and Existing industrial area) was matriculated as demonstrated in (Table 4.18).

Table 4.18 Pairwise comparison of economic criteria

C	MR	HW	RW	EL	SL	EI	W
MR	1,1,1	1.103, 1.597, 2.107	0.308, 0.384, 0.530	0.922, 1.335, 1.835	0.860, 1.246,1.762	0.922, 1.335, 1.835	0.181
HW	0.475, 0.626, 0.907	1,1,1	0.988, 1.490, 2.107	0.922,1.335, 1.835	0.988, 1.490, 2.107	1.182,1.783, 2.421	0.204
RW	1.888, 2.605, 3.245	0.475, 0.671, 1.012	1,1,1	1.320, 1.911, 2.421	0.922, 1.335, 1.835	0.960,1.431, 1.966	0.231
EL	0.545, 0.749, 1.084	0.545, 0.749, 1.084	0.413, 0.523, 0.758	1,1,1	0.788, 1.123, 1.665	0.626,0.933, 1.431	0.125
SL	0.568, 0.803, 1.162	0.475, 0.671, 1.012	0.545, 0.749, 1.084	0.634, 0.922, 1.297	1,1,1	1.182, 1.783,2.421	0.152
EI	0.545, 0.749, 1.084	0.413, 0.561, 0.846	0.509, 0.699, 1.041	0.699, 1.072, 1.597	0.413, 0.561, 0.846	1,1,1	0.107

λ_{max} = 6.2611 , N = 6 , CI = 0.0522 , CR = 0.0421

In (Table 4.18): C= Criteria MR=Major road, HW= Highway, RW=Railway, EL=Elevation, SL=Slope, EI= Existing industrial area and W = normalized weight

Based on Equation (4.6), row sum was normalized, also known as the value of fuzzy synthetic extent were conducted for economic sub-criteria, based on transformed triangular pairwise comparison matrix depicted above (Table 4.18).

$\tilde{S}_{MR}$ = (5.116, 6.897, 9.068) * (1/52.338, 1/39.220, 1/29.135) = (0.098, 0.176, 0.311)

$\tilde{S}_{HW}$ = (5.555, 7.724, 10.377) * (1/52.338, 1/39.220, 1/29.135) = (0.106, 0.197, 0.356)

$\tilde{S}_{RW}$ = (6.565, 8.953, 11.479) * (1/52.338, 1/39.220, 1/29.135) = (0.125, 0.228, 0.394)

$\tilde{S}_{EL}$ = (3.917, 5.077, 7.023) * (1/52.338, 1/39.220, 1/29.135) = (0.075, 0.129, 0.241)

$\tilde{S}_{SL}$ = (4.403, 5.927, 7.977) * (1/52.338, 1/39.220, 1/29.135) = (0.084, 0.151, 0.274)

$\tilde{S}_{EI}$ = (3.579, 4.642, 6.415)* (1/52.338, 1/39.220, 1/29.135) = (0.068, 0.118, 0.220)

Fuzzy weight obtained through (Equation 4.6) were converted into degree of possibility based on (Equation 4.9) to determine crisp weight for factor map.

$\min V(\tilde{S}_{MR} \geq \tilde{S}_{HW}, \tilde{S}_{RW}, \tilde{S}_{EL}, \tilde{S}_{SL}, \tilde{S}_{EI})$ = min (0.907, 0.780, 1.000, 1.000, 1.000) = 0.780

$\min V(\tilde{S}_{HW} \geq \tilde{S}_{MR}, \tilde{S}_{RW}, \tilde{S}_{EL}, \tilde{S}_{SL}, \tilde{S}_{EI})$ = min (1.000, 0.880, 1.000, 1.000, 1.000) = 0.880

$\min V(\tilde{S}_{RW} \geq \tilde{S}_{MR}, \tilde{S}_{HW}, \tilde{S}_{EL}, \tilde{S}_{SL}, \tilde{S}_{EI})$ = min (1.000, 1.000, 1.000, 1.000, 1.000) = 1.000

$\min V(\tilde{S}_{EL} \geq \tilde{S}_{MR}, \tilde{S}_{HW}, \tilde{S}_{RW}, \tilde{S}_{SL}, \tilde{S}_{EI})$ = min (0.755, 0.667, 0.539, 0.879, 1.000) = 0.539

$\min V(\tilde{S}_{SL} \geq \tilde{S}_{MR}, \tilde{S}_{HW}, \tilde{S}_{RW}, \tilde{S}_{SL}, \tilde{S}_{EL})$ = min (0.877, 0.785, 0.658, 1.000, 1.000) = 0.658

$\min V(\tilde{S}_{EI} \geq \tilde{S}_{MR}, \tilde{S}_{HW}, \tilde{S}_{RW}, \tilde{S}_{SL}, \tilde{S}_{EI})$ = min (0.680, 0.592, 0.463, 0.929, 0.806) = 0.463

Finally, the minimum values were normalized according to (Equation 4.13) and the normalized weight result obtained was tabulated above.

Table 4.19 Pairwise comparison of environmental criteria

C	WB	LF	HPL	LULC	SA	W
WB	1,1,1	1.162, 1.692, 2.387	0.983, 1.398, 1.982	0.671, 0.972, 1.473	0.988, 1.597, 2.352	0.245
LF	0.419, 0.591, 0.860	1,1,1	0.988, 1.597, 2.352	0.265, 0.362, 0.530	0.344, 0.483, 0.728	0.137
HPL	0.504, 0.715, 1.017	0.425, 0.626,1.012	1,1,1	0.449, 0.634, 0.896	0.304, 0.409, 0.561	0.095
LULC	0.679,1.029, 1.490	1.888, 2.763, 3.767	1.116,1.578, 2.227	1,1,1	0.595, 0.960, 1.448	0.264
SA	0.425, 0.626, 1.012	1.374, 2.069, 2.908	1.783, 2.446, 3.293	0.691, 1.041, 1.681	1,1,1	0.260

λ_{max} =5.1571 , N = 5 , CI = 0.0393 , CR = 0.0350

In (Table 4.19):WB= Waterbody (rivers and streams), LF= Landfill site, HPL= heavy power line, LULC=Land Use Land Cover, SA= Settlement Area, W= normalized weight

$\tilde{S}_{WB}$ = (4.805, 6.658, 9.194)* (1/38.976, 1/28.590, 1/21.054) = (0.123, 0.233, 0.437)

$\tilde{S}_{LF}$ = (3.017, 4.033, 5.470)* (1/38.976, 1/28.590, 1/21.054) = (0.077, 0.141, 0.260)

$\tilde{S}_{HPL}$ = (2.682, 3.384, 4.486)* (1/38.976, 1/28.590, 1/21.054) = (0.069, 0.118, 0.213)

$\tilde{S}_{LULC}$ = (5.278, 7.331, 9.932)* (1/38.976, 1/28.590, 1/21.054) = (0.135, 0.256, 0.472)

$\tilde{S}_{SA}$ = (5.272, 7.183, 9.894)* (1/38.976, 1/28.590, 1/21.054) = (0.135, 0.251, 0.470)

$\min V(\tilde{S}_{WB} \geq \tilde{S}_{LF}, \tilde{S}_{HPL}, \tilde{S}_{LULC}, \tilde{S}_{RA})$ = min (1.000, 1.000, 0.928, 0.943) = 0.928

$\min V(\tilde{S}_{LF} \geq \tilde{S}_{WB}, \tilde{S}_{HPL}, \tilde{S}_{LULC}, \tilde{S}_{RA})$ = min (0.598, 1.000, 0.519, 0.531) = 0.519

$\min V(\tilde{S}_{HPL} \geq \tilde{S}_{WB}, \tilde{S}_{LF}, \tilde{S}_{LULC}, \tilde{S}_{RA})$ = min (0.439, 0.857, 0.360, 0.369) = 0.360

$\min V(\tilde{S}_{LULC} \geq \tilde{S}_{WB}, \tilde{S}_{LF}, \tilde{S}_{HPL}, \tilde{S}_{RA})$ = min (1.000, 1.000, 1.000, 1.000) = 1

$\min V(\tilde{S}_{SA} \geq \tilde{S}_{WB}, \tilde{S}_{LF}, \tilde{S}_{HPL}, \tilde{S}_{LULC})$ = min (1.000, 1.000, 1.000, 0.985) = 0.985

Table 4.20 Pairwise comparison of geological criteria

CRITERIA	SOT	GFL	Normalized weight
SOT	1,1,1	0.836, 1.320, 1.954	0.593
GFL	0.512, 0.758, 1.196	1,1,1	0.407

λ_{max} = 2.0016 , N =2 , CI = 0.0016, CR =0

In (Table 4.20): GFL= Geological Fault lines, SOT= Soil Type

Table 4.21 Pairwise comparison of population criteria

CRITERIA	Population density	Normalized weight
Population density	1,1,1	1

λ_{max} = 1 , N = 1 , CI = 0, CR =0

4.6.3. Consistency Ratio (CR)

The accuracy of pairwise comparisons was evaluated by calculating the consistency ratio (CR) (Abdulhasan et al., 2019). The CR is designed in such a way that if CR < 0.10, the ratio indicates a reasonable level of consistency. However, CR > 0.10 indicates inconsistent judgments (Maddahi et al., 2017). In this study in order to determine, the comparison is consistent or not in each level of the hierarchy, the consistency ratio was computed using Equation (4.15). The consistency ratio results tabulated above reveals that each hierarchy level was acceptable for further analysis, which is less than 10%. CR was used to estimate the relative weightings of all criteria on a consistency ratio in which values under 10% are considered acceptable (Abdulhasan et al., 2019).

Table 4.22 Random consistence index value (RI) (Maddahi et al., 2017)

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0 0	0.58	0.9	1.12	1.24	1.24	1.41	1.45	1.49

$CR = \frac{CI}{RI}$ Eq. (4.15)

$CI = \frac{\lambda_{max-n}}{n-1}$ Eq. (4.16)

Where: CR- consistency ratio

CI - consistency index

λ - average value of consistency vector

n - number of criteria

RI - random index, the consistency index of a randomly generated pairwise comparison matrix, simply obtained from the table of Random Inconsistency Indices (Table 4.22).

Table 4.23 Summarization of the overall normalized weights of criteria used

Main-criteria (Hierarchy 1)	W_1	Sub-criteria (Hierarchy 2)	W_2	Global weight ($w_1 * w_2$)
Economic criteria	0.453	Major road	0.181	0.082
		Highway	0.204	0.092
		Railway	0.231	0.105
		Elevation	0.125	0.057
		Slope	0.152	0.069
		Industrial area	0.107	0.048
Environmental criteria	0.439	Waterbody	0.245	0.108
		Landfill site	0.137	0.060
		Heavy Power line	0.095	0.042
		LULC	0.264	0.116
		Settlement areas	0.260	0.113
Geological criteria	0.069	Soil type	0.593	0.041
		Geological fault lines	0.407	0.028
Population criteria	0.039	Population density	1	0.039
Summation	**1.00**			**1.00**

4.7. Weighted Linear Combination (WLC)

After using the FAHP method to calculate the weights of the criteria in this study, the whole set of criteria maps was superimposed using the weighted linear combination approach (Maddahi et al., 2017). In this research study to delineate optimal industrial site standardized factor maps such as major road, railway, highway, slope, elevation, existing industrial area, LULC, settlement areas, waterbody, soil type, geological fault lines, heavy power line, landfill site and population density were aggregated by using the below algorithm depicted in Equation (4.17) through Idrisi selva software. Forest and water bodies were assigned zero weights, hence these sites are not considered for industrial development (Johar et al., 2013). Additionally, based on the available literature, rivers/streams and areas within 1000 meters from them were considered restricted for allocating industries (constraint) (Reisi et al., 2011). In the current study, also Water body with in 1000m buffer, vegetation and area within 30m proximity to heavy power lines were considered as a constraint. The produced constraint maps were combined with a Boolean operation to restrict the overall industrial site suitability map see appendix (3).

$$S = \sum w_i x_i * \prod c_j \qquad \text{Eq. (4.17)}$$

Where S is suitability, W is weight of factor i , and x is the criterion score of factor i. C_j is the criterion score of the constraint j .

The resulting map obtained in the above Equation (4.17) was summarized in (Table 4.24) in terms of area and percentage share of each land suitability class. The results revealed five suitability index classes were observed in the study area: restricted, unsuitable, less suitable, moderately suitable, and suitable, with percentage coverage of 57.64 percent, 0.01 percent, 0.97 percent, 28.54 percent, and 12.84 percent, respectively.

Table 4.24 Statistical analysis of industrial site suitability map

Suitability classes	Area in km^2	percentage
Restricted	180.45	57.64
Unsuitable	0.02	0.01
Less suitable	3.03	0.97
Moderately suitable	89.36	28.54
Suitable	40.18	12.84

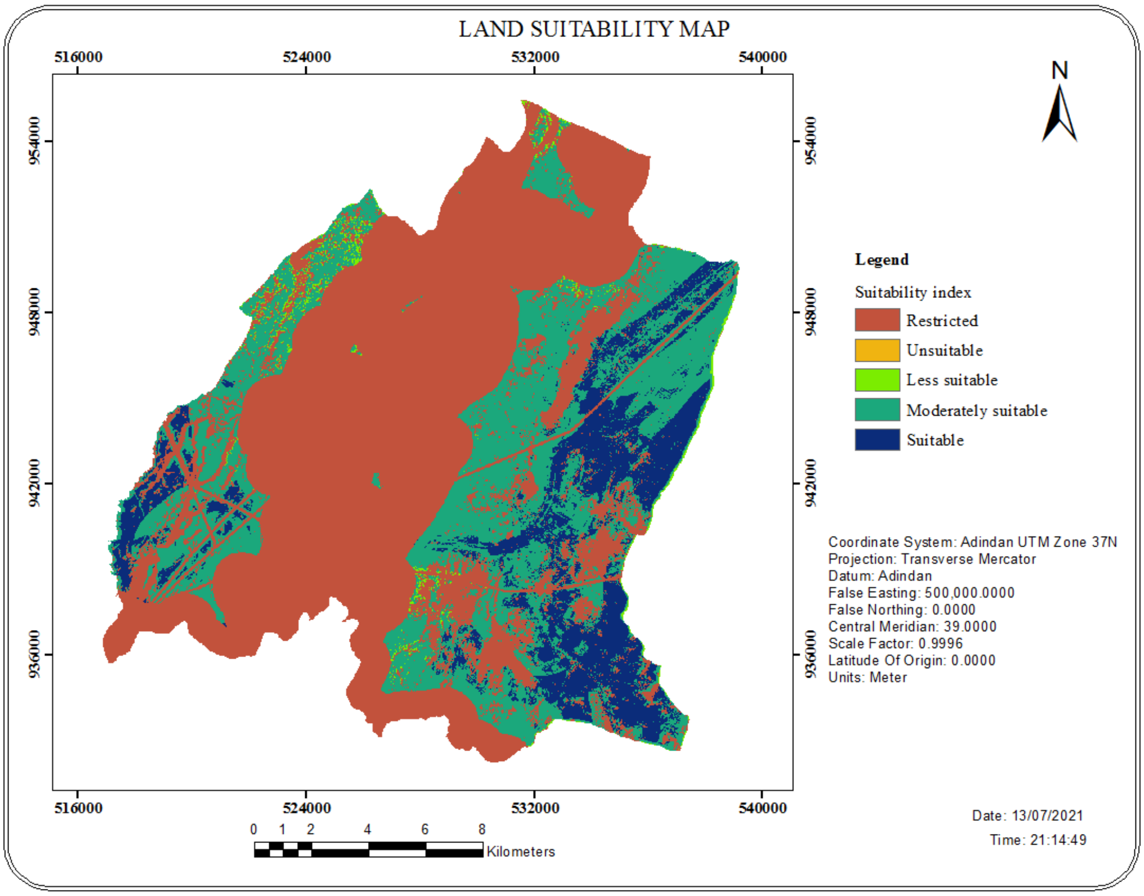

Figure 4.16 Final suitability map for industrial sites selection

The finding obtained by integrating different spatial and non-spatial factor maps reveals that the study area fell under restricted, unsuitable, less suitable, moderately suitable, and suitable classes only out of the expected result from restricted to highly suitable. According to this study's findings, the majority of the study areas were constrained, while the smallest number of areas were unsuitable for industrial utilization. The area coverage of the suitability indexes from the final result map was 180.45km^2, 0.02km^2, 3.03km^2, 89.36km^2, 40.18km^2 and its suitability classes were restrictive, unsuitable, less suitable, moderately suitable, and suitable respectively. According to this study result, the highly suitable class was not found in the study area based on the aggregation of fourteen factors map. The second most suitable land class graded as suitable had a directional distribution in the Eastern, Southeastern, and southwestern parts of the city, whereas the other suitability classes were spread out in all directions.

4.8. Assessment of Existing Industrial Area

For the current study, fourteen factors were utilized to assess site suitability for the best industrial site, including existing industrial areas. However, only thirteen criteria were superimposed to produce an assessment suitability model map and to evaluate the overall compatibility of the current industrial areas. The independent input variable, which is the existing industrial area, was used as a controlled variable. In order to determine the degree of influence for the others thirteen criteria, the existing industrial factor was removed from the pairwise comparison matrix. Thus, the weight allotted for this factor map was distributed to others factors. After that, the EIA area polygons were overlapped to the generated evaluation suitability map then their suitability was analyzed using zonal statistics tool extension of ArcGIS toolbox. Then the majority of suitability pixel value fall under polygons were counted and the agreement between the existing industrial areas and suitability model was analyzed in area coverage as presented in (Table 4.25). The result of this comparison map revealed that the EIA areas fell under only three suitability classes such as restricted, moderately suitable, and suitable. Most of the areas are dominantly aggregated in moderately suitable areas, whereas there are, no areas were observed in unsuitable, less suitable, and highly suitable suitability classes. According to the portrayed (Figure 4.17), the areas and percentage coverage of the EIA on the evaluation map were 7.10 km^2 (24.8%), 20.62km^2 (72.0%) and 0.92km^2 (3.2%) located in restricted, less suitable, moderately suitable, and suitable classes respectively.

Table 4.25 Comparison of suitability model map and EIA

Suitability class	Existing industrial areas	
	Area in (km^2)	Percentage (%)
Restricted	7.10	24.8
Unsuitable	Not observed	-
Less suitable	Not observed	-
Moderately suitable	20.62	72.00
Suitable	0.92	3.20
Total	28.64	100%

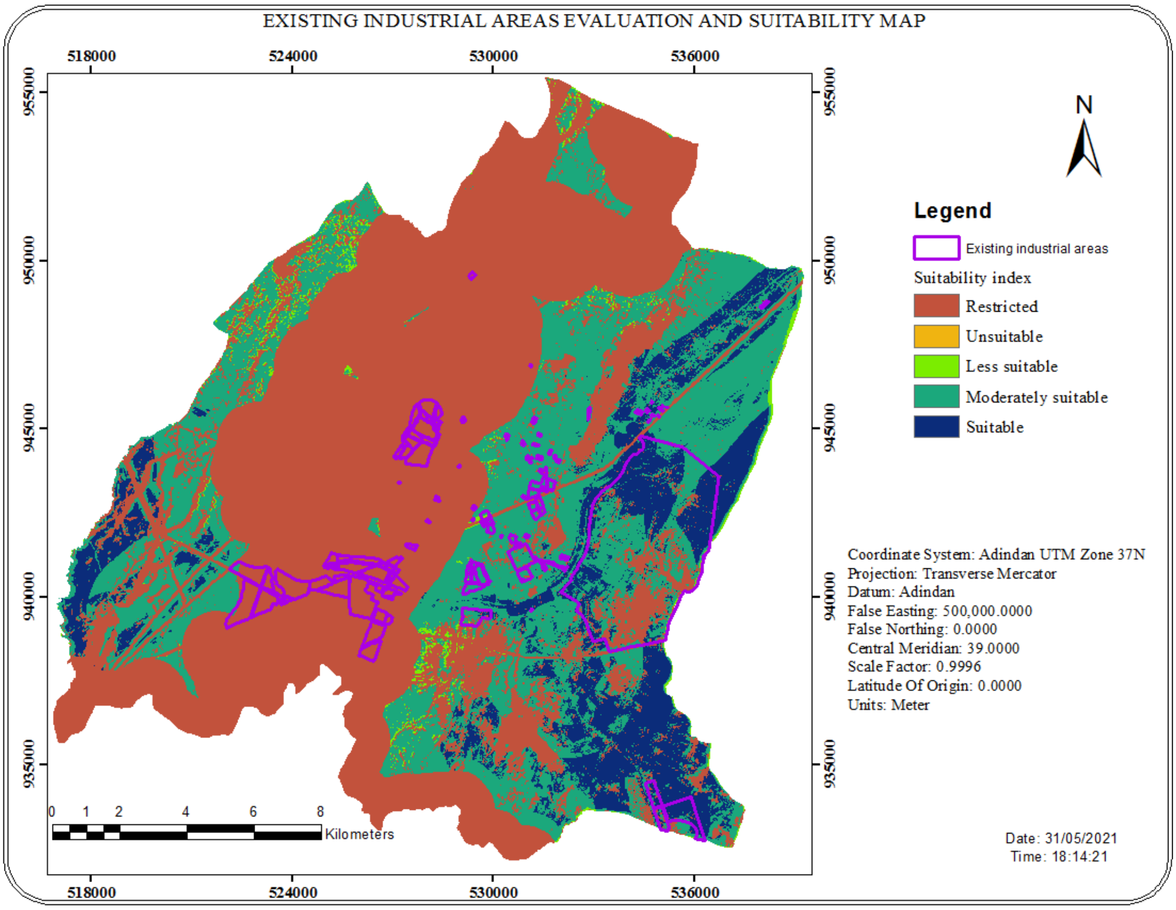

Figure 4.17 Existing industrial areas and suitability comparison map

4.9. Discussion

The primary aim of this study was to examine the overall suitability of land for selection of industrial sites. Therefore, the result of this research confirms two facts first; the optimal site selection for the development of industry is influenced by several factors. These include economic (major roads, railway, highway, elevation, slope, and existing industrial areas), environmental (LULC, waterbody, settlement, heavy power lines and landfill site), geological (geological fault lines and soil type), and population (population density) factors. According to Rikalovic et al., (2015), the industrial site selection process becomes, therefore, a complex multi-criteria analysis, which includes a set of criteria encompassing technical, economic, social, environmental and political issues. Second, for this study, the flaw and vagueness that originate from the decision-making process were overcome by the Fuzzy Analytical Process (FAHP) method. This argument is consistent with the findings of (Hatta et al., 2014) FAHP is an efficient tool to handle the fuzziness of the data involved in deciding the preferences of different decision variables.

The study found that among the identified major criteria, approximately economic has the most weighing influence (45%), followed by environmental variables (44%), geological factors (0.07%), and population factors (0.04%). The result of this study illustrates the weight allotted for land use land cover through pairwise comparison was the highest relatively which accounts around 12% for the analysis this emphasizes that land use land cover spatial factor is the most determinant factor in industrial site selection. Their root is originates from the hierarchy of major environmental factors. Likewise, other scholars (Johar et al., 2013 and Beyene ,2019) reported similar results in their study.

According to the industrial site suitability map result of the current study, Adama Town is in only restricted, unsuitable, less suitable, moderately suitable and suitable zone for industrial site development. In addition to this, the result demonstrates that an unexpectedly highly suitable class was not observed in the final suitability model map. This occurs more frequently than expected because of the fact that the number of criteria used for suitability analysis increases the suitability index will decrease. This is consistent with the findings of (Sarath et al., 2018) which suggest that there was no excellent (highly) suitable site found for the industry zone. However, the study area was different from the current one.

The result revealed that the majority of the study area was found to be restricted or constrained for the establishment of industry that covers 180.45 km^2, which takes the maximum piece of the total area. In the second place, moderately suitable classes occupied 89.38km^2 of the area while unsuitable, less suitable, suitable cover 0.02, 3.03, and 40.18 square kilometers of the study area respectively. This result shows two things first, the number of constraint factor used for the study increase the area coverage of restricted land suitability index in the final result will be also increased. Second, the result was extremely affected by the rivers and streams constraint factor because the used buffer distance significantly affected the result by aggregating the overall suitability area in one land suitability index. Based on the available literature, rivers/streams and areas within 1000 meters from them were considered restricted for allocating industries (constraint) (Reisi et al., 2011).

According to Rikalovic et al., (2015), traditionally industrial areas have been chosen nearly entirely on the basis of economic and technological grounds. Some of the results obtained from this study by coinciding the existing industrial area with produced assessment suitability model map make this statement inevitable because the subsequent largest areas of industry were detected in restricted suitability classes whereas very little coverage of areas was observed in suitable indexes. Relatively the existing industrial areas were aggregated in moderately suitable classes. Its consecutive area coverage in percentage was 24.8%, 0.9%, and 72% respectively. There are no overlapping were observed in the unsuitable and less suitable classes. According to the evaluation map statistical analysis, the second most of the existing industrial areas were accumulated in the rivers and streams constrained buffer area, which flows to Awash rivers and Koka Lake. In today's modernized and complex world establishing industry near any streams or river is not recommended due to the adverse impact of industrial waste in water and the environment. As stated by WHO (2017), there are a huge number of industries developing in the Awash Basin, all of which have an impact on the basin's water quality. Adama Town is one of them located in the Awash basin.

The main strength of this study is the consideration of multiple criteria and uncertainty in the decision-making process by utilizing the FAHP method. Thus, the results obtained and methodology adopted here may have implications for other regions, decision-makers and researchers understanding how can any problem associated with unanswered land use planning problem have been analyzed and assessed based on several geospatial parameters by utilizing GIS, RS and Google Earth technologies. The results obtained here may have additional implications by providing a framework to minimize the negative and maximize the positive impacts of an industrial sites on economic, environmental and geological factors based on the required police and regulatory requirements of the study area or any region of the country.

Finally, this thesis research study indirectly plays a key contribution for Ethiopias industrialization transformation plan in mitigating the impact of industrial sites on the surrounding environment, residence and investors by providing an alternative solution for industrial site decision-makers for reallocating or expanding industrial sites and by demonstrating the cost-effectiveness of geospatial technology for industrial area selection.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The development of industrial areas has a substantial good and negative impact on the national economy and environment. Therefore, this study evaluated the suitability of land for selection of industrial sites in Adama Town based on fourteen criteria that are coined under four pillars economic, environmental, geology and population major factors. Performing proximity analysis and standardization for criteria in site selection process is the initial step for objective accomplishment. However, considering and combining the suggestion of various researchers proximity analysis for industrial site selection criteria is important to compensate the subjectivity of analysis and for the delineation of sustainable industrial site. Pairwise based weight elicitation has theoretical foundation and statistical secured with consistency check. Fuzzy Analytical Hierarchy Process (FAHP) method based pairwise weight calculation is applicable to overcome the vagueness and uncertainty that originate from decision making during choosing the preference of criteria.

The study revealed that economic major criteria in the upper hierarchy and Land Use Land Cover in generally are the most determinant aspects in industrial site selection, which shares 45% and 12 % of weightage for suitability analysis respectively. In all hierarchies, the consistency of judgment was evaluated and the result shows that all of the hierarchies are acceptable (consistent) which are less than 10% minimum requirement. The consistency result indicated that developing a hierarchy for the criteria in suitability analysis is time effective and delivers highly consistent judgment. The final suitability map showed that the study area can be categorized under only restricted, less suitable, unsuitable, moderately suitable, and suitable classes. From this output of the study unexpectedly highly suitable class was not detected in the final suitability model map. Their area coverages are 180.45km^2, 0.02km^2, 2.03km^2, 89.36km^2 and 40.18km^2 as its order from restricted to suitable. Thus, the second suitability index, which covers 12.8% of the study area was considered as the alternative zone for the development of industrial site. which are located in the eastern, southeastern and southwestern directions of Adama Town. The study assured that industrial site selection is a spatial problem affected by multiple criteria, which are economic environmental, geological and social factors.

The second most of the existing industrial areas are clustered in the rivers and streams constrained buffer area. Industries located in rivers and streams periphery could have high rate of environmental contamination. Scientific-based industrial site selection is critical in maintaining a clean environment and sustainable economic growth. Consequently, this study provides further insight to the decision-makers to consider the negative and positive impact of industrial sites on the environment, investors and residence based on multiple criteria before decisions, in the study area and other regions of the country as well. For selecting a suitable industrial site geospatial technology mainly GIS, RS and Google Earth are effective and efficient than the traditional approaches.

Finally, for the transformation plan of Ethiopia from agrarian-based to industry-based economy this kind of suitability analysis is critical to support the transformation and to mitigate the adverse impact in the ecology and to maintain the sustainability of industrialization.

5.2. Recommendation

Based on the methodology adopted and result obtained through this thesis research the following recommendations are forwarded;

The second alternative suitable industrial zone index of this study result is expected to balance the economic advantage of industry, adverse impact of industry on the environment, population, groundwater and impact of geological faultiness on the industry. Therefore, decision-makers can use this zone for further industrial area development with some extent modification. The assessment map found out that the second one maximum of the prevailing industrial areas are aggregated in rivers and streams restricted suitability index. Therefore, regarding decision-makers, environmental and urban planners need to pay attention to those areas. Further, in order to mitigate issues related to industrial site impact on the environment, investors, and residence numerous stakeholders from the various field ought to work collaboratively.

Finally, Future works should focus on selecting a suitable industrial sitee for specific industry type such as food, chemical, and material separately based on additional spatial and non-spatial factors including availability of raw materials, availability of workforce, the income of the community and availability of social service. Further, future works should focus on the comparison of AHP and FAHP methods in industrial site selection.

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APPENDICES

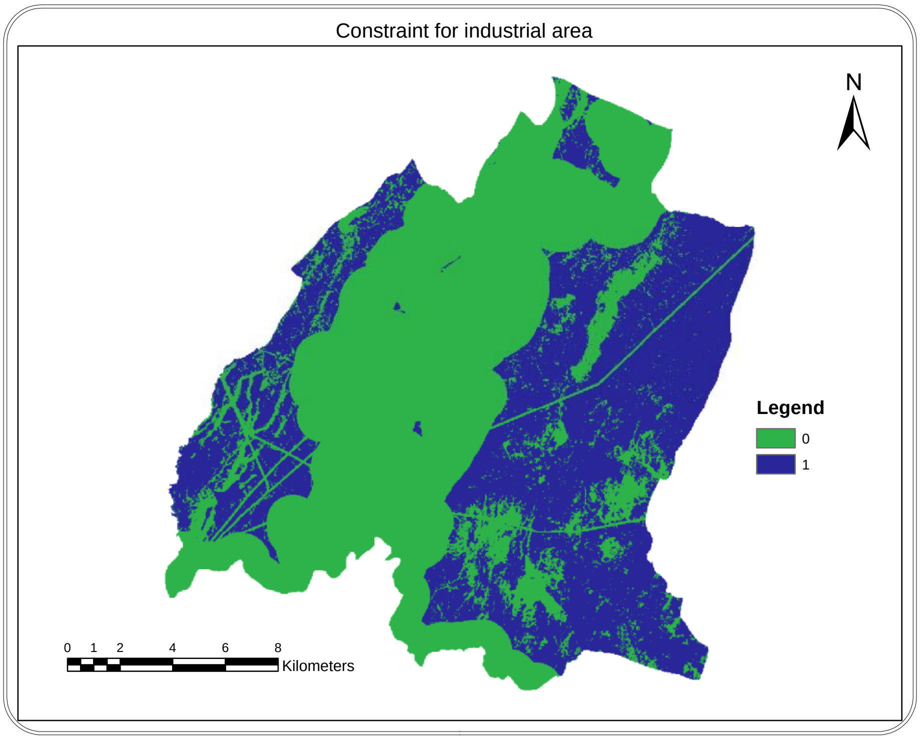
Appendix 1: List of GCP used for accuracy assessment

P	E	N	C	R	P	E	N	C	R
ID#1	535830	944730	21	21	**ID#51**	522870	940710	21	21
ID#2	538170	948900	17	17	**ID#52**	524880	950340	9	9
ID#3	521040	937020	9	9	**ID#53**	526260	946770	9	9
ID#4	521760	938580	9	9	**ID#54**	528180	936750	12	12
ID#5	518310	939960	9	9	**ID#55**	521160	938910	9	9
ID#6	528120	942570	17	17	**ID#56**	536760	946440	21	9
ID#7	531330	945240	17	17	**ID#57**	528180	935640	9	12
ID#8	534810	950250	21	12	**ID#58**	520770	941520	9	9
ID#9	531030	947040	17	17	**ID#59**	519780	937920	9	9
ID#10	533370	949200	21	21	**ID#60**	532950	944580	12	12
ID#11	522420	936930	12	12	**ID#61**	522240	941160	9	9
ID#12	529200	940200	9	9	**ID#62**	529050	936900	9	9
ID#13	527160	948120	12	12	**ID#63**	532680	950310	12	12
ID#14	533370	945990	12	12	**ID#64**	530160	947340	17	17
ID#15	527640	943860	17	17	**ID#65**	526710	950100	9	9
ID#16	524520	949350	9	9	**ID#66**	534000	936930	21	21
ID#17	519210	944190	12	12	**ID#67**	519840	944970	9	9
ID#18	524700	945900	9	9	**ID#68**	532350	941520	17	9
ID#19	524160	948840	17	17	**ID#69**	531180	951000	21	21
ID#20	532200	952950	21	21	**ID#70**	526560	948150	12	12
ID#21	532290	934320	12	12	**ID#71**	531120	935820	12	12
ID#22	520530	944670	9	9	**ID#72**	536550	934710	9	9
ID#23	533340	952350	21	9	**ID#73**	531090	949470	17	17
ID#24	526260	944310	12	12	**ID#74**	531120	934320	17	9
ID#25	537030	945900	21	17	**ID#75**	535890	945210	21	21
ID#26	521370	943170	9	21	**ID#76**	533880	953130	21	21
ID#27	537870	949290	21	21	**ID#77**	522930	942990	21	21
ID#28	523500	941370	9	9	**ID#78**	530310	941160	17	17
ID#29	529170	944160	17	17	**ID#79**	538380	948180	21	21
ID#30	530190	945000	17	17	**ID#80**	534900	953220	12	12
ID#31	526950	943380	17	17	**ID#81**	518790	940680	9	9
ID#32	524910	947880	9	9	**ID#82**	528240	938400	12	12
ID#33	527820	935490	9	9	**ID#83**	532830	935610	21	21
ID#34	526980	946740	9	9	**ID#84**	527490	949440	9	9
ID#35	527340	949380	9	9	**ID#85**	517530	939450	9	9
ID#36	535260	945270	17	17	**ID#86**	525210	949290	17	12
ID#37	534150	936600	21	21	**ID#87**	524280	943170	12	12
ID#38	534840	948420	12	12	**ID#88**	528390	940350	9	12
ID#39	532650	942630	17	17	**ID#89**	523140	936960	12	12

ID#40	527430	946740	12	21	**ID#90**	536490	948450	21	21
ID#41	533700	953040	21	21	**ID#91**	532020	936030	9	12
ID#42	533940	938310	21	21	**ID#92**	518610	938340	9	9
ID#43	518670	942690	12	12	**ID#93**	530850	950550	21	21
ID#44	529500	942870	17	17	**ID#94**	535590	943260	12	12
ID#45	526410	937710	21	21	**ID#95**	520440	942660	12	21
ID#46	533340	953880	21	21	**ID#96**	529590	943740	17	17
ID#47	530520	933360	12	12	**ID#97**	532410	944280	17	17
ID#48	532410	945330	17	17	**ID#98**	534390	938250	21	21
ID#49	536460	946770	21	21	**ID#99**	536880	942360	21	21
ID#50	525870	945240	12	12	**ID#100**	529800	934080	21	21

P=Point, E= Eating, N=Northing, C=Classified, R =Reference 9= Bareland, 12= Vegetation, 17= Settlement and 21= Farmland.

Appendix 2: Constraint factor map used for the study



Appendix 3: Accuracy assessment result of Land Use Land Cover

Reference								
Classified	Vegetation	Settlement	Farmland	Bare land	Classified total	Number of correct	User accuracy	Kappa
Vegetation	20	0	2	0	22	20	90.91%	0.8788
Settlement	1	18	0	2	21	18	85.71%	0.8236
Farmland	1	1	23	2	27	23	85.19%	0.7998
Bare land	3	0	1	26	30	26	86.67%	0.8095
Reference total	25	19	26	30	100			
Number of correct	20	18	23	26				
Producer accuracy	80.00%	94.74%	88.46%	86.67%				
Overall classification accuracy 87.00%								
Overall kappa coefficient 0.8225								

Appendix 4: Sample of pairwise comparison questioner used

	Left Criteria Is Greater									Right Criteria Is Greater								
	Extremely important	Very strong to extremely important	Very strong important	Strong to very strong important	Strong important	Moderate to strong important	Moderate important	Equal to moderate important	Equal important	Equal to moderate important	Moderate important	Moderate to strong important	Strong important	Strong to very strong important	Very strong important	Very strong to extremely important	Extremely important	
Economic																		**Environmental**
Economic																		**Geological**
Economic																		**Population**
Environmental																		**Geological**
Environmental																		**Population**
Geological																		**Population**