Use of Multi-Criteria Decision Analysis Integrated with GIS and Air Pollution Model Inputs for schools site Selection

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Dr. M Kumarasamy Date

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Abstract

Schools site selection is an essential process which needs knowledge of different fields. The process involves scientific justification, judgment and a finding of suitable land, which consider financial, social, ecological and political perspectives, that limit conflicts and supports agreement among the decision makers. Lack of scientific analysis may negatively impact on the economy, health, and safety of the public. However, reports revealed that finding of school location managed without utilization of scientific analysis thus prompted the development of schools in unsuitable areas and caused pupils to face several problems such as long walking distance, heavy traffic, presentation to sound and air pollution (Bukhari et al., 2010). Addis Ababa is the largest city in Ethiopia, and the city needs additional schools to meet the minimum pupil section ratio as per the national standard to improve education excellence (CGAAEB, 2018). Currently, most of the existing schools placed in the central part of the city; thus such scientific analysis is vital to give insight for the decision makers and planners to improve the site selection process for new schools, to provide a fair distribution of education access and utilizing a limited available resource. Nowadays, the application of GIS and Remote sensing datasets widely used to support the site selection process. In this study GIS integrated with MCDA and Remote Sensing, techniques have been used to select suitable school locations. MCDA is a tool that devoted to improving the decision-making process using various qualitative and quantitative criteria goals or objectives of a contradictory nature. This study attempts to use an air pollution model integrated with Remote Sensing, Geographical Information System (GIS) for Multi-Criteria Decision Analysis (MCDA) to identify optimal sites for new schools. The MCDA was done using Analytical hierarchy process (AHP), which classify criterions in hierarchical level and assigns a relative weight to each criteria using pairwise comparison. The selected criteria in this study decompose into three main groups, namely Economy, Accessibility, and Environmental Safety. Besides, Landsat 8 OLI/TRIS satellite image was used to quantify the annual mean concentration of Particulate matter with diameter 10 μm (PM10) for Environmental safety criteria. Subsequently, using Weight overlay tool, the criteria maps combined based on their relative influence, which is obtained from AHP to produce the final map, and the map reclassified as not suitable, less suitable, suitable and most suitable, using Arc GIS 10.4 reclassify tool. The resulting map of the annual mean concentration of PM10 shows that the concentration amounts on airports, factories, and road structures are high. The criteria weights obtained are 54%, 30% and 16% for Economy, Environmental Safety, and Accessibility respectively. The ultimate suitability map shows that 3.89% of the study area is most suitable, 57.47% is suitable, 38.48% is less suitable, and 0.08% is unsuitable, the most suitable areas laid on the city's north-east and south-east part, which are away from existing schools. Therefore, this study successfully suitability model has been used to allocate an optimal place for new schools to be built in Addis Ababa capital using GIS integrated MCDA with Air pollution model input.

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Nomenclature

Acronyms / Abbreviations

AHP Analytical Hierarchy Process

AOT Aerosol Optical Thickness

AR Atmosphere Reflectance

CI Consistency Index

CR Consistency Ratio

CV Consistency Vector

DEM Digital Elevation Model

DN Digital Number

ELECTRE Elimination and Choice Translating Reality

GIS Geographical Information System

MADM Multi-Attribute Decision Making

MAUT Multi-Attribute Utility Theory

MCDA Multi Criteria Decision Analysis

MODM Multi-Objective Decision Making

PM10 Particulate Matter with less than ten micro meter

PROMOTHEE Preference Ranking Organization Method for Enrichment Evaluation

RI Random Index

SR Surface Reflectance

SRTM Shuttle Radar Topography Mission

TOA Top of Atmosphere Reflectance

TOPSIS Technique for Order Preference by Similarity to Ideal Solution

USGS U.S. Geological Survey

WPM Weighted Product Model

WSM Weighted Sum Model

CHAPTER ONE

INTRODUCTION

1.1 Background

Site selection is one of the interdisciplinary and indispensable choices in the start-up step; the procedure is a specific finding of advantageous land for the actual position and predetermined number of possible locales for a particular reason. It is also a key factor and associated with customer groups, resources management and development plan (Zhou and Wu, 2012). Appropriate site determination for a building of new schools is a significant long-haul investment and a primary choice that could fundamentally influence the benefit and loss of the available resource (Abazari et al., 2012; Elsheikh, 2017). Because of wrong site choice result into different issues including; long walking distance, expose for the contaminated area, serve only for the specific group, poor interest for education, increasing of dropout rate, Inadequate academic result, and expands a vast gathering of social issues (Jovinius, 2015; Muskut et al., 2015).

Over the years, the utilisation of topographical information to make a decision has stayed to be an essential wonder in humankind activities (Bojorquez-Tapia et al., 2001; Goodchild, 2009; Huisman and De By, 2009; Rolf et al., 2001). Ground surveying, Satellite, and airborne remote sensing is currently solidly source of geographic data. In this study Air pollution modelling is conducted to quantify the concentration of particulate matter (PM10) over the study area, using the Landsat 8 satellite image where there is no relevant data for the Addis Ababa city. Nowadays, the application of Multi-criteria Decision analysis (MCDA) incorporated with GIS and Remote Sensing approach become preferable and serves for the decision makers and land planners in education sectors (Jayaweera, 2016). The method enables to tackle massive geospatial problems related to land use suitability, site selection, and resource evaluation problems. Usually, it can provide unlimited opportunities for land use planning and management problem (Dadfar, 2014; Daneshvar et al., 2017; Muskut et al., 2015).

MCDA enable to consider both qualitative and quantitative criteria that support the decision maker's judgment to be precise and to choose optimal alternatives based on a scientific approach (Ouma et al., 2011). The method evaluates the available options on different attributes that have a unique character and measurement units to maximise the benefits. The integration of MCDA with GIS and Remote Sensing techniques used to combine, manipulate and convert various attribute's geographical data to support the decision-making process (Szurek et al., 2014). This method applied widely to identify optimal sites for school, water reservoirs, agricultural activities, wind farm, hospitals, hotels, public libraries, waste disposal, food distribution centres and urban land use planning activity (Abazari et al., 2012; Beskese et al., 2015; Ebistu and

Minale, 2013; Elsheikh, 2017; Khan et al., 2015; Shahabi et al., 2016; Shenavr and Hosseini, 2014; Szurek et al., 2014; Zhou and Wu, 2012). This study attempt to identify an optimal site for new schools considering various criteria's standard and geographical dataset using MCDA incorporate with GIS and Air pollution modeling for the school site selection process.

1.2 Statement of the problem

Reports revealed that finding of school location was managing without utilisation of scientific analysis, thus prompted the development of schools in unsuitable areas and caused pupils to face several problems such as long walking distance, heavy traffic, presentation to sound and air pollution (Aschale, 2017; Bukhari et al., 2010).

The capital city of Ethiopia, Addis Ababa faces massive difficulties in its land-use planning that comes from the way that fast population growth of the city and people reside and remains to accommodate newcomers from different regions of the country (Spieker, 2017; Tarekegn and Gulilat, 2018). From the total number of migrants, 80% were moved to the city to get education access (Spieker, 2017). In line to the previously mentioned challenges, overpopulated classrooms, the high traffic loads, the presence of industries nearby school location and other sources of environmental pollutants may cause schools to be recipients of such damaging air pollutants, which has become one of the most critical problems of cities (Tarekegn and Gulilat, 2018). There is also saturation and expansions to new residential sites of the peripheries to North Western and in both North Eastern and South Eastern part of the city (Tarekegn and Gulilat, 2018). Therefore, the city needs additional schools to provide educational access for future population demand and to meet the minimum pupil section ratio as per the national standard to improve educational excellence (CGAAEB, 2018). Hence, scientific site selection for new schools is a vital process for the city to ensure the sustainable economy and feature development plan.

The objective of this study is identifying optimal sites for new schools construction in Addis Ababa, using Air pollution model input integrated with MCDA and GIS method. Currently, the Ethiopian ministry of education has not pointed out standards regarding criterions. Therefore, this research is pioneer in the study area to give insight for decision makers to use the method, and be profitable by bits of proof to choose new sites for school establishments, that ultimately will serve the public in the course of avoiding unnecessary costs and other related suffers which could be imposed due to improper location of schools. Besides, this research study demonstrates that the utilisation of satellite images for Air pollution modelling and coordinated with multi-criteria analysis for school site selection.

1.3 Research questions

How would the GIS integrated MCDA with Air pollution model input be useful for calculating the PM10 value and relative weight for site selection criterion ?

1.4 Aim

The main aim of this study is to use GIS integrated MCDA with Air pollution model input for calculating relative weight and Air pollution concentration for new school site selection in Addis Ababa, Ethiopia.

1.4.1 Objectives

(i) To critically overview the literature on Multi-Criteria Decision making methods theoretical principle and area of application.

(ii) To collect and analyze various geographical datasets such as Landsat 8 satellite images, Digital Elevation Model (DEM), land use, existing school location, road networks, industrial sites, stream networks, high power transmission lines, commercial and religious places, and public facilities.

(iii) To set up and integrate Multi-Criteria Analysis methods with Arc GIS software.

(iv) To process the classification of school site criteria based on different hierarchy levels.

(v) To assign and calculate relative weights for the different criterion.

(vi) To incorporate Air pollution modeling to quantify the concentration of Particulate matter (PM10).

(vii) To reclassify the criterion data set into a common suitability scale.

(viii) To combine the reclassified criterion data sets using weight overlay to identify the optimal school sites.

1.5 Summary

This chapter outlined the background of the research study. It demonstrates that appropriate site selection for a building of new schools is significant that could fundamentally influence the benefit and loss of the accessible resource. Given wrong site choice, result into different issues including; long walking distance, expose for a contaminated area, serve only for the specific group, poor interest, and academic result, increasing of dropout rate, and expands a vast gathering of social issues. However, the finding of school site selection managed without scientific analysis. The city Addis Ababa is facing a challenge due to rapid population growth and land-use planning. Therefore, in this study Air pollution modelling integrated with Remote Sensing and GIS for MCDA method is proposed to give insight for the decision makers and planners to improve the site selection process for new schools. Finally, the chapter presents a general objective, research aim and research question to be answered.

1.6 Structure of the thesis

Chapter One Introduction

This chapter presents the background to the study. It demonstrates the importance and challenges of school site selection. It describes research problems as well as a review of methods that have been used to solve these problems. The chapter introduces the Air pollution model input integrated with Multi-Criteria Decision Analysis (MCDA) and Geographical Information System (GIS) adopted for this study and finally presents problem statement the research questions, objectives, of the study, as well as an outline of this thesis.

Chapter Two Literature review

This chapter gives a brief literature review on the importance of site selection analysis, application of MCDA integration with GIS and Remote Sensing for Air pollution modeling. Also, it provides a comprehensive review of the theoretical framework and types of MCDA methods used to support decision-making problems. Finally, reasonable selecting of MCDA method for this research study is justified.

Chapter Three Methodology

This chapter presents the structure of the research methodology approach for this study. It describes software's and materials utilized in the study, brief research methodology procedure, implementation of MCDA method to assign criterion's weight. It also demonstrates Air pollution modeling to quantify the PM10 concentration, Euclidean distance calculation, Reclassification and ending with combining of datasets through weight overlay.

Chapter Four Result and discussion

This chapter describes the research study area, a source of datasets, criterion's map and data preparation. Also, it presents the key findings of the study and their explanations using evidence from the study.

Chapter Five Conclusion and recommendation

This chapter presents the overall summary of the study. It also provides suggestions and recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Several studies conducted to resolve an issue that related to site suitability analysis. This chapter attempt to review research studies on school site selection and suitability analysis and other related topics including MCDA integrated with GIS application.

2.2 Suitable site selection analysis importance

Site selection has a vital role in human activities. It is a key factor associated with capital expenditure, resources management and development plan (Zhou and Wu, 2012). Locating a suitable site for facilities need to consider various criteria that have to be evaluated relative to their importance, to prevent considerable environmental impact and concerning accessibility and fair distribution of the available resource for the society (Abazari et al., 2012; Elsheikh, 2017). One major issue in early (Mokarram and Aminzadeh, 2010) research, describe land assessment is performed to evaluate the land property for specific purposes to maximise benefit and minimise the loss in the environment, such as a suitable site for farmlands, new schools, hospitals, hotels, and waste disposals. Thus, the land planners and developers used the assessed land as preliminary input for their projects (Beskese et al., 2015).

Many research studies reveal that unscientific and poor site selection approach leads to failure on the development of the project and cause challenges related to transportation access, heavy traffic, and high travelling cost in most cities (Bukhari et al., 2010; Jayaweera, 2016). In (Ebistu and Minale, 2013) the author examined that an inappropriate place for waste disposal sites manifested a cause for soil contamination, water, and air pollution.

Jayaweera (2016) Described educational facilities accessibility for the public is the crucial component on a country's development, socio-economic and lifestyle. This study identified a decreasing trend in students' enrollment over the years due to accessibility issues and parents forced to admit their children on a limited number of schools with excellent services. (Muskut et al., 2015) Demonstrate that school locations should be appropriate and serve uniformly for the community. Overpopulated in the classroom, poor academic result, long walking distance, expose for a contaminated area and serve only for the specific group are the major problem on school locations. Another research paper (Bukhari et al., 2010) highlighted that one of the measurement scales for quality education is a well-structured plan and assessable schools facilities. The process of school site selection pass several levels and associate with different departments. Hence, this multi-step process led to the selection process to delay and caused to allocate the school sites in contaminated places. Therefore the selection of school location is a vital process which needs careful planning using socio-economic and geographical data for the right decision to assuring student's academic achievement and sustainable development.

2.3 Application of MCDA integrated with GIS

There are approaches to handle decision problems, Multi-Criteria Decision Analysis is one of the methods to evaluate the existing alternatives considering different measurement units, incompatible and inconsistent criterion characters to achieve a particular objective (Jamal, 2016; Kumar et al., 2017; Shenavr and Hosseini, 2014). The method is becoming relevant in the various field of application because of its capability to support the decision maker's judgments while in light of all factors and goals at the same time (Kumar et al., 2017). The GIS application capable of a combine, manipulate, convert, retrieve and display the various criteria's map layer to support the decision-making process (Szurek et al., 2014).

In MCDA, problems commonly contain five segments, and this is available options, factor criterion, decision maker's judgment for criterions, result and objectives (Kumar et al., 2017). Several studies examined that it has two main classes Multi-Attribute and Multi-Objective Decision Making (Jamal, 2016; Shenavr and Hosseini, 2014). The use of the methods will depend on the type of the problem, in the case of site selection, land use situation and environmental impact evaluation problems MADM is preferable, and it can quantify qualitative and quantitative data (Beskese et al., 2015; Jamal, 2016). MODM are appropriate for assessment of infinite alternatives based on defined factors in the form of the mathematical formula for location-allocation, transportation and short path related problems (Jamal, 2016; Kumar et al., 2017).

The integration of GIS and MCDA is the process and merging of geospatial data and decision maker's criteria preference to assess the available options concerning factor criteria. The method extensively used and suitable to solve problems related to land use suitability, site selection, and resource evaluation problems (Dadfar, 2014).

The role of GIS technology can handle spatial data to allocating an economical and safe place for the selection process. It is precise, worthwhile, useful, and eliminate humankind bias. All criteria needed to be standardised into common and comparable units to proceed with the suitability selection using Multi-Criteria analysis integrated with GIS (Talam and Ngigi, 2015). Another research study used MCDA integrated with GIS approach to organising the selected criteria to be in a hierarchical structure and assigned decision maker's preference to determine the excellent feature site. In this study constrain, and factor maps were combined to yield the potential site for school which is a safe and Healthy atmosphere for the pupil in the case study area of Mukim Batu, located in Malaysia of Federal Territory of Kuala Lumpur (Bukhari et al., 2010).

Similarly, (Mokarram and Aminzadeh, 2010) examined that the integration of MCDA and GIS may help the decision maker's judgment to be precise and to pick optimal alternatives based on different criteria. In (Richard and Ogba, 2016), research study endeavour to find the desired location for new secondary schools for those students, who come from a lower class family facing challenges due to travelling through river network, in Andoni Local Government Area, Nigeria. In this study three datasets have been used, land use/ land cover, settlement data, and existing secondary dataset, and yield the suitability map utilising Weight overlay tool.

Another research study (Shenavr and Hosseini, 2014) shows that the implementation of GIS application and MCDA technique incorporated to carry out a land evaluation for urban land use plan in the case study area of Baghmalek, Khouzestan province in Iran country. The study highlighted that the use of the method could support the decision maker's judgment on urban land use planning activity (Shenavr and Hosseini, 2014). Similarly, (Ebistu and Minale, 2013) research demonstrated that Bahir Dar is one of the big city in Ethiopia, the city is tackling solid waste disposal problem, The existing dumping sites are very close for rural residences, insufficient distance from a centre of the city and lack of scientific design. In order to resolve the problem, the researcher identified identify a suitable site for the waste dump using MCDA and Remote Sensing techniques.

2.4 Application of Remote Sensing for Air pollution

The result of urban air pollution causes for 800, 000 peoples dead and 4.6 million decline life anticipation on the planet every year every year (Nguyen et al., 2014; Saleh and Hasan, 2014). Vehicle, factories and huge power plants are the primary source of air pollution.

Particulate matter with diameter 10μm (PM10) are aerosols, which is tiny solid and liquid particles stayed in the atmosphere. It is a major type of air pollution and may hurt health because they can easily penetrate to lung and caused respiratory diseases (Chen et al., 2014; Lim et al., 2009; Saleh and Hasan, 2014). Traditionally there are two approaches to quantify air pollution, namely spatial interpolation and air dispersion modelling. Spatial interpolation approach estimates the concentration of air pollutants from a limited surrounding measured ground location (Saleh and Hasan, 2014). However ground-based measurement is quite expensive for the large-scale area, owing to the instruments are expensive. Hence it is challenging to obtain detail information and mapping air pollution concentration for large regions (Chen et al., 2014; Saleh and Hasan, 2014).

Many research studies show that satellite image data is utilising for monitoring environment applications. The use of remote sensing techniques is collecting data from the earth surface without physical contact using onboard built sensors on satellites. The sensors detect and measure atmospheric and earth surface reflectance over a large area with minimum cost and acceptable accuracy (Lim et al., 2009; Nguyen et al., 2014; Saleh and Hasan, 2014).

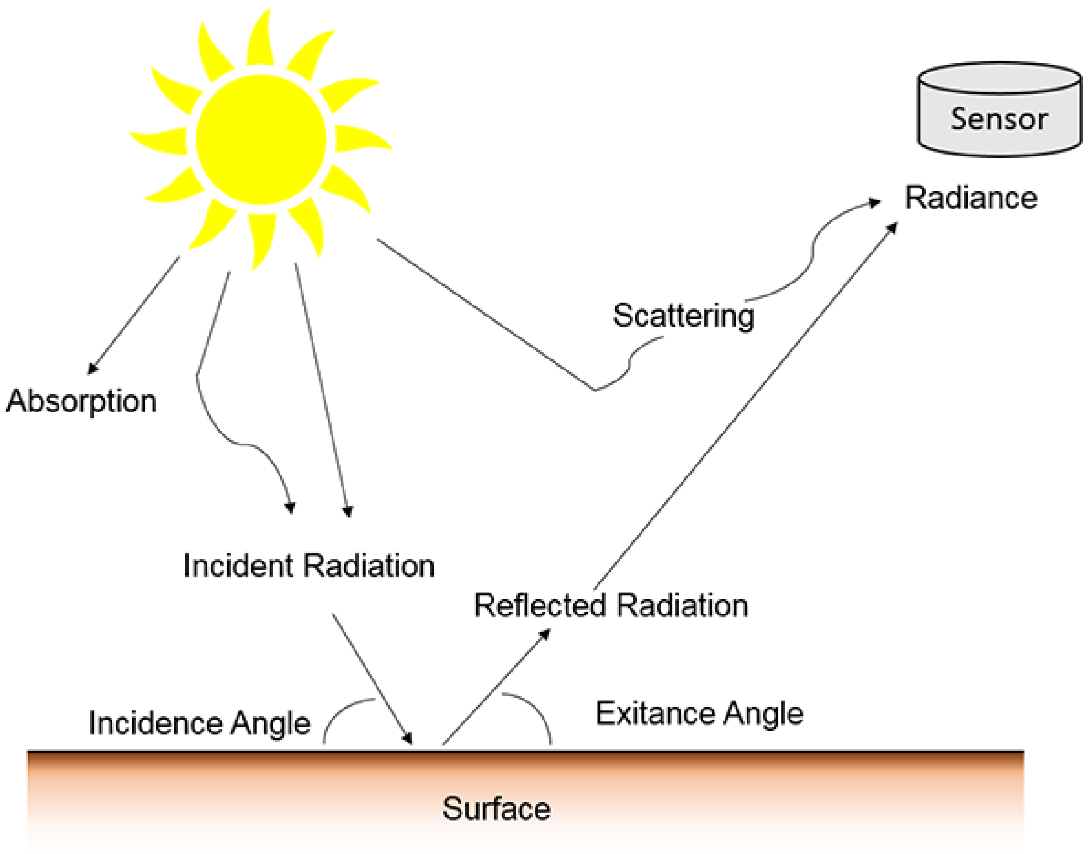


Figure. 2.1 Radiometric Corrections

2.4.1 Aerosol Optical Thickness (AOT) and PM10 correlation

Aerosol Optical Thickness is the measure of aerosols concentration in the top of the atmosphere which is reflected from ground surface and atmosphere using satellites. Landsat 8 OLI satellites have the onboard sensor to acquire reflected solar energy. This reflectance value which is detected by the sensors will be quantised and changed into digital numbers (DN). DN values can be changed to brightness or reflectance value using a radiometric correction (Landsat, 2015). Many studies revealed that the correlation of PM10 and AOT is a linear relation (Nguyen et al., 2014; Othman et al., 2010; Roy et al., 2017; Saleh and Hasan, 2014; Shaheen et al., 2017).

The use of satellite data can allow obtaining the concentration of air pollution on the earth surface. Landsat five, Landsat seven and Landsat eight have regularly used satellites for environmental studies. Landsat 8 OLI data has been used to develop the algorithm and estimate PM10 concentration over Kirkuk and Hanoi cities (Nguyen et al., 2014; Saleh and Hasan, 2014). The algorithm is derived based on ground measurement and reflectance in band correlation. Other studies also revealed that Using Landsat 7 TM and ETM satellite data the concentration of PM10 was mapped over Gaza Strip, Makkah, Saudi Arabia, and Vadodara cities (Lim et al., 2004; Othman et al., 2010; Roy et al., 2017; Shaheen et al., 2017). Similarly Using Landsat TM

5 satellite data, the concentration of PM10 mapped over Penang Island City in Malaysia and ground measurements were taken to calibrate the result (Lim et al., 2009).

2.5 MCDA methods theoretical principles

Multi-criteria decision making evaluates alternatives of the choices with the end goal of selection or ranking, utilising various qualitative as well as quantitative criteria that have different measurement units (Mulliner et al., 2016; Özcan et al., 2011). It has some exclusive qualities, such as the existence of different non-commensurable and clashing criterion, the different unit of measurement among criteria and the presence of the different alternatives (Triantaphyllou, 2013).

There are three stages in using any decision making a procedure for identifying and choosing alternatives: (Triantaphyllou and Mann, 1989).

1. Identifying and selecting the appropriate standards and alternatives.
2. Assigning numerical values for standards based on the effects of the alternatives on these standards.
3. Handling the numerical esteems to decide a ranking of every option.

2.5.1 Classification of Multi Criteria Decision Making Problem (MCDM)

Multi Criteria Decision Making (MCDM) problems are classified based on character of the alternatives; either discrete or constant (Liou and Tzeng, 2012; Mulliner et al., 2016).

1. Discrete: - which contain defined attribute and alternative, those are Multi Attribute Decision Making (MADM).
2. Continuous: - which consist of an infinite number of alternatives, this is Multi-Objective Decision Making (MODM).

In MADM problems contain a finite number of alternatives, apparently known in the start of the solution procedure, and used for taking care of issues which require selection from a defined set of alternatives (De Montis et al., 2000; Zavadskas et al., 2014).

In Multi-Objective Decision Making (MODM) the alternatives are not known and can be found by resolving a mathematical model. The quantity of alternatives is either infinite or not countable (Antucheviciene et al., 2011; De Montis et al., 2000; Majumder, 2015; Pohekar and Ramachandran, 2004; Zavadskas and Turskis, 2011; Zavadskas et al., 2014). One of the primary functions of MODM is to evaluate planning and design problems with various objectives and criteria (Liou and Tzeng, 2012).

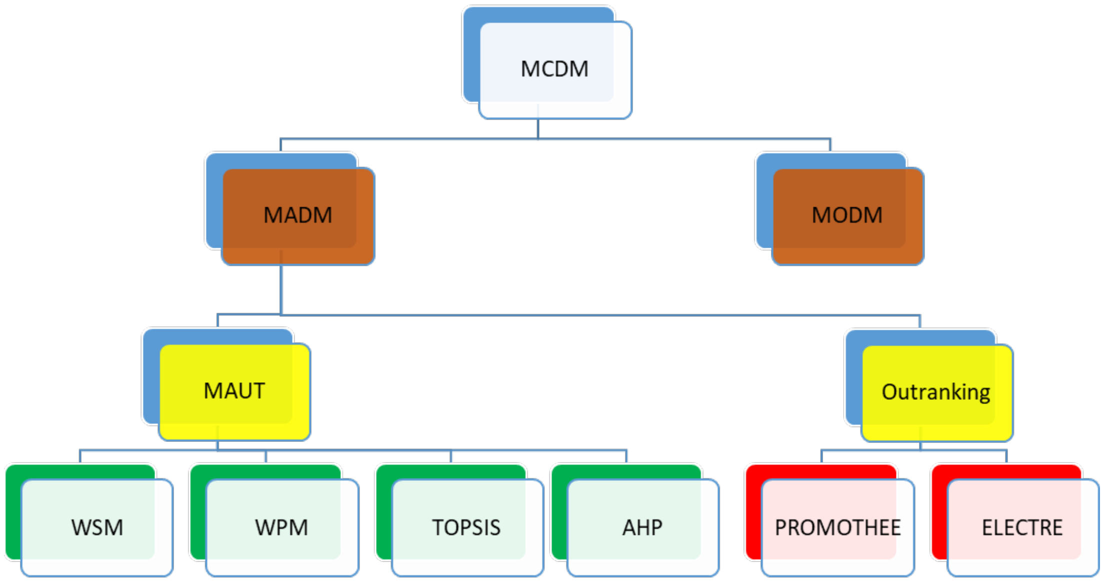


Figure. 2.2 Over all classification of Multi Criteria Decision Making Problem

2.5.2 Types of Multi Attribute Decision Making problem (MADM)

Multi-Attribute Decision Method (MADM) is classified based on the school of thought (Triantaphyllou, 2013) as follows:

1. Compensatory in nature (American school): it is based on multi-attribute utility theory (MAUT), allows counterbalance among criteria. WSM, WPM, AHP, TOPSIS, COPRAS are widely used.

2. Non-compensatory in nature (the French school): this method is essential given the comparison of alternatives concerning with single criteria, those based on outranking methods PROMETHEE and ELECTRE are very common and widely used.

Table 2.1 Comparison between MAUT and outranking method

Outranking method (PROMOTHE, ELECTRE)	MAUT (AHP, WSM, WPM, TOPSIS)
Pairwise comparisons between alternatives	Single score for every alternative
Outranking method (PROMOTHE, ELECTRE)	MAUT (AHP, WSM, WPM, TOPSIS)
Limited compensation	All criteria are directly comparable
In-comparability is allowed	No In-comparability

Outranking allows for in-comparability between alternatives and not always unable for a complete ranking of the alternatives, and might be unsatisfactory for the set of decision problem which required an entire of options. Whereas MAUT commonly has a compensatory nature and principally comprise of cumulative criterion preference value and able to ranked from best to worst (Triantaphyllou, 2013). Some of the widely used MAUT and Outranking method's theoretical principles described as follow:

Weighted Sum Model (WSM)

Weighted Sum Model (WSM) is the most ordinarily used approach, specifically in one dimension issues. If there are many criteria and alternatives for decision making then, the best alternative will be the one that has the highest value when all criteria aggregated (Triantaphyllou and Mann, 1989; Triantaphyllou and Sánchez, 1997).

The theoretical principle of the method is an additive assumption, for finite alternative A_i $(i = 1,2,3,...,m)$, and C_j $(j = 1,2,3,...,n)$, where, m and n are evaluated alternatives and, number of criteria respectively. The best alternative preference P_i calculated as in the following equation.

$$P_i = \sum_{j=1}^{n} (X_{ij} \times W_j) \quad for \quad i = 1,2,3...m \tag{2.1}$$

Where
P_i is the preference of alternatives,
X_{ij} is the preference value of i^{th} alternative with respect to j^{th} criteria,
W_j is criterion's weight,obtained from decision makers

By way of example, let A_1, A_2 and A_3 are finite alternative and C_1, C_2, C_3 and C_4 are criteria of alternatives as shown in Table 2.2.

Table 2.2 Illustrative example for WSM

	Criteria (C_j)			
Alternatives (A_i)	C_1	C_2	C_3	C_4
A_1	X_{11}	X_{12}	X_{13}	X_{14}
A_2	X_{21}	X_{22}	X_{23}	X_{24}
A_3	X_{31}	X_{32}	X_{33}	X_{34}
Criteria's weight	W_1	W_2	W_3	W_4

The preference value for Alternative A1 calculated as,

$$P(A_1) = (X_{11} \cdot W_1) + (X_{12} \cdot W_2) + (X_{13} \cdot W_3) + (X_{14} \cdot W_4) \tag{2.2}$$

The highest $P(A_i)$ value will be the best alternative, and the rest alternatives also ranked according to $P(A_i)$ value. In single-dimensional situations where every criterion's units are similar (e.g., Rand, meter, second) and the WSM can be utilised the WSM utilised without challenge. The complexity of this technique is when it is connecting to a multi-dimensional decision-making problem with distinct units. In this case, the additive utility premise will disregard, and the outcome is like adding banana and grape (Triantaphyllou and Mann, 1989).

The method applied for many application areas such as to evaluate the business environment in West Africa, selection of different brands of servers, and agricultural activities (Esangbedo and

Che, 2016; Sarika, 2012). Another study Shahabi et al. (2016) identified an optimal place for a water reservoir to solve the future water demand issue in Batu Pahat town in the Johor state of Malaysia. In this paper, the WSM method compared with Fuzzy logic and the result shows that both methods provide reliable accuracy.

Weighted Product Model (WPM)

The weighted product model (WPM) is fundamentally the same as the Weighted Sum Model. The notable dissimilarity is that rather than addition in the model there is multiplication. Every alternative compared with others by multiplying various proportions, one for every criterion, and every proportion is raising to power equivalent of the corresponding criterion's weight (Triantaphyllou and Mann, 1989).

For alternative a_1 and a_2, $P\left(\frac{a_1}{a_2}\right)$ is higher than or equivalent to one, at that point it demonstrates that the alternative a_1 is preferable than the alternative a_2 (in maximization case). The desirable alternative is the one that is superior or possibly equivalent to all alternatives (Triantaphyllou and Sánchez, 1997). For the evaluated alternative $A_i(i = 1,2,3,\dots,m)$ and criteria $C_j(j = 1,2,3,\dots,n)$ where m and n are is number of options and criteria. The preference value for a_1 and $a_2, (a_1, a_2 \varepsilon A_i)$ calculated in the following equation.

$$P\left(\frac{a_1}{a_2}\right) = \prod_{j=1}^{n} \left(\frac{a_1}{a_2}\right)^{w_j} \tag{2.3}$$

Where,
a_1 and a_2 is alternatives,
a_{1J} and a_{2J} is the preference value of i^{th} alternative concerning to j^{th} criteria,
W_j is criterion's weight,obtained from decision makers.

By way of example, let A_1, A_2 and A_3 are finite alternative and C_1, C_2, C_3 and C_4 are criteria of alternatives as shown in Table 2.3.

Table 2.3 Illustrative example for WPM

	Criteria (C_j)			
Alternatives (A_i)	C_1	C_2	C_3	C_4
A_1	X_{11}	X_{12}	X_{13}	X_{14}
A_2	X_{21}	X_{22}	X_{23}	X_{24}
A_3	X_{31}	X_{32}	X_{33}	X_{34}
Criteria's weight	W_1	W_2	W_3	W_4

The preference value for a_1 and a_2, calculated as in the following.

$$P\left(\frac{a_1}{a_2}\right) = \left(\frac{X_{11}}{X_{21}}\right)^{w_1} + \left(\frac{X_{12}}{X_{22}}\right)^{w_2} + \left(\frac{X_{13}}{X_{23}}\right)^{w_3} + \left(\frac{X_{14}}{X_{24}}\right)^{w_4} \tag{2.4}$$

The same procedure will be applying for all alternatives compared one to another. The WPM is once in a while known as dimensionless analysis since its structure removes all measurement units. WPM can be utilised as a part of unique and multi-dimensional decision-making issues.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS formerly developed by Hwang and Yoon (1981). The method widely used and applied in many complex decision problems because of its simplicity, such as employee performance assessment, selection of manufacturing process and production system (Opricovic and Tzeng, 2004; Özcan et al., 2011; Srikrishan et al., 2014; Wang and Chan, 2013).

The core principle of TOPSIS is to identify the best alternative from the proposed options which is closest to the positive (best) ideal solution and far from the negative (worst) ideal solution simultaneously (Marković, 2016; Srikrishan et al., 2014). The best ideal solution is the one which satisfies both benefit and cost at the same time. Conversely, the worst ideal solution is to minimise benefits and increase cost (Chen et al., 2011; Pohekar and Ramachandran, 2004). Essential calculation procedure in TOPSIS is as the following (Srikrishan et al., 2014).

Step one: established the decision matrix $(A)_{mxn}$ will be,

$$(\mathbf{A})_{\mathbf{mxn}} = \begin{array}{c} \begin{matrix} C_1 & C_2 & C_3 & \cdots C_n \end{matrix} \\ \begin{bmatrix} X_{11} & X_{12} & X_{13} & \cdots X_{1n} \\ X_{21} & X_{22} & X_{23} & \cdots X_{2n} \\ X_{31} & X_{32} & X_{33} & \cdots X_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & X_{m3} & \cdots X_{mn} \end{bmatrix} \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \end{array} \tag{2.5}$$

The relation matrix will be associated to i^{th} alternatives $(a_1, a_2, a_3, \ldots, a_m)$, concerning to j^{th} criteria $(C_1, C_2, C_3, \ldots, C_n)$, 'i' is the alternative index (i=1, 2 ,... m) and 'j' is attribute index (j= 1, 2 ,..., n) where m and n are number of alternatives and attribute (criteria) respectively, also X_{ij} is the preference value of i^{th} alternative with respect to j^{th} criteria.

Step Two: - obtain the normalization decision matrix A_{Norm} , the normalization matrix calculated for every j^{th} column decision matrix.

$$A_{Norm} = N_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}, (i = 1, 2, \ldots, m) \;\; and \;\; (j = 1, 2, \ldots, n) \tag{2.6}$$

Where,

X_{ij}- the value of i^{th} alternative concerning to j^{th} criteria,

N_{ij}- The normalized decision matrix will be.

$$\mathbf{N_{ij}} = \begin{array}{c} \\ \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & \cdots C_n \end{array} \\ \begin{bmatrix} N_{11} & N_{12} & N_{13} & \cdots N_{1n} \\ N_{21} & N_{22} & N_{23} & \cdots N_{2n} \\ N_{31} & N_{32} & N_{33} & \cdots N_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ N_{m1} & N_{m2} & N_{m3} & \cdots N_{mn} \end{bmatrix} \end{array} \begin{array}{c} \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{array} \tag{2.7}$$

Step Three: - Establish the weighted decision matrix V by multiplying each column of normalised decision matrix N by the corresponding weight. TOPSIS is not able to construct pairwise comparison for criteria so the relative importance for criteria may obtain using AHP or other rating methods. The weighted decision matrix calculated as the following,

$$V = V_{ij} = N_{ij}.W_j, (i = 1, 2, \ldots, m) \ \ and \ \ (j = 1, 2, \ldots, n) \tag{2.8}$$

$$\mathbf{V_{ij}} = \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & \cdots C_n \end{array} \\ \begin{bmatrix} V_{11} & V_{12} & V_{13} & \cdots V_{1n} \\ V_{21} & V_{22} & V_{23} & \cdots V_{2n} \\ V_{31} & V_{32} & V_{33} & \cdots V_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ V_{m1} & V_{m2} & V_{m3} & \cdots V_{mn} \end{bmatrix} \end{array} \begin{array}{c} \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{array} \tag{2.9}$$

Step four: - obtain the positive ideal solution (A^+) and negative ideal solution (A^-) from the weighted decision matrix.

For beneficial criteria

$$A^+ = Max(V_{ij}, (i = 1, 2, \ldots, m) \tag{2.10}$$

$$A^- = Min(V_{ij}, (i = 1, 2, \ldots, m) \tag{2.11}$$

For cost criteria

$$A^+ = Min(V_{ij}, (i = 1, 2, \ldots, m) \tag{2.12}$$

$$A^- = Max(V_{ij}, (i = 1, 2, \ldots, m) \tag{2.13}$$

Step five: - calculate the separation distance from the best ideal solution (A^+) and worst ideal solution (A^-) for all alternatives.

$$D^+ = \sqrt{\sum_{j=1}^{n} (V_{ij}^+ - V_{ij})^2, \ for \ i = 1, 2, \ldots, m} \tag{2.14}$$

$$D^{-} = \sqrt{\sum_{j=1}^{n} (V_{ij}^{-} - V_{ij})^2}, \ for \ i = 1,2,\ldots,m \quad (2.15)$$

Where
D^{+} Indicate distance from positive ideal solution,
D^{-} Indicate distance from negative ideal solution,
V_{ij}^{+} Indicate the maximum value of i^{th} alternative with respect to j^{th} criteria obtained from weighted decision matrix and called positive ideal solution,
V_{ij}^{-} Implies the minimum value of i^{th} alternative with respect to j^{th} criteria obtained from weighted decision matrix and called negative ideal solution,
V_{ij} Implies weighted alternatives value i^{th} concerning to j^{th} criteria.

Step six: - determine the relative closeness of each alternative to positive ideal solution.

$$C_i^{+} = \frac{D_i^{-}}{(D_i^{+} + D_i^{-})}, \ 0 \leq C_i^{+} \leq 1 \quad (2.16)$$

Step Seven: - Identifying the alternatives rank form the best to the worst according to C_i^{+} value; and, the alternative which has highest C_i^{+}value will be the best and least C_i^{+} value will be inadequate.

This method utilised in many applications and some of them presents as follow. Dadfar (2014), attempted to improve the accuracy of locating new school sites, using TOPSIS and WLC method in the case study area of the City of Calabasas, America. The study considered the distance from existing school, population data, land use, proximity to major roads and proximity to a restaurant as a primary criterion, and The WLC and TOPSIS used to assign the weights for the criterions and ranking alternatives from best to the worst. Also, Beskese et al. (2015) proposed a GIS-based model for solid waste management plan in the city of Istanbul, to manage solid wastes for sustainable use and to keep the environment healthy. The study presents the integration of Fuzzy AHP and Fuzzy TOPSIS to evaluate the proposed three landfill sites in the case study area. The Fuzzy theory can avoid vagueness while the decision maker's judgment on the pairwise comparison and the method of Fuzzy TOPISIS evaluate and assign a weight for the selected criteria to choose the optimal site. Similarly, Khan et al. (2015) concern to identify the optimal location for food distribution in the case study area of in Pakistan Red Crescent Society. The paper demonstrates the use of the Rough Set Theory has been used to evaluate and classify the data and the result obtained by RST for 40 sites used by TOPSIS multi-criteria analysis approach to identify the ideal and worst sites in Pakistan Red Crescent Society.

Preference Ranking Organization Method for Enrichment Evaluation (PROMOTHEE)

PROMOTHEE is one of outranking based method developed by Brans (1982). The method uses a pair of alternative's difference under every criterion and avoids small differences among criteria which make it a big difference in the evaluation of alternatives (Brans and Vincke, 1985; Brans et al., 1986; Macharis et al., 2004; Zhaoxu and Min, 2010).

The principle of PROMOTHEE is ranking alternatives by comparing a set of two alternatives in every criterion using their preference values (Zhaoxu and Min, 2010). The method needs two initial information, the weight of criteria and decision maker's preference, for alternatives on every criterion (Macharis et al., 2004; Zhaoxu and Min, 2010). The preference function will be established based on the numerical value of a set of two alternatives which is given by decision makers among every criterion.

Let $a_1, a_2, \dots, a_m$ is possible alternatives, $C_1, C_2, \dots, C_n$ is alternatives criteria, and X_{ij} is the value of i^{th} alternative A_i concerning j^{th} criteria C_{ij}, then the preference function will be established as follow,

$$P_j(A_1, A_2) = 0, \quad if \quad X_{1j} \leq X_{2j} \tag{2.17}$$

$$P_j(A_1, A_2) = P(A_{1j} - A_{2j}), \quad if \quad X_{1j} > X_{2j} \tag{2.18}$$

$$0 \leq P_j(A_1, A_2) \leq 1 \tag{2.19}$$

The necessary steps in PROMOTHEE described in many kinds of literature as follow (Athawale and Chakraborty, 2010).

Step One:- establish decision matrix X_{ij}

$$\mathbf{X_{ij}} = \begin{matrix} C_1 & C_2 & C_3 & \cdots C_n & \\ \left[\begin{matrix} X_{11} \\ X_{21} \\ X_{31} \\ \vdots \\ X_{m1} \end{matrix}\right. & \begin{matrix} X_{12} \\ X_{22} \\ X_{32} \\ \vdots \\ X_{m2} \end{matrix} & \begin{matrix} X_{13} \\ X_{23} \\ X_{33} \\ \vdots \\ X_{m3} \end{matrix} & \left.\begin{matrix} \cdots X_{1n} \\ \cdots X_{2n} \\ \cdots X_{3n} \\ \vdots \\ \cdots X_{mn} \end{matrix}\right] & \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \end{matrix} \tag{2.20}$$

Where
$a_1, a_2, \dots, a_m$ is possible alternatives,
$C_1, C_2, \dots, C_n$ is alternaives criteria,

X_{ij} stands for i^{th} alternative value concerning to j^{th} criteria.

Step One:-Normalize the decision matrix,

$$N_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})}, \quad (i = 1,2,\ldots,m, \;\; i = 1,2,\ldots,n) \tag{2.21}$$

For non-beneficial criteria normalization will be,

$$N_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})}, \quad (i = 1,2,\ldots m, \;\; i = 1,2,\ldots,n) \tag{2.22}$$

The normalized matrix will be,

$$\mathbf{N_{ij}} = \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & \cdots C_n \end{array} \\ \begin{bmatrix} N_{11} & N_{12} & N_{13} & \cdots N_{1n} \\ N_{21} & N_{22} & N_{23} & \cdots N_{2n} \\ N_{31} & N_{32} & N_{33} & \cdots N_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ N_{m1} & N_{m2} & N_{m3} & \cdots N_{mn} \end{bmatrix} \end{array} \begin{array}{c} \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{array} \tag{2.23}$$

Normalization for the first N_{11} will be,

$$N_{11} = \frac{X_{11} - min(X_{11}, X_{21}, \ldots, X_{m1})}{\max(X_{11}, X_{21}, \ldots, X_{m1}) - min(X_{11}, X_{21}, \ldots, X_{m1})}, (i = 1,2,\ldots,m, j = 1,2,\ldots,n) \tag{2.24}$$

If criteria C_1 is economic criteria normalization will be as follow,

$$N_{11} = \frac{\max(X_{11}, X_{21}, \ldots, X_{m1}) - X_{11}}{\max(X_{11}, X_{21}, \ldots, X_{m1}) - min(X_{11}, X_{21}, \ldots, X_{m1})}, (i = 1,2,\ldots,m, j = 1,2,\ldots,n) \tag{2.25}$$

Step Three:- Determining the preference function, In this step, alternatives deference calculate from the decision matrix.

$$P_j(a_1, a_2) = \begin{cases} 0, & if \;\; N_{1j} \leq N_{2j} \\ 1, & if \;\; N_{1j} > N_{2j} \end{cases} \tag{2.26}$$

Step Four:- obtain the aggregated preference function using the following equation.

$$A(i, i^{'}) = \frac{\sum_{j=1}^{n} W_j \times p_j(i, i^{'})}{\sum_{j=1}^{n} W_j} \tag{2.27}$$

Where,
W_j weight of criteria,
$P_j(i,i^{'})$ preference value of alternatives.

Step Five:- calculate the leaving (positive) and entering (negative) outranking flow. The positive flow shows how much the alternative excels the other alternative, conversely entering flow implies the amount of one alternative dominated by the other alternative (Athawale and Chakraborty, 2010).
The leaving and entering flow will be calculated using the following equation,

$$Positive flow \ \ (\varphi)^{+} = \frac{1}{n-1} \times \sum_{i^{'}=1}^{n} A(i,i^{'}),(i \neq i^{'}) \tag{2.28}$$

$$Negative flow \ \ (\varphi)^{-} = \frac{1}{n-1} \times \sum_{i^{'}=1}^{n} A(i^{'},i),(i \neq i^{'}) \tag{2.29}$$

Where n is a number of possible alternatives.

Step Six:- determine the net flow φ_i for every alternative,

$$\varphi_i = \varphi^{+} - \varphi^{-} \tag{2.30}$$

Step Seven:- obtain the alternatives rank on the value of net flow. The alternatives with the highest net flow value will be the best, and the alternative with the lowest net flow value will be the least.

Elimination and Choice Translating Reality (ELECTRE)

ELECTRE is one of outranking method, developed by B. Roy in 1960, and applied to support in many decision problems to allocate the best alternatives (Supraja and Kousalya, 2016; Wu and Chen, 2009). The core principle of the method is identifying and ranking the possible alternatives based on a pair of an alternative to being compared and ranked under each criterion (Hartati et al., 2011; Supraja and Kousalya, 2016; Triantaphyllou and Mann, 1989; Triantaphyllou et al., 1998; Wu and Chen, 2009). In outranking relation, it is a challenge for decision-makers to prefer one alternative from another if two alternatives are not dominating each other. Then, the dominant alternative is the one excels the other alternatives in one or more criteria and equal to the remaining criteria (Hartati et al., 2012; Triantaphyllou et al., 1998).

The outranking relations will be evaluated using a concordance and discordance index for the paired alternatives A_1 and A_2. Moreover, the concordance index implies how A_1 is better than A_2, and discordance index indicates how A_1 is worse than A_2 (Hartati et al., 2012; Triantaphyllou et al., 1998; Wu and Chen, 2009). Necessary steps to perform the ELECTRE method described in the literature as follows (Supraja and Kousalya, 2016; Triantaphyllou et al., 1998; Wu and

Chen, 2009).

Step One:- Established and define Criteria and possible alternatives for decision matrix X_{ij},

$$\mathbf{X_{ij}} = \begin{array}{c} \begin{matrix} C_1 & C_2 & C_3 & \cdots C_n \end{matrix} \\ \begin{bmatrix} X_{11} & X_{12} & X_{13} & \cdots X_{1n} \\ X_{21} & X_{22} & X_{23} & \cdots X_{2n} \\ X_{31} & X_{32} & X_{33} & \cdots X_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & X_{m3} & \cdots X_{mn} \end{bmatrix} \end{array} \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \tag{2.31}$$

Step Two:-The normalisation of decision matrix, the use of normalisation is to transform the criteria's measurement unit in to be comparable, and can be obtained using the following equation.

$$X_{Norm} = N_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}, \tag{2.32}$$

Where
X_{ij}- the value of i^{th} alternative concerning to j^{th} criteria in the decision matrix,
N_{ij} The normalized decision matrix,

The normalized decision matrix (N_{ij}) will be:

$$\mathbf{N_{ij}} = \begin{array}{c} \begin{matrix} C_1 & C_2 & C_3 & \cdots C_n \end{matrix} \\ \begin{bmatrix} N_{11} & N_{12} & N_{13} & \cdots N_{1n} \\ N_{21} & N_{22} & N_{23} & \cdots N_{2n} \\ N_{31} & N_{32} & N_{33} & \cdots N_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ N_{m1} & N_{m2} & N_{m3} & \cdots N_{mn} \end{bmatrix} \end{array} \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \tag{2.33}$$

Step Three:- Calculate the weighted decision matrix W_j by multiplying each column of normalized decision matrix N_{ij} by the corresponding weight. Decision makers assign Criterion's weight from initial.

$$W_{ij} = N_{ij}.W_j, (i = 1, 2, \ldots, m) \ \ and \ \ (j = 1, 2, \ldots, n) \tag{2.34}$$

$$\mathbf{N_{ij}} = \begin{array}{c} \\ \\ \\ \\ \\ \\ \end{array} \begin{matrix} C_1 & C_2 & C_3 & \cdots C_n \\ \end{matrix}$$

$$\mathbf{N_{ij}} = \begin{bmatrix} N_{11}(W_1) & N_{12}(W_2) & N_{13}(W_3) & \cdots N_{1n}(W_n) \\ N_{21}(W_1) & N_{22(W_2)} & N_{23}(W_3) & \cdots N_{2n}(W_n) \\ N_{31}(W_1) & N_{32}(W_2) & N_{33}(W_3) & \cdots N_{3n}(W_n) \\ \vdots & \vdots & \vdots & \vdots \\ N_{m1}(W_1) & N_{m2}(W_2) & N_{m3}(W_3) & \cdots N_{mn(W_n)} \end{bmatrix} \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \tag{2.35}$$

$$\sum_{j=1}^{n} W_j = 1 \tag{2.36}$$

Where

W_{ij}- Weighted normalized decision matrix,

N_{ij}- The normalized decision matrix,

W_j- Criteria's weight.

Step Four:- calculate concordance and discordance index, the concordance set (C_{KI}), obtained for two alternatives A_K and A_I.

$$C_{KI} = \{ \ such \ \ that \ \ : Y_{Kj} \geq Y_{Ij} \}, \ \ for \ \ j = 1,2,3,\ldots,n \tag{2.37}$$

$$C_{KI} = \sum_{j \in C_{KI}} W_j, \ \ for \ \ j = 1,2,3,\ldots,n \tag{2.38}$$

The concordance value shows, how A_K is better than A_I and the value of C_{KI} is $0 \leq C_{KI} \leq 1$ the concordance index matrix will be as follow,

$$\mathbf{N_{ij}} = \begin{bmatrix} - & C_{12} & C_{13} & \cdots C_{1m} \\ C_{21} & - & C_{23} & \cdots N_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ C_{m1} & C_{m2} & C_{m3} & \cdots - \end{bmatrix} \tag{2.39}$$

Also, discordance index D_{index} will calculate for paired alternative A_K and A_I as the following equation,

$$D_{KI} = \frac{\max |Y_{Kj} - Y_{Ij}|, \ \ j \in D_{KI}}{\max |Y_{Kj} - Y_{Ij}|, \ \ j = 1,2,\ldots,n} \tag{2.40}$$

Step Five:- Obtaining the concordance and discordance dominance matrix from concordance and discordance index by using threshold value. The concordance value D_{KI} for paired alternatives A_K and A_I, should excel the threshold value to say A_K has the possibility to dominate A_I (Supraja and Kousalya, 2016; Triantaphyllou et al., 1998; Wu and Chen, 2009). Threshold value calculated as follow,

$$\bar{C} = \frac{1}{m(m-1)} \times \sum_{K=1}^{m} C_{KI} \sum_{I=1}^{m} C_{KI} \tag{2.41}$$

Where
$\bar{C}$- Threshold value,
m- Number of alternatives,
C_{KI}- concordance index of paired alternatives A_K and A_I

The discordance dominance matrix (h) is also obtained by using threshold value $(\bar{d})$ and calculated for paired alternatives A_K and A_I as follow,

$$\bar{d} = \frac{1}{m(m-1)} \times \sum_{K=1}^{m} d_{KI} \sum_{I=1}^{m} d_{KI} \tag{2.42}$$

Where
$\bar{d}$- Threshold value,
m- Number of alternatives,
d_{KI}- discordance index of paired alternatives A_K and A_I Using threshold value $(\bar{d})$ the discordance dominance matrix (h_{KI}) will be,

$$h_{KI} = 1, \ \ if d_{KI} \geq \bar{d} \tag{2.43}$$

$$h_{KI} = 0, if d_{KI} < \bar{d} \tag{2.44}$$

Step Six:- Determine the aggregate dominance matrix (A),

$$A_{KI} = g_{KI} \times h_{KI} \tag{2.45}$$

Where
A_{KI}- Aggregate dominance matrix,
g_{KI}- concordance dominance matrix,
h_{KI}- discordance dominance matrix
Step Seven:- Finally ranking alternatives based on the aggregate dominance matrix. If $A_{KI} = 1$, this directs that alternative A_K is preferable than A_I.

Analytical Hierarchy Process (AHP)

AHP is the most broadly applied Multi-Attribute Analysis method, initially developed by prof. Thomas. L. Saaty in the 1960's. The method can decompose the problem into several problems among the hierarchy level, and each level shows the criteria of the decision problem. Every element in the hierarchy level could be measured in qualitatively or quantitatively (Forman and Gass, 2001; Triantaphyllou, 2013; Wang and Chan, 2013). A detailed description of the method is found in chapter three.

Analytic Hierarchy Process method used for different types of application. A recent study Jamal (2016), identify optimum location for school construction in isolated mountainous communities to minimizes construction cost, the exposure for a landslide, rock-fall, and avalanches in Khorog and porshnev, Eastern Tajikistan. The study used MCDA along with AHP methods to assign the relative significance of the selected criterions and ranking alternatives from best to the worst. Also, the study suggests the decision maker's preferences and expert knowledge avoid judgment bias. In the study, criterion preference determines by researcher personal filling and knowledge. According to Zhou and Wu (2012) the researcher identified that hospital service in the city of Haidian District of Beijing, Chana is not sufficient, and a shortage of hospital bedrooms are much significant for the society. Therefore, the study proposed a suitable site for new hospitals with adequate space to meet the required medical demand using GIS and AHP approach for the city. Moreover, the method used to support the selection of different decision problems, such as suitable sites for hotels, wind farmland and public library buildings (Abazari et al., 2012; Elsheikh, 2017; Szurek et al., 2014).

Another research finding Talam and Ngigi (2015) attempt to allocate the potential site for new schools in the case study area of Belgut Constituency in Kericho country, which is the existing school locations are exposing for flood-prone, overpopulated classrooms and smaller land size from the standard. Hence, GIS incorporated with MCDA yield for the study area. The AHP approach used to categorise the factor criteria in the hierarchy level and applied pairwise comparison to assign relative importance to the criterions. Moreover, the method used to support the selection of different decision problems, such as suitable sites for hotels, wind farmland and public library buildings (Abazari et al., 2012; Elsheikh, 2017; Szurek et al., 2014).

2.5.3 Summary on Multi criteria decision analysis

The following table shows the types of multi-criteria decision methods, and initial data need to perform the method. The necessary theoretical procedures of the methods and application of areas described by different studies as follow (Kumar et al., 2017; Velasquez and Hester, 2013).

Table 2.4 Summary on Multi Criteria Decision Analysis

Methods	Theoretical principle	Advantage	Disadvantage	Area of application	Initial Information needed
WSM	Additive assumption.	The method efficiently performed without difficulty in Layman level.Suitable for single dimension problems.	Only applicable for single dimension problem.	Energy development Server selection Evaluating Business Environment.	Possible alternative, defined criteria, Weight for criteria and Criteria score value.
WPM	Alternatives compared by multiplying the number of ratios, one for each decision criterion.	Can be utilized for both single and multi-dimensional decision-making problems. Its structure removes any units of measurement thus helps to solve problems with different criterions.	It doesn't have a method to assign weights for criteria. Improper assigning of relative importance for criterions leads to the imprecise result.	Allocating of labor based on many criterions. Bidding strategies.	Possible alternative, defined criteria, Weight for criteria and Criteria score value.

TOPSIS	Identifying the best alternative the one which is near for a positive and far from the negative solution.	Simple process. Can obtain a full ranking of alternatives.	The Euclidian distance doesn't take into account the mutual relation of two criteria.	Supply chain management and logistics, design, engineering and manufacturing system, environmental management, human resource management, and water resource management.	Possible alternative, defined criteria, Weight for criteria and Criteria score value.
AHP	Decompose the problem into several problems among hierarchy level, and Pairwise comparison applied for each hierarchy level.	Ease of use and Able to decompose the large problem into hierarchy structure and also provide a pairwise comparison method to assign criteria weight.	Inconsistency may occur due to bias judgment on the pairwise comparison because it doesn't allow to score criteria individually.	Resource management, corporate policy, political strategy, and planning.	A possible alternative, defined criteria, the decision maker's linguistic value for pairwise comparison to obtain criteria weight and Criteria score value.

PROMOTHEE	The alternatives rank obtained based on the difference value of positive and negative outranking flow, which is called net flow.	It allows in-comparability between criteria. Consider uncertainty and fuzzy information.	It doesn't have a method to assign weights for criteria. Criterions weight depends on the decision maker's preference.	Environmental management, hydrology and water management, business and financial management, chemistry, logistics, and transportation.	Possible alternative, defined criteria, the decision maker's preference value, criteria's weight and Criteria score value.
ELECTRE	Alternatives outranking relations will be evaluated using concordance and discordance index.	Allow in comparison with alternatives, possible to add an option at the end, and it considers uncertainty and vagueness.	It is not able to identify the alternatives weakness and strength directly. The result may difficult at Layman level.	Applied in energy, economics, environmental,water management, and transportation problem.	Possible alternative, defined criteria, the decision maker's preference value, criteria's weight and Criteria score value.

This chapter provides brief information about MCDA methods. Tables 2.4 summarises some Multi-Criteria Decision Analysis methods based on their theoretical framework, advantage, disadvantage, the area of application and initial information needed. All methods required preference score and the weight value for criterion, and they do not have such a technique to assign a relative weight for the selected criterion and obtain the best alternative except AHP. Therefore, AHP method is promising for this research study rather than other methods due to its ease of use, its ability to structure a complex and assign a relative weight percentage for criterion through pair-wise comparison, and particularly suited to decisions made with limited information. Also, the method is to enable to check the comparison consistency.

2.6 Summary

In this chapter, a comprehensive literature review on proper site selection analysis is presented. It describes that unscientific and poor site selection approach leads to failure on the development of the project and cause challenges related to transportation access, heavy traffic, and high travelling cost in most cities. Hence, many researchers proposed MCDA integrated with GIS method to solve problems related to land use suitability, site selection, and resource evaluation problems. The method used in many application such as to find the optimal place for schools, water reservoirs, agricultural activities, wind farm, hospitals, hotels, public libraries, waste disposal, food distribution centres and urban land use planning activity. Also, the two primary classifications of Multi-Criteria Decision Making problems namely MCDA and MODM are discussed. The chapter briefly demonstrates the theoretical principle and dissimilarities of MCDA methods such as WSM, WPM, TOPSIS, PROMOTHEE, ELECTRE and AHP. Finally, rational selection of the research method for this study is presented.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the structure of the research methodology that address the fundamental research questions in the study. It describes the implementation of MCDA method to assign criterion's weight, Air pollution modelling to quantify the concentration of particulate matter (PM10) and ending with Weight overlay analysis to combine the criterion's map according to their relative importance. Licensed Arc GIS 10.4, QGIS and Microsoft Excel 2013 utilised for criterion's weight computation and data processing. Figure 3.1 shows the research methodology procedures.

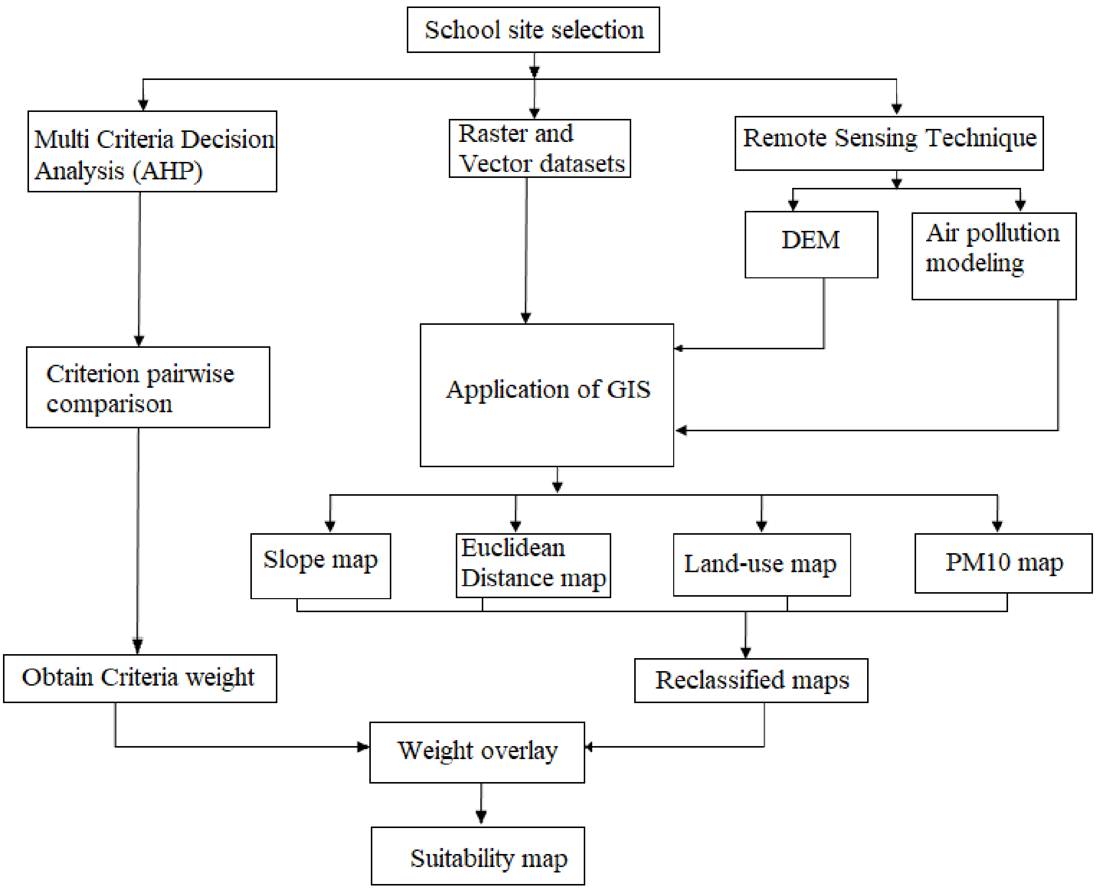


Figure. 3.1 Research methodology procedure

3.2 Analytic Hierarchy Process (AHP) method

AHP is a Multi-Attribute analysis method; the primary task in the method is constructing a hierarchy structure for the decision problem (Triantaphyllou, 2013; Wang and Chan, 2013). A decision problem criteria breakdown into main criteria, similarly main criteria decompose to mini criteria, and so on regarding hierarchy level, moreover it is suitable for a complex problem which has finite criteria (Forman and Gass, 2001).

In this study, the alternatives will be identified based on the selected criterions. Thus, the relative importance of the criterions is vital for the final suitable site selection. AHP is suitable for this research study rather than other methods because it can assign a weight for criterions through pair-wise comparison, and the method is to enable to check the comparison consistency. The following steps show how the method is implementing in this research study.

Step One:- constructing hierarchy structure for school site selection.

Table 3.1 Hierarchy level for school site selection

Level one	Level Two	Level Three
School Site selection	Economy	Existing school
		Land use
		Major Roads
	Safety and Environment	Distance from commercial
		River
		Industrial sites
		slope
		Air pollution
		High tension transmitters lines
	Accessibility	Public libraries
		Emergency facilities

Step Two:- Constructing a decision matrix and applying a Pairwise comparison. Based on hierarchical structure decision *mxm* element matrix has been constructed for this research study, Where m is the number of comparison elements.

$$\begin{array}{cc} & \begin{array}{ccccc} a_1 & a_2 & a_3 & \cdots a_m \end{array} \\ \mathbf{A} = & \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots a_{1m} \\ a_{21} & a_{22} & a_{23} & \cdots a_{2m} \\ a_{31} & a_{32} & a_{33} & \cdots a_{3m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots a_{mm} \end{bmatrix} \begin{array}{c} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{array} \end{array} \tag{3.1}$$

Consequently, Pairwise comparison applied for each hierarchy levels to assign the relative importance of the criteria weight one over another (Mu and Pereyra-Rojas, 2018*b*; Wang and Chan, 2013).

A nine-point measurement scale introduced by Saaty (1994), support the pairwise comparison by converting the decision maker's linguistic value into a numerical value to determine the relative weight for criteria (Mu and Pereyra-Rojas, 2018*a*; Triantaphyllou and Sánchez, 1997).

Table 3.2 Preference scale for pairwise comparisons

Preference Level	Numerical Value
Equally important	1
Equally to Moderately important	2
Moderately important	3
Moderately to Strong important	4
Strongly or essential important	5
Strongly to Very Strongly important	6
Very Strongly important	7
Very Strongly to Extremely important	8
Extremely important	9

When pairwise comparison applied between two elements i and j, the relative importance value a_{ij} will be,

$$a_{ij} = 1 \quad if\ element\ i\ and\ j\ are\ equal\ important \tag{3.2}$$

$$a_{ji} = \frac{1}{a_{ij}}\ for\ i \neq j \tag{3.3}$$

Where a_{ij} stands the relative importance value of i^{th} element over j^{th} element.

In this research study, the pairwise comparison matrix and preference score for the criterions is assigned based on previous research studies experience and personal point of view to obtain a relative weight of the criterion. Saaty (1994) introduce a nine-point measurement scale to compare criterion one to the other based on their relative importance. Table 3.2 presents detailed information about the numerical values and their corresponding preference level. Therefore the evaluation matrix has been done for each hierarchy level by as follow;

Table 3.3 Pairwise comparison matrix for School site selection

school site selection	Economy	Safety and Environment	Accessibility
Economy	1	2	3
Safety and Environment	1/2	1	2
Accessibility	1/3	1/2	1

Table 3.4 Pairwise comparison matrix for Economy

Economy	Existing school	Land use	Major Roads
Existing school	1	1	3
Land use	1	1	2
Major Roads	1/3	1/2	1

Table 3.5 Pairwise comparison matrix for Safety and Environment

Safety and Environment	Industrial sites	slope	High tension transmitters	Stream Network	Distance from commercial	Air pollution
Industrial sites	1	1	3	2	2	1
slope	1	1	2	3	2	1
High tension transmitters	1/3	1/2	1	1	2	1
Stream Network	1/2	1/3	1	1	2	1
Distance from commercial	1/2	1/2	1/2	1/2	1	1
Air pollution	1	1	1	1	1	1

Table 3.6 Pairwise comparison matrix for Accessibility

Accessibility	Public libraries	Emergency facilities
Public libraries	1	2
Emergency facilities	1/2	1

Step Three:- After applying pairwise comparison for every hierarchy level, it is feasible to obtain a normalised correlation matrix, by dividing each cell value by its corresponding column total. The first a_{11} calculated as follows;

$$N_{(a_{11})} = \frac{a_{11}}{a_{11} + a_{21} + a_{31} +, \ldots, a_{1m}} \tag{3.4}$$

General formula for each element will be calculated as follow.

$$A_{Norm} = N_{ij} = \frac{a_{ij}}{\sum_i^m a_{ij}}, (i = 1, 2, \ldots, m) \; and \; (j = 1, 2, \ldots, m) \tag{3.5}$$

The normalized result matrix will be;

$$\mathbf{N_{ij}} = \begin{array}{c} \begin{matrix} a_1 & a_2 & a_3 & \cdots a_m \end{matrix} \\ \begin{bmatrix} N_{11} & N_{12} & N_{13} & \cdots N_{1m} \\ N_{21} & N_{22} & N_{23} & \cdots N_{2m} \\ N_{31} & N_{32} & N_{33} & \cdots N_{3m} \\ \vdots & \vdots & \vdots & \vdots \\ N_{m1} & N_{m2} & N_{m3} & \cdots N_{mm} \end{bmatrix} \begin{matrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \end{array} \tag{3.6}$$

Step Four:- After obtaining a normalised comparison matrix, it is possible to determine the criteria weight vector (W) by averaging the entries each row of the normalised matrix.

$$W_{ij} = \frac{\sum_{i=1}^{m}(N_{ij})}{m} \tag{3.7}$$

Where,
W_{ij} Stands for weighted vector,
N_{ij} Stands for normalized comparison value,
m is number of compared elements.

The weight vector (W_{ij}) for the first-row yield as follows;

$$W_{a_1} = \frac{N_{11} + N_{21} + N_{31} +, \ldots, N_{m1}}{m} \tag{3.8}$$

The result weight vector will be;

$$W_{a_m} = \begin{bmatrix} W_{a_1} \\ W_{a_2} \\ W_{a_3} \vdots \\ W_{a_m} \end{bmatrix} \tag{3.9}$$

Step Five:- Consistency vector calculation. When applying the pairwise comparison, the preference value for criteria is established based on the decision maker's knowledge and experience. However, human judgment may have a slight bias and makes the comparison matrix inconsistent (Mu and Pereyra-Rojas, 2018*b*; Wang and Chan, 2013). To illustrate further, let compare the element X, Y, and Z. If element X is twice of an element Y, and an element Y is twice of Z, logically element X is four-time greater than Z, then the judgment is consistent. However, if the judge's score for X is six times greater than Z, then the comparison matrix will be inconsistency. For this reason, the consistency ratio value will calculate for each hierarchy level of the judgment matrix, which is suggested by (Saaty 1980). Therefore consistency vector (CV_{ij}) will be obtained by multiplying the decision comparison matrix by a weight vector.

$$W_{a_m} = \begin{bmatrix} A_x & A_y & A_z \\ B_x & B_y & B_z \\ C_x & C_y & C_z \end{bmatrix} * \begin{bmatrix} W_{a_1} \\ W_{a_2} \\ W_{a_3} \end{bmatrix} = \begin{bmatrix} CV_{a_1} \\ CV_{a_2} \\ CV_{a_3} \end{bmatrix} \tag{3.10}$$

Therefore the average consistency vector λ obtained by;

$$\lambda = \sum_{i=1}^{n} (CV_{ij}) \tag{3.11}$$

Where,
CV Stand for consistency vector,
λ Stand for average consistency vector,

Step Six:- calculating consistency Index (CI) and consistency ratio (CR).

$$CI = \frac{\lambda - n}{n-1} \tag{3.12}$$

Where,
CI Stand for Consistency Index which shows a degree of consistency,
λ Stand for average consistency vector,
n Stand for the order of comparison matrix.

The consistency ratio will calculated in the following equation.

$$CR = \frac{CI}{RI} \tag{3.13}$$

Where
CR Stand for Consistency Ratio,
CI Stand for Consistency Index which shows a degree of consistency,
RI stands for random index,

The random index is a mean CI for a vast figure of arbitrarily produced matrices of the same form and obtained from random consistency index, proposed by (Saaty 1980).

Table 3.7 Random consistency Index (RI) for n= 10 (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Finally, for all hierarchy level, consistency ratio will be calculated, and the result less than or equivalent to 0.10 is satisfactory, the value which is higher than 0.10 of consistency ratio needs evaluates the preference of criterions value (Pohekar and Ramachandran, 2004).

3.3 Air pollution modelling

Aerosol Optical Thickness is the measuring of the concentration of solid and liquid particles on the atmosphere such as particulate matter, dust, sea salt crystals and others using satellite imagery. The primary aim of this air pollution modelling is to quantify and mapping the concentration of particulate matter (PM10) for the study area using Landsat 8 OLI/TIRS satellite imagery data.

3.3.1 Radiometric calibration

The satellite sensor detects and record the reflected sunlight energy from the surface and atmosphere features, and changed to a digital number (DN). Therefore, the digital numbers converted into meaningful information such as surface reflectance, atmospheric reflectance or brightness temperature. The primary aim of this calibration is to extract atmospheric reflectance from top of atmospheric reflectance, and definite sensor information is required to carry out this calibration.

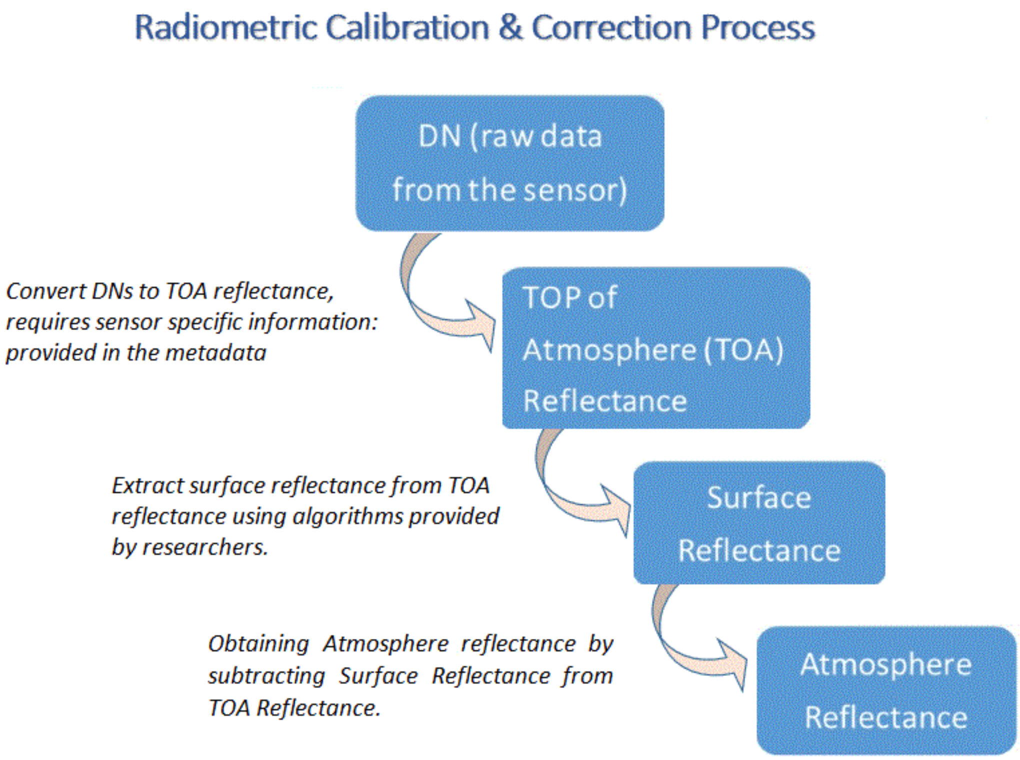


Figure. 3.2 Radiometric Calibration process

3.3.2 Converting digital numbers to the top of atmosphere reflectance (TOA)

Landsat 8 imagery data can be directly changed into TOA using sensor information. Conversion of DN value at the sensor to radiance at earth surface (TOA) will be carried out using equation two provided by (Landsat, 2015).

$$\rho\lambda' = M_\rho * Q_{cal} + A_\rho \tag{3.14}$$

Where,
$\rho\lambda'$ = TOA Reflectance, without correction for solar angle,
M_ρ = Reflectance multiplicative scaling factor for the band from the meta-data,
A? = Reflectance additive scaling factor for the band from the meta-data,
Q_{cal} = pixel value in DN.

The TOA ($\rho\lambda'$) which contain the correction for solar elevation angle will be;

$$\rho\lambda = \frac{\rho\lambda'}{Sin(\theta SE)} \tag{3.15}$$

Where,
$\rho\lambda$ = TOA Reflectance,
θSE = sun elevation angle (provided from the meta-data,).

3.3.3 Extracting Surface Reflectance

After converting DN to Top of Atmosphere reflectance for all bands, it is possible to obtain surface reflectance by correlation of visible bands (band 1, 2 and 3) and Mid Infrared bad (band 7). Thus the surface reflectance will be calculated using the following equation 3.16, 3.17, and 3.18, given by (Lim et al., 2004; Shaheen et al., 2017).

$$S_R(B_1) = \frac{TOA(B_7)}{4.26} \tag{3.16}$$

$$S_R(B_2) = \frac{TOA(B_7)}{1.94} \tag{3.17}$$

$$S_R(B_3) = \frac{TOA(B_7)}{2.11} \tag{3.18}$$

Where,
S_R is surface reflectance,
B_1, B_2 and B_3 are visible bands,
TOA (B_7) is top of Atmosphere reflectance for band seven.

3.3.4 Extracting Atmosphere Reflectance

After obtaining surface reflectance for band 1, 2 and 3, Atmosphere reflectance will extracte by subtracting surface reflectance from TOA reflectance.

$$TOA\ \ Reflectance = Atmosphere\ \ Reflectance + Surface\ \ Reflectance$$

Atmosphere reflectance for band 1, 2 and 3 will be obtained using the following equations.

$$A_R(B_1) = TOA(B_1) - S_R(B_1) \tag{3.19}$$

$$A_R(B_2) = TOA(B_2) - S_R(B_2) \tag{3.20}$$

$$A_R(B_3) = TOA(B_3) - S_R(B_3) \tag{3.21}$$

The correlation of Atmosphere reflectance, PM10 and AOT (Aerosol Optical Thickness) The correlation of AOT and Atmosphere reflectance for a single band and multiband simplified as (Nguyen et al., 2014; Othman et al., 2010; Roy et al., 2017).

$$AOT(\lambda) = A_R(B_n) \tag{3.22}$$

The equation for multiband will be;

$$AOT(\lambda) = a_1A_R(B_1) + a_2A_R(B_2) + a_3A_R(B_3) + a_4A_R(B_4) \tag{3.23}$$

Where,
AOT-Aerosol Optical Thickness,
$A_R(B_n)$-is atmospheric reflectance $(B_n = 1,2,3,\ldots, corresponding\ \ Bands)$
(a_n)-is algorithm cofficent $(n = 1,2,3,\ldots, is\ \ obtainedemperically\ \ determinded)$

Several studies showed the relation of AOT and PM10 is a linear relationship (Roy et al., 2017; Saleh and Hasan, 2014; Shaheen et al., 2017). By replacing PM10 in terms of AOT into equation 3.23;

$$PM10 = a_1A_R(B_1) + a_2A_R(B_2) + a_3A_R(B_3) + a_4A_R(B_4) \tag{3.24}$$

Where,
$PM10$ - Particulate matter with diameter $10\mu m$,
$A_R(B_n)$-is atmospheric reflectance $(B_n = 1,2,3,\ldots, corresponding\ \ Bands)$
(a_n)-is algorithm cofficent $(n = 1,2,3,\ldots, is\ \ obtained\ \ emperically\ \ determinded)$

Therefore, in this study, the concentration of PM10 has been calculated using equation 3.24 that has been given by (Nguyen et al., 2014; Othman et al., 2010).

$$PM10 = 396R(\lambda_1) + 253R(\lambda_2) - 194R(\lambda_3) \tag{3.25}$$

3.4 Application of GIS

GIS is a tool that enables capturing, storing, handling, evaluating, displaying, retrieving and presenting of criterion map layers. In this study, all vector and raster dataset of criteria manipulated by Arc GIS 10.4 and QGIS software. Different tools have been used to analyse the criterions datasets such as slope, clip, resample, projection, Euclidean distance, reclassify and weight overlay, the primary analysis tools described as following.

3.4.1 Euclidean distance

Euclidean distance is linear distance, measured from the midpoint of origin cell value to the nearest cell value. The separation to each origin cell governed by estimating the hypotenuse of the triangle, with an opposite and adjacent maximum. Euclidean distance tool in Arc GIS, able to calculate the distance for both vector and raster datasets. If the input is feature class, the software changes internally into raster to perform the distance analysis. The output raster resolution can determine with the output cell size parameter.

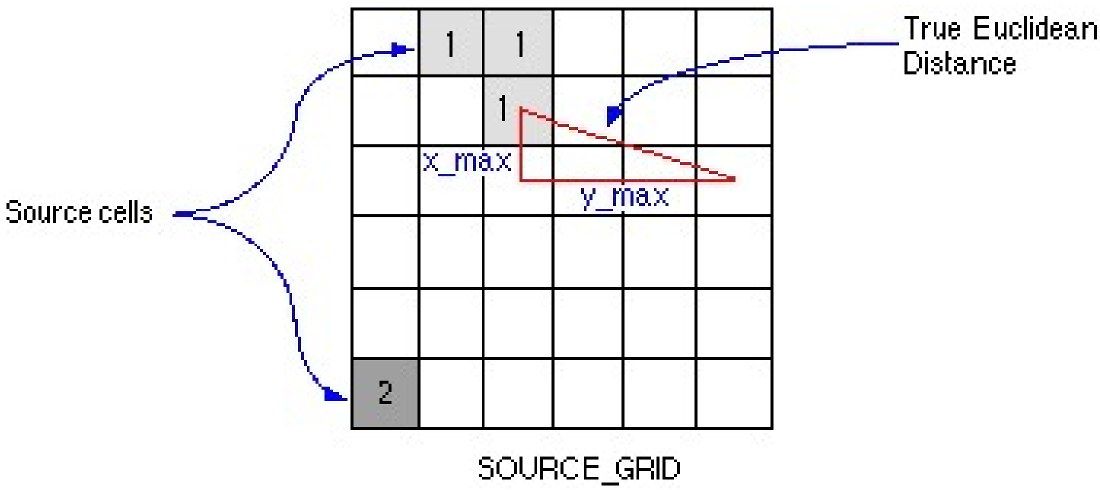


Figure. 3.3 Euclidean distance calculation (Source: ESRI)

3.4.2 Reclassification

Reclassification is changing the raster cell value into new value. In this study for every dataset, proximity distance is calculated using Euclidean distance tool except land use slope and PM10. The output cell value reclassified into a common suitability scale from one to four. Therefore the reclassified suitability class represents one for not suitable, four for most suitable, the cell value two and three are less suitable and suitable respectively.

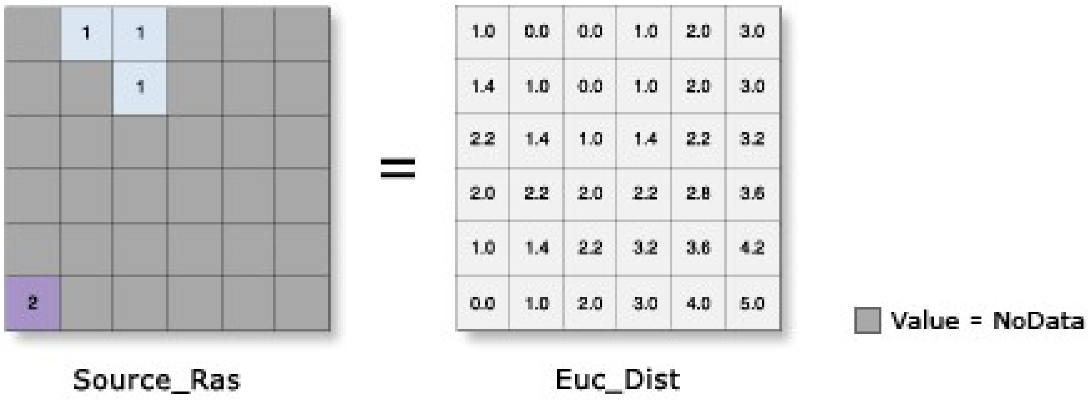


Figure. 3.4 Euclidean distance calculation outcome

Table 3.8 Raster dataset reclassification

Reclassified raster cell value score	Reclassification
1	Not suitable
2	Less suitable
3	suitable
4	Most suitable

Ethiopian ministry of education has not pointed out standards regarding criterions. Hence in this study criteria's standard adopted from different research studies. Similarly, the annual mean concentration of PM10 value obtained from Air pollution modelling is reclassified based on US EPA Air Quality Index (AQI). This AQI is divided into six categories representing increasing levels of health concern.

Table 3.9 Standardization for criterion scores

Slope in percent	Reclassified raster cell value score
0 - 10	4
10 - 15	3
15 - 25	2
>25	1
Proximity distance from High power transmission lines in meter.	
0 - 150	1
150 - 300	2
300 - 450	3
>450	4
Proximity distance from roads networks in meter	
<150	1
150 - 1000	4
1000 - 2000	3

>2000	2
Proximity distance from existing schools in meter	
0 - 1000	1
1000 - 1500	2
1500 - 2000	3
>2000	4
Distance from industries and factories in meter	
0 - 500	1
500 - 750	2
750 - 1000	3
>1000	4
Distance from streams in meter	
0 - 150	1
150 - 300	2
300 - 450	3
>450	4
Distance from commercial and religions places in meter	
0 - 300	1
300 - 650	2
650 - 1000	3
>1000	4
Distance from public libraries in meter	
0 - 1000	4
1000 - 2000	3
2000 - 3000	2
>3000	1
Distance from Emergency facilities in meter	
0 - 300	1
300 - 1000	4
1000 - 2000	3
>2000	2
PM10 ($\mu g/m^3$)	
0-50	4
50 - 75	3
75 - 100	2
>100	1

Land use	
Administration/Commercial/Cultural Social Welfare/Education/Health/Infrastructure and utilities/Mixed Residential/Municipal Service	1
Special use	2
Green/Urban Agriculture	3
Field crop/Open space	4

3.5 Weight overlay

All criterion may not have equal influence in the analysis. Hence, using the Analytical Hierarchy Process method, the relative criterion weight has been obtained. Consequently, weight overlay tool capable of integrating the reclassified maps based on their relative weight, of producing a suitable map. There are two basic requirements to perform weight overlay techniques.

1. Reclassified criterion map into a common suitability scale.
2. A weight of Criterion according to their importance, obtained from AHP and change into percentage influence.

The basic concept of how the technique works described as follow;

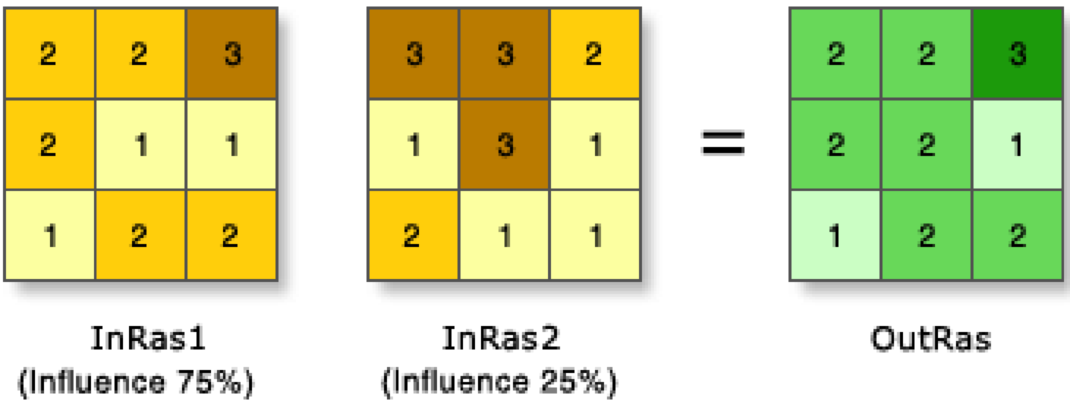


Figure. 3.5 Basic concept how weight overlay works

The two raster datasets reclassified into a common scale from one to three, also relative weight 75% and 25% assigned. The cell values multiplied by its influence percentage and combined, to produce the output raster value. For instance consider the first row, first cell values for both raster datasets, the input values is $(2*0.75) = 1.5$ and $(3*0.25) = 0.75$. The sum of 1.5 and 0.75 will be 2.25; however, the output value should be an integer, so the value rounded to the nearest integer which is 2. This will be performed by using a weighted linear combination (WLC) method of MCDA calculated as in the following mathematical formula (Bukhari et al., 2010; Jayaweera, 2016).

$$S_{ij} = \sum(X_{ij} \times W_c) \tag{3.26}$$

Where

S_{ij} is Suitable score of ij location,

X_{ij} Criterion map cell value for C criteria of i.j location,

W_c is weightage of relative importance for C criteria,

3.6 Summary

In this chapter, the structure of the research methodology and procedure is explicitly described. The AHP method is capable of decomposing the decision problems in the hierarchy level and perform the pairwise comparison in each level. Also, Air pollution modelling is conducted to quantify the concentration of PM10 using Landsat 8 satellite imagery. The algorithm used in Air pollution modelling is adopted from the previous research studies. Moreover, different software and tools that have been used to analyse the criterions datasets are concisely described, such as Euclidean distance, reclassification, and weight overlay.

CHAPTER FOUR

Result and discussion

4.1 Introduction

This chapter embraces a description of the research study area, a source of data-sets, criterion's geographical location and importance, data preparation, results and discussion which obtained from Analytical Hierarchy Process, Air pollution modelling, Euclidean distance, slope calculation, Reclassification, and ends with weight overlay for the final land suitability map.

4.2 Study area

This research study focused on Addis Ababa, Ethiopia, which is the capital and largest city in Ethiopia, located with the GPS coordinates of 9° 0' 19.4436" N, 38° 45' 48.9996" E and elevation of 2356 meter. The city covers 527 km² land area and has a population of 3,384,569 according to 2007 E.C census report projection. Also, it is the headquarters of the United Nations Economic Commission for Africa (ECA) and the African Union (AU). The city has 806 Primary schools (grade 1-8) and 150 Secondary schools (grade 9-12) both governmental and private. The study considers only governmental schools, which is 221 Primary schools (grade 1-8) and 66 Secondary schools (grade 9-12) (CGAAEB, 2018). The geographical setting of the study area presents in Figure 4.1.

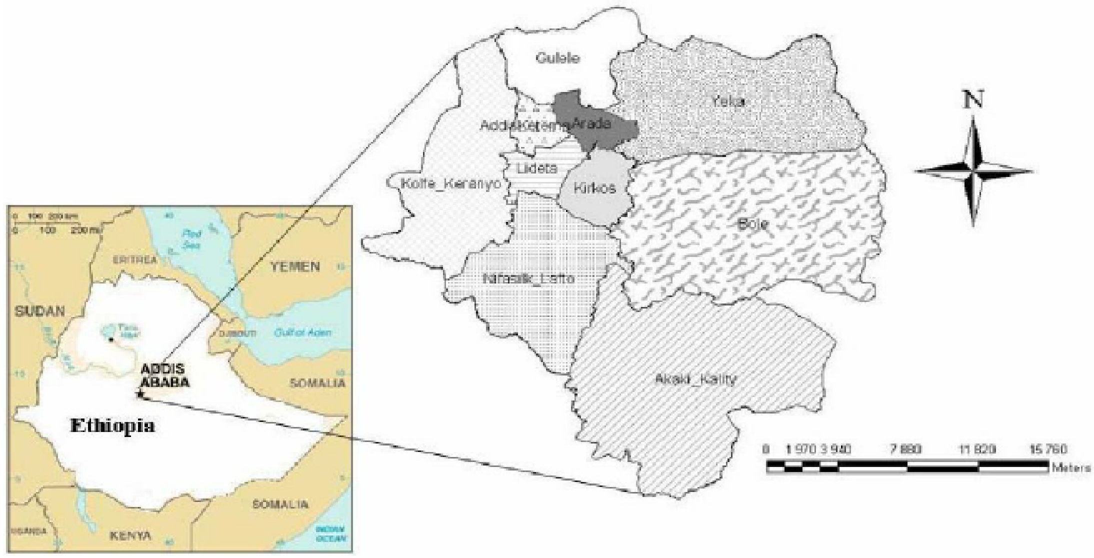


Figure. 4.1 Geographical Location of study area

4.3 Data collection

Suitable site selection needs to consider various geographical data. In this study, many datasets have been used to achieve an objective. Source of dataset and types described clearly in Table 4.1.

Table 4.1 Data used for school site selection

Dataset Name	**Description**	**Source**
DEM	SRTM elevation data at a resolution of 30 meters.	USGS (https://earthexplorer.usgs.gov/).
Satellite image	Landsat 8 satellite image, 30 meter resolution.	USGS (https://earthexplorer.usgs.gov/).
Schools	Existing Primary and secondary schools location in Point futures in Shapefile.	Addis Ababa Integrated Land Management Bureau.
Land use	Addis Ababa city land use in shape file.	Addis Ababa Integrated Land Management Bureau.
Road	Major road infrastructure. Datasets in Shape file.	Addis Ababa Integrated Land Management Bureau.
High power transmission line	High power transmission lines that carry electric power.	Addis Ababa Integrated Land Management Bureau.
commercial and religious places	Trade activity and religious places. Point future.	Addis Ababa Integrated Land Management Bureau.
streams	Polyline features that shows river networks.	Addis Ababa Integrated Land Management Bureau.
Industrial sites	Huge factory sites, shape file format.	Addis Ababa Integrated Land Management Bureau.
Public library	Existing public libraries	Addis Ababa Integrated Land Management Bureau.
Emergency facilities	Medical facility, police stations, and fire stations.	Addis Ababa Integrated Land Management Bureau.

4.4 Data preparation

4.4.1 Distance from existing schools

Proximity distance from existing schools has great influence regarding utilising the available resource. New schools should be placed apart from the existing schools to accommodate extensive service to the community. Many research studies show that minimum distance to the other school should be one kilometre (Jamal, 2016; Talam and Ngigi, 2015) in this study greater than a two-kilometre distance to other school considered as most suitable. Geographical location of existing schools shows in Figure 4.2.

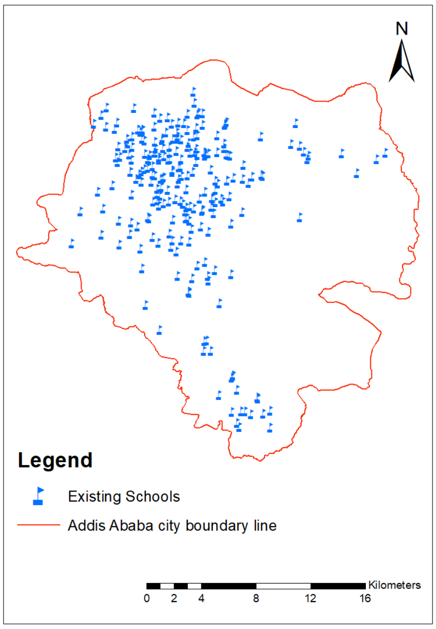


Figure. 4.2 Existing School location

4.4.2 Land use

Land-use is a significant factor for suitability analysis. It gives information and occupation of the natural land resource. Its concern, how the available land resource is more prolific in the land administration activities. Based on the previous research studies information the land –use map reclassified from suitable to unsuitable which is described in chapter three in section 3.4.2. The study area, land use information shows in Figure 4.4.

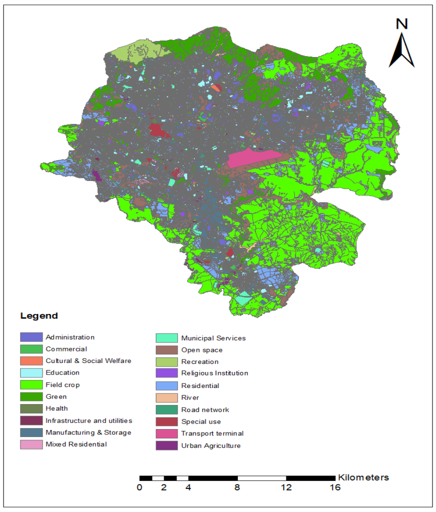


Figure. 4.3 Land use dataset of Addis Ababa city

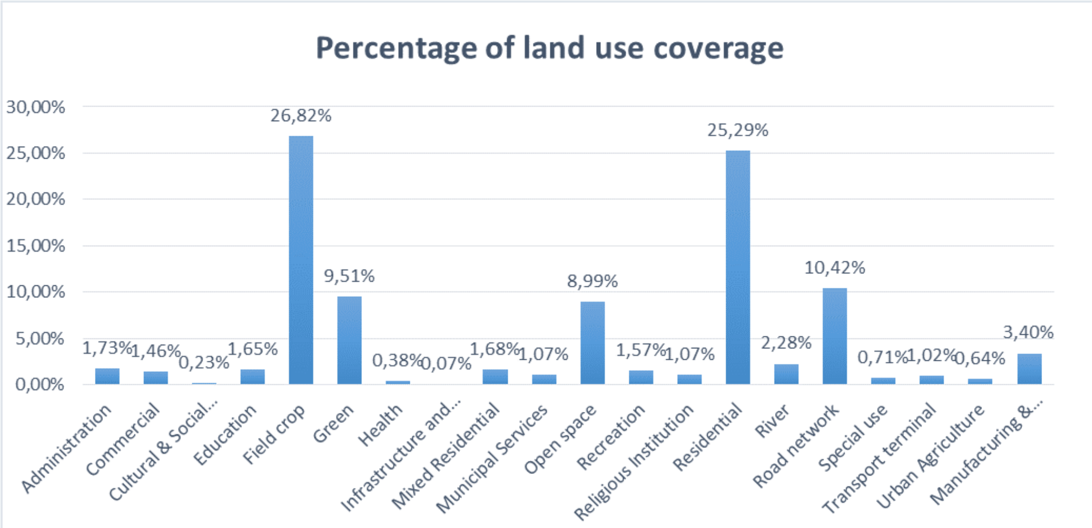


Figure. 4.4 Addis Ababa Percentage of the land-use coverage

4.4.3 Road Networks

Optimum distance to road infrastructures is vital for schools; being close for road networks will avoid long walking distance, and bring a convenient transportation system for pupils. In contrast, roads are the primary source of air and sound pollution, and it may affect the educational programs. Hence the schools should not be far and close to the main road network (Jamal, 2016; Jayaweera, 2016). In this study, the optimum distance adopted from different research studies, and 500 meters assigned as minimum proximity and 2,000 meters considered as the maximum distance. Existing road infrastructure of the city presented in Figure 4.5.

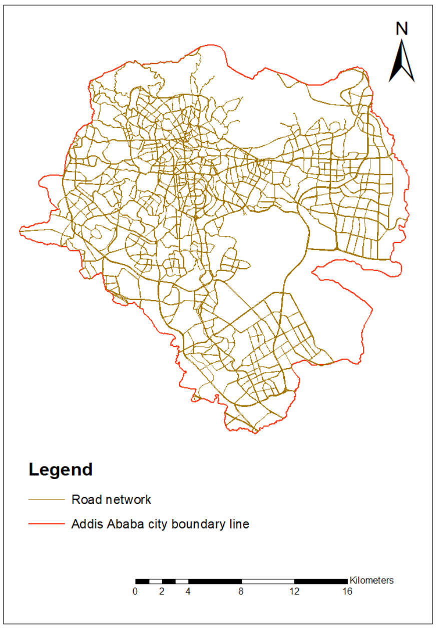


Figure. 4.5 Existing Road network

4.4.4 High power transmission line

High voltage transmission lines use to transmit bulk electrical energy from power plants to cities and residential areas. Whereas these high voltage electric transmission lines produce a high magnetic and electric field, this may affect human health (Kulkarni and Gandhare, 2012). School sites should be away from those electrical transmission lines to ensure student's and staff's safety. In this study, the minimum proximity distance for this utility zone adopts from the previous research studies (Bukhari et al., 2010; Jamal, 2016).

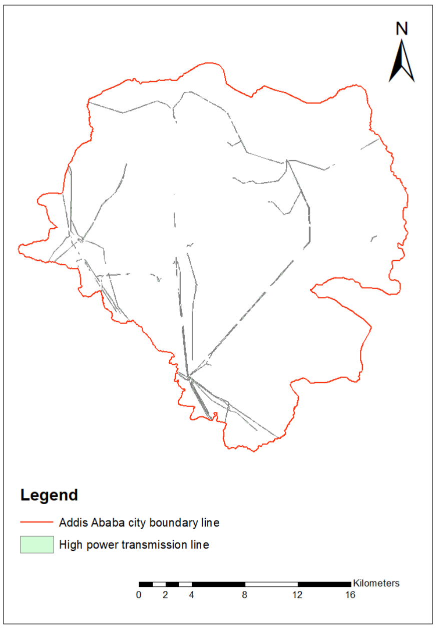


Figure. 4.6 Existing High power transmission lines

4.4.5 Slope

A slope is one of the aspects of school site selection; it should not be low or steep. Steep slopes expose for natural disasters such as landslides, snow slip, and rock-fall, besides school construction on a steep area is not cost-effective. Thus the site should be reasonably level to have sufficient playing space for pupils. Many research studies show that slope value less than 10 % is convenient for school construction (Bukhari et al., 2010; Dadfar, 2014; Jamal, 2016; Jayaweera, 2016; Talam and Ngigi, 2015). In this study the slope data is not readily available; therefore the Digital Elevation Model (DEM) data has been used to generate a slope map. The Shuttle Radar Topography Mission (SRTM) elevation at a resolution of 30 meters data obtained from the U.S. Geological Survey (USGS) website. It is a free download available on (https://earthexplorer.usgs.gov/). Using Arc GIS 10.4 spatial tools, from DEM dataset slope value map is generated for the study area. Finally, based on previous studies, the slope map has been reclassified from suitable to unsuitable according to slope value.

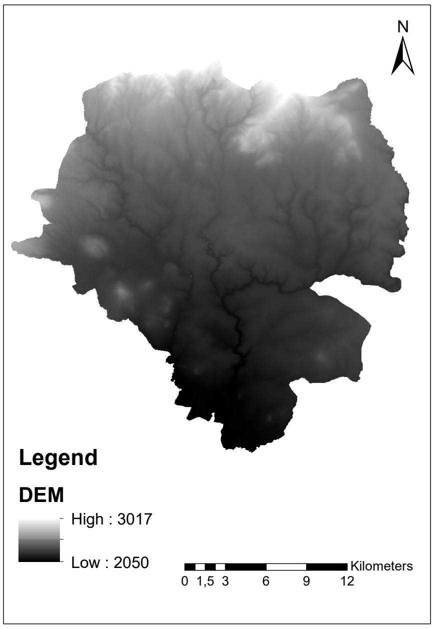


Figure. 4.7 Digital Elevation Model dataset

4.4.6 Distance from Industrial sites

Factories are a source of air pollution and noise, hence schools sites should be located away from these sites to make the educational program safe and convenient. According to the previous research studies, depending on the type of the industry, schools recommended being apart from factories at least 450 meters (Bukhari et al., 2010; Jayaweera, 2016; Talam and Ngigi, 2015).

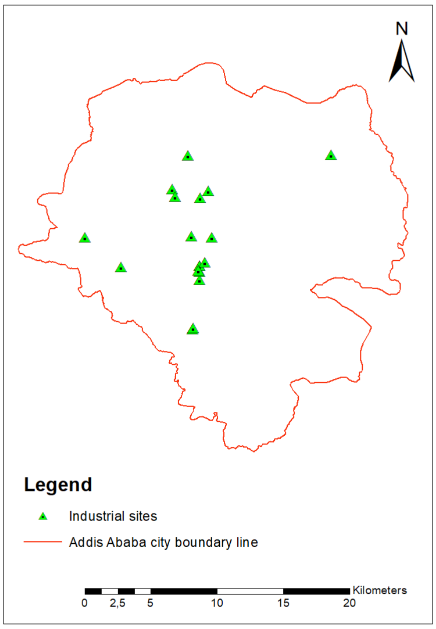


Figure. 4.8 Existing Industrial Sites

4.4.7 Proximity to commercial sites and religious places

Commercial and religious places are typically worship and business activity areas, such as downtowns, shopping centres, commercial buildings, service station, banks, grocery store, hotel, office, pharmacy, movie theatre, and restaurants. This activity zone causes high traffic flow, air and sound pollution which affect the educational program. Based on the previous studies the new schools should not be situated within 300 meters to commercial and religion places (Bukhari et al., 2010; Jayaweera, 2016; Talam and Ngigi, 2015).

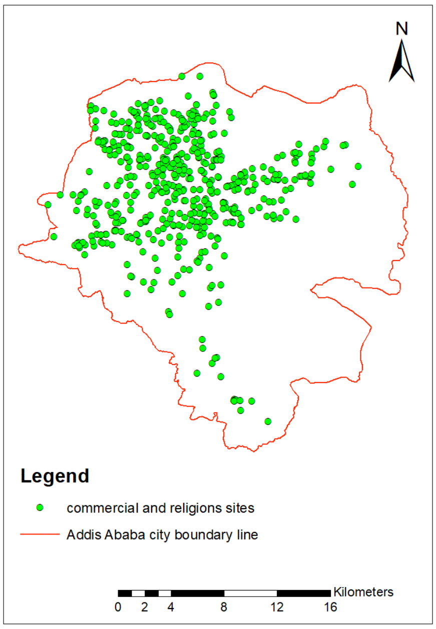


Figure. 4.9 Commercial and religious data-set

4.4.8 Air pollution (PM10)

Air Polluted school sites have an adverse effect on the educational environment and pupil health. Therefore, find of a decontaminated area is vital. The primary air pollution types are Particulate matter, nitrogen oxide, ozone, sulfur dioxide and carbon monoxide. However, this study only considered the particulate matter with less than 10µm diameter (PM10), because of its significant adverse effect on pupil's health (Tarekegn and Gulilat, 2018). Clear PM10 data is not available for the study area. Therefore, air pollution modelling is conducted using Landsat 8 OLI/TIRS satellite image data to map the annual mean concentration of PM10 for the year 2017. Eight satellite images were selected based on less cloud cover; the data is a free download, available online on the USGS website (HTTP: // landsat.usgs.gov). The Landsat 8 image data contain 11 spectral bands with a spatial resolution of 30m for bands 1 to 7 and 9, 15m for band 8 and 100 meters for thermal bands 10 and 11 (Landsat, 2015). Table 4.2 shows detail information about the satellite images.

Table 4.2 Landsat 8 satellite imagery information

Scene ID:	Path	Row	Cloud Cover	Sun Elevation	Acquisition Date:
LC81680542017010LGN01	168	54	0.03	49.22584293	2017-01-10
LC81680542017026LGN01	168	54	0.03	50.62067977	2017-01-26
LC81680542017042LGN00	168	54	0.02	53.24989653	2017-02-11
LC81680542017074LGN00	168	54	0.07	60.16803661	2017-03-15
LC81680542017154LGN00	168	54	2.47	62.13834340	2017-06-03
LC81680542017330LGN00	168	54	0.18	53.04529291	2017-11-26
LC81680542017346LGN00	168	54	0.03	50.47240101	2017-12-12
LC81680542017362LGN00	168	54	0.02	49.16617241	2017-12-28

4.4.9 Distance from streams

Schools sites should not be placed near to stream networks to prevent a flash flood, mud flood, and erosion. Therefore in this study, new schools sites should be away from stream networks at least 150 meters. Higher than 500 meters is considered suitable, based on earlier experience (Bukhari et al., 2010; Talam and Ngigi, 2015).

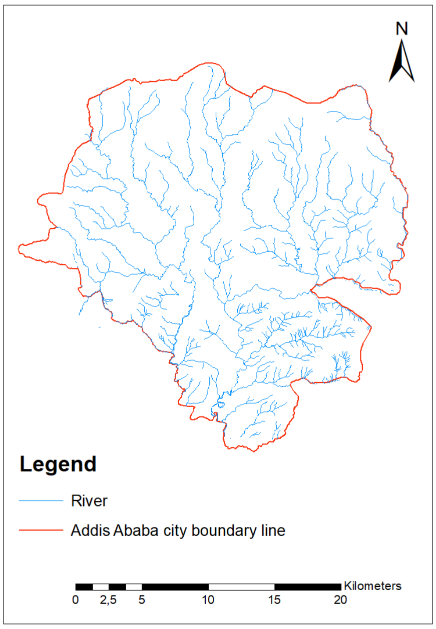


Figure. 4.10 Steams network data-set

4.4.10 Distance from emergency facilities

Emergency facilities in this study considered as a medical facility, police stations, and fire stations. This facility should be accessible to schools in the case of natural and human-made disasters. The proximity distance from 0 up to 1000 meters to this facility considered as suitable in this study. which adopted from a previous study (Jamal, 2016).

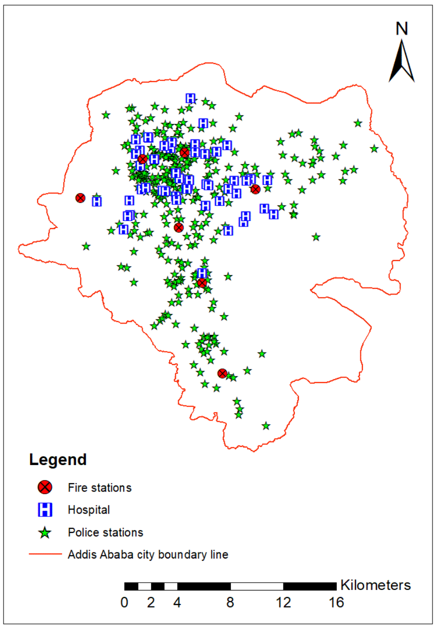


Figure. 4.11 Emergency facilities location dataset

4.4.11 Distance from Public libraries

Access to public libraries will give children an additional broad variety of reading, the California Department of Education suggested that cooperative planning is recommended such as public libraries, recreational and schools for better educational area appropriateness (California, 2018).

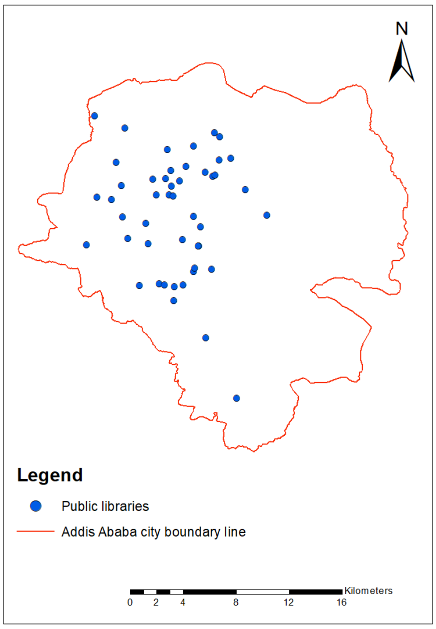


Figure. 4.12 Public library location dataset

4.5 Result and Discussion

In this chapter the key finding of the study is presented and discussed regarding the objective of the study, which was to identify optimal places for new school construction in Addis Ababa capital, using the application of the MCDA, GIS, and Remote Sensing techniques. Results from AHP, Air pollution modelling, Euclidean distance, reclassification and weight overlay presented in separate section respectively.

4.5.1 Results from Analytical Hierarchy Process (AHP) method

The advantage of AHP in this research study enabled to categorised criteria into three main groups and assigned a relative weight for each hierarchy level which is presented in Table 4.3 to Table 4.6. The corresponding cell value for criterion indicates the result of normalising decision matrix obtained from Equation 3.5. Similarly, the result in average weight column represents the degree of the criterion importance in that hierarchy level. Hence, the Economy group weighted the highest value which is 54% and followed by safety and environment 30%, and accessibility 16%. The criterions were grouped under these main groups and assigned a weight for each criterion. Also, the consistency ratio value shows the accuracy of the comparison matrix. The following Tables show that results obtained from AHP for each hierarchy level.

Table 4.3 School site selection's normalized decision matrix, criteria's weight and consistency ratio result

School Site Selection	Economy	Safety and Environment	Accessibility	Average Weight	consistence vector
Economy	0,545	0,571	0,500	54%	3,015
Safety and Environment	0,273	0,286	0,333	30%	3,008
Accessibility	0,182	0,143	0,167	16%	3,004
Eigenvector ()		3,009			
Number of comparison criterions (n)		3			
consistency Index (CI)		0,005			
Random consistency Index (RI)		0,580			
Consistency Ratio (CR)		0,008			

Table 4.4 Accessibility normalized decision matrix, criteria's weight and consistency ratio result

Accessibility	Public libraries	Emergency facilities	Average Weight	consistence vector
Public libraries	0,667	0,667	0,667	2,000
Emergency facilities	0,333	0,333	0,333	2,000
Eigenvector()		2,000		
Number of comparison criterions		2,000		
consistency Index (CI)		0,000		
Random consistency Index (RI)		0,000		
Consistency Ratio (CR)		0,000		

Table 4.5 Safety and Environment's normalized decision matrix, criteria's weight and consistency ratio result

Safety and Environment	Industrial sites	slope	High tension transmitters	River Network	Distance from commercial	Air pollution	Average Weight	consistence vector
Industrial sites	0,231	0,231	0,353	0,235	0,200	0,167	24%	6,352
Slope	0,231	0,231	0,235	0,353	0,200	0,167	24%	6,352
High tension transmitters	0,077	0,115	0,118	0,118	0,200	0,167	13%	6,248
River Network	0,115	0,077	0,118	0,118	0,200	0,167	13%	6,248
Distance from commercial	0,115	0,115	0,059	0,059	0,100	0,167	10%	6,161
Air pollution	0,231	0,231	0,118	0,118	0,100	0,167	16%	6,227
Eigenvector(λ)			6,212					
Number of comparison criterions			6,000					
consistency Index (CI)			0,042					
Random consistency Index (RI)			1,240					
Consistency Ratio (CR)			0,034					

Table 4.6 Economy's normalized decision matrix, criteria's weight and consistency ratio result

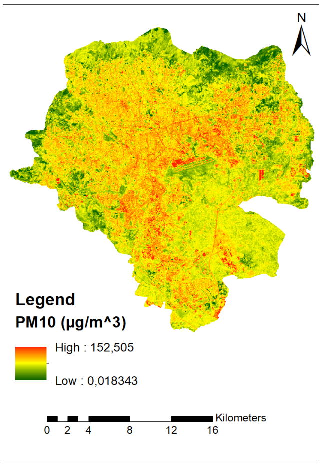
Economy	Existing school	Land use	Major Roads	Average Weight	Consistence vector
Existing school	0,429	0,400	0,500	44%	3,025
Land use	0,429	0,400	0,333	39%	3,020
Major Roads	0,143	0,200	0,167	17%	3,009
Eigenvector()		3,018			
Number of comparison criterions		3,000			
consistency Index (CI)		0,009			
Random consistency Index (RI)		0,580			
Consistency Ratio (CR)		0,016			

The acceptable consistency ration value in AHP method is less 0.1. In this study, the maximum consistency value is 0.034. Therefore, the comparison is consistency. Proximity to the existing school criteria is the maximum value in the economy group because of highest preference value was gave on a pairwise comparison, and then followed by Land use type and proximity to road networks consequently. Similarly, in safety and environment group equal maximum weight value is obtained for proximity to industrial sites and slope — the minimum weight value assigned for proximity distance to commercial and religious place criteria. Correspondingly in the accessibility group, proximity to the public libraries and emergency facilities weighted highest and lowest respectively. Therefore, criteria which have the highest preference value in pairwise comparison resulted in the highest relative weight. The supreme weight indicates that the weight of the criteria is significant. On the other hand, the minimum weight scored criterions are less critical.

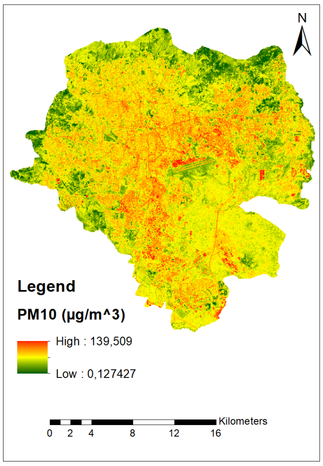
4.5.2 Result from Air Pollution modelling

Results from air pollution modelling for the selected month presented in Figure 4-13. The outcome shows that the concentration of PM10 value in January, March, and November is range between $139\mu g/m^3 - 152\mu g/m^3$, in February and December $123\mu g/m^3 - 129\mu g/m^3$.

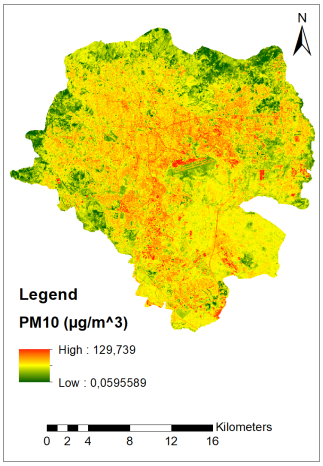
Diversely in June, a high concentration value is obtained which is $209\mu g/m^3$, the possible reason is the cloud coverage is slightly higher than the others.



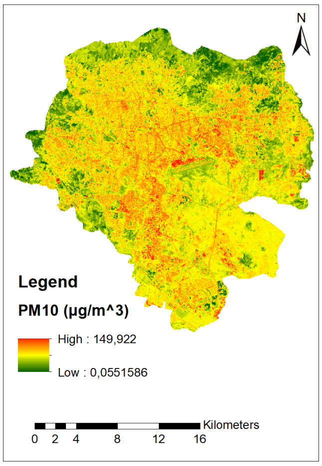
(a) 2017-01-10



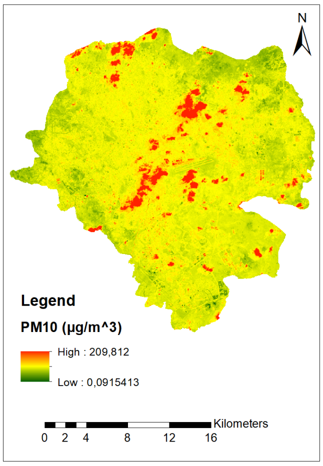
(b) 2017-01-26



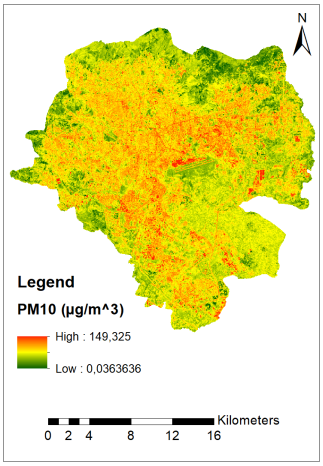
(c) 2017-02-11



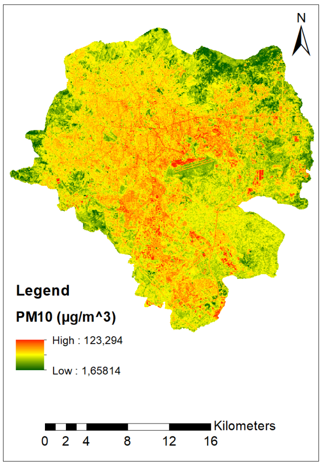
(d) 2017-03-15



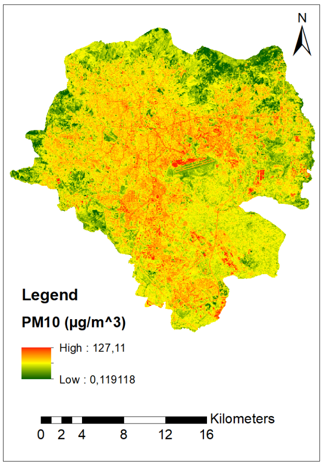
(e) 2017-06-03



(f) 2017-11-26



(g) 2017-12-12



(h) 2017-12-28

Figure. 4.13 PM10 concentration for a year 2017

The maximum and minimum concentration value recorded in December and June month and the annual mean concentration derived by averaging the month's concentration values. The Annual mean concentration of PM10 $(\mu g/m^3)$ map presented in Figure 4.14.

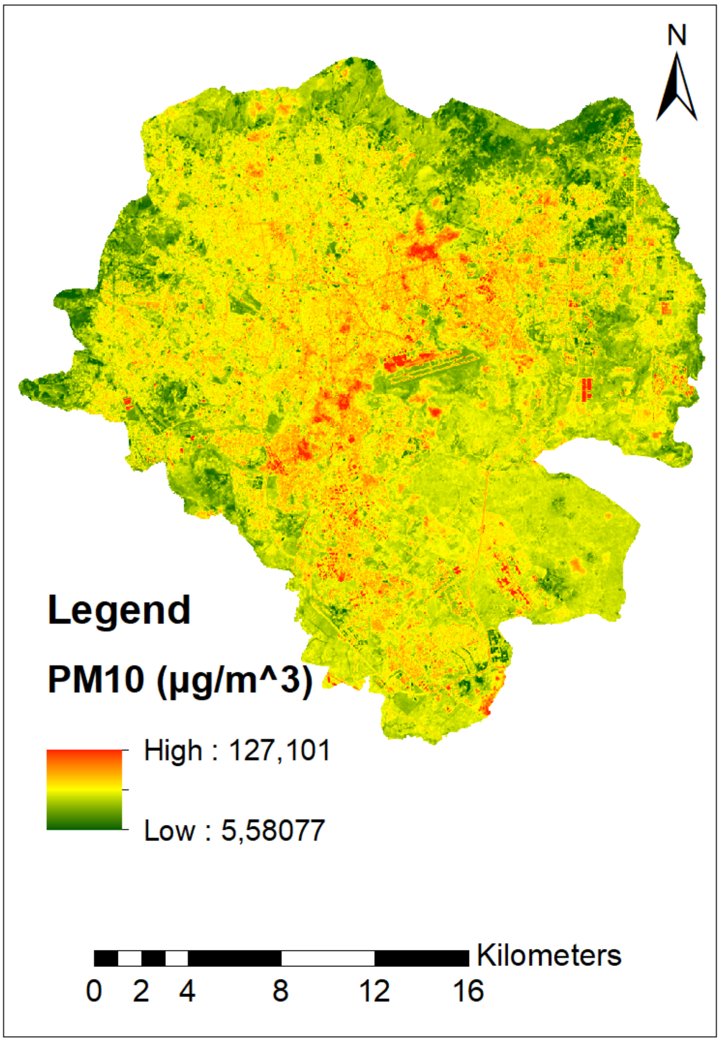


Figure. 4.14 Annual mean concentration of PM10 $(\mu g/m^3)$

Thus the result shows that the concentration range is between $5-127\mu g/m^3$. In all month the maximum PM10 concentration value is quantified nearby road network, airport station, and industrial palaces. A similar result was obtained nearby roads in two previous studies using ground measurement techniques in 2004 and 2010 for the city (Etyemezian et al., 2005; Gebre et al., 2010). On the other hand, the minimum concentration value identified at nearby forest zones which is northern and western part of the study area and a similar result obtained by the earlier study (Etyemezian et al., 2005). The central part of the city has both maximum and minimum value. Generally, 95% of the study area annual mean concentration value is below $50\mu g/m^3$, 4.09% is range between $50-100\mu g/m^3$ and 0.01% of the area is $100-127\mu g/m^3$. Based on U.S Environmental Protection Agency air quality index (AQI) standard, the result annual mean concentration value laid on three categories which are $0-50\mu g/m^3$ is good, $51-100\mu g/m^3$ is moderate, and $101-150\mu g/m^3$ is unhealthy for a sensitive group. However, some of the study areas exceed from $100\mu g/m^3$ which affect some groups.

4.5.3 Result maps for slope and Euclidean distance

The slope result which calculated from Digital Elevation Model (DEM) shows that the slope value from the total area, 340.57 sq. Km or 66% is less than 10%, which means it is most suitable for construction. Also 84.52 sq. Km or 16% of the area is 10-15%, 65.70 sq. Km or 13% is the slope value between 15-25% and 28.7 sq. Km or 6% of the area slope value is higher than 25% which means not suitable because of challenging for construction and safety, and most of this area lies on the northern part of the city. The result shows that most of the study area slope value is suitable for school construction. The calculated slope map presented in Figure 4.15.

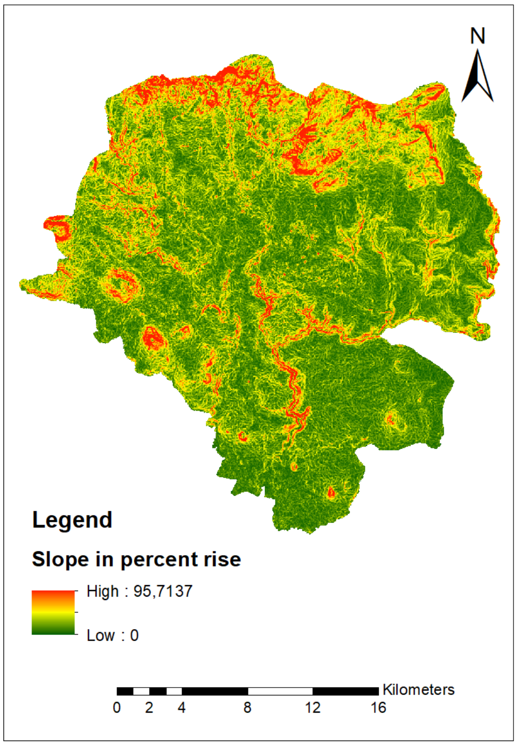
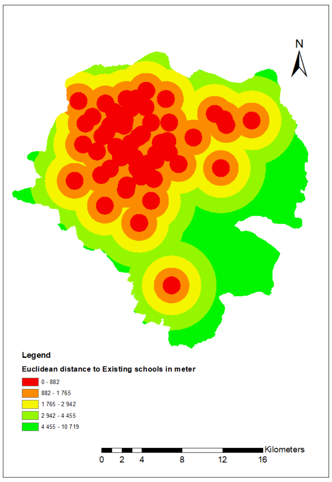
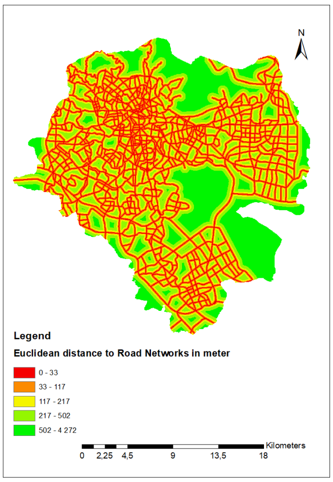


Figure. 4.15 Slope in percent rise

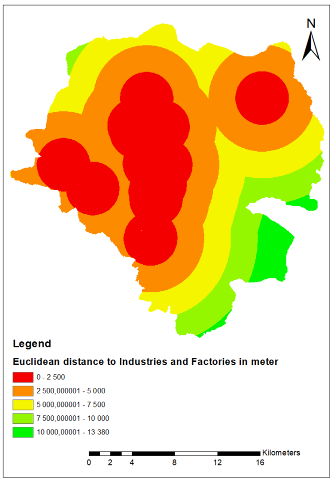
Euclidean distance calculated for eight criteria datasets. The result of proximity distance to existing school, road networks, river networks, high power transmission lines, industrial sites, commercial and religions, public libraries and emergency facility raster maps illustrate that each cell value represents the nearest distance to these criteria location. The result maps for Euclidean and slope presented in Figure 4.16.



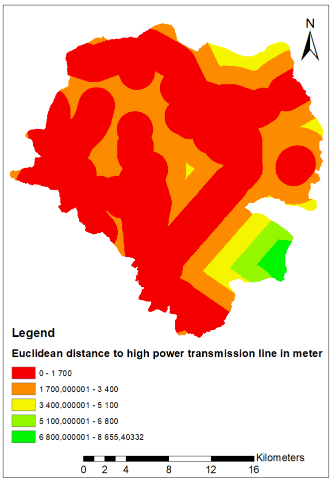
(a) Existing schools



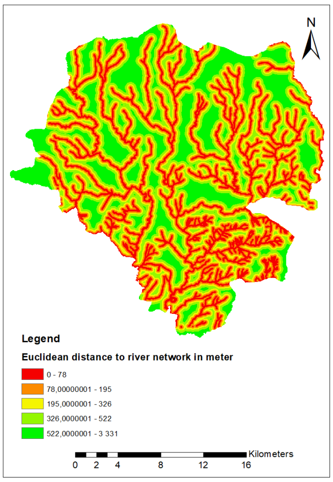
(b) Road networks



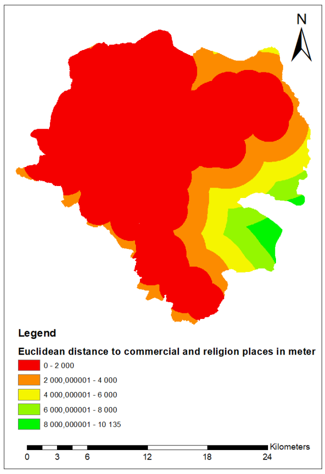
(c) Industries and Factories



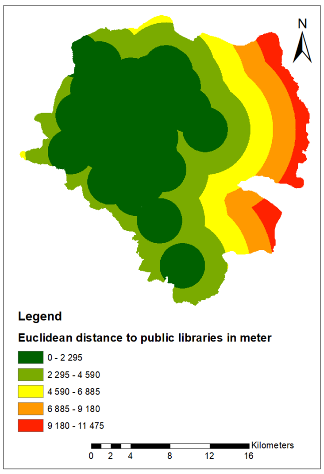
(d) High power transmission lines



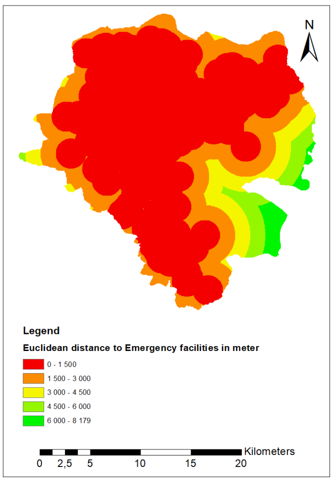
(e) Stream network



(f) Commercial and Religious places



(g) Public libraries



(h) Emergency facilities

Figure. 4.16 Euclidean distance maps

4.5.4 The result of reclassified criteria's maps

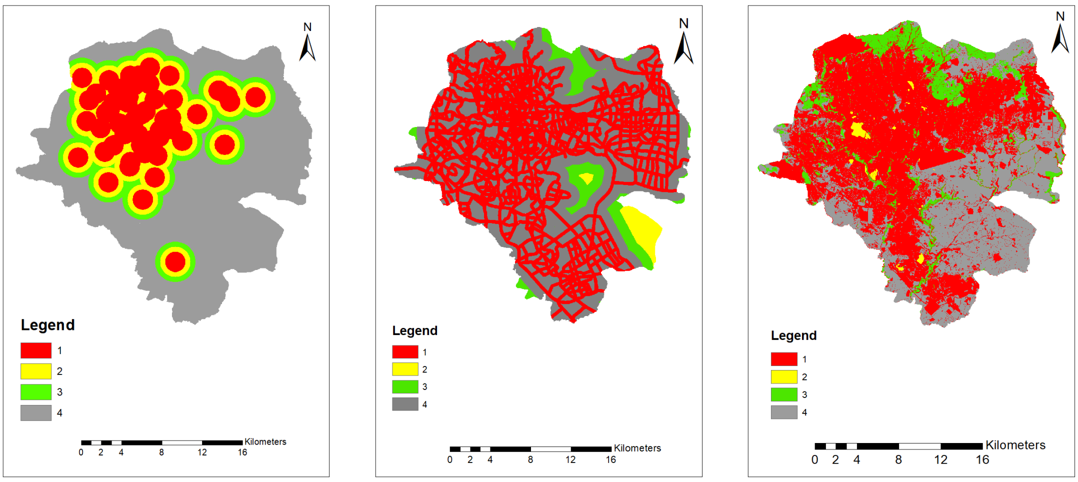
All criterion's map result of Euclidean distance, slope, land-use and the annual mean concentration of particulate matter (PM10) reclassified and ordered from most suitable to not suitable based on criteria's standard score which described in the methodology part in Table 3.9 using the reclassifying tool in Arc GIS. The result obtained from the reclassification maps described in the Table 4.7.

Table 4.7 Detail of classified criterion maps

Criteria's type	Classified raster cell value	Reclassification	Percentage coverage over all	Area of coverage in meter square
Land-Use	1	Not suitable	53.33%	276572826,62
	2	Less suitable	0.71%	3682105,88
	3	Suitable	10.15%	52638555,97
	4	Most suitable	35.81%	185712974,34
Existing school	1	Not suitable	22%	116561000
	2	Less suitable	12%	63153900
	3	Suitable	10%	51010200
	4	Most suitable	56%	288735000
Road network	1	Not suitable	51%	266863000
	2	Less suitable	2%	12002400
	3	Suitable	6%	31838400
	4	Most suitable	40%	208757000
Industries and Factories	1	Not suitable	2%	10797300
	2	Less suitable	2%	11375100
	3	Suitable	3%	14976000
	4	Most suitable	93%	482312000
Slope	1	Not suitable	6%	28696600
	2	Less suitable	13%	65696100
	3	suitable	16%	84516600
	4	Most suitable	66%	340574000
High power transmission lines	1	Not suitable	9%	45687600
	2	Less suitable	7%	36603000
	3	suitable	7%	33777900
	4	Most suitable	78%	403392000
Streams	1	Not suitable	34%	175545000
	2	Less suitable	24%	124396000
	3	suitable	17%	89310600
	4	Most suitable	25%	130208000

commercial and religious places	1	Not suitable	18%	95928300
	2	Less suitable	22%	113088000
	3	suitable	12%	62210700
	4	Most suitable	48%	248234000
PM10	1	Not suitable	0,01%	48600
	2	Less suitable	0,17%	900900
	3	suitable	4,93%	25591500
	4	Most suitable	95,90%	498190500
public libraries	1	Not suitable	43%	222312000
	2	Less suitable	16%	81125100
	3	suitable	22%	115530000
	4	Most suitable	19%	100493000
Emergency facilities	1	Not suitable	54%	281658000
	2	Less suitable	10%	49726800
	3	Suitable	14%	70828200
	4	Most suitable	23%	117248000

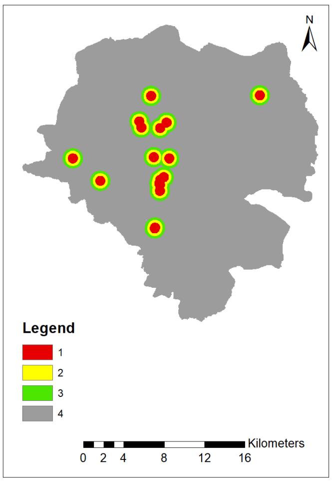
The result of reclassified criterion maps presented in Figure 4.17, 4.18 and 4.19.



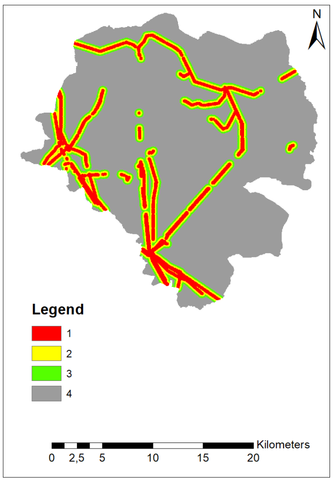
(a) Existing schools (b) Road networks (c) land-use

Figure. 4.17 Economy reclassified maps

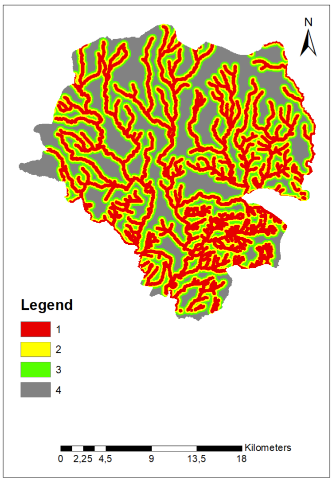
The reclassified existing school map shown in the Figure 4.17a demonstrates that from the total area of 22% is reclassified as not suitable, 56% is most suitable, and the rest 12 and 10% are less suitable and suitable respectively. On account of the existing school's location is close to each other, the unsuitable areas placed in one place which is the western part of the city, On the other hand, the most suitable areas located in eastern part of the city which is far away from existing schools location. In the case of proximity to a road, the reclassified map result presented in the Figure 4.17b, from the total area of 51% lied on not suitable, 2% is less suitable, 6% is suitable, and 40% is most suitable. In this study recommended the proximity distance standard adopted from the previous studies. Hence, the minimum and maximum proximity distance are 150 meters away from and should not exceed from 1000 meter from existing road networks. Adversely, the land use criterion is challenging to reclassify because of many land use types available, however, in this study the land which is already occupied by infrastructures such as Administration/Commercial/Cultural Social Welfare/Education/Health/Infrastructure and utilities/Mixed Residential/Municipal Service considered as not suitable. Field crop and Open space considered the most suitable. The result classified map which shows in Figure 4.17c, 53.3% and 35.81% of the area is not suitable and suitable respectively.



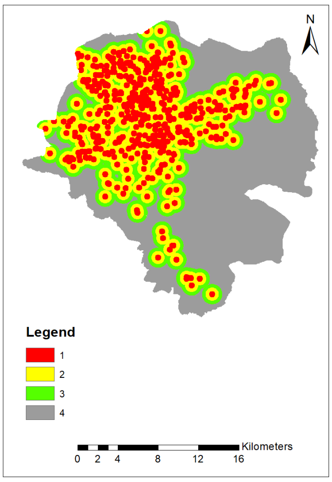
(a) Industries and Factories



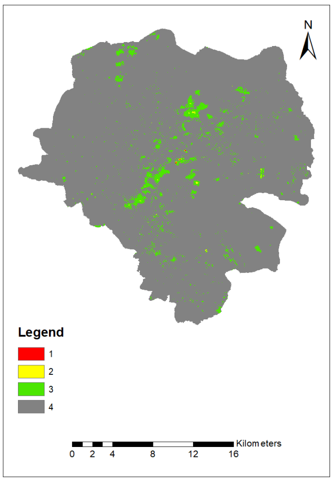
(b) High power transmission lines



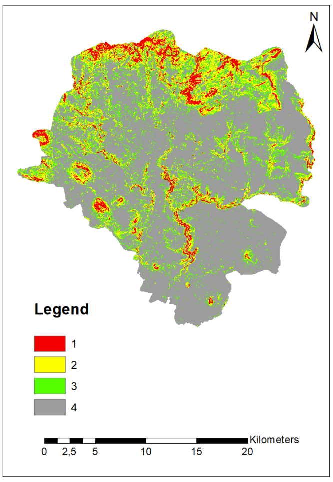
(c) streams network



(d) commercial and religious places



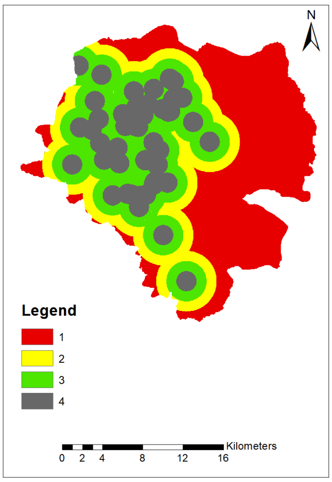
(e) Annual PM10



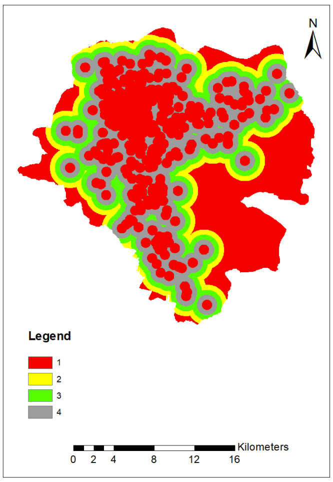
(f) Slope

Figure. 4.18 Safety and Environment reclassified maps

In regarding closeness to an industries and factories sites, the resulting map shows in the Figure 4.18a, illustrates a vast amount of land is classified as the most suitable because of a few industries exist in the city. The result shows that from the overall land 93% of the area is classified as most suitable, 2% is not suitable, and the rest 2% and 3% categorised as less suitable and suitable. Even if most of the area is convenient regarding these criteria but, the PM10 concentration value nearby industrial sites are high. Therefore, new school sites should not be placed near to these sites. Similarly, the reclassified map of High power transmission lines criteria in the Figure 4.18b, demonstrates that 78% of the total area is most suitable and placed east part of the city and 9% is not suitable the rest 14% categorised as suitable and less suitable. Another factor criteria are a stream, between 0 – 450-meter buffer distance suggested by both previous studies, (Bukhari et al., 2010; Talam and Ngigi, 2015). In this study, the minimum distance from steams is 150 meter and higher than 450 meters considered as most suitable. Hence, the result shows in Figure 4.18c from the total land of 34% is not suitable, and 25% is most suitable. In reviewing the proximity distance to commercial and religious places, 250 – 1000 meter and 500 – 1500 meter is the suggested minimum, and maximum distance by previous studies (Bukhari et al., 2010; Jayaweera, 2016). In this study the distance with less than 250 and higher than 1000 meters considered as not suitable and most suitable respectively. The reclassified result shows in Figure 4.18d, the total area of 48% are most suitable, and 18% is not suitable. The annual PM10 reclassified map shows in Figure



(a) public libraries



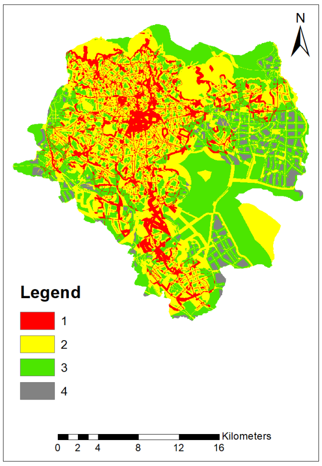
(b) Emergency facilities

Figure. 4.19 Accessibility reclassified maps

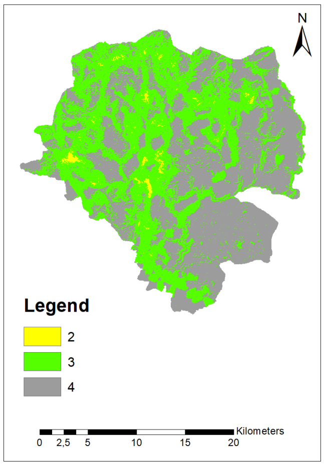
Distance from a public library and emergency facilities reclassified maps result shows in the Figure 4.19 most of the land is not suitable for both criteria because of the existing libraries and emergency facilities are few and placed in a central part of the city.

4.5.5 Weight overlay result maps

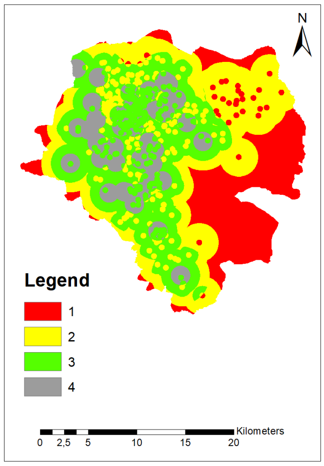
The criterion's weight obtained from AHP and classified maps were integrated using weight overlay tool to yield the suitability map. Therefore, the economy map created by combining the existing classified school, road and land use criterion maps. The result shows in Figure 4.20.



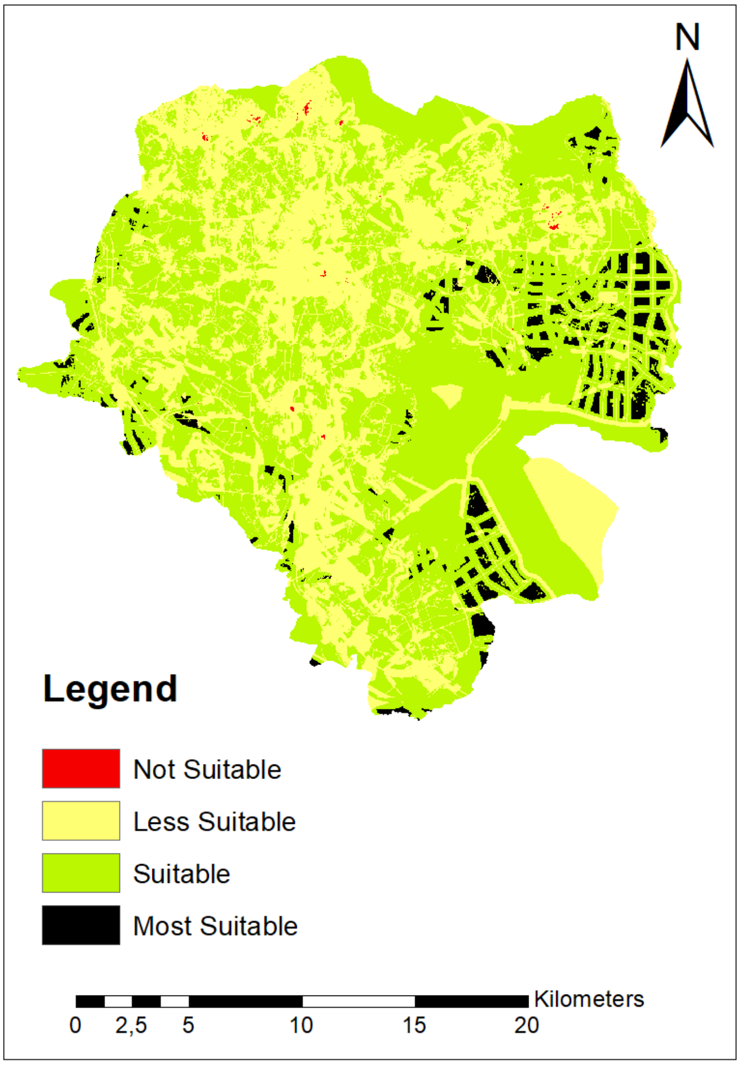
(a) Economy map



(b) Safety and environment map



(c) Accessibility map



(d) Final suitability map

Figure. 4.20 Weight overlay result maps

The result of Economy map which shows in the Figure 4.20a, demonstrate that a small amount of land identified as the most suitable and not suitable, in contrast, the large part of the area placed on less suitable and suitable. From the total area of the land, only 5% is most suitable, 39% is less suitable, 41% is less suitable, and 15% is not suitable. Oppositely, the result of safety and Environment map illustrates in Figure 4.20b that no land classified as not suitable also a small amount of area is laid on less suitable. Moreover, the rest land classified as suitable and most suitable. In regards, accessibility map results illustrate in Figure 4.20c small part of the area is identified as most suitable which is 12%, 31% is suitable, 33% is less suitable, and 24% is not suitable.

Finally, by combining the three main criteria based on their relative weights, it was able to obtain the final suitable places. Considering the maximum weight value is assigned for an economy map which is 54% and followed by safety and environment 30% and the rest 16% is for accessibility. The result of the suitability map shows in Figure 4.20, from the entire part of the land 0.4 sq. km (0.08%) is not suitable, 199.6 sq. Km (38.48%) is less suitable, 57.54 sq. Km (57.47%) is suitable and 20.2 sq. Km (3.89%) is the most suitable. The unsuitable areas scattered throughout northern, south-west and central part of the city. Also from north to south and western part of the city is laid on less suitable. Similarly, a suitable area scattered throughout in all direction. The most suitable areas prevalent north-east, the south-east and western part of the city, from the total suitable area15% laid on the western part of the city, and the rest 85% is prevalent on the eastern part.

The selected most suitable areas satisfy the minimum requirement of the criterion's standard which stated in Table 3.9. Thus, 89% of the most suitable area placed 2 km apart from existing school, 93% of the area is not located within 150 m proximity distance to road networks which means it fulfilled the criteria standard. Similarly, 88% of the selected land satisfied the requirement of proximity distance to commercial and religious places. In regarding proximity to streams, 72% of the most suitable area is placed 450 m away from these streams. Moreover, 96% of the designated land slope is less than 10% which implies a covenant for construction. Likewise, regarding air pollution, the PM10 value for the chosen are less than $50\mu g/m^3$ which is categorised as well based on the U.S Environmental Protection Agency air quality index (AQI) standard. In the case of proximity to high power transmission lines and industrial places, 81% and 97% of the selected area meet the required proximity distance standard. The designated most suitable areas do not meet the required result in regarding proximity distance to emergency and public libraries, due to minimum relative weight is given for this criterion.

There were many limitations in this study due to lack of data-sets which may improve the result of the present study. The following are suggested data-sets that should integrate into future studies.

1. Soil type map.

2. Population density map

3. High resolution satellite image

4. Traffic flow data for road networks

5. Proximity to Flood prone map

6. Amount of discharge for streams.

7. Expertise and decision makers preference value for pairwise comparison

4.6 Summary

This chapter outlined the case study area of Addis Ababa, Ethiopia, which is the capital and largest city in Ethiopia. Besides, it is headquarters of the United Nations Economic Commission for Africa (ECA) and African Union (AU). The chapter describes datasets for a criterion is collected from Addis Ababa Integrated Land Management Bureau and USGS web site. Also, data preparation for criterion and main findings are briefly described. Results from AHP shows that the Economy group weighted the highest value which is 54% and followed by safety and environment 30%, and accessibility 16%. Similarly, the Air pollution model result shows that the maximum annual mean PM10 concentration value is quantified nearby road network, airport station, and industrial palaces. Also, the ultimate suitability map shows that 3.89% of the study area is most suitable, 57.47% is suitable, 38.48% is less suitable, and 0.08% is unsuitable. Therefore, in this study successfully suitability model has been developing to allocate an optimal place for new schools to be built in Addis Ababa capital using Remote Sensing and GIS integrated with MCDA.

CHAPTER FIVE

CONCLUSION

5.1 Introduction

The final comments on the study are presented in this chapter, providing a summary and conclusion of the research attempt. The study gives a highlight of its contribution to the field and its limitations. Suggestions are made concerning perspectives that could be investigated in future research, particularly for Air pollution modelling.

5.2 Summary and Conclusion

The present study was designed to determine the optimal site for new schools construction in Addis Ababa using GIS integrated MCDA with Air pollution model input. The importance of this research is highly substantial because of the city's population growth and the need for additional schools. Most of the desirable area placed on the eastern part of the city, where there are no existing schools, and it is adjacent to residential places. In this research study, air pollution modelling was conducted using Landsat 8 satellite image to identify optimal school sites and considering a permissible PM10 value as per the standard. The result of air pollution modelling illustrates that even if most of the area PM10 concentration value is below 50 $\mu g/m^3$, conversely, the most remainder area which is a nearby road network, airport, and industrial places are above 100 $\mu g/m^3$. According to the United States Environmental Protection Agency, the values above 100 $\mu g/m^3$ is categorised as unhealthy for sensitive groups. Thus, proximity to roads, airports and industrial sites are essential criteria for school selection process to ensure pupil's health and comfort. Air pollution model integrated with GIS was useful to describe improved weight, unlike pre-decided values.

The use of MCDA, GIS, and remote sensing techniques with air pollution model input was successfully demonstrated for the site selection process. While using pairwise comparison in AHP, it is essential to carefully assign preference scores for criterions in comparison, in this study the selected most suitable site's proximity distance to public libraries and emergency facilities did not meet the required result. The main reason is that the list preference scores were given to this factor criterions in the comparison and result in less relative weight. Therefore, the availability of many expertise and decision makers' in the criterion comparison process is significant to avoid bias. The proposed method in this research is economical, less time consuming and more productive than the traditional approaches to potential site selection for locating new schools. In this case, planners and decision-makers can reduce field visits and surveys. The other significant feature of this research is the capability to identify all the options at the same time.

5.3 Recommendation and future research scope

The analytical method of this research is more flexible and is a comprehensive approach to school site suitability assessment. Therefore, it has the possibility to change the present criteria and their corresponding relative weighted values. The considering criteria for the model must be different according to the geographical background of the study area. Some new criteria should be affected to the result such as population density, soil type and streams discharge and other new conditions which have not been considered in this study. Therefore, this possibility of changing parameters has many benefits for the future developments of the model. Ethiopian ministry of education has not pointed out criterions regarding school site selection. Therefore, this research study gives insight for the decision makers and planners to incorporate such scientific analysis for site selection process to ensure sustainable land planning and management.

This study may be expanded by collecting and analysing various criterion such as population density, soil type, steams discharge, traffic ow data for road networks, expertise and decision makers preference value for pairwise comparison and flood-prone map. Also, high-resolution satellite imagery and other air pollutant's ground measurement data for the study area will be incorporate to Air pollution modelling. Development of graphical user interface and improved approach in MCDA with regards to the calculation of relative weight while integrating air pollution model may also be considered for future research.

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