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FACULTY OF GEOSCIENCES AND ENVIRONMENTAL STUDIES
DEPARTMENT OF GEOMATIC ENGINEERING

A THESIS REPORT ENTITLED

SELECTION OF SOLID MINE WASTE DUMP SITES USING GIS AND MULTI-CRITERIA DECISION TECHNIQUES (AHP-TOPSIS): CASE STUDY AT THE GHANA MANGANESE COMPANY LIMITED

BY

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN GEOMATIC ENGINEERING

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AUGUST 2023

DECLARATION

I declare that this thesis is my own work. It is being submitted for the degree of Master of Science in Geomatic Engineering in the University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination in any other University.

………………………………………………

(Signature of student)

Submitted on this ………….. day of…………..…..2023.

ABSTRACT

The traditional methods used in selecting mine solid waste dump sites within the Ghana Manganese Company Limited Concession (GMCL) has some limitations which include encroachment on human settlement and utilities and depletion of water bodies. Due to this, modern technology and decision making techniques were employed in selecting new mine solid waste dump sites within GMCL concession to replace the existing dump site which is close to its full capacity. The research sought to select appropriate sites for mine solid waste dump using Geographic Information System (GIS) integrated with Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarities to Ideal Solutions (TOPSIS) and to do a comparative analysis on the sites selected by GIS and criteria with equal importance, GIS and criteria with different weights obtained from AHP and GIS combined with weighted criteria from AHP and alternatives ranked by TOPSIS. Nine alternatives were selected within the GMCL concession of which the first alternative closer to the active mine production site was chosen as the most suitable site. GIS overlay analysis based on criteria of equal importance yielded a generalised map useful only for preliminary analysis. GIS integrated with AHP and TOPSIS produced a suitability map which is in the interest of stakeholders. Since the TOPSIS ranks alternatives based on the closeness of the alternatives to the ideal suitable site. It does not only rank based on criteria with higher weights but rather criteria with higher weights that are closer to the ideal site.

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DEDICATION

I dedicate this research to my family and my wife.

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My utmost thanks goes to the Almighty Lord for his unending mercies towards me.

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CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Mining is the process of excavating the earth to extract minerals in their natural state (Down and Stocks, 1977). It is less important only to agriculture globally. It ranks as the fifth largest industry in the world and it has greater impact on the global economy (Amponsah-Tawiah and Dartey-Baah, 2011). Most ores are hidden in the earth and through mining operations, they are exploited either by the use of open cast or underground methods (Baffoe and Suleman, 2017). Before the ore is mined using open cast method, the overburden is stripped-off to reach the ore body. Extraction, beneficiation and processing of the ore in order to obtain the precious minerals are the main sources of mining waste production.

In designing waste dumps, several range of criteria must be considered simultaneously. However, there are few standard models which combine these criteria for selecting sites for waste dump (Baffoe and Suleman, 2017). The various criteria must be clearly defined and used to determine and rank suitable sites at an early stage of decision making (Hawley and Cunning, 2017). Earlier studies such as; Hawley and Cunning, (2017); Baffoe and Suleman, (2017); Hekmat *et al.* (2008), considered some criteria and sub-criteria in their studies which include: regulatory, mining, environmental, topography, geology and geotechnical factors.

The first step in a mine solid waste dump design is to locate a suitable area for the facility based on the factors identified. This is an important stage that ought to be critically examined as it can impact on successive stages. A bad area selection can delay the design and time to apply for a permit. Multi-criteria Decision Analysis (MCDA) tools together with Geographic Information System (GIS) have recently been used to identify and select potential waste disposal sites in different locations (Mussa and Suryabhagavan, 2019). MCDA tools can combine the chosen site’s performance over several criteria and results in a solution requiring a consensus, whiles GIS is able to manipulate, analyse and display spatially referenced data and complex queries (Malczewski, 1990; Malczewski and Rinner, 2017; Jozaghi *et al.*, 2018; Ali *et al.*, 2020).

Ghana Manganese Company Limited (GMCL) currently has only two solid mine waste dumps. These include a soft dump (overburden) and a ballast dump (waste rocks). Both are almost at their full capacity. These locations were chosen for the solid mine waste disposal based on experts and management's understanding of operations cost and benefit analysis. Some of the challenges posed by the current dumps include: encroachment of public space and utilities, regular filling of waterbodies and proximity to nearby communities. These problems could be curtailed if modern technologies and decision making techniques were considered. Geographic Information System (GIS), Analytic Hierarchy Process (AHP) and Technique for the Order of Preference by Similarity to Ideal Solutions (TOPSIS) have been widely used by researchers for various purposes.
GIS is capable of undertaking spatial analysis for the selection of suitable site and has therefore been used to solve problems related to suitable site selection. These include; mine waste dump sites selection (Suleman and Baffoe, 2017), Check dam site selection (Padmavathy *et al.*, 1993), Suitability site selection for urban development (Jain *et al.*, 2007) and Land-use suitability analysis (Malczewski, 2004). Although GIS has proven to be an important engine in solving spatially related problems (Peprah *et al.*, 2018), its capabilities in conjunction with MCDA techniques have been employed in solving numerous problems in the geospatial environment. Some site suitability analysis using GIS include; Dam site selection (Jozaghi *et al.*, 2018 and Hagos *et al.*, 2022), Oil and gas site selection (Peprah *et al.*, 2018), Mine waste dump site selection (Baffoe and Sulemana, 2017) and Landfill site selection (Osra and Kajjumba, 2020).

There are several MCDA techniques. Neither of the methods give perfect solutions nor can they be applied to all problems. Each method has its pros and cons (Ishizaka and Nemery, 2013). The selection of a method is influenced by its usability, accuracy, degree of decision-maker's knowledge, theories supporting it, accessibility of computer software, and ability to be included into GIS-based multi-criteria decision analysis (Malczewski, 1999). AHP is scalable and the pairwise comparison makes the weighting of criteria easy for decision makers. It has therefore been applied in several site selection research works (Jozaghi *et al.*, 2018; Shaikh *et al.*, 2020; Ali *et al.*, 2020 etc.) but has been criticised on it proneness to inconsistencies in ranking and decision making (Velasquez and Hester, 2013). Topsis on the other hand measures distances concurrently to the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) and an order of preference is determined based on how close these solutions are to each other. Jozaghi *et al.*, (2018); Onut *et al.*, (2009) and Erdin and

Akbas, (2019) hails the ranking of alternatives by TOPSIS but the TOPSIS method is also criticized for depending on other techniques to weight criteria.

This research therefore aims at selecting solid mine waste dump sites using GIS, AHP and TOPSIS at Ghana Manganese Company Limited (GMCL).

1.2 Objectives of Research

The research objectives are to:

- Select appropriate sites for mine solid waste dump sites ; and
- Compare the suitability maps generated from the various methods used.

1.3 Methods Used

- The (TOPSIS) method was used to rank Multi-Criteria Decisional Alternatives based on the shortest distance from the ideal solution and the farthest from the negative ideal solution;
- AHP was also used to determine weights of various criteria (including that of the TOPSIS method) and also decide on the best alternative for decision makers; and
- GIS weighted Overlay Analysis was used to integrate the AHP and TOPSIS models into geographic visualization.

1.4 Facilities Used for Research

- ArcGIS Software (Version 10.5) from the Geomatic Engineering Department ,UMaT, Tarkwa;
- The UMaT Geomatic Engineering GIS laboratory
- Topographical Map of the Mine Site from Ghana Manganese Survey Department.
- ASTER Digital Elevation module obtained from USGS Earth Explorer.

1.5 Organisation of Thesis

This report is made up of six chapters. Chapter 1 is the introduction and it includes the statement of problem, the objectives, the methods and the facilities used. Chapter 2 provides relevant information about the study area and Chapter 3 presents the literature review of the work. Chapter 4 details the materials and methods used in carrying out the thesis. Chapter 5 presents and discusses the results obtained. Chapter 6 is the conclusion and recommendations.

CHAPTER 2

RELEVANT INFORMATION ABOUT THE STUDY AREA

2.1 History of the Mine

Albert Ernest Kitson, a British Australian mining engineer and colonial official discovered Manganese in Ghana during the Western Rail Line construction in 1914. Mining activities commenced in 1916 by Wassa Exploration Syndicate and the Fanti Consolidated Mines Limited. The African Manganese Company Limited, a division of the Union Carbide Corporation, USA was established to operate the mine in 1923. In the subsequent years the mine was developed into the only most productive manganese mine in the world (Kesse, 1985).

In the year 1973, the government of Ghana became the owner of the mine. The Ghana National Manganese Corporation was formed to operate the mine for more than 22 years. In accordance with the general policy of national economic recovery and privatisation of state owned enterprises, Ghana International Manganese Corporation (GIMC) acquired the mine in November 1995 and Ghana Manganese Company Limited (GMCL) was formed to privately run the mine (Nyame, 1998).

2.2 Location

The Ghana Manganese Company Limited (Nsuta mine) is an Open cast mine that is located in Nsuta-wassa and its neigbouring environs. It can be found in the Tarkwa Nsuaem Municipal but the whole mine concession expands to some parts of the Prestea Huni-valley district which was initially the Wassa-West district. It can be found in the western region of Ghana. The mine is about 4 km south-east of Tarkwa township. It lies on the Takoradi – Kumasi railway line, about 60 km inland from the port of Takoradi by rail and 80 km by road. Figure 2.1 shows map of the study area.

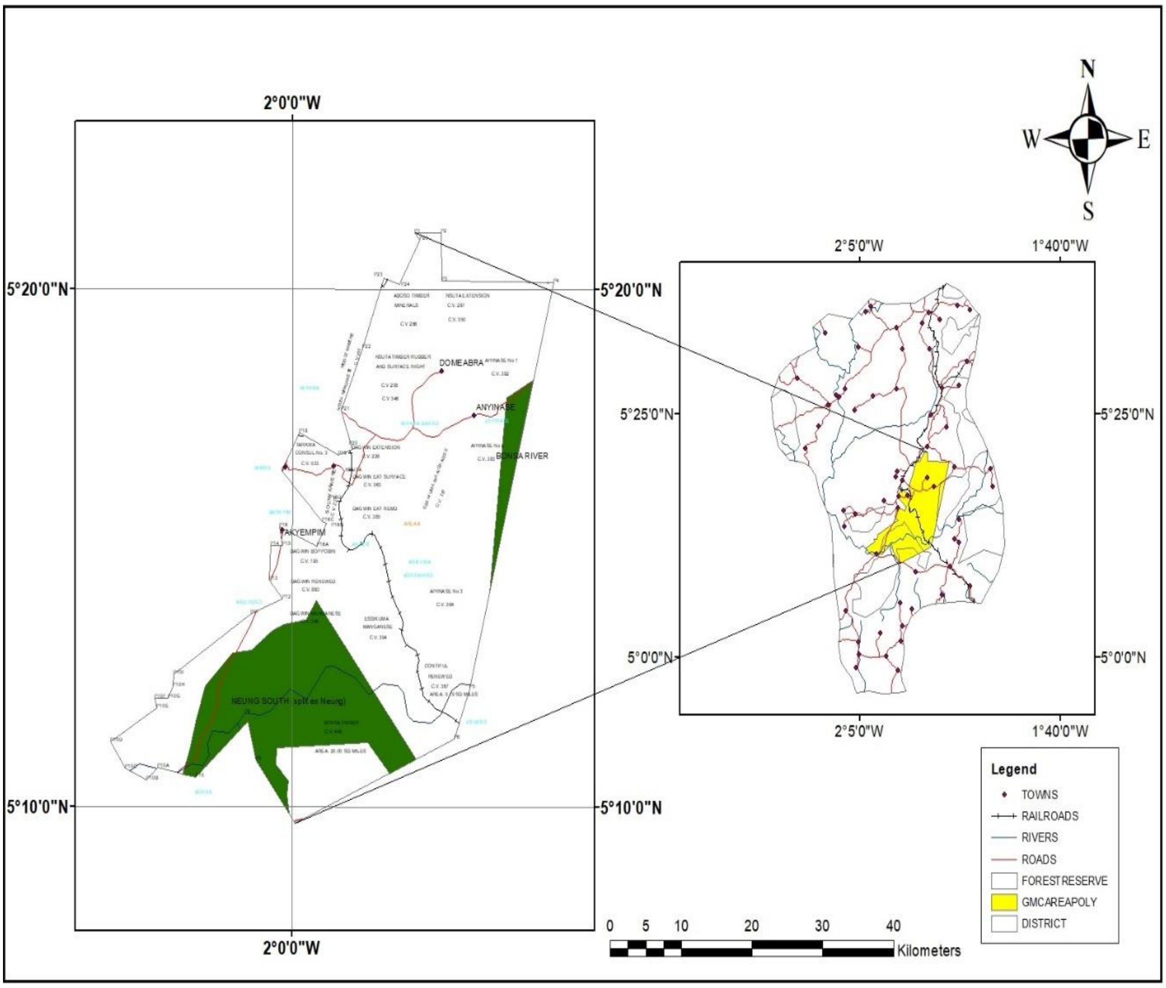

Figure 2.1 Map of GMCL Concession

2.3 Climate

The South-Western Equatorial climate zone encompasses GMCL. The temperature of the area ranges from 26 °C in August to 30 °C in March. Seven hours per day of sunshine are present annually. Throughout the year, relative humidity is often high, ranging from 70 to 80 percent in the dry season and 75 to 78 percent in the wet season (Quansah *et al.*, 2011). The major rainfall season, which runs from March to September, has a twofold maximum rainfall with an average yearly rainfall of 1500 mm. The north-east trade winds blow over the regions between November and February, and extremely dry conditions result (Anon., 2014).

2.4 Vegetation

The Ghana Manganese Mine Concession encompasses part of the Bonsa forest Reserve to the east and part of Neung South reserve to the south. These reserves have average heights ranging between 15 and 40 metres high forming wide canopies (Anon., 2014). These reserves contain economically viable trees like mahogany, wawa, odum, and sapele. Most of the forest zones within the concession have been reduced to herbs and bushes due to settlement (encroachment), farming and mining operations.

2.5 Geology

2.5.1 Regional Geology

The Nsuta Manganese deposit is found on the eastern edge of the Southern Ashanti Belt in the Birimian Supergroup. The Paleoprotozoic domain of the West African Craton contains remnants of the Archean basement, the Man Shield, and the Archean core (Milesi *et al.*, 1992). Individual volcanic belts are separated from one another by metasedimentary basins that can be up to 200 km wide and extend for about 500 km in a NE-SW direction. While the metasedimentary basins contain sedimentary rocks such as volcanoclastic, wackes, and argillites, the volcanic belts are composed of metamorphosed volcanic rocks that range in composition from tholeiitic to calc-alkaline (Kesse, 1985). These volcano-sedimentary strata are known as the Birimian Supergroup which was deposited between 2180-2170 Ma. The volcano-sedimentary package of the Birimian sequence is unconformably overlain by the younger (2132±3 Ma) sedimentary rocks (conglomerates and sandstones) of the Tarkwaian Basin (Taylor *et al.*, 1992).

The Birimian Supergroup is a viable source of gold, diamonds and manganese for commercial purpose. Chemical sedimentary rocks are relatively minor constituent within the Supergroup but contain the large volume of manganese carbonates (Eisenlohr and Hirdes, 1992). The overlying Tarkwaian Group contains auriferous conglomerates. It consists of a thick series (1800 m-3000 m) of argillaceous and arenaceous sedimentary rocks with two well-defined zones of auriferous conglomerates in the lower formation of the succession (Bart, 2001). The conglomerates are thought to be alluvial fan deposits with associated braided stream channels. Both groups of rocks are intruded by pre- and syn- to post tectonic granitoids of calc-alkalic and alkalic varieties (quartz diorite, tonalite, granodiorite, quartz monzonite and granites) (Leube *et al.*, 1990). Post-tectonic granitoids characteristically contain phenocrysts of alkali feldspar (Leube *et al.*, 1990; Eisenlohr and Hirdes, 1992).

The Ashanti Belt is bordered by the Kumasi Basin to the northwest and by the Cape Coast basin to the southeast, both filled with Birimian sedimentary rocks (Fig. 2.4). Regional metamorphism and structural deformation occurred during the Eburean tectonothermal event (Taylor *et al.*, 1988; Hirdes *et al.*, 1992; Milesi *et al.*, 1992; Vidal and Alric, 1994) which affected the entire West African Craton. Overall, the Southern Ashanti Belt has a synclinal structure with the Tarkwaian Group in the core of the syncline (Eisenlohr and Hirdes, 1992; John *et al.*, 1999). Lithologies within the Ashanti Belt dip steeply and strike to the northeast. The northwestern margin of the belt is strongly tectonised and displays a well-developed cleavage and steeply plunging stretching lineations, and here the Birimian rocks are thrusted over the Tarkwaian Group in an oblique manner (Eisenlohr and Hirdes, 1992).

Folding in the Tarkwaian Group is mostly isoclinal in the northwest but is openly folded around Prestea and Tarkwa located west of Nsuta manganese mine (Fig. 2.4) (Eisenlohr and Hirdes, 1992). These folds emerge at the Ashanti Belt's center, where they are briefly reversed to create a number of antiforms and synforms that moderately dip to the northeast (Hirdes *et al.*, 1992). With reference to fold and thrust structures in the Birimian Supergroup, it is known that the Nsuta deposit is situated in an area of northward plunging synclinal and anticlinal structures that are pre- and post-Tarkwaian in age. To the west of the Tarkwaian, a series of overturned synclines and anticlines are associated with westerly dipping thrust faults (Eisenlohr and Hirdes, 1992).

2.5.2 Local Geology

The Nsuta mine consist of hills which are interconnected by saddles ranging in height from 120 m to 180 m above sea level. The major feature in the area is abrupt change in the nature of the country rocks at the boundary between the Birimian and the Tarkwaian systems (Leube *et al.*, 1990).

The deposit is situated on five hills (known as Hills A-E from south to North). These hills contain the manganese horizon. They exist as a result of resistance to weathering of the volcanic tuffs and argillites compared to the surrounding mass of “greenstone”. Cross-faulting has caused marked breaks in the continuity of the ridges with substantial displacement between the hills from A – C North (Hirdes *et al.*, 1992).

CHAPTER 3

LITERATURE REVIEW

3.1 Mine Operations

GMCL operates by the open cast method. The procedure include; drilling, blasting, loading and hauling with fleet consisting of excavators and dump trucks, dozers, front end loaders, water tankers, wheel dozers and graders. The overburden and waste rocks are stockpiled at designated area to be used during reclamation and rehabilitation (Coffie-Anum, and Bansah, 2016). The ore is crushed and screened to various sizes and grades as specified by clients. It is then stockpiled for transportation by rail and road to Takoradi Port in the Western Region of Ghana for export.

3.2 Mine Waste Management

Extraction of minerals and ore processing generate huge amount of waste. Almost 99% of waste is produced in the extraction and processing of precious metals (Vriens *et al.*, 2020). Blasting and hauling of extracted materials generate waste stockpiles such as debris, soil, and waste rocks. These wastes which are of lesser importance are dumped in heaps within the mine concession and at times within the catchment community lands during the life of the mine. The amount of waste materials produced increases with the size of the mine. When waste rocks are not managed well, it accumulate acids, metalloids and other impurities that negatively affect the environment (Vriens *et al.*, 2020). Generally, mining activities directly or indirectly affect the environment; these include air, water and noise pollution. Some socio-cultural challenges associated with mining activities are land and forest degradation, disposal of hazardous elements from solid and liquid mine waste into water bodies among others (Jain and Das, 2017). The removal of mine waste from some mining regions results in suspended dust from the waste dumpsites, which pollutes the environment and has an adverse impact on the health of both onsite employees and the residents within the buffer distance (Fernando and Claudio, 2020).

According to Hawley and Cunning (2017), mine waste dump is one of the most dangerous structures that has caused the loss of many lives. More than thousand people have been killed by failed waste dumps in the past 80 years. This shows that mine wastes needs to be monitored, controlled, disposed safely and selected carefully (Shariati *et al.*, 2014). Mine waste dump site selection is a major component in waste dump design. It therefore needs to be critically considered since it can have a major effect in the design process (Hawley and Cunning, 2017). Due to the perennial nature of a waste dumpsite, it is very important to consider the geotechnical, geological, hydrological and environmental impacts of the dump site throughout the long term period. In view of this, it is prudent to select a site which has strong foundation and the waste dump site design must fit the technical, ecological and economical viewpoints. Site selection in the past was quite simple, since only cost estimate was the criterion for iteration (Hekmat *et al.*, 2008). But selecting waste dump site locations these days is a herculean task involving several contradicting criteria (Shariati *et al.*, 2014). This has made the selection of waste dump site a complex practical challenge with several interest groups and criteria. The criteria such as environmental, economic and safety issues among others can also be divided further into sub-criteria (Shariati *et al.*, 2014). This therefore makes the selection of mine waste dump sites a multi-criteria decision making (MCDM) problem.

3.3 Multi-Criteria Decision Making

Although there are traditional techniques in solving strategic problems, these techniques are modelled to solve only deterministic problems that are certain (Bushan and Rai 2004). However, most decision problems are stochastic and fuzzy in nature which cannot be solved entirely by modelling with the traditional decision making techniques.

While Chakar and Mousseau (2007) assumed that multi-criteria analysis commenced in the 1960s, Zardari *et al.* (2015) dates the idea of multi-criteria decision making to 1971. The purpose of MCDM is to give decision-makers a tool to help them advance in solving multi-criteria decision problems, where several factors are taken into consideration (Zardari *et al.*, 2015).

MCDA was developed to counter the single-criterion optimisation techniques, most notable is the linear programming. These were created during World War II and refined in the early stages of operations research, a business management discipline. The potential negative effects of several criteria issues were not taken into account in either circumstance (Green *et al.*, 2011). The ability of the MCDA to concurrently take into account both qualitative and quantitative criteria is one of its strongest points. The study of techniques and procedures by which numerous and various factors can be taken into consideration during the decision-making process is what the International Society defines as MCDM (Zardari *et al*, 2015). MCDM problems involve making choices that are evaluated with criteria that vary qualitatively and quantitatively. The criteria used for evaluating the alternatives are incommensurable and conflicting in nature (Malczewki and Reinner; 2015, Green *et al.*, 2011; Malczewski, 1999). Chakar and Mousseau (2007) also define MCDA as a decision-aid or mathematical tool that compares different alternatives in view of several criteria which conflicts with each other in order to help the decision maker to make the right choices. The main elements of MCDM problems are the Decision Maker(s), Choices/alternatives and evaluating criteria (Malczewki and Reinner, 2015).

3.3.1 Decision Problem

The decision problem have six components including:

- Goal;
- Decision maker;
- Evaluation criteria;
- Decision Alternatives;
- Decision Environment; and
- Outcome and consequence.

To analyse a multi-criteria decision problem, there should be a clearly defined goal which is real, measurable, agreed, specific and time dependent (Pearson and Philips, 2009). The goal in decision making stipulates the desired expectations of decision makers (Malczewski, 1999). Decision makers are pivotal in the decision making process. Decision maker is the one responsible in taking decision (Malczewki and Reinner, 2015). A criterion is a tool that allows decision makers to compare alternatives based on a particular point of view (Bouyssou, 2004). Decision alternatives are assessed using a set of criteria. To accurately depict the multi-criteria nature of the decision problem, both single and multiple criteria should have certain qualities (Malczewki and Reinner, 2015). Decision alternatives are various options for action from which the decision-maker must select (Chakar and Mousseau, 2007). The decision environment is made up of a number of uncontrollable factors or natural phenomena (Malczewski, 1999). The collection of criteria used to evaluate the alternatives has an impact on decision results as well.

Individual or group decision-maker problems, decisions under certainty or decisions under uncertainty, and multi-objective decision making (MODM) or multi-attribute decision making (MADM) are some categories for multi-criteria decision problems (Malczewski, 1999).

Discrete or Multi-Attribute Decision Making (MADM) deals with finite alternatives whiles Continuous or Multi-objective Decision Making (MODM) deals with infinite decision alternatives (Chakar and Mousseau, 2007). The goals, not the decision maker, are what are considered in both individual and group decision-making. No matter how many decision makers are actually involved, if there is only one goal-preference structure, the issue is referred to as individual decision making. On the other hand, the issue of collective decision-making arises when individuals (interest groups) have divergent goals or preferences. If the decision-maker is aware of the decision environment, clarity prevails during the decision-making process. The truth is that, making decisions can be risky and difficult to anticipate hence in reality decisions are taken in an uncertain environment (Malczewski, 1999).

3.4 Multi-Criteria Decision Methods and GIS

GIS has proven to be an important engine in solving spatially related problems (Peprah *et al.*, 2018). Its capabilities in conjunction with MCDA techniques have been employed in solving numerous problems in the geospatial environment. Some include: Dam site selection (Jozaghi *et al.*, 2018 and Hagos *et al.*, 2022), Oil and gas site selection (Peprah *et al.*, 2018), Mine waste dump site selection (Baffoe and Sulemana, 2017) and Landfill site selection (Osra and Kajjumba, 2020).

There are several MCDA techniques. Neither of the methods give perfect solutions nor can they be applied to all problems. Each method has its pros and cons (Ishizaka and Nemery, 2013). The selection of a method is influenced by its usability, accuracy, degree of decision-maker knowledge, theories supporting it, accessibility of computer software, and ability to be included into GIS-based multi-criteria decision analysis (Malczewski, 1999).

According to Velasquez and Hester (2013), the Multi-Attribute Utility Theory (MAUT) has an advantage of accounting for uncertainties but requires several criteria and preferences, and it must be precise and discrete. Although Case-Based Reasoning (CBR) does not require enormous data, it is very sensitive to inconsistent data. The AHP is scalable and the pairwise comparison makes the weighting of criteria easy for decision makers. Even though it requires more data to produce the pairwise comparison matrix, it does not require huge data as compared to the MAUT but due to the interdependencies of criteria and alternatives in the pairwise comparison matrix, the Analytic Hierarchy Process is prone to inconsistencies in ranking and decision making (Velasquez and Hester, 2013). The distances to the positive ideal solution (PIS) and the negative ideal solution (NIS) are measured concurrently by TOPSIS, and an order of preference is determined based on how close these solutions are to each other. The greatest option is also the option that is closest to the PIS and farthest from the NIS (Yue, 2010). It struggles to weight criteria and keeps consistency of judgment, especially with additional traits (Velasquez and Hester, 2013).

Several MCDM techniques have been exploited in recent years. Most methods have had some improvement but the combination of multiple methods answer inherent disadvantages of other methods. MCDM techniques are not mutually exclusive due to complexity in their usage and varied aspects in the MCDA techniques. For instance, one technique can be used in weighting the criteria whiles another method can be used in choosing from various alternatives (Green *et al.*, 2011). If their benefits and drawbacks are appropriately weighed, the combination of these strategies can be very effective in their applications. Most techniques, when properly integrated, can tackle issues that cannot be resolved by any one technique. (Velasquez and Hester, 2013).

3.5 Analytic Hierarchy Process

Thomas L. Saaty created and developed the AHP theory of measurement between 1971 and 1975. It is used to create ratio scales from paired comparisons that are continuous or discrete. These comparisons might be made on a fundamental scale that indicates the relative strength of preferences and feelings or on actual measurements (Saaty, (1987). Malczewski (1999) based Saaty's work on three principles. These include: decomposition, comparison analysis, and priority synthesis. According to the decomposition principle, the decision problem must be divided into a hierarchy that includes all of its key components. The pairwise comparisons of the items at each level of the hierarchical structure are necessary to apply the comparative judgment principle.

The weights of criteria determined by:

- The creation of the pairwise comparison matrix; the pairwise comparison of criteria is based on the expertise of experts regarding which criteria are significant in relation to the decision aim (Josaghi *et al.*, 2018). A numerical scale from 1 to 9 is used to quantify the relative relevance of two criteria, as indicated in Table 3.1.

Table 3.1 Scale of Relative Importance

Level of Importance	**Definition**	**Explanation**
1	Similar Importance	The goal is equally benefited by the two activities.
3	Weak importance of one over the other	One activity is marginally preferred over another by experience and judgment.
5	Important or very important	One activity is greatly preferred over another by experience and judgment.
7	exhibited importance	Strong support is given to one activity, and its dominance is evident in use.
9	the highest priority	The strongest argument in favour of favouring one

		activity over another is evidence.
2,4,6,8	Intermediate values between two adjacent judgements	When compromise is needed
Reciprocals of above non-zero	If activity I has one of the above non-zero numbers assigns to it when compared with activity j, then j has the reciprocal value when compared with i	

Source: Saaty, 1980

A pairwise comparison matrix created at random yields the random Consistency Index, as shown in Table 4.2.

Table 3.2 Random consistency index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, 1980

- Normalisation of the pairwise comparison matrix
- Computation of weight of the criteria
- Determination of the consistency vector
- Calculate the consistency index using ***Eqn* 3.1**

$$\mathrm{CI} = \frac{\lambda - \mathrm{n}}{\mathrm{n} - 1} \ldots\ldots\ldots\ldots \boldsymbol{Eqn\ 3.1}$$

λ= Average value of consistency vector.

n= Total number of criteria

CI= Consistency Index

- Finally the consistency ratio of the criteria weights was determined using ***Eqn* 3.2**
-

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}} \ldots\ldots\ldots \boldsymbol{Eqn\ 3.2}$$

CR= Consistency Ratio

CI= Consistency Index

RI= Random Consistency Index

3.6 Technique for the Order of Preference by Similarity to Ideal Solution

In 1981, Hwang and Yoon created TOPSIS. The technique is used to evaluate and rank a variety of options. The distance between each alternative and the positive ideal solution (PIS) or the negative ideal solution (NIS) is used to rank them (Jozaghi et al, 2018). By allowing collaboration across various criteria, TOPSIS makes it possible to make up for a poor performance in one criterion with a good outcome in another. TOPSIS has been used in several literature to select suitable sites for various designs (Erdin and Akbas, 2019; Shaikh et al, 2020; Jozaghi *et al*, 2018). The TOPSIS method include;

- Construction of TOPSIS decision matrix;
- Determination of weight;
- Normalisation of decision matrix using ***Eqn* 3.4;**

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum (X_{IJ})^2}} \ldots\ldots\ldots \boldsymbol{Eqn\ 3.4}$$

  R_{ij} = Normalised decision matrix

  Xij = Each element in the Table 4.3

- Calculation of weighted normalised decision matrix using *Eqn* 3.5;

$$V_{ij} = R_{ij} * W_j \ldots\ldots\ldots \boldsymbol{Eqn\ 3.5}$$

  V_{ij}= Weighted normalised decision matrix

  $W_{j=}$ Weights of various criteria

- Determination of Positive Ideal Solution (PIS= V^+) and Negative Ideal Solution (NIS= V^-);
- Calculate the separation distance of each alternative from the ideal and non- ideal solution;

$$S^+ = \sqrt{\sum (V_j^+ - V_{ij})^2} \ldots\ldots\ldots \boldsymbol{Eqn\ 3.6}$$

$$S^- = \sqrt{\sum (V_j^- - V_{ij})^2} \ldots\ldots\ldots \boldsymbol{Eqn\ 3.7}$$

S^+= Separation distance from PIS

S^-= Separation distance from NIS

- Calculate the relative closeness of each location to the ideal solution using;

$$C = \frac{\mathrm{S}_{\mathrm{i}}^{-}}{\mathrm{S}_{i}^{+} + S_{i}^{-}} \ldots\ldots\ldots \boldsymbol{Eqn\ 3.8}$$

C= Relative closeness of each location to the ideal solution

- Rank the order of preference according to the results from Eqn. 3.8.

In this thesis, the AHP was used in criteria weighting whiles the Geographic Information System's overlay analysis tools were used in determining the suitable alternatives. Finally, the alternatives were ranked by the Technique for Order of Preference by Similarity to Ideal Solution.

3.7 Choice of Criteria

The choice of criteria is as important as the selection of the site. The four main criteria considered for suitable site selection, namely mining, terrain, geotechnical and environmental factors are:

- Mining; the closer the waste dump site is to the active mine pit (source of waste material), the more economically viable the overall production. All other things being equal, sites that are closer to the open pit are aesthetically impressive compared with those sites that are remote. With cost being the prime factor for this criterion, access route and haulage grades were sternly considered. According to Hawley and Cunning (2018) and considering exhibits from stakeholders, the spatial attributes considered for this criterion include: proximity to map of the ore body (active pit), map of roads and a slope map of the area. Further studies clearly states that, Euclidean distances of 50 m – 500 m from the ore body is suitable for the site selection but distances < 50 m and > 500m are unsuitable areas for selection. Also areas 100 m farther away from roads are suitable to be selected. The gradient of the haul roads must be at most 10%
- Terrain and Geology; understanding the topography, geomorphology and geology of an area is a key factor in selecting suitable solid mine waste dump site. Waste

dumps located on level ground are easier to construct and more stable than those located on steep hills Site selection was thought to be influenced by having a thorough grasp of the bedrock geology of the area, including the lithology, weathering, stratigraphy, and regional structure. Sites with strong, fresh bedrock, favourable stratigraphy, and a stable structure are preferable to sites with weak or weathered or changed rocks, unfavourable stratigraphy, or unstable structures that could provide problems with foundation stability. Aside from that, it was thought to be crucial to comprehend the site's surface geology. The distribution and characteristics of both anthropogenic and natural deposits may have an impact on a site's suitability or how a site is developed. In view of these, the spatial attributes considered for this criterion were the topographical and Geology map of the study area.

- Geotechnical factor; the geotechnical factor includes any attribute that impact the total stability of the wastes dump site. These include the slope of the foundation, the type of overburden and its thickness. The slope of the foundation has a direct influence on the overall stability and general performance of the waste dump. Embankments constructed on steep foundations are much more likely to be unstable or perform poorly compared to those constructed on flat foundations. Overburden materials can have a substantial impact on the stability of a waste dump. For example weak and thin overburden such as organic soils and sensitive clays poorly affects the stability of the Waste dump. The spatial criteria for the geotechnical factor include the slope map of the study area and the soil type map of the area.
- Environmental factor; the environmental factor is one of the most important factors to be considered. The impact of mine waste dump on the environment can be disastrous if the right site is not carefully selected. Vegetation, waterbodies, human settlement and air pollution in the environment were critically considered in the site selection process. To account for such, the forest reserve map, settlement map and map of water bodies were the spatial attributes considered. A buffer distance > 200 m from waterbodies is suitable for siting mine waste dumps and distance >100 m is measured from all forest reserves. Also areas not less than 500 m from settlement are suitable for siting mine solid waste dumps.

CHAPTER 4

MATERIALS AND METHODS USED

4.1 Materials Used

The material used for this study comprises of dataset and software. Secondary dataset used for the study include maps on the following features: Mine Concession of Ghana Manganese Company, Soil types, Geology, Railroad, Rivers, Settlements and Road maps of the study area obtained from Ghana Manganese Survey department. The main software used is the ESRI ArcMap, and Global Navigation Satellite System equipment obtained from UMaT's GIS laboratory and Instrumentation room respectively were also used for data validation. The slope map was derived from Aster data obtained from Global Digital Elevation Module (ASTER G6DEM) downloaded from the United States Geological Survey (USGS) Earth Explorer and NASA Earth (www.earthexplorer.usgs.gov,2022). Other datasets used were extracted from Google Earth Pro Desktop.

4.2 Methods Used

The methods used in the study is illustrated using the flow chart in Figure 4.1. Data derivation, preparation and validation are also presented. The four main criteria considered for suitable site selection, namely mining, terrain, geotechnical and environmental factors are presented in this chapter.

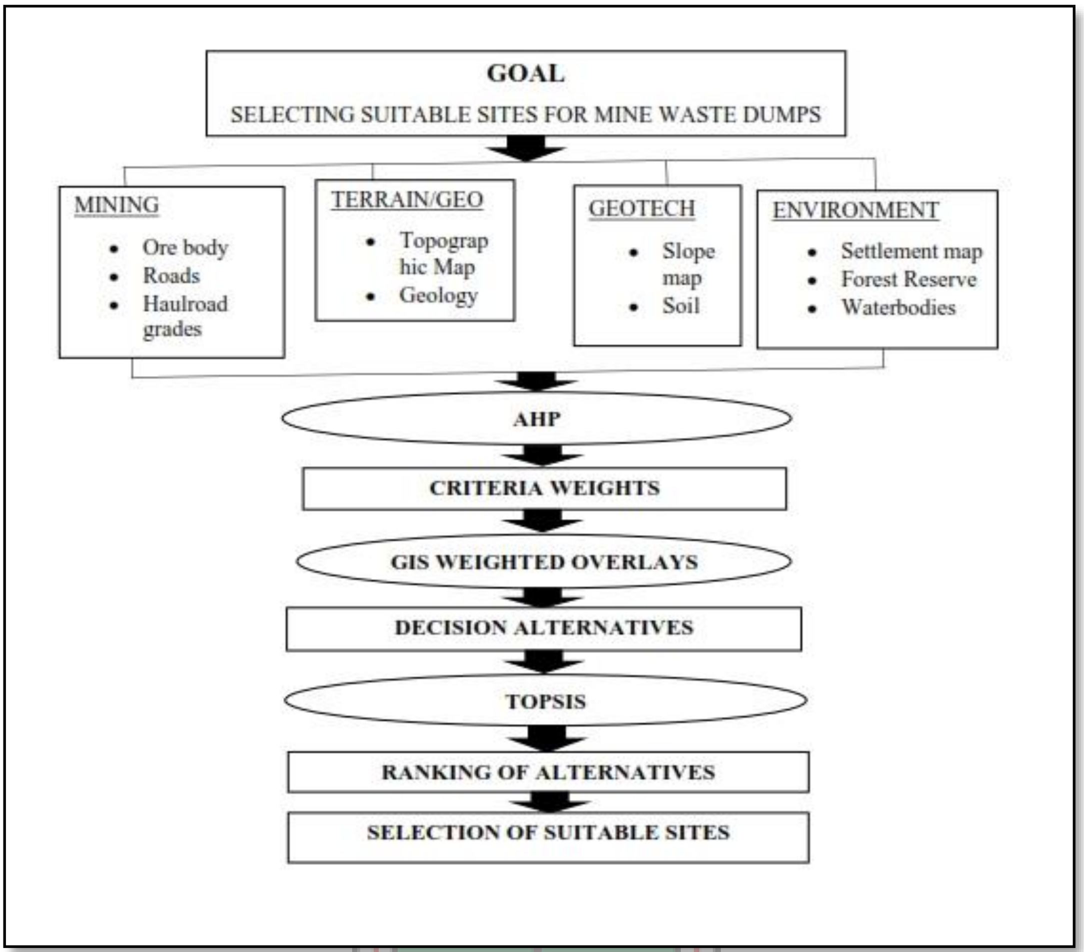

Figure 4.1 Flow Chart of the Methods Used

4.3 AHP Method

The Analytic Hierarchy Process was used to generate weights for the criteria. It include the formation of the pairwise comparison matrix which was based literature and experts' knowledge on the importance of a criterion over the other. The pairwise comparison matrix was normalised. Weights were derived from the normalised matrix. The consistency ratio was of the weights were computed using Eqn. 3.1 and Eqn. 3.2.

4.4 GIS Suitability Analysis

The spatial features used as proxy for the criteria include: map of the active mine pit and old dump site, map of roads and railways, geology map, map of soil type, settlement, forest and rivers within the mine concession were fed into ESRI ArcMap, version 10.5. The Suitability Analysis techniques used include Creation of buffers and measuring of Euclidean distances from and around specific criteria. A multiple ring buffer with a total extent of 9144 m was generated around the ore body (active mine pit and old dump), Roads, Settlement, Forest and Rivers. Constraints are imposed on each criteria. These constraints are the various distances set apart for all the criteria. Geology and Soil type were rasterised based on their suitability index. For the purpose of this work, overlay analysis was performed on the various evaluation criteria layers. Hence all the vector layers were rasterised. The various criteria were standardised to common values. These common values further represent the suitability index and the weights from the PCM are incorporated into the ArcGIS environment. Weighted criteria are then combined for the Suitability Analysis.

4.5 TOPSIS Method

The TOPSIS method was used to rank the alternatives. In this research, the construction and weighting of decision matrix was done by the AHP method. The decision matrix and weighted decision matrix were normalised using **eqn 3.4** and **eqn 3.5**. The positive and negative ideal solutions were determined using **eqn 3.6** and **eqn 3.7**. Ranking of the alternatives according to the relative closeness was done by **eqn 3.8**.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Results

The results obtained from the research are presented in this section. These include: the weights derived from the pairwise comparison, suitable sites obtained from only GIS and criteria with equal importance, suitable sites obtained from GIS integrated with AHP and suitable sites obtained from GIS integrated with AHP and TOPSIS.

5.1.1 Result from Analytic Hierarchy Process

Tables 5.1, 5.2 and 5.3 shows the pairwise comparison matrix of the various criteria, normalised pairwise comparison matrix and weights of criteria respectively. Table 5.4, Table 5.5, Eqn 5.1, Eqn 5.2, Eqn 5.3 were used to determine the consistency of the pairwise comparison matrix.

Table 5.1 Pairwise Comparison Matrix

CRI	**ORE**	**ROADS**	**GEO**	**SLOPE**	**SOIL**	**SETTLE**	**FOR**	**RIV**
OREBODY	1.00	7.00	8.00	3.00	9.00	2.00	4.00	5.00
ROADS	0.14	1.00	3.00	0.25	4.00	0.14	3.00	4.00
GEOLOGY	0.13	0.33	1.00	0.20	2.00	0.17	0.25	0.33
SLOPE	0.33	4.00	5.00	1.00	7.00	0.50	2.00	3.00
SOILTYPE	0.11	0.25	0.50	0.14	1.00	0.14	0.33	0.25
SETTLEMENT	0.50	7.00	6.00	2.00	7.00	1.00	5.00	4.00
FOREST	0.25	0.33	4.00	0.50	3.00	0.20	1.00	2.00
RIVERS	0.20	0.25	3.00	0.33	4.00	0.25	0.50	1.00
TOTAL	**2.66**	**20.17**	**30.50**	**7.43**	**37.00**	**4.40**	**16.08**	**19.58**

Table 5.2 Normalised Pairwise Comparison

OREBODY	0.38	0.35	0.26	0.40	0.24	0.45	0.25	0.26
ROADS	0.05	0.05	0.10	0.03	0.11	0.03	0.19	0.20
GEOLOGY	0.05	0.02	0.03	0.03	0.05	0.04	0.02	0.02
SLOPE	0.13	0.20	0.16	0.13	0.19	0.11	0.12	0.15
SOILTYPE	0.04	0.01	0.02	0.02	0.03	0.03	0.02	0.01
SETTLEMENT	0.19	0.35	0.20	0.27	0.19	0.23	0.31	0.20
FOREST	0.09	0.02	0.13	0.07	0.08	0.05	0.06	0.10
RIVERS	0.08	0.01	0.10	0.04	0.11	0.06	0.03	0.05

Table 5.3 Weights of Criteria

CRITERIA	**WEIGHTS**
OREBODY	**0.324**
ROADS	**0.096**
GEOLOGY	**0.031**
SLOPE	**0.150**
SOILTYPE	**0.023**
SETTLEMENT	**0.242**
FOREST	**0.075**
RIVERS	**0.060**

Table 5.4 Weighted Sum Vector

CRI	**ORE**	**ROADS**	**GEO**	**SLOPE**	**SOIL**	**SETTLE**	**FOR**	**RIV**
OREBODY	0.32	0.67	0.25	0.45	0.21	0.48	0.30	0.30
ROADS	0.05	0.10	0.09	0.04	0.09	0.03	0.22	0.24
GEOLOGY	0.04	0.03	0.03	0.03	0.05	0.04	0.02	0.02
SLOPE	0.11	0.38	0.15	0.15	0.16	0.12	0.15	0.18
SOILTYPE	0.04	0.02	0.02	0.02	0.02	0.03	0.02	0.01
SETTLE	0.16	0.67	0.19	0.30	0.16	0.24	0.37	0.24
FOREST	0.08	0.03	0.12	0.08	0.07	0.05	0.01	0.12
RIVERS	0.06	0.02	0.09	0.05	0.09	0.06	0.02	0.06

Table 5.5 Determination of consistency vector

WEIGHTS	**WEIGHTED SUM**	**CONSISTENCY VECTOR**
0.324	2.980	9.198
0.096	0.862	8.979
0.031	0.258	8.322
0.150	1.406	9.373
0.023	0.194	8.434
0.242	2.334	9.645
0.075	0.563	7.406
0.060	0.462	7.700

The average value of the consistency vector (λ) is computed using ***Eqn* 5.1** as;

$$\lambda = \frac{8+8.979+8.322+9.379.193+8.434+9.645+7.406+7.700}{8} = 8.632 \ldots\ldots\ldots \boldsymbol{Eqn\ 5.1}$$

λ= Average value of the consistency vector

Subsequently the consistency index (CI) and the consistency ratio (CR) are computed using Eqn 5.2 and Eqn 5.3 respectively.

$$CI = \frac{8.632 - 8}{7} = 0.095 \ldots\ldots\ldots \boldsymbol{Eqn\ 5.2}$$

CI= Consistency Index

$$CR = \frac{0.095}{1.41} = 0.067 \ldots\ldots\ldots \boldsymbol{Eqn\ 5.3}$$

CR= Consistency Ratio

5.1.2 Suitable Sites from GIS Suitability Analysis

Figures 5.1. 5.2, 5.3, 5.4, 5.5 show the criterion maps that have been standardised based on the allowable distances within which solid mine waste dumps can be sited. Figure 5.6 is standardised based on the geological era series, figure 5.7 is standardisedd based on the group of the soil type and figure 5.8 is standardised based on the percentage rise of the slope. The criterion maps were reclassified to suitable and unsuitable classes. Overlay analysis was performed using the reclassified criterion maps as layers to produce figure 5.9. Weights from Table 5.3 were integrated into the GIS overlay analysis to produce figure 5.10.

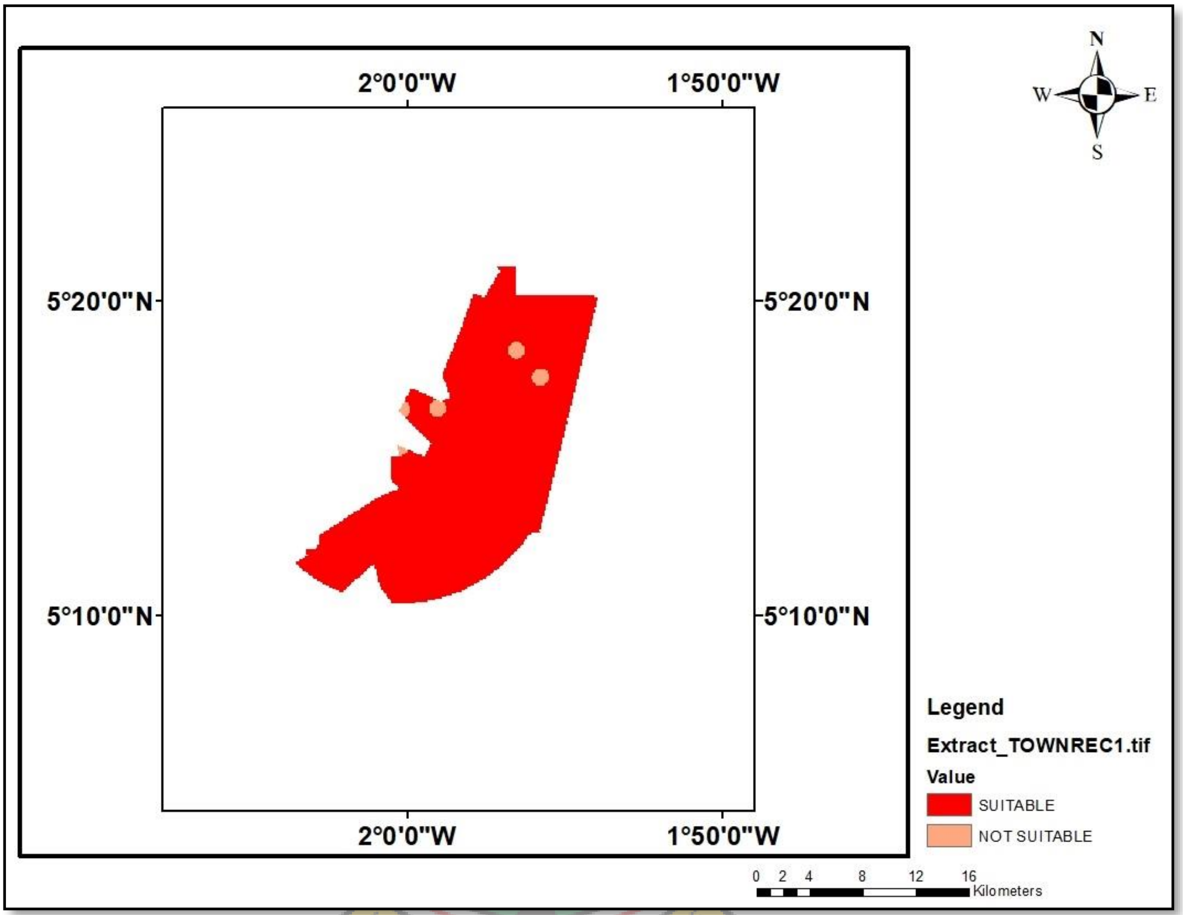

Figure 5.1 Standardised map settlement

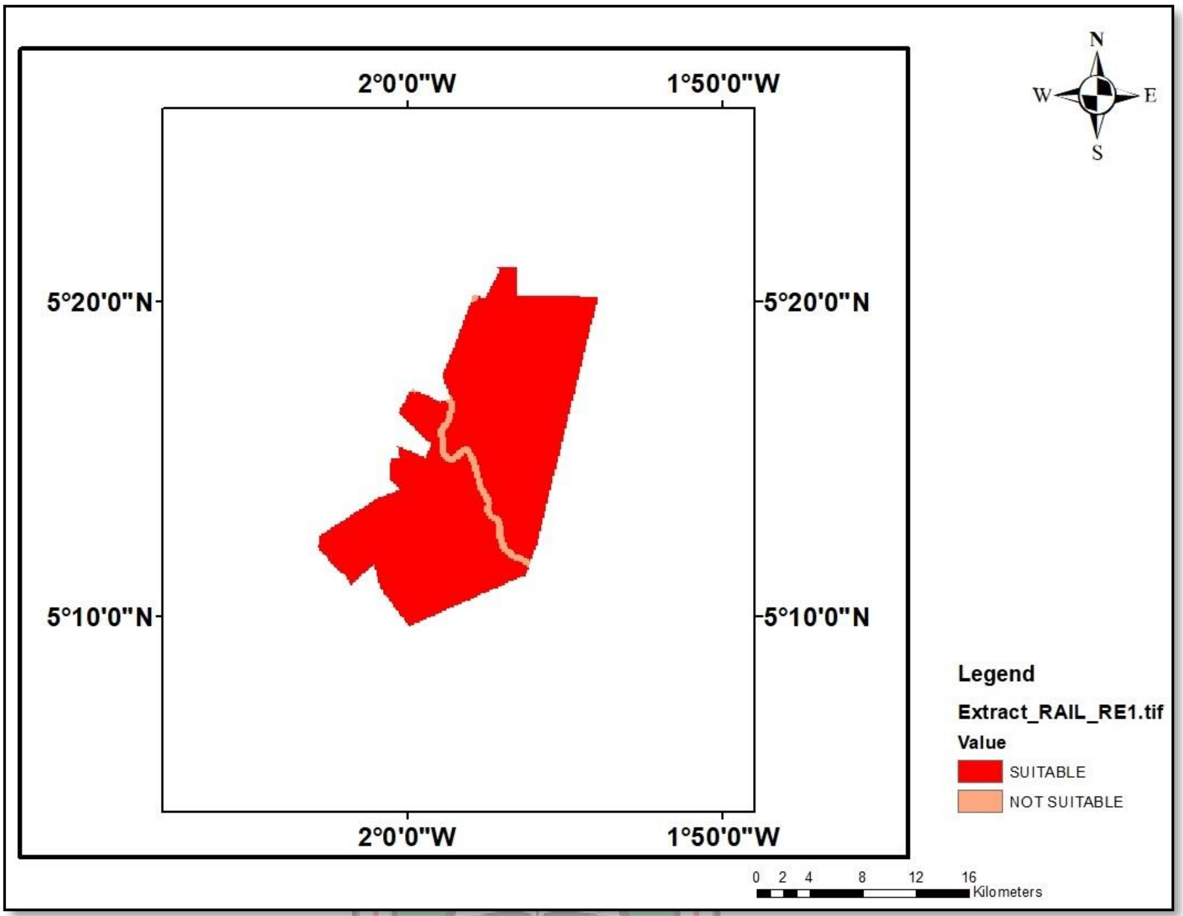

Figure 5.2 Standardised map of Rail road

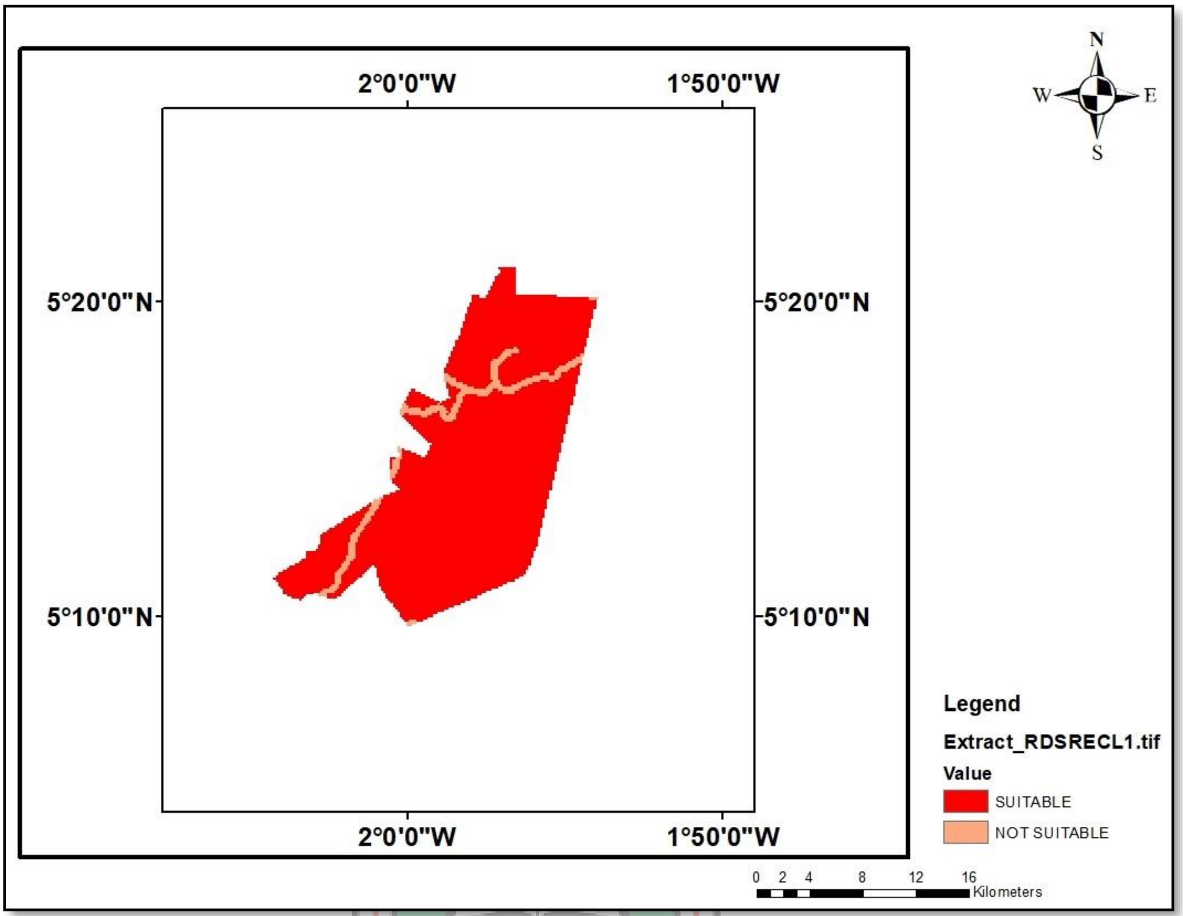

Figure 5.3 Standardised map of roads

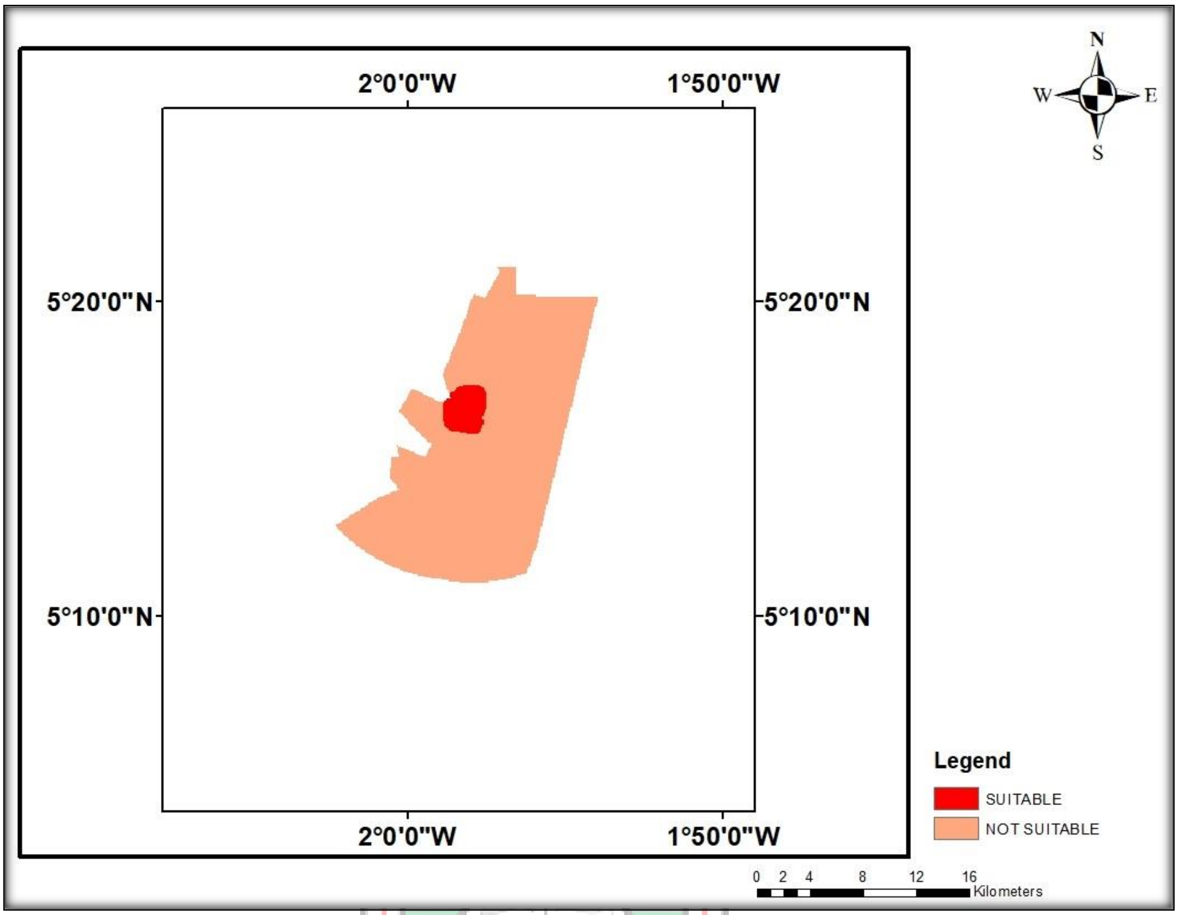

Figure 5.4 Standardised map of Active mine pit (orebody)

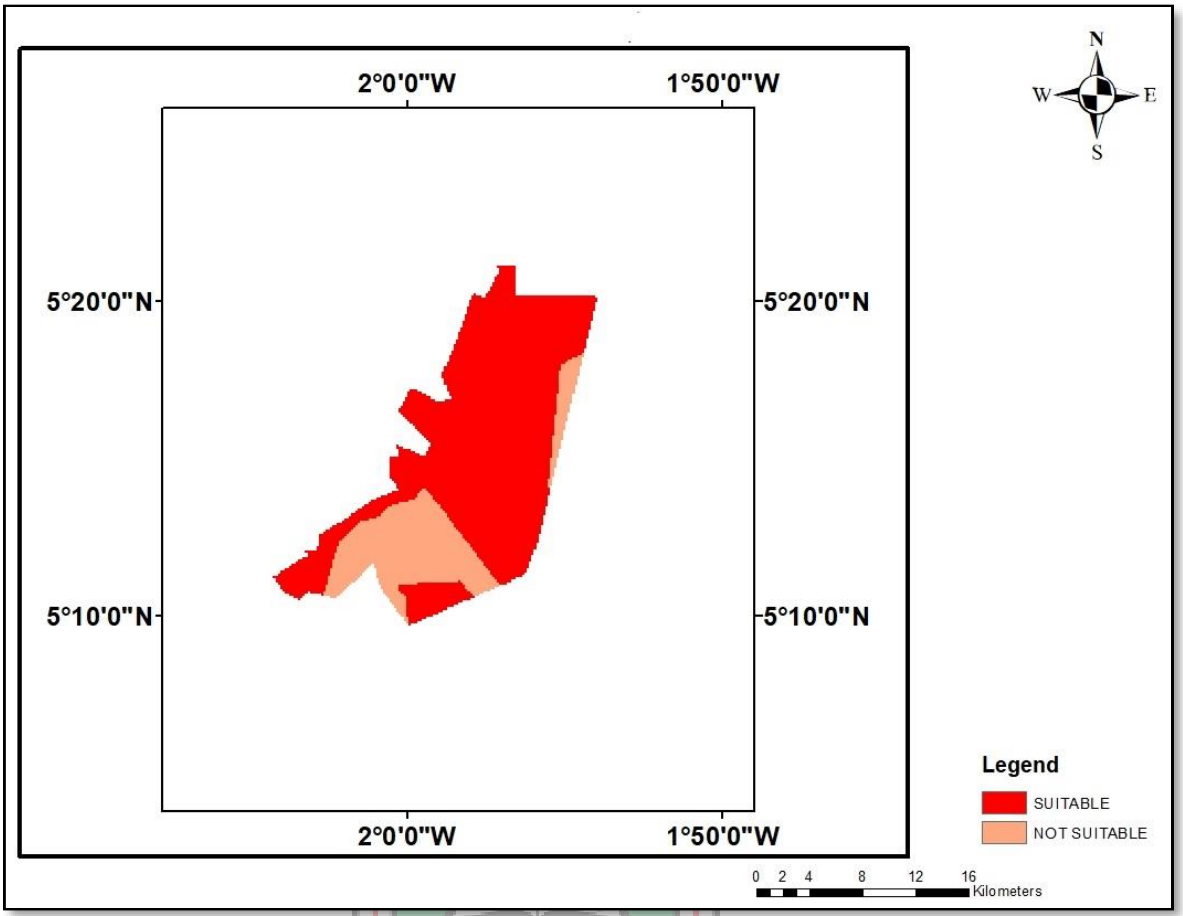

Figure 5.5 Standardised map of forest reserve

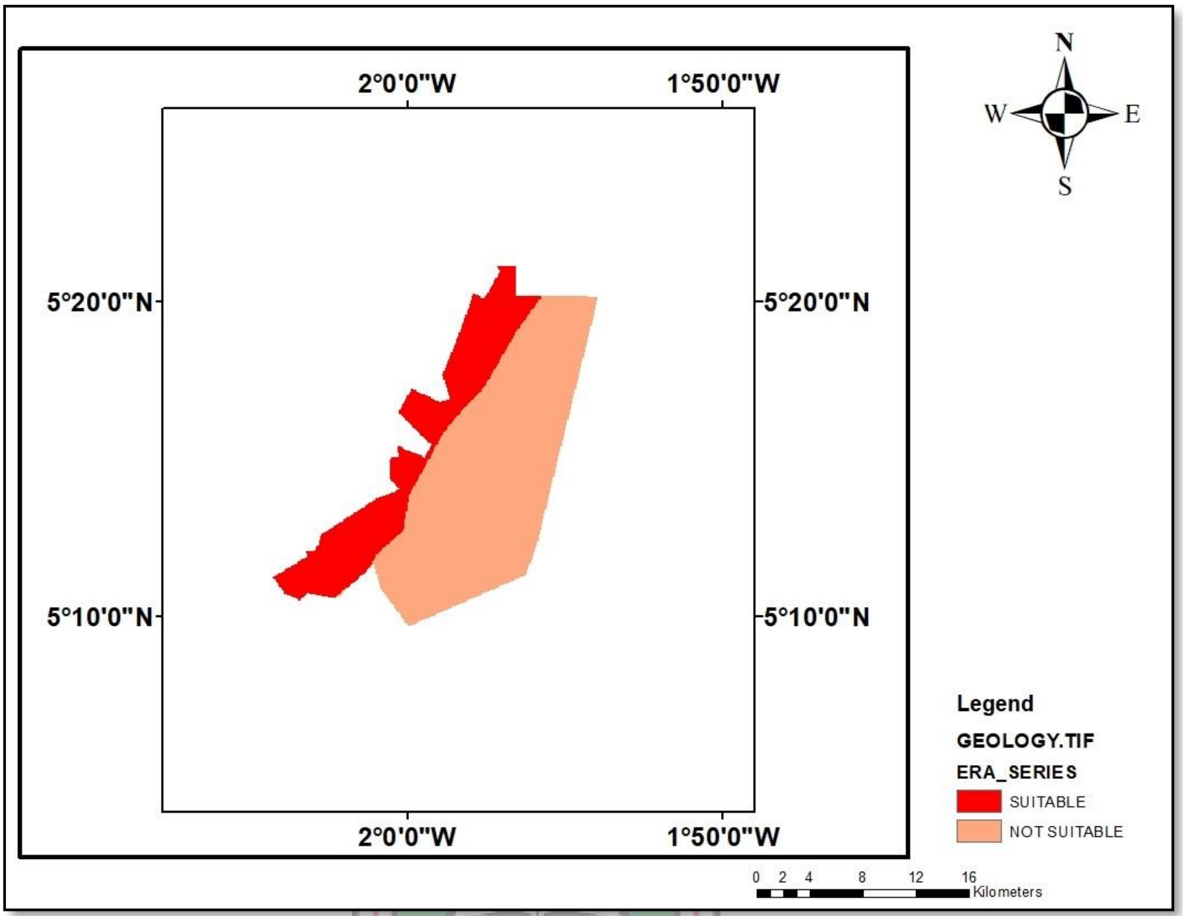

Figure 5.6 Standardised map of geology

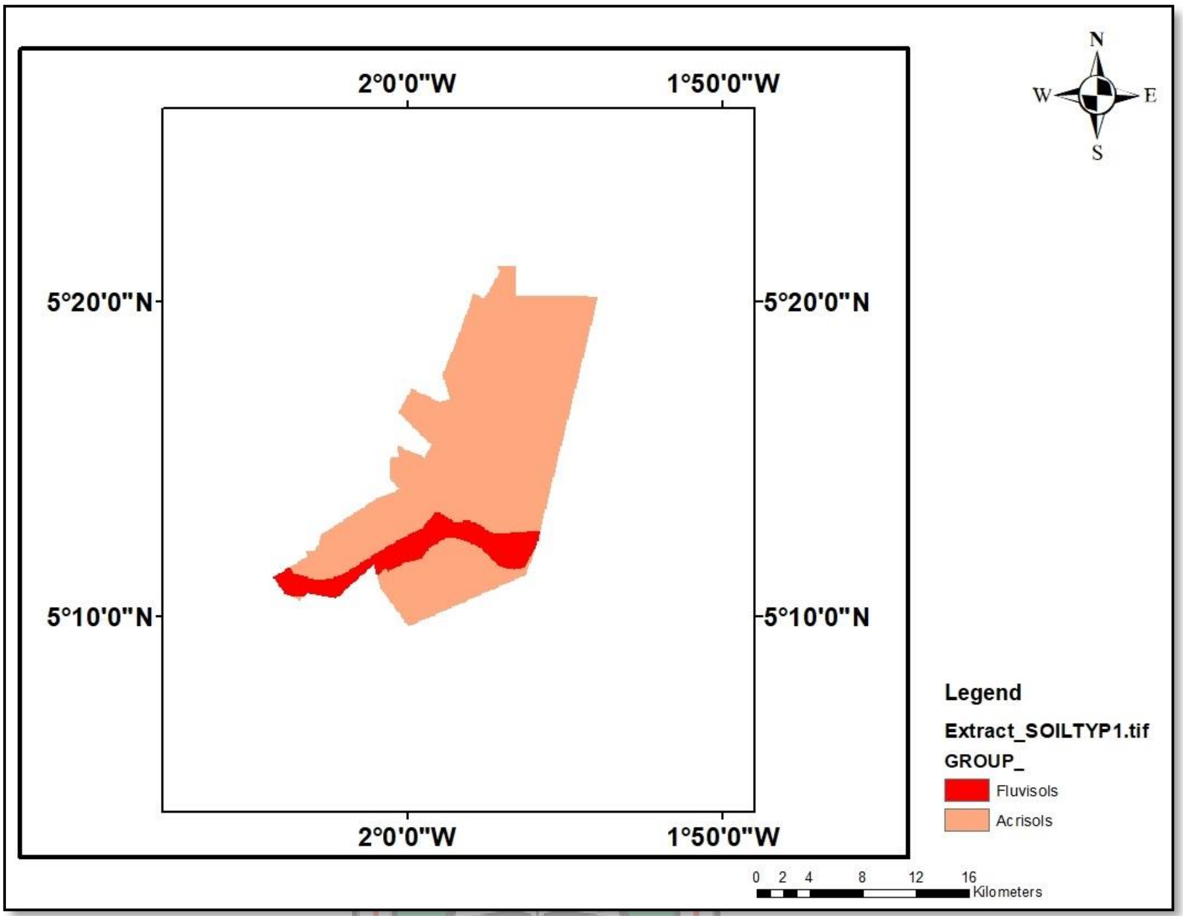

Figure 5.7 Standardised map of soil type

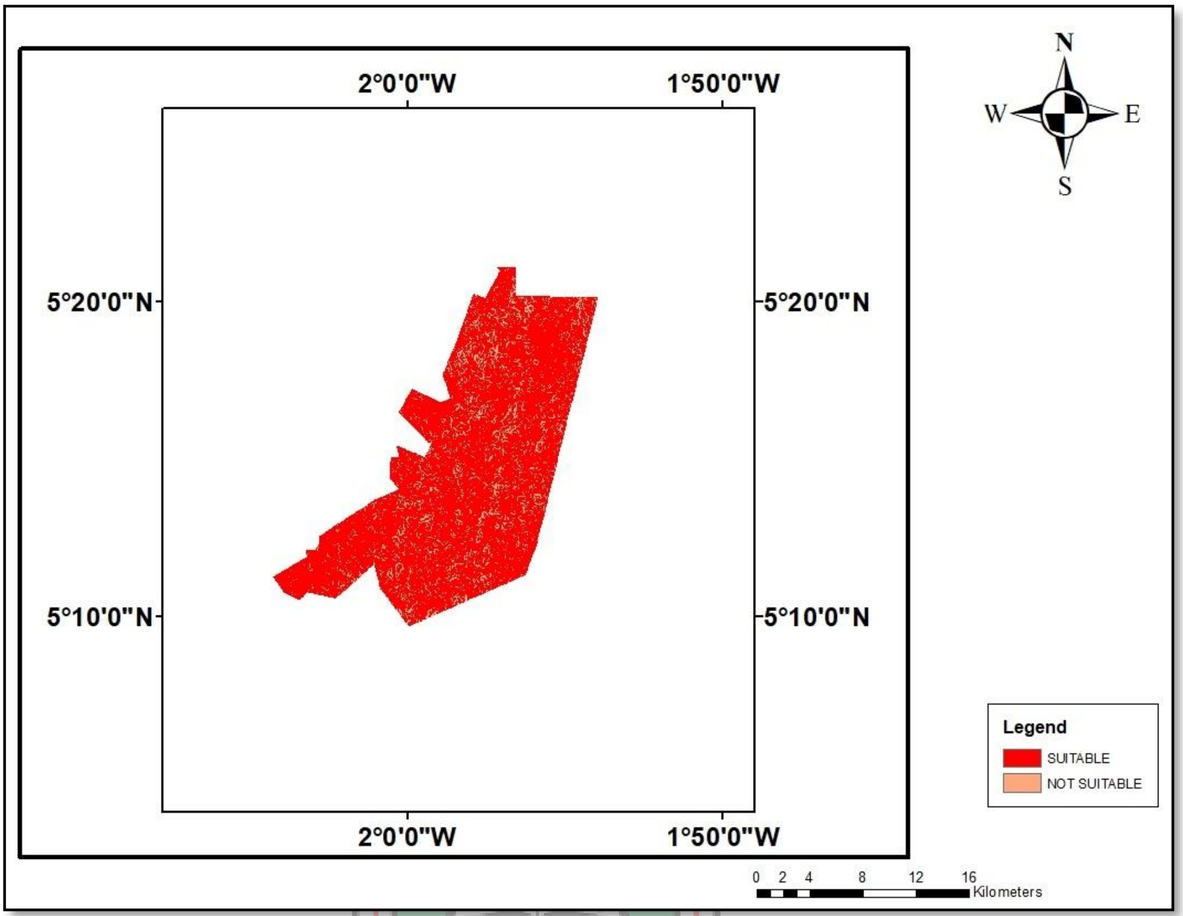

Figure 5.8 Standardised map of slope

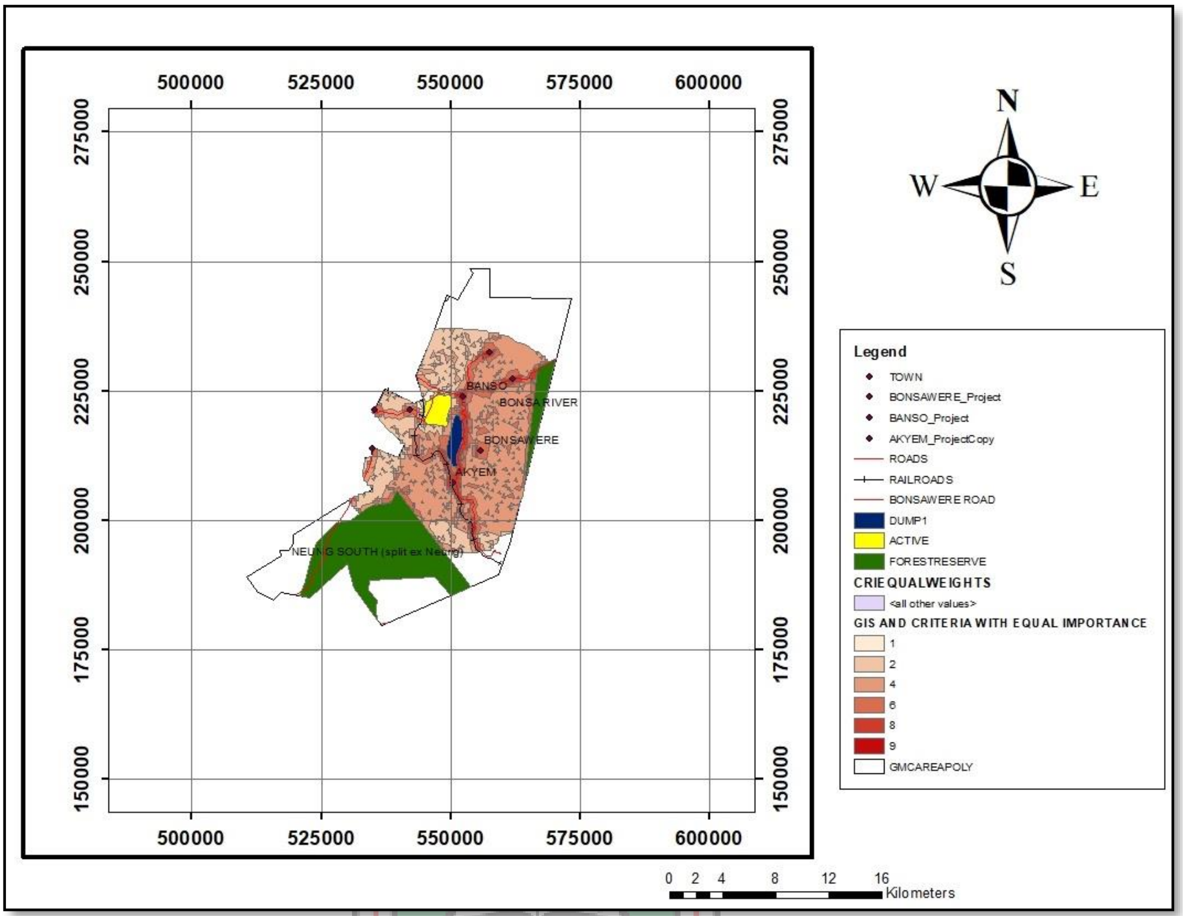

Figure 5.9 Site suitability map using only GIS and criteria based on with equal importance

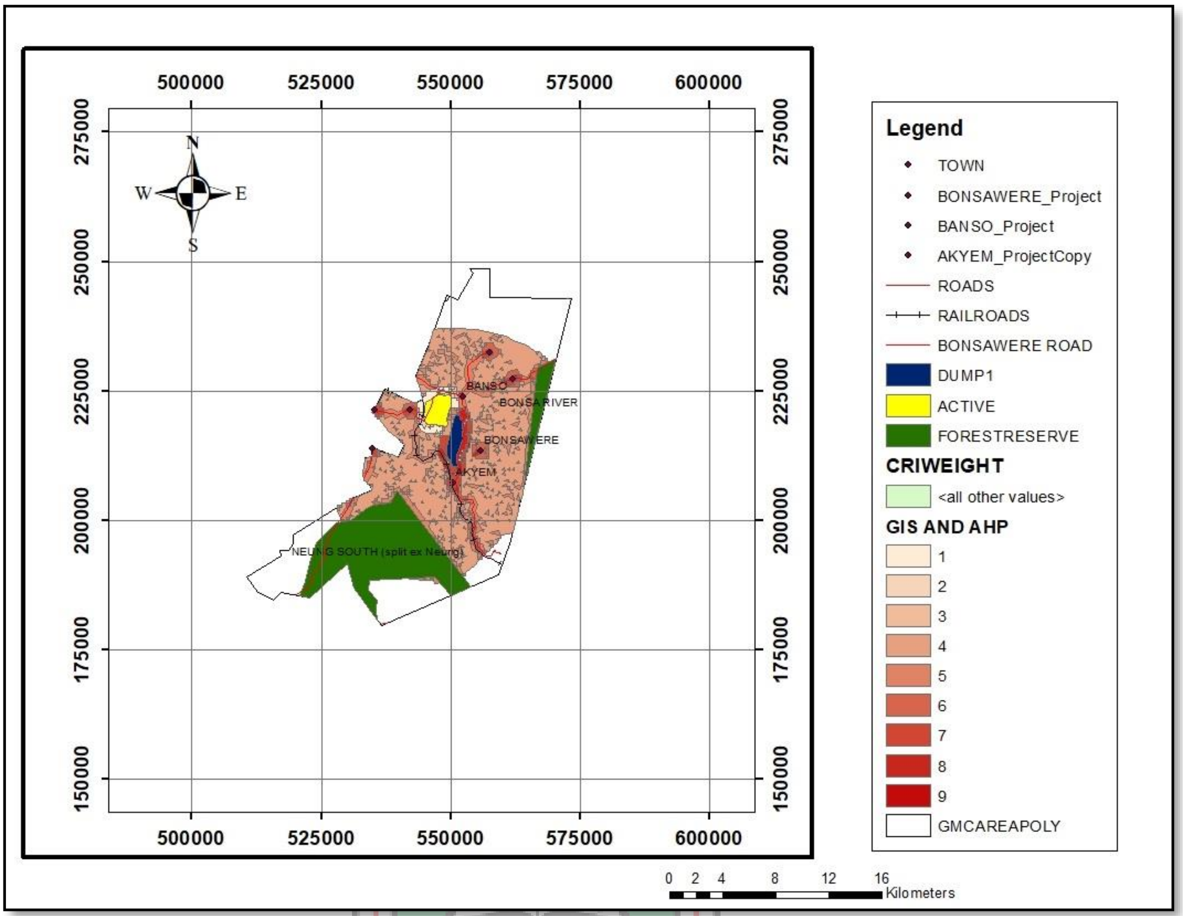

Figure 5.10 Suitability map for solid mine waste dump site using GIS and AHP

5.1.3 Result from TOPSIS

Table 5.6 shows the TOPSIS decision matrix, Table 5.7, 5.8, 5.9, 5.10, 5.11 and 5.12 show the normalised TOPSIS decision matrix (R_{ij}), weighted normalised decision matrix (V_{ij}), PIS(V^+) and NIS(V^-), separation measures for alternatives (S^+ and S^-) and relative closeness of each alternative to the ideal solution (C) using eqn 4.4 to 4.8 respectively. Result from C was use to rank the alternatives and also applied in the GIS overlay analysis to produce Figure 5.11.

Table 5.6 TOPSIS Decision Matrix

Alts (i)/Cri (j)	ORE	ROAD	GEO	SLOPE	SOIL	SETTLE	FOR	RIV
Weights	**0.30**	**0.10**	**0.07**	**0.15**	**0.02**	**0.24**	**0.05**	**0.06**
1	1.00	7.00	8.00	3.00	9.00	2.00	4.00	5.00
2	0.14	1.00	3.00	0.25	4.00	0.14	3.00	4.00
3	0.13	0.33	1.00	0.20	2.00	0.17	0.25	0.33
4	0.33	4.00	5.00	1.00	7.00	0.50	2.00	3.00
5	0.11	0.25	0.50	0.14	1.00	0.14	0.33	0.25
6	0.50	7.00	6.00	2.00	7.00	1.00	5.00	4.00
7	0.25	0.33	4.00	0.50	3.00	0.20	1.00	2.00
8	0.20	0.25	3.00	0.33	4.00	0.25	0.50	1.00

Table 5.7 Normalised TOPSIS Decision Matrix

CRI	ORE	ROADS	GEO	SLOPE	SOIL	SETTLE	FOR	RIV
WGT	**0.30**	**0.10**	**0.07**	**0.15**	**0.02**	**0.24**	**0.05**	**0.06**
1	0.81	0.65	0.63	0.79	0.60	0.86	0.54	0.59
2	0.12	0.09	0.24	0.07	0.27	0.06	0.40	0.47
3	0.10	0.03	0.08	0.05	0.13	0.07	0.03	0.04
4	0.27	0.37	0.39	0.26	0.47	0.21	0.27	0.36
5	0.09	0.02	0.04	0.04	0.07	0.06	0.04	0.03
6	0.41	0.65	0.47	0.53	0.47	0.43	0.67	0.47
7	0.20	0.03	0.32	0.13	0.20	0.09	0.13	0.24
8	0.16	0.02	0.24	0.09	0.27	0.11	0.07	0.12

Table 5.8 Weighted Normalised TOPSIS Decision Matrix

CRI	ORE	ROADS	GEO	SLOPE	SOIL	SETTLE	FOR	RIV
WGT	**0.30**	**0.10**	**0.07**	**0.15**	**0.02**	**0.24**	**0.05**	**0.06**
ooi1	0.24	0.07	0.04	0.12	0.01	0.21	0.03	0.04
2	0.03	0.01	0.02	0.01	0.01	0.01	0.02	0.03
3	0.03	0.00	0.01	0.01	0.00	0.02	0.00	0.00
4	0.08	0.04	0.03	0.04	0.01	0.05	0.01	0.02
5	0.03	0.00	0.00	0.01	0.00	0.01	0.00	0.00
6	0.12	0.07	0.03	0.08	0.01	0.10	0.03	0.03
7	0.06	0.00	0.02	0.02	0.00	0.02	0.01	0.01
8	0.05	0.00	0.02	0.01	0.01	0.03	0.00	0.01
MAX	**0.24**	**0.07**	**0.04**	**0.12**	**0.01**	**0.21**	**0.03**	**0.04**
MIN	**0.03**	**0.00**	**0.00**	**0.01**	**0.00**	**0.01**	**0.00**	**0.00**

Table 5.9 Positive and Negative Ideal Solution

PIS	NIS
0.245	0.002
0.065	0.001
0.048	0.001
0.129	0.000
0.014	0.002
0.168	0.000
0.044	0.001
0.051	0.001

Table 5.10 Separation Measures for Alternatives (S^+)

CRI	ORE	ROADS	GEO	SLOPE	SOIL	SETTLE	FOR	RIV
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.044	0.003	0.001	0.012	0.000	0.037	0.000	0.000
3	0.046	0.004	0.001	0.012	0.000	0.036	0.000	0.001
4	0.026	0.001	0.000	0.006	0.000	0.024	0.000	0.000
5	0.047	0.004	0.002	0.013	0.000	0.037	0.000	0.001
6	0.015	0.000	0.000	0.002	0.000	0.011	0.000	0.000
7	0.033	0.004	0.000	0.010	0.000	0.034	0.000	0.000
8	0.038	0.004	0.001	0.011	0.000	0.033	0.000	0.001

Table 5.11 Separation Measures for Alternatives (S^+)

SUM	S^+
0.000	0.000
0.096	0.310
0.100	0.316
0.058	0.241
0.103	0.322
0.027	0.165
0.083	0.287
0.087	0.295

Table 5.12 Separation Measures for Alternatives (S^-)

CRIT	ORE	ROADS	GEOLOGY	SLOPE	SOIL	SETTLE	FOREST	RIV
1	0.047	0.004	0.002	0.013	0.000	0.037	0.001	0.001
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.003	0.001	0.001	0.001	0.000	0.001	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.009	0.004	0.001	0.005	0.000	0.008	0.001	0.001
7	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.13 Separation Measures for Alternatives (S^-)

SUM	S^-
0.104	0.322
0.001	0.037
0.000	0.006
0.008	0.089
0.000	0.001
0.029	0.170
0.002	0.044
0.001	0.030

;

Table 5.14 Ranking of Criteria

CRITERIA	C	RANK
1	1.00	1
2	0.11	2
3	0.02	4
4	0.27	3
5	0.00	6
6	0.51	5
7	0.13	7
8	0.09	8

Table 5.15 Area (hectares) of alternatives in each map

SITE	AREA_HAFig 5.15	AREA_HA Fig 5.16	AREA_HA Fig 5.17
1	66	377	406
2	2167	104	73
3		32	14
4	5209	6546	6033
5		3514	2718
6	2266	727	449
7		431	260
8	706	251	459
9	48	44	45

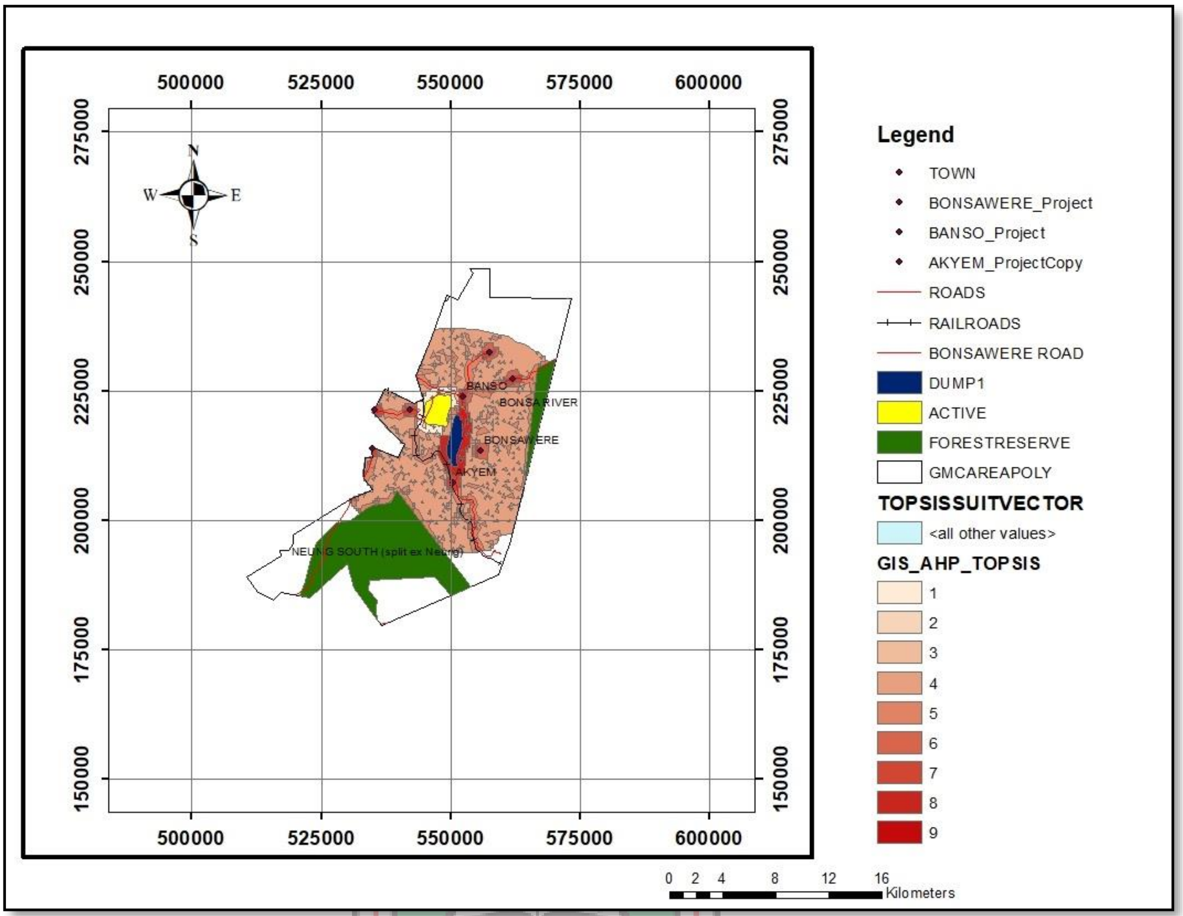

Figure 5.11 Suitability solid mine waste dump sites at GMCL using GIS, AHP and TOPSIS

5.2 Discussion

In this study, GIS and MCDA techniques (AHP and TOPSIS) were combined to produce a solid mine waste dump suitability site selection for GMCL. Eight evaluation criteria were determined and used as the main input layers in the suitability analysis. Three suitability maps were generated using only GIS and criteria with equal importance, GIS integrated with AHP, and GIS integrated with AHP and TOPSIS. After the spatial suitability analysis was performed, the result of each map was reclassified into 9 classes where the first alternative was deemed the most suitable site and the last alternative being the worst site to be considered.

Comparing and analysing the three maps produced (Fig 5.9, Fig 5.10 and Fig 5.11), Fig 5.9 which is the map produced from GIS and evaluating criteria with equal importance produced a generalised map. The extreme simplification of the selection assuming all the criteria contributed equally in the site selection inhibits the research from achieving its objectives. Since all criteria had equal weight, they equally influenced the selection of the sites hence ignoring most of the areas considered to be more suitable. This accounted for the least area selected as the suitable site. The GIS integrated with AHP prioritises the criteria with higher weights over those of lower weights. In fig. 5.10, the most suitable site was therefore selected around the active mining area which was the criteria with the highest weight and therefore had the greatest influence. Since AHP only considers weights of the criteria, other criteria with higher weights also had greater influence on the site selection. This contributed to the smaller area selected around the active mining area. In Fig 5.11, when TOPSIS was integrated with AHP in the GIS environment, ranking of the alternatives was based on both the weights of various criteria and the criteria that has the closest equidistant distance to the ideal suitable site. The TOPSIS also ignores alternatives that are farther away from the ideal suitable sites. In view of this, higher priority was given to areas around the active mine pit. Fig 5.11 therefore had the largest suitable site as compared to Fig 5.9 and 5.10.

According to Hwang and Yoon (1981), the first step in using the TOPSIS method is to construct a decision matrix (m*n) of alternatives (m) on criteria (n) as applied by Jozaghi *et al.*, (2018) in their research themed selection of dam sites using GIS, AHP and TOPSIS techniques. This was possible because hydrological analysis had already been done to propose some alternatives. But assuming alternatives under land suitability analysis is difficult to be achieved hence evaluating criteria were used to create the decision matrix in this research. Constructing a TOPSIS decision matrix using the criteria as enshrined in Nyimbili *et al.*, 2018 research titled Integration of GIS, AHP and TOPSIS for earthquake hazard analysis subject the work to a pairwise comparison just as the AHP. Also constructing another decision matrix for TOPSIS based on experts' knowledge whiles a pairwise comparison matrix of evaluating criteria have already been created for criteria weighting by same experts would transfer inherent inconsistency from one method to the other. To avoid such inconsistencies, the decision matrix from the AHP weighting method was used as input for the TOPSIS ranking method.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Nine alternatives were selected within the GMCL concession. Among these, the first alternative which was closer to the active mine production site was chosen as the most suitable. Any other site apart from site one must undergo further examination;
- Comparing the three maps generated from the various methods, using only GIS and evaluating criteria of equal importance only produced a generalised map which can be used for reconnaissance purpose;
- GIS and AHP produced a map which can adequately be used for suitability analysis but since ranking of alternatives are based on weights of criteria, criteria of higher weights can produce suitable sites that are of no importance to stakeholders;
- GIS integrated with AHP and TOPSIS produced a suitability map which is in the interest of stakeholders. Since the TOPSIS ranks alternatives based on the closeness of the alternatives to the ideal suitable site, it does not only rank based on criteria with higher weights but rather criteria with higher weights that are closer to the ideal site.

6.2 Recommendations

- It is recommended that suitable alternatives generated from GIS and criteria with equal importance map be used as preliminary alternatives in constructing an alternative (m) by criteria (n) TOPSIS decision matrix other than using criteria to create such decision matrix;
- It is recommended that this research be replicated in other aspects of waste management within GMCL;
- It is also recommended that other mining and related companies use these methods to select suitable mine solid waste dump sites to avoid encroachment to human settlement, protect lives and the environment.

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