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**ADDIS ABABA UNIVERSITY  
FACULTY OF SCIENCE  
SCHOOL OF GRADUATE STUDIES  
DEPARTMENT OF EARTH SCIENCES**

**A COMPARISON OF EXPERT SYSTEMS AND  
WEIGHTED OVERLAY ANALYSIS FOR  
MILITARY PLANNING**

**By**

**Gebreslasie Gebremedhin**

**June, 2009**

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**A Thesis submitted to School of Graduate Studies: Addis Ababa University  
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***“People sleep peacefully in their beds at night only because rough men stand ready to do violence on their behalf”.***

**George Orwell**

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## **LIST OF ABBREVIATIONS**

a.s.l	Above Sea Level
DEM	Digital Elevation Model
DSS	Decision Support Systems
ERDAS	Earth Resource Data Analysis Software
ESRI	Environmental Science Research Institute
ETM	Enhanced thematic Mapper
FM	Field Manual
GCPs	Ground Control Points
GPS	Geographic Information Systems
IBP	Intelligence Preparation of Battle field
KB	Knowledge Base
KBGIS	Knowledge based GIS
KBS	Knowledge based systems
KE	Knowledge Engineer
MCDA	Multi Criteria Decision Analysis
MCE	Multi Criteria Evaluation
MCOO	Modified Combined Obstacles Overlay
MoD	Ministry of defense
SAR	Synthetic Aperture Radar
SDSS	Spatial Decision Support Systems
SPME	Spatial multi criteria evaluation
UCSB	University of California, Santa Barbara
USGS	United States Geological Survey
UTM	Universal Transversal Mercator
WGS	World Geodetic System
WLS	Weighted Linear Sum
WOA	Weighted Overlay Analysis

## **NAMES OF ORGANIZATIONS**

MoARD Ministry of Agriculture and Rural Development

MoND Ministry of National Defense

FAO Food and Agricultural Organization

NMSA National Metrological Service Agency

GSE Geological Survey of Ethiopia

## **ABSTRACT**

The successes of military operations depend on how decision makers and planners have evaluated the battle field prior to the deployment of armed forces on the ground. The study of off-road trafficability of the terrain is one of the key military operations that should be provided for military commanders at all levels in a real time scenario. This can rarely be provided using paper maps. This thesis comparatively evaluates the state-of-the-art of spatial modeling techniques for off-road trafficability analysis of wheeled military vehicles using GIS and remote sensing techniques. The Expert systems and Weighted Overlay Analysis were comparatively studied for modeling off-road trafficability. Similar data layers of Lu/Lc, Soil, Slope, Rivers and Manmade obstacles were used to generate the off-road trafficability maps from the two methods. The goal of comparison of these decision making tools was to test whether data in an ordinal scale from the Weighted Overlay Analysis produce comparable result with the Expert system that use hierarchy of decision tree. The results showed that there was a strong spatial correspondence between the outputs from the two methods with a spatial correlation of 0.78. Besides, a zonal cross tabulation between results showed that the two methods strongly accord to each other in the SLOW-GO and NO-GO trafficability classes with 86% and 75% summarized in the same zone respectively. However, results of comparison also showed that there was a significant disagreement between the two methods in the GO and VERY SLOW-GO classes with only 53% and 31% summarized in the same zone respectively. The disagreement between the two methods was mainly due to reclassification of data, and the factor weights ( $w_j$ ) used in the WOA method which can't be employed in the Expert system and the detail knowledge of experts used in the Expert system to yield expert level performance that can't be entertained in the WOA.

## **KEY WORDS**

GIS and Remote Sensing, Expert systems, Knowledge base, Decision tree, Weighted Overlay analysis, Off-road trafficability, Military operations, Decision making tools, Comparison.

# **CHAPTER 1. INTRODUCTION**

## **1.1. BACKGROUND AND JUSTIFICATION OF THE STUDY**

The process of planning a military operation remains relatively cumbersome, inflexible and slow even when conducted by a planning staff trained extensively (Rao et al., 1993). Although, military plans are generally produced in accordance with the military doctrine of the troops involved (FM 5-33, 1990), military planners in one way or the other emphasize considerations of all features of the terrain as the most significant part of the planning and decision making process in order to achieve the specific goals and objectives that are designed by the military operational plans.

Nowadays, the modern battlefield is highly mechanized with heavy arms and ammunitions to shift around. The mobility of any armored column depends upon the terrain conditions over which it has to move. Ground conditions have always played an important role in all conflicts over the ages. The parameters like topography, soil type and land use land cover have a direct bearing to key activities like mobility of both men and machines, methods of crossing obstacles, selection of tactically important areas etc (Baijal et al., 2006).

Replenishment of ammunition, fuel and other supplies are required to reach the fighting troops in time. These require careful planning in terms of routes to be taken and movement of various types of vehicles to ensure success. Thus, in today's modern battlefield, speed of planning and execution of operations is of prime importance (Baijal et al., 2006). The movement and delivery of logistics to the army in the battle field during war and peace times is therefore determined by the trafficability of the land or the possibility of movement on the ground both in vehicles and personnel. Off-road trafficability maps have to be prepared during peace times so that the possibility of movement is well studied in advance and prepared for war times.

According to Satyanarayana et al. (2006), nearly all military activities are terrain sensitive and need careful planning and reconnaissance to ensure success. This makes operations planning more complex process in military than it is in other sectors. It is evident that the complexity of the planning process results in difficulty and uncertainty in decision making. Geographic Information System (GIS) play a pivotal role in Military operations as they are

essentially spatial in nature. It speeds up terrain based decisions thereby improving the quality and management of terrain based information for military operations planning. Besides to the availability of information on the terrain of the battle field, the way it is manipulated and delivered to decision makers in a very accurate and scientific manner is of more importance. Fortunately, GIS has come out as an emerging tool to address the need of decision makers and to cope with problems of uncertainties (Sahoo et al., 2000).

There are different techniques by which spatial information is analyzed to solve a particular spatial problem in GIS. Many of these techniques are integrated with GIS. Among these, Multi- Criteria Decision analysis (MCDA) is used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities (Dodgson, 2000). Among the techniques of Spatial Multi-criteria Evaluation (SMCE), the Weighted Overlay Analysis (WOA) is commonly used in modeling many spatially indexed problems and selection of suitable sites for several purposes. WOA is considered in this research to model a trafficable map for military operations and compared with the Expert system in GIS environment.

On the other hand, there is a need to emphasize on domain-specific knowledge, rather than more general problem solving strategies. Since the knowledge of experts tends to be domain-specific rather than general, Expert systems are often termed knowledge-based (Benfer et al., 1991). Goodchild et al. (1989), argue that an SDSS should incorporate knowledge used by expert analysts to guide the formulation of the problem, the articulation of the desired characteristics of the solution and the design and execution of a solution process. A knowledge-based GIS would be able to link spatial analysis and GIS intelligently for specific domains closer and would assist the user to choose the best set of spatial analysis procedures and tools to solve his problem within the constraints of data, data quality, cost and accuracy (Fischer et al., 1992).

## **1.2. STATEMENT OF THE PROBLEM**

Ministry of Defense in any country gathers spatial data on routing, filtering, analyzing and presenting information for decision-making. The regional conflicts, rapid deployment and flexible response imposes heavy burden on military commanders, their staff and supporting system to keep up-to-date situation on the ground (Satyanarayana et al., 2006).

Ethiopia is in a state of no war no peace situation with its adjoining neighbour Eritrea after the border dispute that took place a decade before. The geographic region in Ethiopia is known to be one of the militarily active and hostile regions in the world. The recent war with Islamist extremists in Somalia is enough to mention the current situation. The defense forces have to be on alert at all times to defend the sovereignty of the nation. In case of any emergent situations, the army has to move towards the border at a very short notice. As a matter of fact, the movement of the troops is highly influenced by the nature of the trafficability of the land under consideration. A cross-country mobility map is therefore necessary to provide the Army with a readymade mobility map.

In today's modern battlefield, speed of planning and execution of operations is of prime importance (Baijal et al., 2006). Whereas in reality, military officers manually combine terrain-based information and the tactical significance of various terrain features (Grindle et al., 2004). Manually combining terrain information is cumbersome for experts and time taking and results vary from expert to expert. Such terrain based tasks can effectively be automated using GIS based decision making tools.

As the Weighted Overlay Analysis is widely used in solving many spatial problems and Expert systems are emerging approaches in GIS, it is interesting to test whether the results are comparable for a specific military operations planning. There are very little, if not, at all researches conducted in comparing these widely used decision making tools in military context in Ethiopia. This problem is therefore worth studying as far as the need for selecting appropriate and effective methods of spatial decision making tools for successful military operations is concerned. This will contribute towards preparing a cross country mobility map of the country making military deployment activity easy.

### **1.3. OBJECTIVE OF THE STUDY**

#### **1.3.1. GENERAL OBJECTIVE**

- The objective of this research is to compare Expert systems and Weighted Overlay Analysis for military operations planning with special emphasis on off-road trafficability analysis in GIS environment.

#### **1.3.2. SPECIFIC OBJECTIVES**

- Produce a classified trafficability map ranging from impossibility to advance to possibility to advance using Expert systems and Weighted Overlay Analysis.
- To compare the two methods based on their respective results using GIS techniques.
- To propose the most convenient method in the context of military operations planning.

### **1.4. SCOPE OF THE STUDY**

This study is mainly concerned in automating the methods of spatial modeling in military operations planning and thus focuses mainly on issues that are within in the context of military operations particularly with off-road trafficability of wheeled military vehicles.

The study specifically gives emphasis on the comparison of methods of Multi-criteria evaluation in spatial modeling with a special emphasis on the Expert system and Weighted Overlay Analysis and proposing the convenient approach for military operations planning. Among the military operations planning tasks, the off-road trafficability modeling is considered in this thesis as it is key terrain based problem that includes many ill-structured parameters. In terms spatial extent, this research will consider Mulonasuluta Woreda of North Showa zone in Oromia region.

### **1.5. SIGNIFICANCE OF THE STUDY**

Despite the wider potential applications, the defense sector is the most unresearched in the application of GIS and Remote Sensing. The intent of this research is to stimulate interest in

usage of WOA and Expert systems coupled with GIS for terrain related decision making in the military community. Introducing such systems will improve efficiency and accuracy of terrain based decisions in military planning. Applying the methods of generating land suitability maps for military planning purposes and adopting the appropriate methods for the appropriate reality will ease the task of military topographic analysis.

Manually combining terrain information is cumbersome for experts and time taking. off-road trafficability of wheeled military vehicles deserve to be automated using GIS and remote sensing techniques as it is necessary in daily movement of armed forces. Such models of off-road vehicle mobility can help military commanders in supplying fuels and ammunition among other things during war times. Besides, it will help in landmine clearing using unmanned vehicles and for effective off-road patrolling of border territories and anti-terrorist operations. Finally, this research will stimulate researches in the field of Geoinformatics and extend it towards a cross country mobility map in a real world scenario.

## **1.6. LIMITATIONS OF THE STUDY**

This research has faced several limitations throughout the course. Shortage of literatures in the area is one of the critical limitations encountered. This has resulted in the absence of standards, relationships and importance of the various factors. Hence, the opinion of experts has been mainly used to quantify the weights of the factors and data analysis. The absence of authentic soil map of study area for the purpose of such applications is another constraint in this research resulting the use of agricultural soil classification. Besides, the elevation data, (90m DEM) obtained from Geological Survey of Ethiopia is of coarse resolution, which generalizes even well known surface configurations in the study area that in turn affected the analysis.

## **CHAPTER 2. LITRUTURE REVIEW**

### **2.1. GENERAL OVEREVIEW**

Currently, intelligence officers manually combine terrain-based information, information about the tactical significance of certain terrain features as well as information regarding enemy assets and doctrine to form hypotheses about the disposition of enemy forces and enemy intent (Grindle et al., 2004). According to Glinton et al. (2004), manual terrain analysis is time consuming and requires the expertise of a trained specialist. The result is typically a map on which terrain is classified into three categories based upon trafficability: go, slow-go, and no-go.

The emergence of GIS and remote sensing as a means of spatial data acquisition has revolutionized decision making in the civil sector and in the military as well. Terrain information supplies an important context for ground operations. The layout of terrain is a determining factor in arraying of forces, both friendly and enemy, and the structuring of Courses of Action (COAs) (Grindle et al., 2004). The knowledge of the terrain is therefore invaluable to conduct successful military operations or terrain based military planning.

The measure of ease of movement (trafficability) of forces throughout the terrain is important terrain information in military operations planning. Traditionally, the possibility of mobility over a given terrain is manually identified by military topographers and/or commanders in the battle field. This may result insurmountable miscalculations and failures as terrain based decisions need to be highly accurate for military activity.

### **2.2. MILITARY APPLICATION OF GIS**

The history of Geographic information systems shows that GIS has being used by the military community through out the world. According to Longley et al. (2005), the Defense Mapping Agency of USA began to investigate the use of computers to support the editing of maps, to avoid the expensive and slow process of hand correction and redrafting. Now a day the use of Geographic Information systems in the military sector is getting more sophisticated and significant as the computational efficiency develops from time to time.

For military purposes, it is of importance to have available actual and accurate terrain information for a specific area of interest anywhere on the world. Geographic information only forms one segment of this story, but well an essential one. Geographic information on the one side is of importance as a base for the command and control. At the other side it is of importance for the operation of individual weapon systems, which all use their own information database (Persie, 2000). Persie emphasized the importance of GIS mentioning the crises in Iraque, Bosnia and Kosovo, all illustrated that the success of military operations is increasingly depending on the availability of good information and a good information infrastructure.

GIS technology is rapidly moving from its historic niche usage within defense to becoming a critical defense wide infrastructure because of the fact that defense operations of all kinds depend on a sound understanding of terrain or geography. This, in turn, fosters the development of spatial knowledge from the flood of data (ESRI, 2005). Many authors in military planning (Baijal et al., 2006 and Heller et al., 2002) pointed out that defense sectors in many countries are now using GIS as a tool to solve many terrain related problems in decision making process in many critical areas.

The most important thing here is to make use of the available remote sensing imagery integrated with GIS systems in handling key military tasks. The availability of high resolution data with the increasing efficiencies of spatial decision support systems is interesting application for military planning. The importance of the study and analysis of terrain has been recognized for hundreds of years in military science. Currently, such analysis is called the Intelligence Preparation of the Battlefield (IPB) (Glinton et al., 2004). Currently, IPB is done manually by intelligence officers using hardcopy maps on which they notate various significant areas, such as key terrain or defensible terrain. This manual process suffers from a number of inefficiencies.

The significance of GIS in operations planning is increasing as it is integrated with other important technological innovations with time. This in turn has simplified many of military tasks that are related to the terrain including the replacement of manually combining terrain information. This is even manifested through the integration of GIS and other technological innovations like remote sensing. Drummond (1998) stated that the ease of the task of creating GIS inventories of battlefield resources by the spread of Global Positioning Systems (GPS)

technology in explaining the integration of GIS with other powerful technological innovations of our times. This enables military commanders to spatially catalogue terrain information without the need for expensive surveying. Further more, the integration of GIS and remote sensing data are more powerful and important in the military community.

### **3.3. MILITARY APPLICATION OF REMOTE SENSING**

Initially, remote sensing was used only for military purposes (Babic et al., 2004). Remote sensing has long been recognized as a means of obtaining data and information to meet perceived needs. Literatures indicate that systematic remote sensing began in the period between World Wars I and II with aerial photography used for military reconnaissance and photogrammetry. This was a period when military friction was at its top in the history of human beings. The Cold War emphasis on collecting intelligence to monitor the U.S.-Soviet arms race stimulated the rapid technological advancement of satellite remote sensing capabilities for military applications (Babic et al., 2004).

The advent of remote sensing technology has provided great flip to intelligence units in defense forces to acquire data on enemy activities from eyes in the sky. Spy satellites constantly acquire the high-resolution satellite data in peacetime to monitor the development in acquisition of modern warfare gadgets by the enemy forces (Satyanarayana et al., 2006). As far as these satellites are concerned, there is no privacy and imageries of very high resolution, commercially found in the market. Developed countries are extensively using remote sensing technology in monitoring enemy activities in the installation of nuclear energy and terrorist activities in the world. According to Santarayana et al. (2006), these are brought to the notice of International Agencies coordinating the prevention of use of nuclear weapons.

Satellite or aircraft-based remote sensing technology can provide the information for terrain analysis and trafficability studies in denied or otherwise inaccessible areas. For example, Multispectral satellite imagery can be used to remotely map soil and rock types based on the spectral reflectance of minerals. High-resolution satellite imagery can also be used to visually interpret geologic and topographic conditions. It is worth mentioning that the Shuttle Radar

Topography Mission, flown in February 2000, used Synthetic Aperture Radar (SAR) to produce an elevation data set covering 80% of Earth's land surface (William, 1998).

The use of remote sensing data combined with ground information would provide a common platform for analyzing the ground situation in time of war. The introductions of satellites providing high-resolution images in the present era enhanced the ability of accurate map-making by making the latest information available to the forces. For example, satellite remote sensing data can be used to generate a wide range of products such as landuse/landcover maps, obstacle maps, slope maps, road mobility maps, line of sight plots, etc. A GIS can receive process, create, store, retrieve, update, manipulate and compress digital terrain data to generate a number of products.

GIS and remote sensing techniques are being used in many sectors of in Ethiopia. There are many researches in many fields of study that have used GIS and remote sensing in one way or the other. Yet, there is no a single work in the country that is done regarding the application of GIS and remote sensing for military needs.

## **2.4. WEIGHTED OVERLAY ANALYSIS**

Weighted Overlay Analysis is one the components of the methods of spatial modeling using spatial Multi-criteria evaluation. Weighted Overlay Analysis assigns more importance to some criteria over the others. It has been used by several authors (Seid, 2007; Zelalem, 2007; Hailegebriel, 2007; Alemayehu, 2006). They have adopted the Weighted Overlay Analysis method in undertaking spatial modeling for several purposes. IDRISI software is commonly used to generate the weight factors for each criterion in the context of analytical hierarchy process. These authors have adopted the Weighted Overlay Analysis method for site selection of new housing sites in urban areas; mapping vegetation vulnerability analysis; live stock production; crop suitability.

Hopkins (1977) compared the advantage and disadvantages of eight methods of generating suitability maps using GIS, and remarked that the best approach is to use the Weighted Overlay Analysis and concluded that most of the spatial modeling tasks involved in suitability modeling, usually use the WOA analysis. Another comparative research

undertaken between Multi-criteria evaluations in GIS environment is conducted of Barredo et al. (1998), who have compared the Weighted Overlay Analysis, and the precedence (ranking) method to allocate urban areas. In their finding, the two approaches have brought about similar result except in a slight difference in the classes that are out of the highly suitable range. Barredo et al. (1998) argued that the fact that the accord is not good for intermediate groups is not very important because these places are not of much interest for territorial planning.

Although factor weights using analytical hierarchy process are used for decision making in military operations planning(Jaiswal,1997), the Weighted Overlay Analysis of spatial data layers is rarely used if not at all in terrain based decision making and suitability modeling for various military tasks. Despite the fact that weighted overlay analysis method is a more convenient method and easy to be used Barredo et al. (1998), this method has not been exhaustively used in the military sector, while it is the most prominent method in the civilian sector in handling various decision making processes that are of multiple criteria in nature and spatial in context.

## **2.5. EXPERT SYSTEMS IN GIS**

Military use of Expert systems is rapidly growing because of the increasing complexity of weapons systems and warfare and the need of military leaders to make ever faster operational decisions (Franklin et al., 1998). A KBGIS (Knowledge Based GIS) has been developed by the U.S. Geological Survey which incorporates AI techniques such as learning, Expert systems, new data representation, and more Albert (1998). According to him, a project was established in 1982 to develop a KBGIS. The Information systems Division in the USGS has, since then, been supporting research on and development of KBGIS at the University of California, Santa Barbara (UCSB).

An initial study of Smith et al. (1983) examined the possibility of combining three technologies: data base management systems, AI, and GIS. This was deemed feasible and work was begun on a proof-of-concept system. This was successful, so work proceeded to develop a working research system. The research or prototype system was completed successfully and it is now installed at the USGS where further experimentation is continuing

Albert (1988). Albert explained the potential of KBGIS by calling it the next generation of Geographic information Systems as well as an example of general purpose intelligent data handling system. Valdo (1998) has also defined the KBGIS as the linkage between GIS and Knowledge Based System (Expert systems), often referred as Knowledge Based GIS. This definition is shared by many authors.

The Expert systems are an emerging computer aided system being applied in many applications where expert level performance is required for accurate and well informed decisions. The need for systems that can effectively handle complex spatial problems is pushing forward for the development of more effective computer aided system in GIS environment

The emerging Knowledge-based Systems emphasize on domain-specific knowledge, rather than more general problem solving strategies. Since the knowledge of experts tends to be domain-specific rather than general, Expert systems are often termed knowledge-based (Benfer et al., 1991). This is because the knowledge based systems provide a system by which knowledge engineering is performed to create knowledge base of experts. The knowledge base is fed with rules of the various relationships of different criteria under consideration based on the knowledge acquired through various means of knowledge acquisition. Spatial knowledge can be acquired through questionnaire, field visit or from experts.

Knowledge based systems in geography are being designed as a separate course in some Universities. Klinkenberg (1997) has for instance a designed a course called Knowledge based techniques in geography in collaboration with Santa Barbara University in California. In this particular teaching material, Klinkenberg (1997) described the difference between DSS and Expert systems. According to him, DSS is one response to ill-structured problems concentrating on delivering a wide range of functions to the user, rather than one solution and leaves the user with the role of expert. This implies that DSS, like the MCE in GIS, is not comfortable to decision makers as they do not provide a well organized knowledge of the expert that can easily be manipulated by the decision makers.

Knowledge based techniques, on the other hand, concentrate on making use of all available knowledge by emulating the reasoning of an expert and the system takes the role of expert

(Klinkenberg, 1997). According to him the term artificial intelligence suggests the role of the machine in emulating the reasoning power of humans. This emphasizes the power of the Expert systems in GIS, both in decision making and knowledge representation of experts by emulating the knowledge of experts.

There are many works in different applications on which a prototype Expert systems are embedded by customizing to preexisting GIS Softwares like ArcGIS or by using softwares that already include modules for Expert systems. The knowledge engineer along with the expert classifier in ERDAS IMAGINE is one that is powerful and used both for expert knowledge based image classification and the advanced GIS modeling ERDAS (1999).

The application of Knowledge based (Expert systems) integrated with GIS has been used in solving several spatial problems in many fields including military operations planning. Valdo (1998) has integrated knowledge based systems and GIS capabilities together in supporting site suitability assessment and environmental impact prediction. He has prepared a prototype that brings the model, data, domain knowledge, and the system's knowledge acquisition and reasoning mechanism together into environment of GIS and developed the integration of GIS and Expert systems to illustrate how GIS could be used to support site suitability analysis for urban development, which is usually handled using Weighted Overlay Analysis. Seid (2007), has for example, used the application of Weighted Overlay Analysis in GIS environment while modeling site suitability for housing in the growing city of Adama. As a matter of fact, all the researches that have some thing to do with the site suitability modeling have mainly used the Weighted Overlay Analysis among the existing spatial Multi-criteria evaluation methods.

In selecting site suitability for urban development, Valdo (1998) prepared prototype KBGIS in ArcView desktop GIS software. Data storage, query and retrieval capabilities of ArcView give the prototype KBGIS a convenient method to create a location-based inventory required for identifying the site-specific environmental constraints. This type of integrating GIS and knowledge based systems is known as a tight coupling according to Eldrandaly et al. (2005) definition of the level of integration of the Knowledge based systems and GIS. This is an example when by one system providing a user interface for viewing and controlling the entire application that may be built of several programmes. As the trend of the strategy of coupling

is towards a tight and more integrated one rather than the loose coupling, which depends on sharing files between systems.

Besides, the application of the KBGIS in managing decision making for problems with spatial context in many applications, the Expert system has been integrated with GIS for military applications. Since military tasks are usually related to the terrain information in one way or the other, the need for more developed means of decision making in GIS environment has resulted about the application of knowledge based Expert systems in military planning. Baijal et al. (2006) have effectively used IMAGINE's knowledge engineer in developing a knowledge based approach for military operations in GIS environment. Knowledge of experts is a key input for any C4I system. Knowledge Based (KB) Systems are being developed for war planning that can process inputs from remotely sensed and GIS derived products and use the knowledge gained to aid the decision making process, thereby allowing the military commanders make better battle plans. GIS embedded C4I systems aim to give this KB to field commanders and their staff who despite having little knowledge of GIS, can work on such systems. Currently only a few C4I systems are in use with embedded GIS, but their numbers are likely to rise substantially soon as more and more systems are developed around the world (Baijal et al., 2006).

As military operational planning that are naturally related to the terrain require good interpretation skills of experts that are in turn subjected in to personal judgment resulting variation in the interpretation of governing factors in the terrain. Baijal et al. (2006) proposed KBGIS to standardize procedures and incorporate systems, which use the existing knowledge acquired by experts, intelligence agencies and other means.

However, Baijal et al. (2006) disregarded the use of remote sensing data in generating the landuse/landcover of the study area. Only GIS data (topographic map) map was used in generating the suitability map for all the military operations discussed in western borders India. Besides, it has been effectively applied in using the knowledge shell in ERADS IMAGINE in using as a knowledge base for the knowledge of experts in the military.

## **2.6. TRAFFICABILITY ANALYSIS**

The movement of troops on foot, on horseback, or in motorized vehicles can be hindered by topography and soil conditions Haneberg (2002). He emphasized Expert systems is the best approach in modern terrain trafficability studies. Trafficability analysis is necessary as the results for any military operation is affected by how the resources at hand like wheeled and tracked vehicles are effectively used. Off-road trafficability study is the study of the possibility for the movement and estimation of speed of armored vehicles over a given terrain and availability of alternative avenues of approach (MoND, 1998). Authors in military geology (Haneberg, 2006) insist that one of the principal concerns of military geologists is trafficability, or the ease with which a landscape can be traversed by troops.

Detailed trafficability analysis helps tactical decision makers determine likely enemy avenues of approach and possible friendly avenues of approach. However, manual processing of trafficability analyses is time consuming and coarse. The output of the manual terrain analysis process often takes days and results in a product known as the Modified Combined Obstacles Overlay (MCOO) (Slocum et al., 2003).

Manual terrain analysis is time consuming and requires the expertise of a trained specialist. The result is typically a map on which terrain is classified into three categories based upon trafficability: go, slow-go, and no-go. Current research is aimed at the creation of computer Expert systems that will be able to combine map layers showing roads, soil types, topography, rivers, vegetation, landcover and man made obstacles to produce probabilistic estimates of trafficability for military vehicles.

Military estimates rely heavily on an understanding of the trafficability of terrain (James et al., 1999). The movement and delivery of logistics to the army in the battle field during war and peace times is therefore determined by the trafficability of the land or the possibility of movement on the ground both in vehicles and personnel. Off-road trafficability maps have to be prepared during peace times so that the possibility of movement is well studied and prepared for war times. Many common geospatial reasoning tasks rely heavily upon estimates of trafficability, and in some domains, off-road trafficability is of primary concern and maps rarely provide the appropriate representation of space for such problems (James et al., 1999).

GIS and remote sensing techniques play pivotal role in the automation of modeling off-road trafficability both for civilian and military cross country mobility.

Many researchers, James et al. (1999); Slocum et al.(2003); Suvinen et al.(2005); David. (2006) have conducted studies regarding the cross country mobility of military forces to help military commanders with automated terrain based decision support systems. Similarly mobility studies are also conducted for development purposes like agricultural mechanization and forest development. They described a concept for GIS based terrain mobility modeling and optimization of off-road route and the concept of generation of cost surface are based on machine, terrain, tree coverage, road and weather objects and conducted their research with a special emphasis to forest tractor, the interaction between wheeled tractor and soil was taken as the most important parameter in modeling the off-road route.

James et al. (1999) proposed that GIS can be used to produce representations for qualitative spatial reasoning. In using a Geographic Information system for qualitative spatial reasoning about trafficability. They accounted for a wide range of military vehicle types, which allows them to reason about a variety of trafficability scenarios. The interaction of each military vehicle type with the terrain was considered in modeling trafficability problems specifically, the trafficability of military vehicles for cross-country movement. They have broadly categorized military vehicles in to two as tracked and wheeled and Vehicles like tanks have excellent cross country mobility due to the presence of tracks over its wheels.

However, vehicles having wheels but without tracks do need careful route planning before cross-country movement can be attempted. Vehicles carrying essential war stores like ammunition; fuel and other supplies are all wheeled. As a result, the mobility map in thesis mobility study represents the wheeled vehicles which are highly influenced by the terrain but are critically important in ground operations.

Various researches have emphasized different terrain factors in modeling off- road trafficability in GIS environment. Baijal et al. (2006) used Geographic Information System for qualitative spatial reasoning about trafficability emphasizing soil as a primary factor that governs the mobility of military vehicles in off-road condition besides to landuse/landcover and slope of the terrain that are used in modeling suitable land for vehicular mobility for the western boundary of India. James et al. (1999) used three factors that affect cross-country

mobility of military forces namely: Vegetation; soil and slope of the terrain. Satyanarayana et al. (2006) have also emphasized that the daily movement of the forces in the front is highly determined by the nature of the topography, geology, landuse/landcover and soil of the battle field the commanders both in the battle field and in the command posts have to be provided with near real time information of the terrain.

Generally, trafficability analysis is conducted manually using paper maps which subjected to errors. This is even more exacerbated in countries like Ethiopia, where the technological innovation like GIS and remote sensing are in their infancy. As Ethiopia is characterized by rugged terrain with varying soil types and vegetation cover, the off-road trafficability analysis in this research is based on five main factors, such as, Landuse/landcover; slope of the terrain; soil type, drainage systems and utilities like electric power lines of the study area. Although some researchers have considered rivers and power cables to be addressed by drivers themselves during movement, they are incorporated as important factors in this research. Experiences from the opinion of experts indicate that such terrain features should not be disregarded as only obstacles as some negotiable sections can be identified, which are helpful information prior to the movement of vehicles.

## **CHAPTER 3. DATA SOURCES, MATERIALS AND METHODS**

### **3.1. DATA SOURCES**

Reliable data are necessary to realize the desired objectives for any problem and hence the study was based on both the primary and secondary data. Frequent field observations using GPS was carried out to generate primary information regarding the ground truth for the major landcover classes of the study area. The study area lay in two scenes of Landsat ETM 2001 imagery (P168R54 and P169R54). The images were subjected in to moaick tool of ERDAS IMAGINE 9.1 to create a continuous surface of the study area. The image was then geometrically corrected using the topographic map of the study area to make it consistent with other layers extracted from the topographic map. Linear stretch and pansharpning techniques were applied to improve the image classification.

In classifying the images, both unsupervised and supervised image classifications techniques were applied. For the latter case training sites were established based on the ground truth taken during field work. The unsupervised classification was done before field work. Among different algorithms in the drop down lists of supervised classification, maximum likelihood image classification was utilized. Sixty five representative sample sites of known cover type, called training areas were used to create the parametric signatures of each class. Each pixel in the data set was then compared numerically to each category in the interpretation key and labeled with the name of the category it looks like most (Lillesand and Kiefer, 2004). And the different landcover classes in the image were classified based on the field data collection.

The 1:100,000 topographic map and satellite image of the study area and other ancillary data used in this research were accessed from the authorized body. Table 3.1 shows the list of data to be used in this study and their respective sources from which they were obtained.

*Table 3.1. Material and Data Source*

<b>Materials and data used</b>	<b>Source of data</b>
Topographic map (1:100,000)	Ministry of National Defense
Landsat ETM, 2001 imagery	Ethiopian Mapping Authority
DEM	Geological Survey of Ethiopia
Boundary of the study area	Ministry of Agriculture and Rural Development, Federal Democratic Republic of Ethiopia
Power lines	Ethiopian Electric Power Corporation
Land cover	Landsat ETM, 2001 imagery
Soil Map	Food and Agricultural organization (FAO)
Slope Map	Generated from DEM
Drainage (River)	Extracted from Topographic map
Temperature and Rainfall Data	National Metrological Agency

All the layers obtained from various sources are projected in to the same Projection, i.e. World Geodetic System (WGS 1984 UTM Zone 37N) for compatibility during data analysis. All the thematic maps produced in this thesis therefore have this projection.

### **3.2. MATERIALS USED**

In conducting this research, several softwares were used from the data preparation up to processing and analysis. All the softwares were accessed from the Remote Sensing and GIS laboratory of Addis Ababa University and Ministry of National Defense. Besides, GPS and digital camera were used for field data collection. Table 3.2 lists all materials used and their application in this research.

Table 3.2. Software used

<b>Software Used</b>	<b>Remark</b>
ArcGIS 9.3	1. Digitizing and Generating the needed data layers (vector and raster data models) in a compatible format for the Knowledge engineer (KE).  2. The WOA Process
3DEM	Patching and DEM file conversion
ERDAS IMAGINE 9.1	1. Knowledge acquired in the form of GIS data layers will be converted into rules that are transformed into a knowledge base using the Knowledge Engineer (KE) shell of ERDAS Imagine 9.1.  2. Image classification
IDRISI Andes	Calculation of eigenvector of factors/weight
GPS	Field point data collection
Digital Camera	Field survey/ field photograph

### **3.3. METHODS OF DATA PROCESSING**

The GIS data layers that were generated in ArcGIS 9.3 were prepared in a manner that was also compatible format in Knowledge Engineer (KE) and Knowledge Classifier Shells of the ERDAS IMAGINE 9.1. The Knowledge acquired in the form of GIS data layers in ArcGIS 9.3 were then converted in to rules in the knowledge base using the knowledge engineer in ERDAS IMAGINE 9.1. The suitability map of a trafficable land was generated using the already created knowledge base and rules already set. The ERDAS Expert classifier was then used to select the criteria as an output file. This method of knowledge based systems was used by researchers for military operations planning (Baijal et al., 2006). The WOA also has used the same data layers to generate of-road trafficability map. IDRIS software was used to

obtain factor weights using analytical hierarchy process. A model of the whole process of the WOA was constructed in ArcGIS 9.3 software.

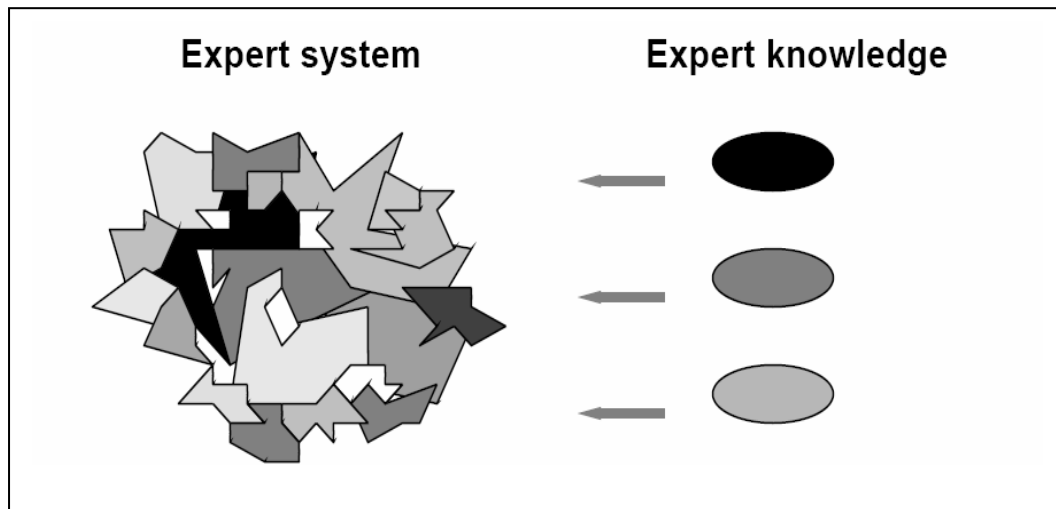
### **3.4. KNOWLEDGE ACQUISITION**

Knowledge acquisition techniques, like the author's own knowledge about the study area through field visiting, literature review, interviews with experts in this field, ancillary datasets stored within a GIS, and RS and GIS processing due to which some new facts were generated. Informal assessment was undertaken to acquire the experts' knowledge throughout the development of the knowledge base.

Three senior experts of military topography that were participating through out the development and execution in the course of knowledge based systems and of the WOA were obtained from GIS and military topography section of the Ministry of National Defense. The knowledge acquired to construct the decision tree in the Knowledge base is therefore obtained by asking experts to break their knowledge down into its individual facts and rules and deducing rules from the behavior of experts, and this widely used in the development of many expert systems.

### **3.5. KNOWLEDGE BASE CREATION AND REPRESENTATION**

Continuous and persistent communication was undertaken to understand the intent opinion of the experts to convert their knowledge in to a quantified manner to the knowledge base and weighting the factors in the Weighted Overlay Analysis. This system means that rules can be entered into an expert system in the ERDAS knowledge engineer exactly as provided by the expert and the growth of the system's knowledge records the way in which knowledge was acquired from the experts. The knowledge of the experts in defining each parameter was quantified from the experts and their opinion was converted in to rules in the knowledge base creating a hierarchy of decision tree in the knowledge base for the mobility of military vehicles over a given terrain with out overlapping the rules enforced. Figure 3.1 displays the general picture of knowledge representation in the Expert systems.



*Figure 3.1. General picture of knowledge representation in Expert systems*  
 Source: Compton et al. (1989).

Using the same GIS data layers, suitability maps for a trafficable land again were produced using a different method i.e. Weighted Overlay Analysis. A model builder was developed for the whole process of the Weighted Overlay Analysis in ArcGIS 9.3. The knowledge and opinion of experts was used in ranking and weighting the different criteria for analysis. IDRISI Andes software was used for the calculation eigenvectors of weight for each criterion through analytical hierarchy process (AHP).

### **3.6. METHODS OF COMPARISON**

Several GIS techniques were adopted in comparing the results from the two methods. First, a difference map was generated to show spatial variation of the outputs from the two methods. This showed areas where there was similarity and where there was deviation in a generalized manner based on a standard deviation between the resulting maps. A difference map was in the Raster Calculator produced with seven values and zero at center. The deviation increases both directions from zero (no change).

Latter, a zonal cross tabulation was computed to show the spatial correspondence of each trafficability class of results by summarizing each trafficability classes in the two methods to each other. This method showed how one class in one method was distributed over the corresponding classes in the other method. It enables to know which class in one method is classified in which class in the other method.

Finally, a multivariate statistics tool was used to assess the general spatial correlation of the results. The correlation matrix shows the values of the correlation coefficients that depict the relationship between two datasets. The correlation between two layers is a measure of dependency between the layers. It is the ratio of the covariance between the two layers divided by the product of their standard deviations. Because it is a ratio, it is a unitless number. The equation to calculate the correlation is:

$$Corr_{ij} = \frac{Cov_{ij}}{\delta_i \delta_j}$$

Finally, the off-road trafficability modeling conducted in this research was undertaken for wheeled military vehicles. Military vehicles are generally classified into two broad categories as tracked and wheeled. Vehicles like tanks have excellent cross country mobility due to presence of tracks over its wheels as vehicles having wheels but without tracks do need careful route planning before cross-country movement can be attempted (Baijal et al., 2006). Military analysts insist that vehicles carrying essential war supplies like ammunition; fuel and other tools are all wheeled vehicles. It was therefore, important to consider wheeled vehicles to study the possibility of movement for war planning. There was also a possibility of inferring the trafficability conditions for a tracked vehicle from a mobility map originally prepared for wheeled vehicles. Figure 3.2 describes the research method adopted in research diagrammatically.

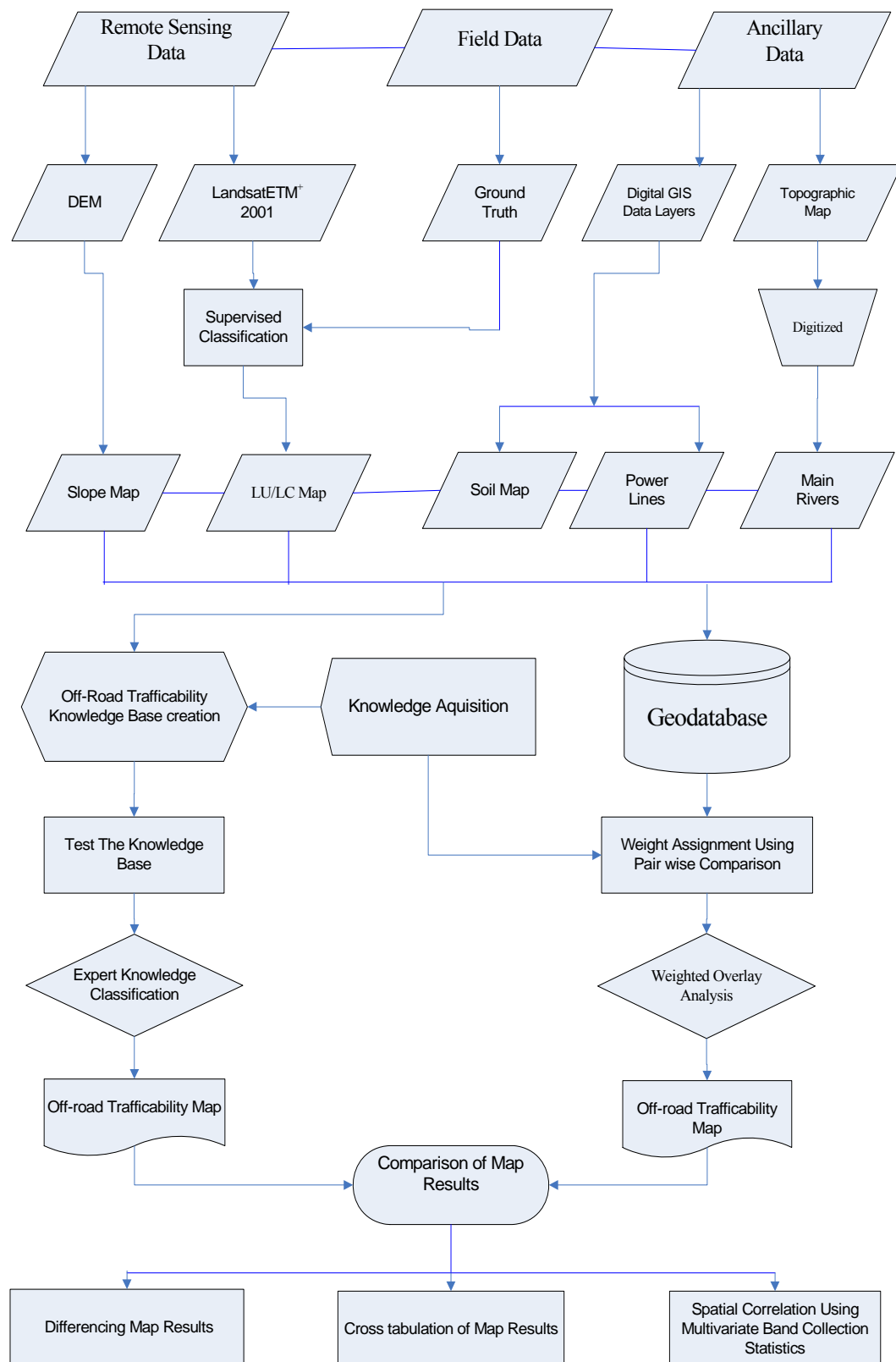


Figure 3.2. General research methodology

# CHAPTER 4. STUDY AREA DESCRIPTION

## 4.1. LOCATION, EXTENT AND BOUNDARIES

The Expert systems and of the Weighted Overlay Analysis presented here has been designed keeping in mind its effective use in the borders of Ethiopia. The border areas are characterized by a rugged terrain interspersed by many rivers in the north to the tick vegetation cover and some swampy water bodies in the south and south western Ethiopia to the lowland plains areas of eastern and western part of the nation. However, as the use of topographical maps and other spatial data of the border area is restricted for security reasons, an area out side the border area with a diversified terrain characteristics has been selected to test the Expert systems and the Weighted Overlay Analysis developed for mapping an area of trafficable land for military vehicles movement in a comparative basis. Mulona Sululta Woreda is selected to be a study area by which the two methods are compared for military applications. The map of the study area is given in Figure 4.1.

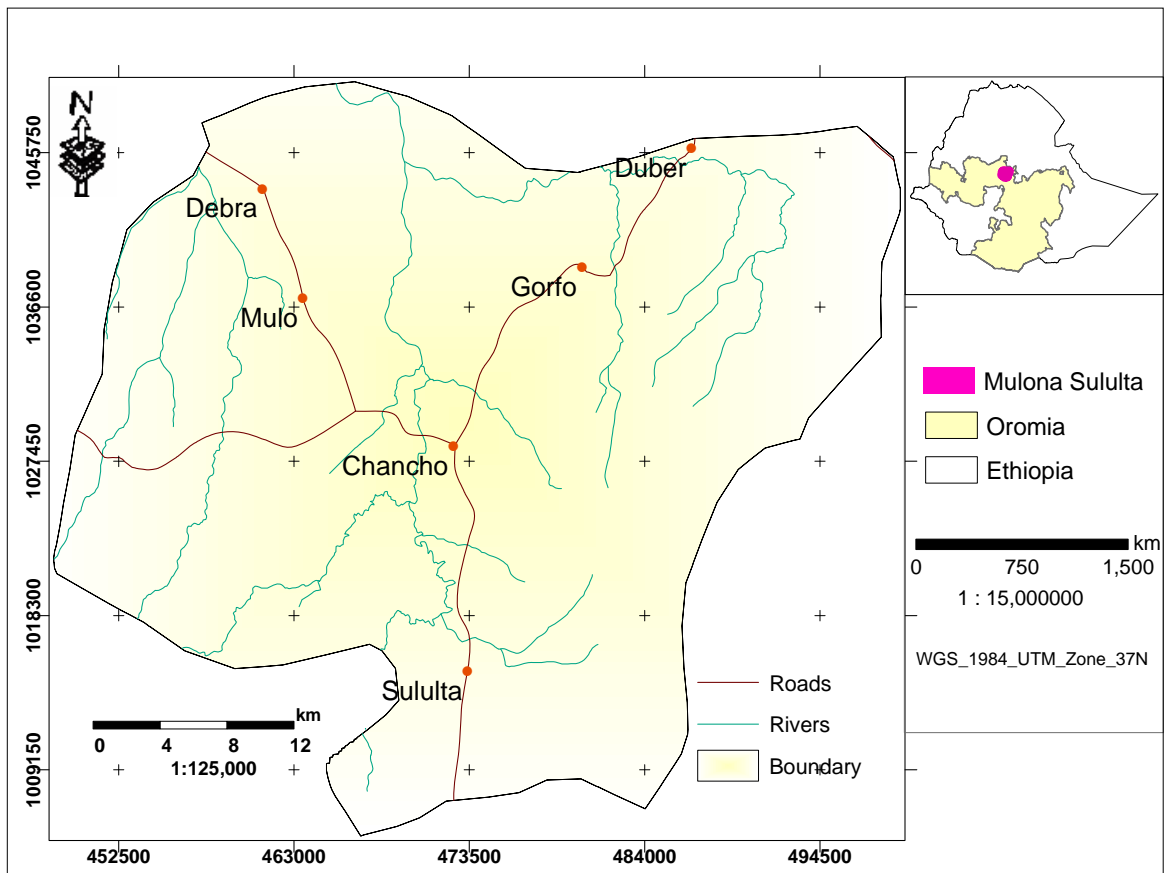


Figure 4.1. Locational Map of Mulona Sululta.

Mulona Sululta Woreda is found in Oromia Regional State, North Shawa Zone. It is found 45km from Addis Ababa, and 80km from North Shawa city (Fitcha). It is bounded by Wuchale and Yaye Gulale Woredas in the North, Barak Woreda in the East and Walmara Woreda in the West, and Addis Ababa city Administration in the South. The area extends North of Addis Ababa between Latitude 9°9'18" to 9°30'47" and Longitude 38°30'48" to 38°58'30" with a map sheet number of C37-90 and C37-102. The area covered is approximately 146355 hectare. Mulona Sululta is found in the Southern part of the Nile basin traversed by the main road connecting Addis Ababa with North Western part of the Nation.

## 4.2. TOPOGRAPHY

The area is of a rolling terrain of rugged topography of ups and downs. The elevation ranges from 1556 to 3455 a.s.l. The rugged terrain of Sululta Woreda is characterized by many rivers and streams. There are eleven seasonal streams and permanent rivers that are used for drinking, irrigation and Irrifacha (cultural celebration of beliefs). With increase in elevation, farm land dominates the land use pattern even in the highlands with steep slopes (up to 50 degrees). Figure 4.2 Show the elevation map the study area.

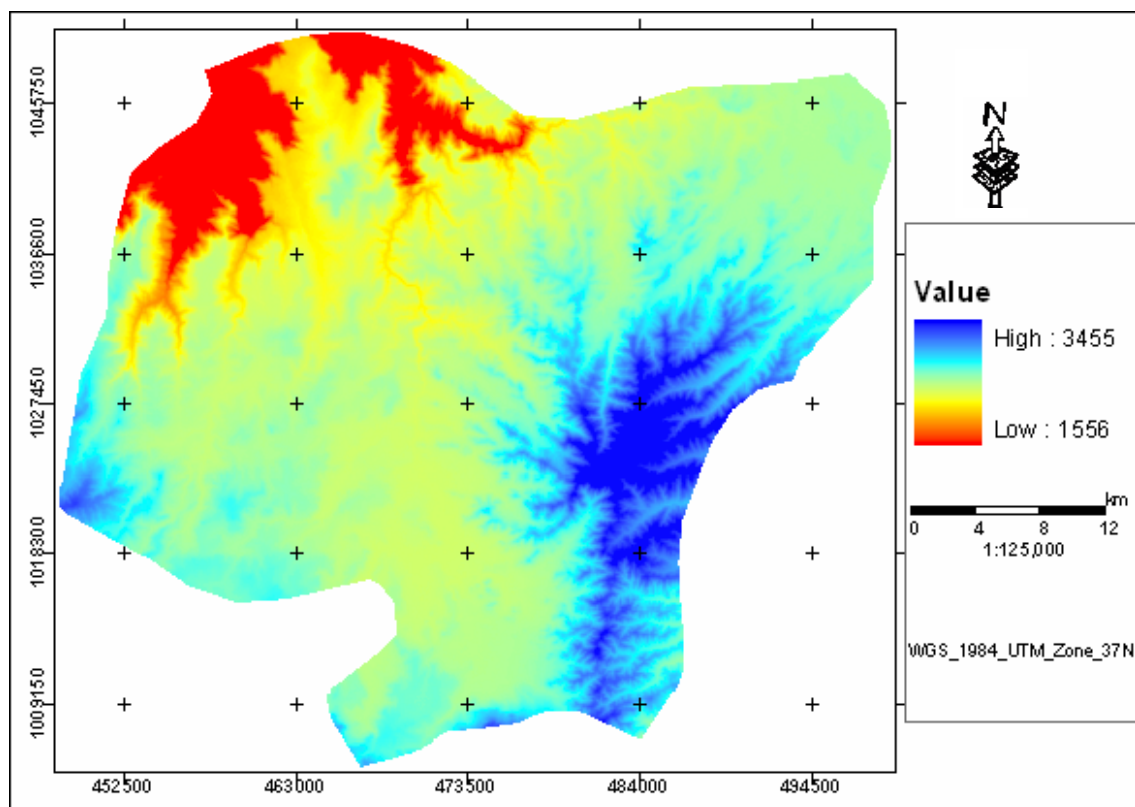
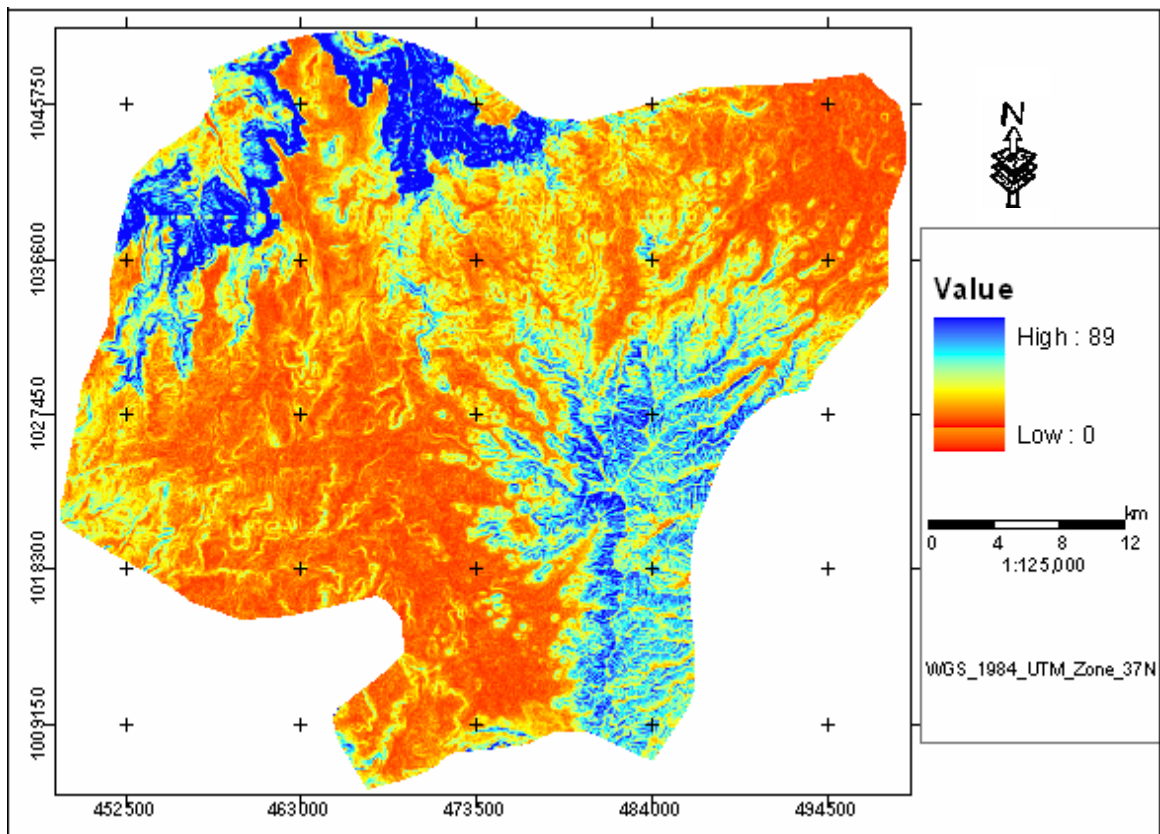


Figure 4.2. Elevation map of Mulona Sululta.

The slope of the study area ranges from 0 degree in the plain areas up to 90 degree in the rugged highlands where the Chelalaka forest is found. The lower elevation of the Woreda is characterized by plain areas covered by grasses dominantly because they are flooded during the rainy season resulting the impossibility of farming. Figure 4.3 Shows the slope of the study area.



*Figure 4.3. Slope map of Mulona Sululta.*

### **4.3. SOIL**

Soil type is one of the most important terrain factors that affect the possibility of off-road trafficability in military operations. The availability of authentic soil map is therefore important in modeling off-road trafficability and other military operation tasks. Several soil types are identified in the Woreda. Table 4.1 shows the coverage of each soil type in percent and Figure 4.5 shows the soil description of the study area.

Table 4.1. Soil coverage of Mulona Sululta.

Source: Woreda Agricultural and Rural development Office.

No	Soil Type	Coverage in percentage
1	Luvisols	23
2	Leptosols	16
3	Nitisols	26
4	Vertisols	4
5	Cambisols	31

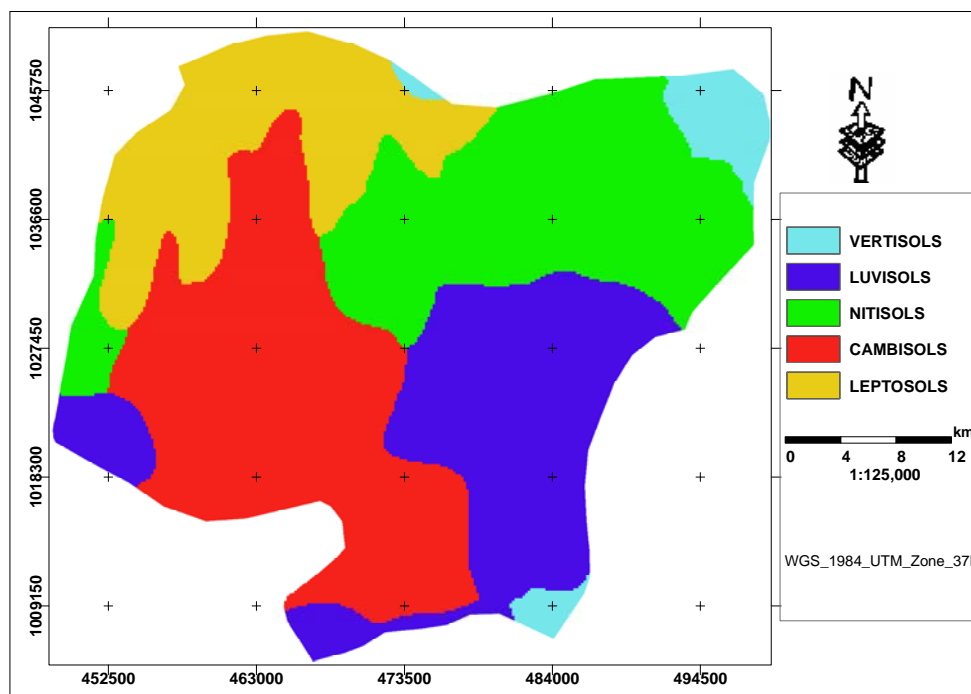


Figure 4.4. Soil description of Mulona Sululta.

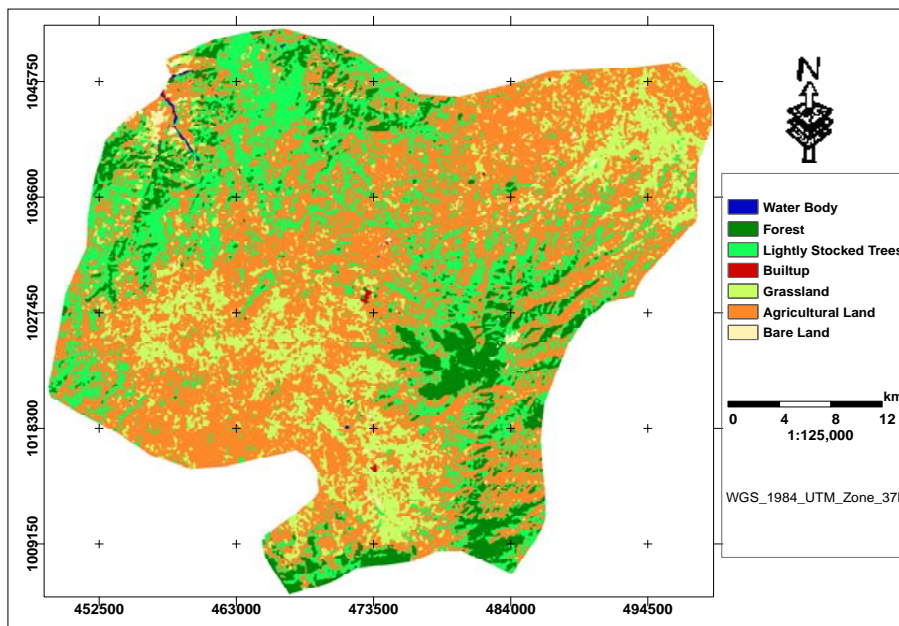
#### 4.4. LANDUSE/LANDCOVER

According to the Environmental Management Plan of the Woreda prepared in the year 2007, forest being one of the profound natural resources of the Woreda is reported as devastated to the point of extinction both in size and diversity. The forest area is composed of rare variety of tree species growing naturally and manmade plantation. The sparsely populated natural forest is composed of Juniperous procera, Hygenia abyssinica, Olea, Acacia albida and Golole

absesha (local name) and a wood lot and homestead plantations of eucalyptus and Cupyresses lusitanica. The forest size indicated in table 4.3 includes natural forest, private forest as well as state and communal forest. The area of each landuse/landcover class of the Woreda is obtained and given in table 4.2 obtained from the Woreda agriculture and Rural Development office. The landuse/landcover map is also given in Figure 4.5 obtained by supervised classification of Landsat ETM imagery of the year 2001.

*Table 4.2. Landuse/Landcover area of the Mulona Sululta.  
Source: Woreda Agriculture and Rural Development Office*

No	Land Use system	Size in hectares
1	Arable land	47885
2	Cultivated	38709
3	Forest	15390
4	Grazing land	32045
5	Waste land	5440
6	Others	22397



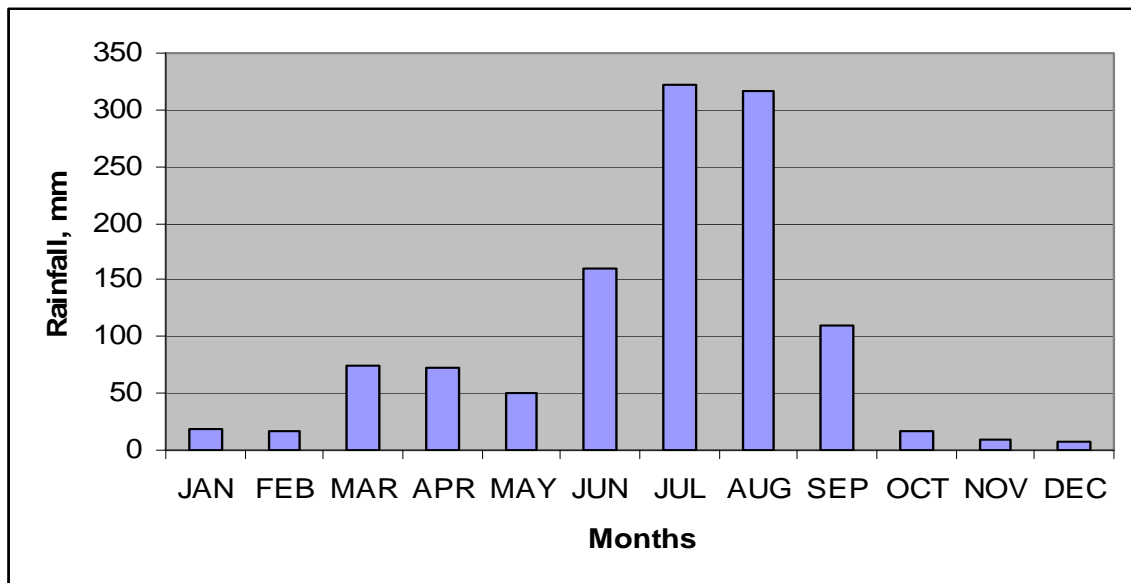
*Figure 4.5. Landuse/Landcover map of Mulona Sululta.*

Reliable information about the existing landuse/landcover extent of the area is important in military studies and terrain based decisions in military. The landuse/landcover classification is undertaken based on the digital land use land cover map of the Woreda prepared by MoARD.

## 4.5. CLIMATE

### 4.5.1. RAINFALL

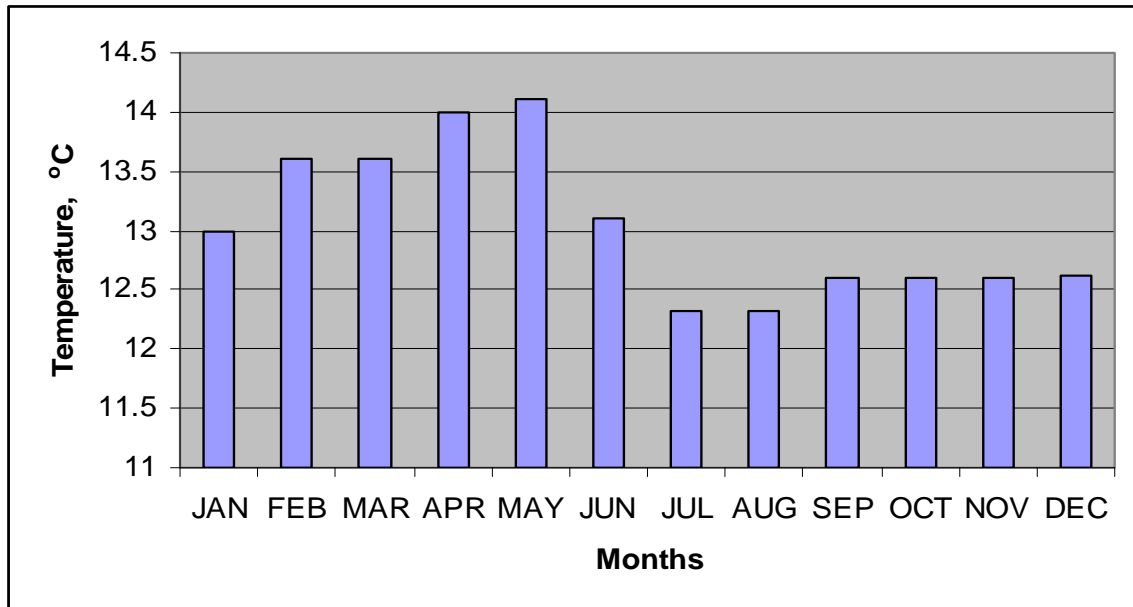
According to the Agriculture and Rural Development Office, the Woreda is found with in a climatic zone of Dega, Woyna Dega and Kola characterized by medium to cold weather conditions. Excess rainfall intensity and distribution occur in the summer from July to mid September, where as the remaining season is characterized by little or no rain. Figure 4.6 shows the mean monthly rainfall of Mulona Sululta Woreda. The mean monthly rainfall is averaged for thirty years.



*Figure 4.6. Mean monthly rainfall of Mulona Sululta.  
Source: Ethiopian Metrological Agency.*

#### 4.5.2. TEMPERATURE

According to Agricultural and Rural Development Office, the annual average temperature varies from 12.8 to 22.5 degree celcies. Figure 4.7 shows the mean monthly temperature of the Woreda averaged for thirty years.



*Figure 4.7. Mean monthly Temperature of Mulona Sululta.  
Source: Ethiopian Metrological Agency*

## CHAPTER 5. DATA ANALYSIS

### 5.1. FACTORS FOR OFF-ROAD TRAFFICABILITY ANALYSIS

The key terrain factors that influence the off-road movement of military vehicles for ground operations were systematically studied using GIS techniques. The terrain parameters were used in modeling off-road mobility using Expert systems and Weighted Overlay Analysis in GIS environment separately in a comparative basis. The factors of off-road trafficability analysis are discussed in the forthcoming sections.

#### 5.1.1. SURFACE CONFIGURATION (SLOPE)

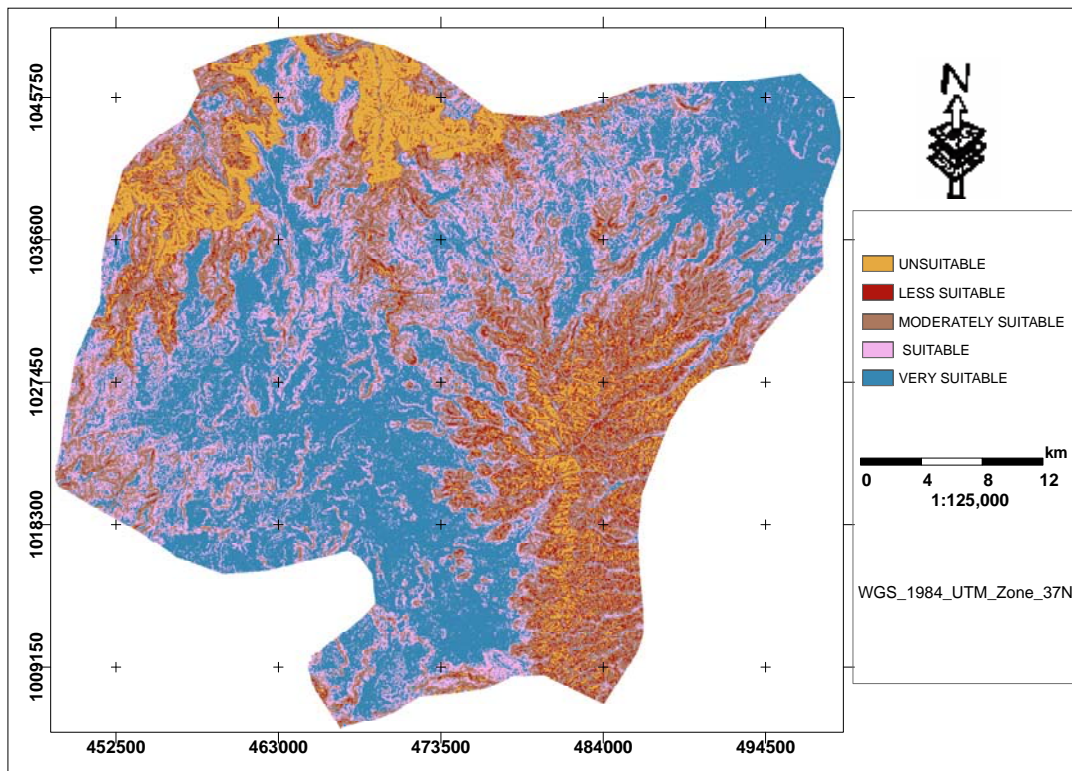
The surface-configuration overlay was used to depict the inclined surface of the terrain and was expressed using percent of slope or change of elevation (rise) divided by the horizontal distance (run). This overlay was one of the primary overlays used in determining the cross-country movement capability of troops and vehicles. Although military topographers traditionally calculate overlay slope information manually from paper maps, this was done faster and with better accuracy using GIS techniques.

At all altitudes the slope of the ground has an appreciable effect on the cross-country mobility of vehicles. The slope of the terrain is therefore used and reclassified accordingly in to suitability classes. *The FDRE Military Topography Officers Handbook* (Addis Ababa, 1998) yields the following figures that are adopted in this research.

*Table 5.1. Slope Gradient and effect on vehicles.*

*Source: FDRE Military Topography Officers Handbook (Addis Ababa, 1998)*

<b>Gradient in degrees</b>	<b>Effect on tracked Vehicle</b>	<b>Effect on wheeled vehicle</b>
Up to 5	Easy	Passable
5-10	Passable	Passable Slowly
10-20	Passable Slowly	Passable very slowly
20-25	Passable very slowly	Passable very slowly with great difficulty
Over 25	Passable very with great difficulty (25-30)	Impassable



*Figure 5.1. Reclassified Slope Map.*

The slope was generated from a 90m DEM (Figure 4.3) and classified based on the Ethiopian Military Forces slope classification for the purpose of mobility of military vehicles. Based on this, the slope of the study area was classified in to five classes and were reclassified and ranked such as unsuitable, less suitable, moderately suitable, suitable, and very suitable classes with raster values as 1,2,3,4 and 5, respectively.

For the Expert systems, there was no need to reclassify the slope as the knowledge engineer takes float data type. As a result, the slope of the terrain was reclassified for the WOA while it is not for the Expert systems. This helps to avoid confusion during the course of the development of the knowledgebase.

### **5.1.2. LANDUSE/LANDCOVER**

Land use land cover mapping was used to determine if it was sufficient for a given vehicle type to by pass. Further, expanding the illustration, a region was too vegetated for the cross-country movement if the vegetation was both too closely spaced for the vehicle to drive around and too thick for the vehicle to override. According to the opinion of experts, bare

grounds are the most suitable ones while forests and water bodies are not possible to traverse. In the study area, the grasslands are found in plain areas where there is seasonal flooding. Agricultural lands are assumed to provide a better traction for the mobility of military vehicles than grasslands

For the purpose off-road traffcability modeling, the landuse/landcover of the study area was classified in to seven classes (Figure 4.5). Although landcover can be identified in paper maps, remote sensing data was used in this research to delineate the major landuse/landcover of the study area as the topographic maps were outdated and do not include detailed features of the terrain. Landsat ETM of the year 2001 was used to identify the major landcover classes through digital image processing. For the ease of modeling in the WOA, Bare lands are merged with agricultural lands as very suitable and Water bodies are merged with forests as unsuitable and reclassified accordingly. Similarly the land cover map is not reclassified in the case of the Expert systems. This is because reclassifying them in to suitability ranges doesn't bring any computational advantage other than generalizing the analysis. In the Expert system the water body, forests, lightly stocked tress, built-up areas, grasslands, agricultural lands and bare lands are assigned with raster values; 1,2,3,4,5,6 and 7 respectively. Accordingly, the different classes were reclassified and ranked in to five suitability classes such as unsuitable, less suitable, moderately suitable, suitable, and very suitable classes with raster values as 1,2,3,4 and 5, respectively for the WOA.

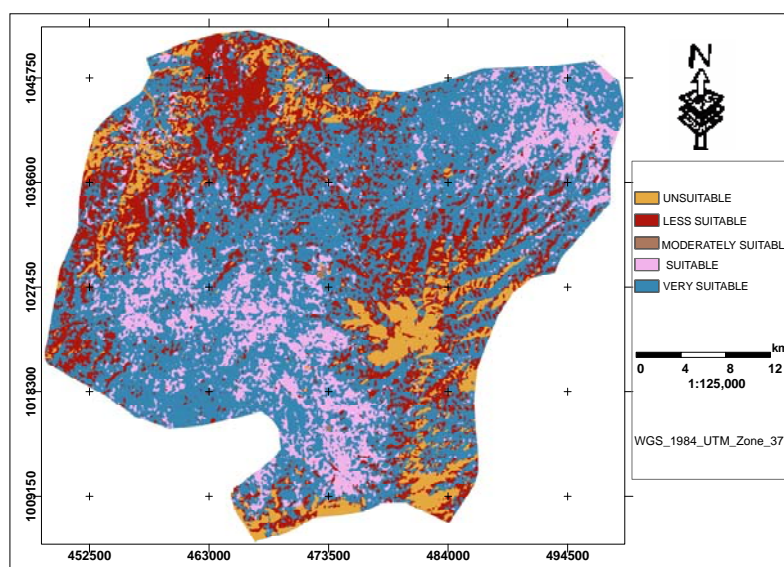


Figure 5.2. Reclassified Landuse/Landcover Map.

### 5.1.3. SURFACE MATERIALS (SOILS)

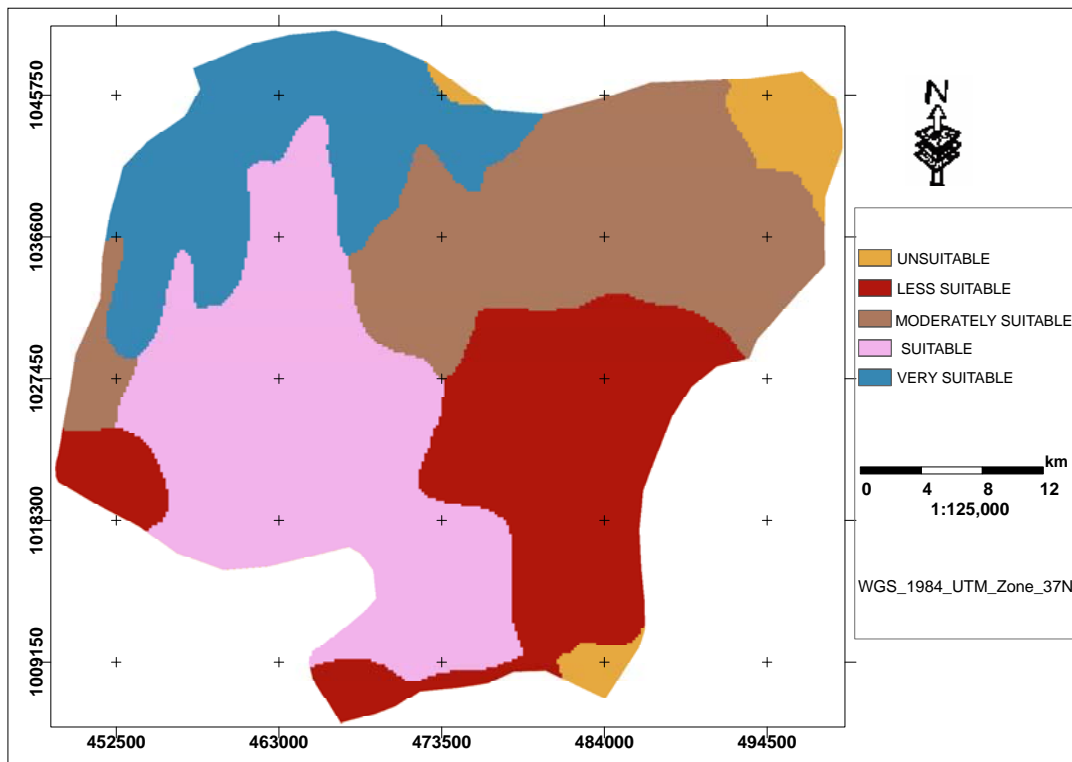
Because of the absence of authentic soil map of the country for such applications, the Soil map of the study area is obtained from the Digital Soil and Terrain Database of East Africa prepared by Food and Agricultural Organization (FAO) in a 1:1000,000 scale. The Agricultural classification of the soil is translated in to their engineering characteristics by considering the load bearing capacity of the soils by taking their clay content. This is undertaken by consulting experts in soil science and civil engineering. The load bearing capacity of the soils is obtained by the amount of clay content and depth of each soil. Several literatures and knowledge of experts has been used to categorize these soils according to their clay content and depth and their impact for the movement of military vehicles in off-road condition and in a natural soil. High clay content reduces affordability of the soil and raises dust which in turn reduces visibility (FM 5-33, 1990).

According to GlobalSecurity.org, (2000), the slipperiness and stickiness of the soils impact the trafficability of soils and is determined by the bearing capacity of soils. The bearing capacity of the soil type is considered in this research to model the trafficability of the soils that are initially prepared for agricultural purpose. Several literatures and mainly soil experts are used to transfer the agricultural soil classification in to their engineering characteristics and associated with the *FDRE Military Topography Officers Handbook* (Addis Ababa, 1998) which categorizes the impact of soil types on the mobility of vehicles in a generalized manner.

A terrain analysis manual prepared by the United States Department of Army, FM 5-33 (1990) ranked soil types according to their affordability for Off-road trafficability by considering their clay content. According to this manual, soil types are ranked in order of decreasing affordability for off-road mobility as Grave; Sand; Silt and Clay.

As there is no soil map of the country classified in this respect, the soil of the study area (Figure 4.4) was ranked according to increasing content of clay in each soil as described by the soil reference base for soil resources prepared by FAO (2006) and knowledge of experts in the field. Accordingly, the different classes are reclassified and ranked in to five suitability classes unsuitable, less suitable, moderately suitable, suitable, and very suitable classes with

raster values as 1,2,3,4 and 5, respectively. Figure 5.3 shows the reclassified soil map of the study area according to their suitability based on clay content and soil depth.



*Figure 5.3 shows the reclassified soil map of the study area.*

Soil reference base for soil resources prepared by FAO (2006) yields the following characteristics of the soil types identified in the study area.

1. **Leptosols:** Are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony.
2. **Cambisols:** Are medium and fine-textured materials derived from a wide range of rocks characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay.
3. **Nitisols:** Are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 percent clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedral (nutty) elements.
4. **Luvisols:** Are soils that have higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an argic subsoil

horizon. Luvisols have high-activity clays throughout the argic horizon and a high base saturation at certain depths.

5. **Vertisols:** Are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years.

The agricultural soil classification in the study area is translated in to its engineering characteristics by consulting experts. As a result, the soil is reclassified in to five suitability classes according to clay content and depth. Leptosol soil types are found to be the most suitable soil types while Vertisols with the highest clay content are the least suitable in the suitability class.

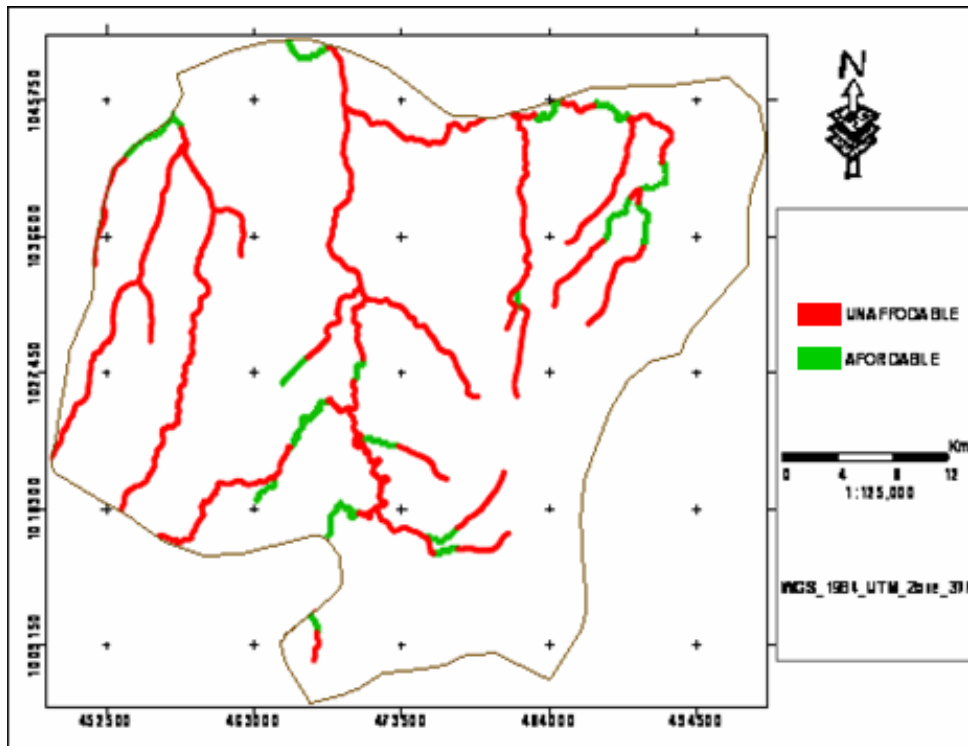
#### **5.1.4. RIVERS**

Drainage systems generally are shaped like asymmetrical trees, each branch of which empties its contents into a larger stream until the biggest tributaries connect with the trunk. Waterways are very important to military calculations, and especially in flat country, where they are frequently the only obstacles of any value (Faringdon, 1989).

The slope of the bank deserves particular attention. Any difference between the two banks has to be considered and note their height above the surface of the water. The approaches to the chosen crossing point must be firm enough to support a considerable volume of traffic with a maximum entry gradient of 25-30 degrees beyond which neither tracked nor wheeled vehicles can not manage (Faringdon, 1989). In order to prepare for a set piece of crossing of water obstacles, the banks and water need to survey by engineer reconnaissance patrols and this is labor intensive and expensive cost wise. It is obtained by following all streams and rivers and look for areas where the contour lines converge and looking for areas where flat terrain transitions into more rugged, steep terrain (FM 5-33, 1990)

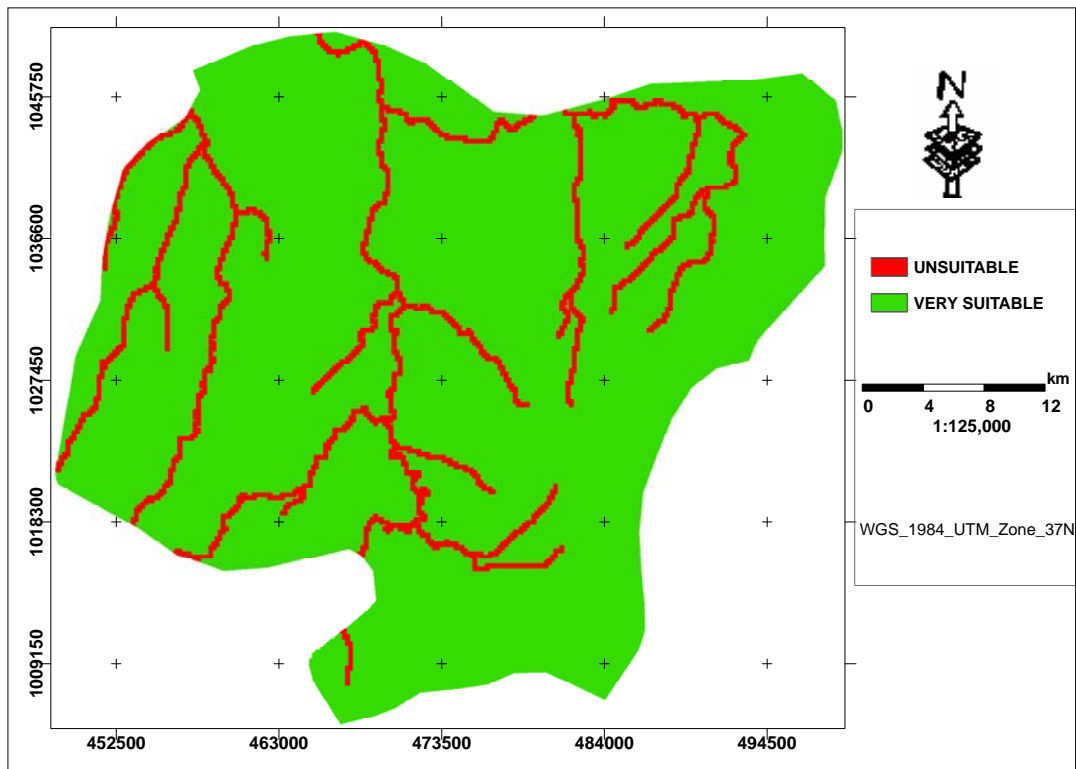
The topographic map of the study area of a scale 1:100,000 was used to digitize the sections of the main rivers and delineate them in to two classes as affordable and unaffordable sections. The river sections where the contour lines converge are classified as unaffordable and those sections of the rivers where contour lines diverge are classified as affordable. Besides, water bodies like natural reservoirs and swampy areas were obtained from Landsat

ETM of the year 2001. The river sections extracted from the topographic map were categorized as affordable and affordable river sections. Such classification of river sections was used for the Expert system. The Expert system can handle linear features with such height value. Figure 5.4 shows river sections of main rivers as unaffordable and affordable river sections with raster values 1 and 2 respectively.



*Figure 5.4. Reclassified Map of River Sections.*

In the case of the WOA the computational technique does not allow to use such classification of linear features classified according to their vertical impact. Instead, Euclidian distance with a maximum distance of 200 meter was used to depict the rivers as obstacles. The maximum distance of 200 meter is defined by the experts as logically; the impact of rivers beyond such distance is not significant. The distance is used to avoid double crossing a given river unnecessarily. The Euclidian distance from rivers is reclassified in to unsuitable and very suitable with a raster value of 1 and 2 respectively. Figure 5.5 shows the reclassified map of rivers.



*Figure 5.5. Reclassified Map of Rivers.*

#### **5.1.5. MANMADE OBSTACLES (POWER LINES)**

Power lines are another manmade obstacles that can affect off-road trafficability. There can also be elements other than rivers, which inhibit the mobility vehicles in off-road fashion. Mobility near power cables or similar objects requires special caution from the driver (Suvinen et al., 2005). These power cables have to be mapped prior to any operational activity is under taken over any space. Two power cables traverse the study area. A high voltage power cable traverses Mulona Sululta Woreda in two sections. The one which carries 66 KV Which Traverses from Fiche to Geffersa and the other Addis Ababa to Debrebirhan which carries 132 KV. The data is obtained from the Ethiopian Electric Power Corporation.

The longer the distances from this power cables, the safer the mobility around will be so that distances from the power cables were calculated by proximity analysis techniques and reclassified according to their preferences. In this study, Euclidean distance was calculated with maximum of 200 meter and Reclassified. Logically, the impact of the power cables is zero from a certain distance and there is no need to calculate a continuous distance map of the whole area

while its impact was limited to a certain distance. It is therefore limited to distance of 200 meter and reclassified accordingly as per the judgment of the experts. The power cables were reclassified in to Unsuitable and very suitable with raster values 1 and 2, respectively.

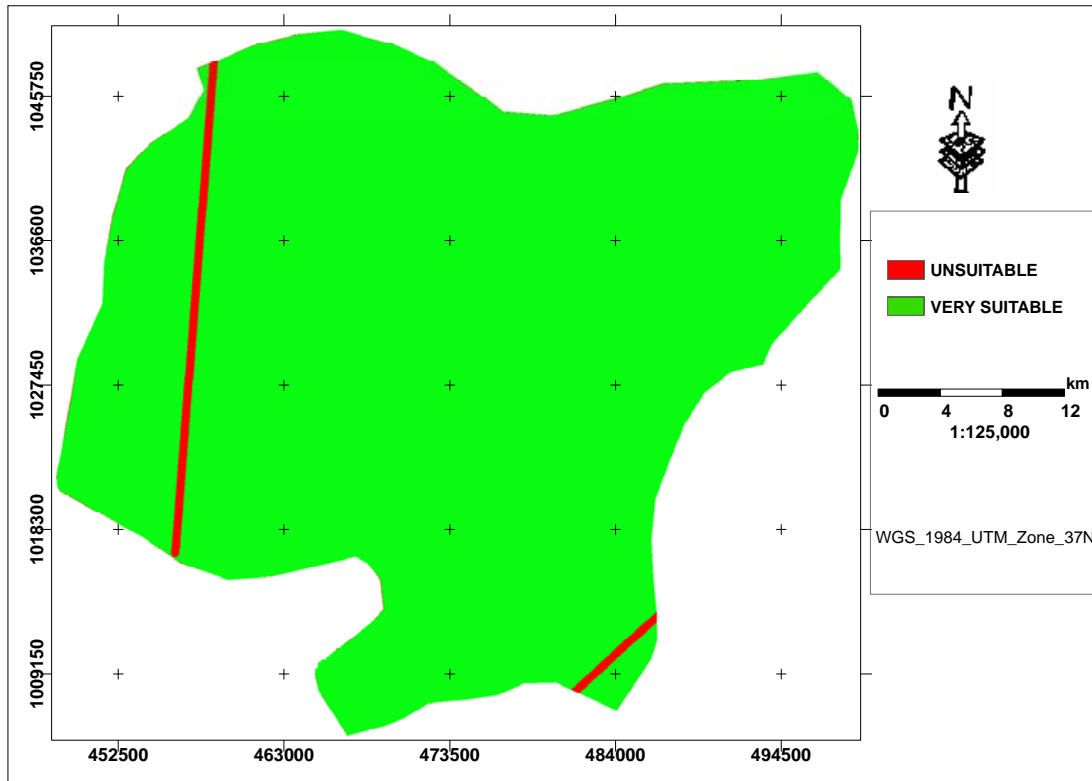


Figure 5.6. Reclassified Map of Power Lines.

## 5.2. OFF-ROAD TRAFFICABILITY ANALYSIS

### 5.2.1. USING EXPERT SYSTEMS

The opinion of the experts was quantified and converted in to rules in the knowledge base using a decision tree. Finally, the expert knowledge classifier was used to classify the knowledge and opinion of experts' in terms of a thematic map as output. The decision tree developed in the knowledge was constructed through logic of nodes evaluated as True or False.

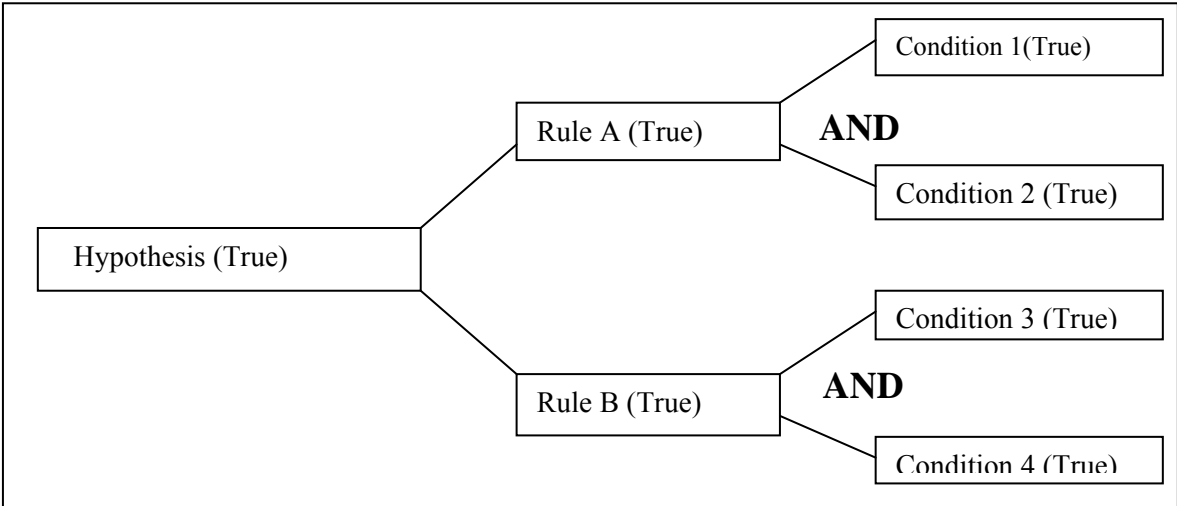
The logic of a node depends upon how its components were evaluated. A node is an object that contains properties for a hypothesis, a rule, or a condition. Nodes were displayed as rectangles in the knowledgebase window. Logical connections between nodes are displayed as lines between the rectangles. Nodes were evaluated as True or False. A condition

compares a pixel to a real value. A rule assigns a meaning to one or more conditions. A hypothesis forms a classification based on the truth of one or more rules. The conditions on how each pixel was evaluated in ANDing and ORing logic are graphically explained in the Figures 5.7 and 5.8.

**True**

In the following example, in order for the Hypothesis to be evaluated as true, either Condition 1 and Condition 2 must be true or Condition 3 and Condition 4 must be true.

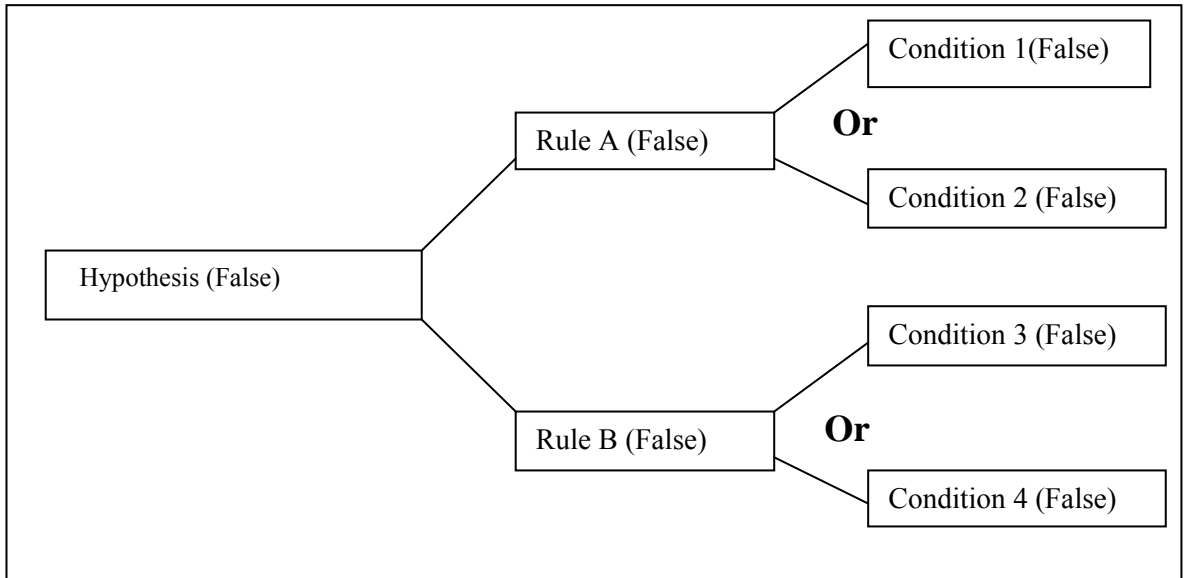
The rule indicated in figure 5.7 is split in to two and the ORing operator makes it possible for hypothesis to be true if any of the rules are true and the process will continue evaluating the pixels. While both conditions must still be false to fire a rule, only one rule must be true to satisfy the hypothesis.



*Figure 5.7. A logic of nodes for a hypothesis to be true.*

**False**

In the following example, In order for the hypothesis to be evaluated as false, either Condition 1 or Condition 2 must be false and Condition 3 or Condition 4 must be false.



*Figure 5.8. A logic of nodes for a hypothesis to be false.*

In this case the hypothesis turns out to be true if either of the conditions are false. While both conditions must still be true to satisfy a rule, only one rule must be false to fire the hypothesis.

All the opinions and knowledge of experts through out the process of modeling the off-road trafficability modeling is organized in this manner in the knowledge base. Eighty conditions have been generated in the knowledge engineer that are latter brought in the expert classifier to produce a trafficability map from possibility to advance to impossibility to advance in four trafficability classes. Figure 5.9 shows the off-road trafficability knowledge base for off-road trafficability of military vehicles.

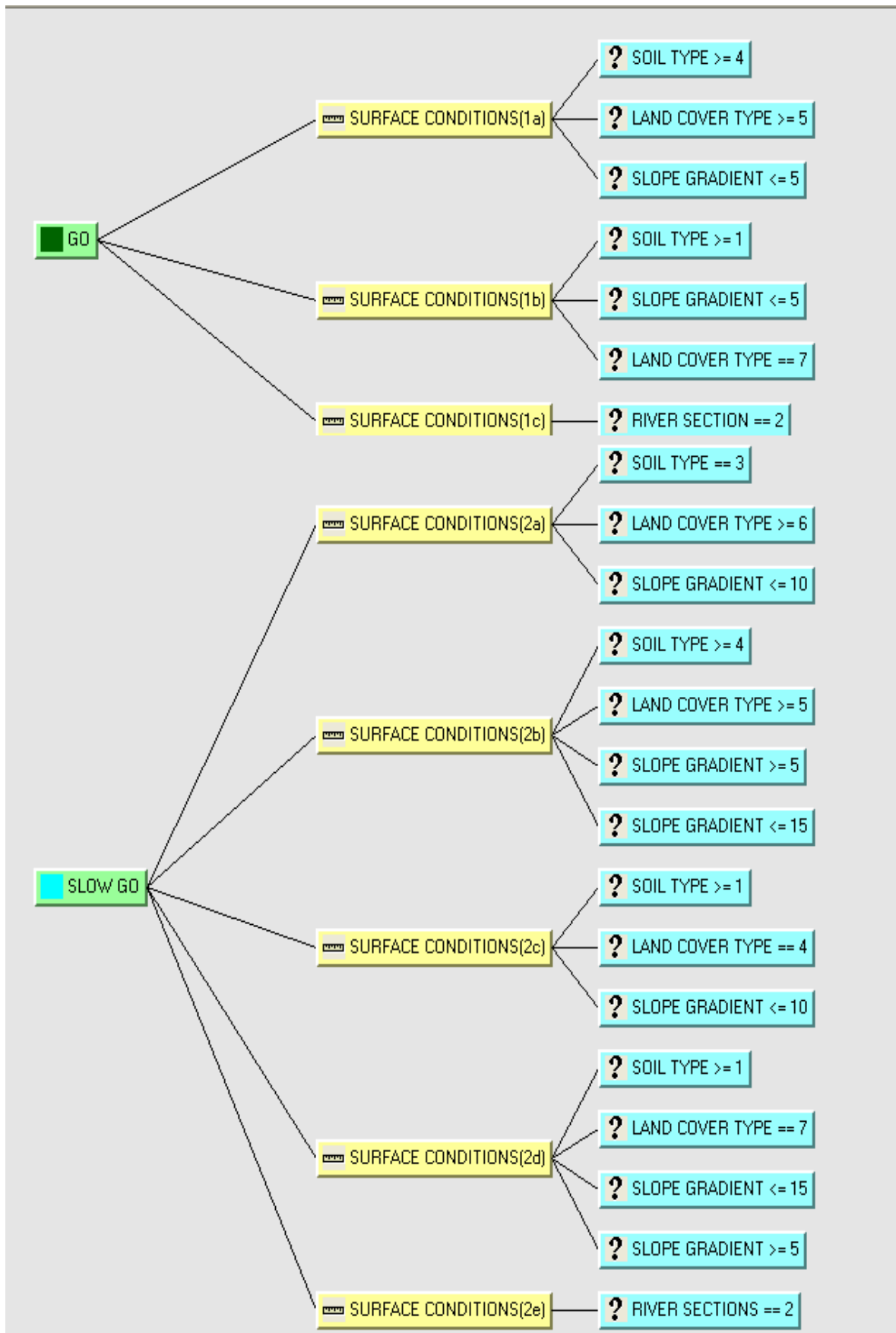


Figure 5. 9A. A graphical representation of the decision tree in the knowledge base.

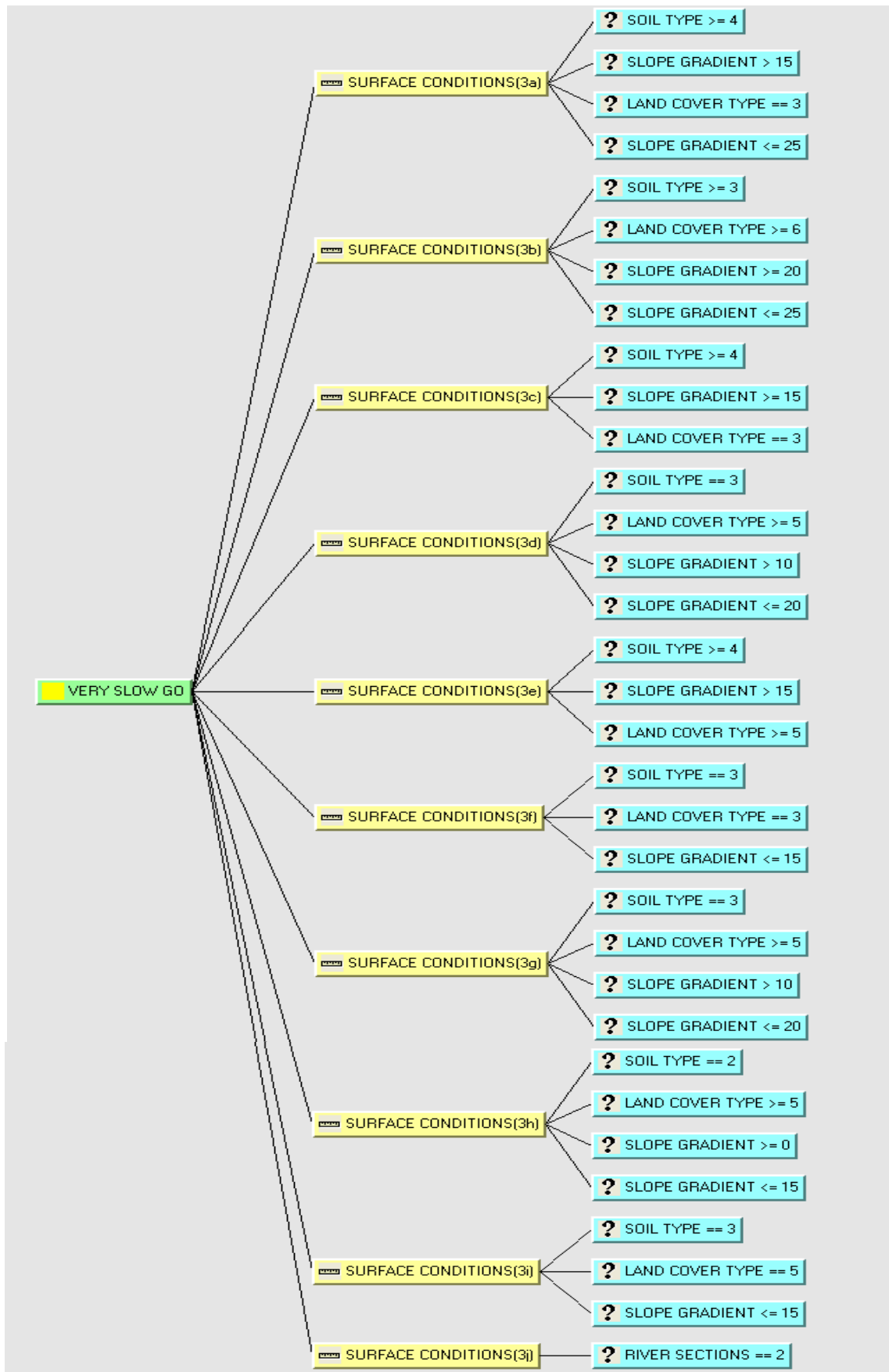


Figure 5. 9B. A graphical representation of the decision tree in the knowledge base.

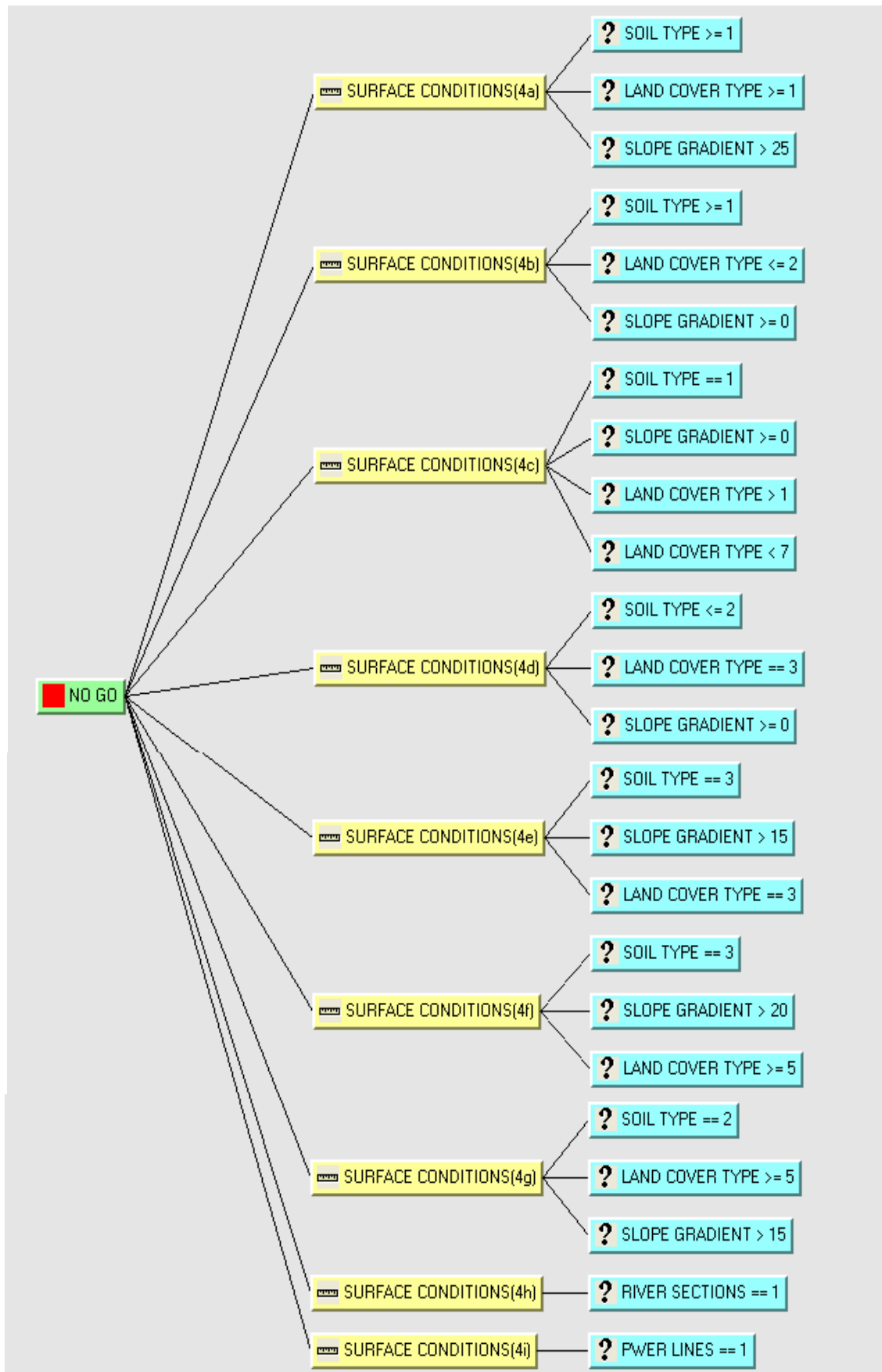
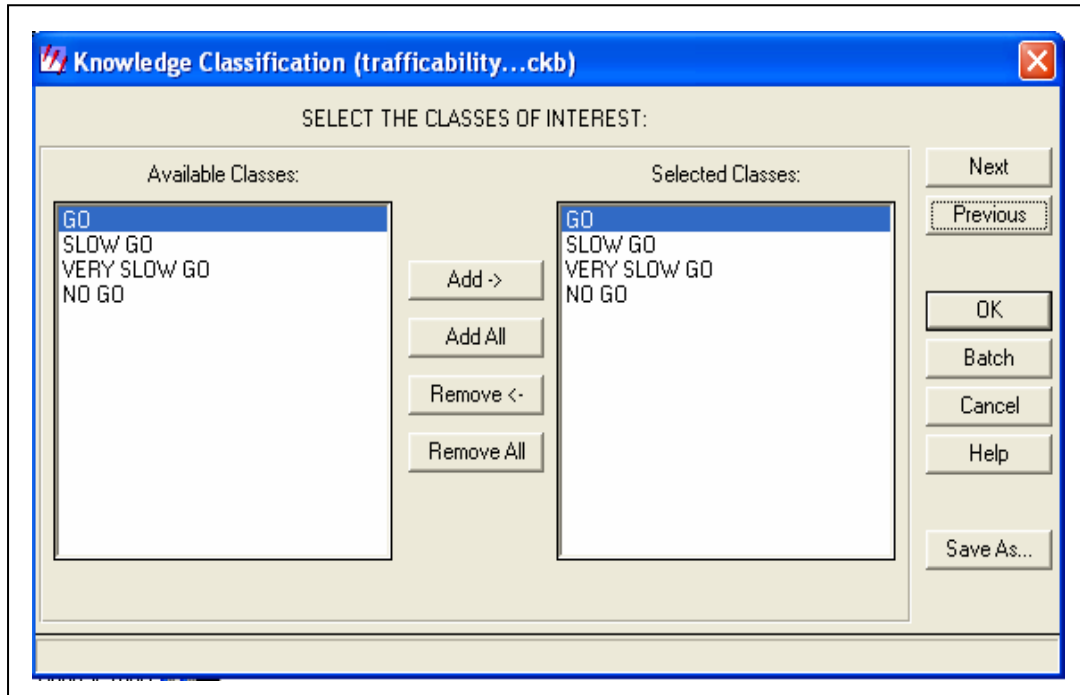


Figure 5.9C. A graphical representation of the decision tree in the knowledge base.

Finally, The Knowledge Base page is displayed when the program begins. The knowledge base file is selected before continuing the procedures of classification. The knowledge classifier page is shown in the Figure 5.10 as the off-road trafficability is selected in the knowledge classifier.



*Figure 5.10. Knowledge classifier page.*

The knowledge base opened from the expert classifier for final classification of the knowledge of experts. Finally the knowledge stored in terms of rules is classified in to four classes of a thematic map. The following Figure 5.11 shows the results form the Expert systems.

## **5.2.2. USING WEIGHTED OVERLAY ANALYSIS**

### **5.2.2.1. THE ANALYTICAL HIERARCHY PROCESS (AHP) IN WOA**

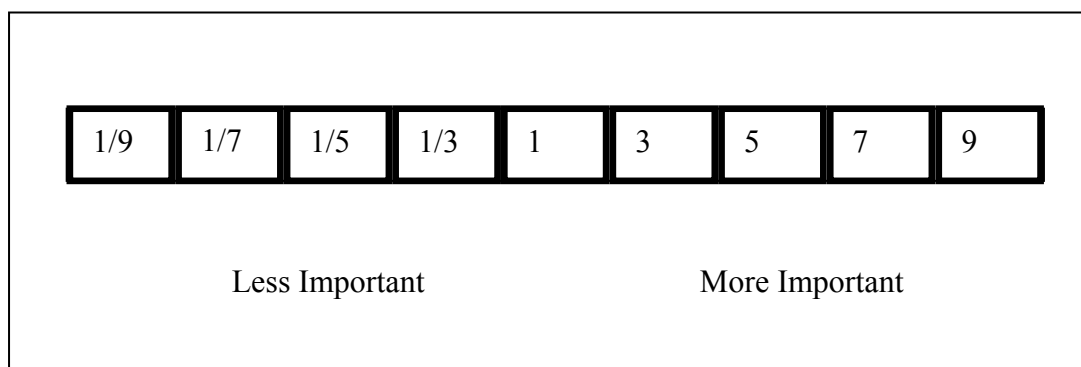
Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis. This method of MCDA was used in this thesis in comparison with the Expert systems in GIS environment.

In applying WOA, the analytic hierarchy process (AHP) is used as a comprehensive, logical and structural framework, which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure. The incorporation of all relevant decision criteria, and their Pairwise comparison allows the decision maker to determine the trade-offs among objectives. Such Multi-criteria decision problems are typical for modeling off-road trafficability map. The AHP allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), sub objectives, and alternatives. Uncertainties and other influencing factors can also be included. It not only supports decision makers by enabling them to structure complexity and exercise judgments, but also allows them to incorporate both objective and subjective considerations in the decision process (Saaty, 1980).

In this research because of the absence of standards set for this particular application, the opinion of experts in the field was used to weight the factors and to keep the relationship consistent; the analytical hierarchy process is used to drive the logical relationship and weights of the conflicting factors using a Pairwise comparison in IDRISI Software.

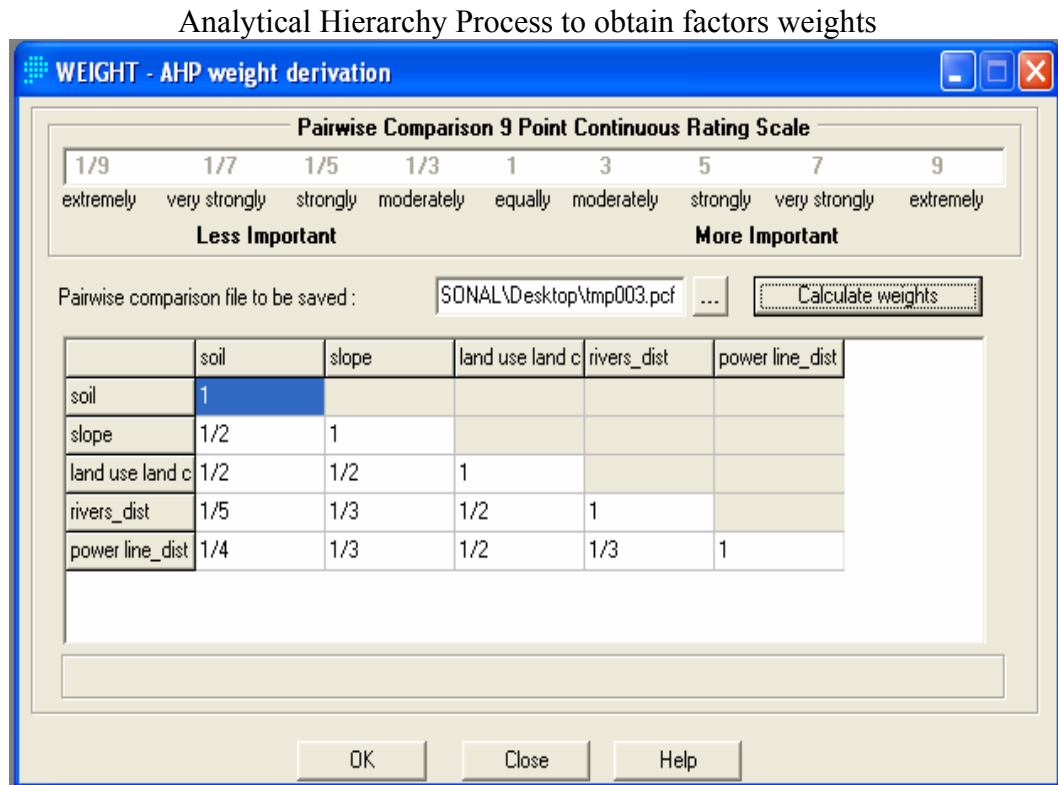
### 5.2.2.2 THE METHOD OF PAIRWISE COMPARISON

The Pairwise comparisons method was developed by Saaty (1980) in the context of the Analytical Hierarchy Process (AHP). This method involves Pairwise comparisons to create a ratio matrix. As input, it takes the Pairwise comparisons of the parameters and produces their relative weights as output. Figure 5.13 shows the rating scale used in IDRISI software.



*Figure 5.11. Pairwise Continuous Rating Scale*

Based on the above continuous rating scale, the factors were compared in pair by pair basis. The relative importance of each factor was computed against each other pair by pair according to the opinion of experts. As a result, consistency ratio of the factor weights is computed in the IDRISI Andes Software. Figure 5.14 shows the analytical hierarchy process followed to compute factor weights.



*Figure 5.12. AHP weight derivation*

*Table 5.2. Weights calculated by IDRIS Software*

<p>The eigenvector of weights is:</p> <p style="text-align: center;">Soil: 0.35 Slope: 0.30 Land cover: 0.23 Rivers: 0.08 Power: 0.04</p> <p>Consistency ratio = 0.07 Consistency is acceptable.</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: center;">No</th> <th style="text-align: center;">Factors</th> <th style="text-align: center;">Weights Assigned</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">1</td> <td>Soil</td> <td style="text-align: center;">35%</td> </tr> <tr> <td style="text-align: center;">2</td> <td>Slope</td> <td style="text-align: center;">30%</td> </tr> <tr> <td style="text-align: center;">3</td> <td>Land cover</td> <td style="text-align: center;">23%</td> </tr> <tr> <td style="text-align: center;">4</td> <td>Distance to Rivers</td> <td style="text-align: center;">8%</td> </tr> <tr> <td style="text-align: center;">5</td> <td>Distance to power lines</td> <td style="text-align: center;">4%</td> </tr> <tr> <td colspan="2" style="text-align: center;">TOTAL</td> <td style="text-align: center;">100%</td> </tr> </tbody> </table>	No	Factors	Weights Assigned	1	Soil	35%	2	Slope	30%	3	Land cover	23%	4	Distance to Rivers	8%	5	Distance to power lines	4%	TOTAL		100%
No	Factors	Weights Assigned																				
1	Soil	35%																				
2	Slope	30%																				
3	Land cover	23%																				
4	Distance to Rivers	8%																				
5	Distance to power lines	4%																				
TOTAL		100%																				

Given the above factor weights, the GIS layers were brought in to GIS overlay operation to generate the off-road trafficability map of military vehicles. The GIS overlay process can be used to combine the factors and constraints in the form of a Weighted Overlay process. The result was then summed up producing a suitability map ranging from possibility to advance to impossibility to advance as shown by the formula;

$$\text{Suitability Map} = \Sigma [\text{factor map (cn)} * \text{weight (wj)} * \text{constraint (b0/1)}]$$

Where,

Cn = Standardized raster cell,

Wj = Weight derived from AHP Pairwise, comparison, and

b0/1 = Boolean map with values 0 or 1

Using IDISI 32 software, all factors were given specific weights to manage the trade off between factors and the weights. The weighted overlay operation for the off-road trafficability map was operated using model builder in ArcGIS 9.3 Software. By combining all the factors in a spatial analysis the modeler is used to undertake the whole process of modeling off-road trafficability map. Figure 15 and 16 show the model builder of the whole process and the WOA window, respectively.

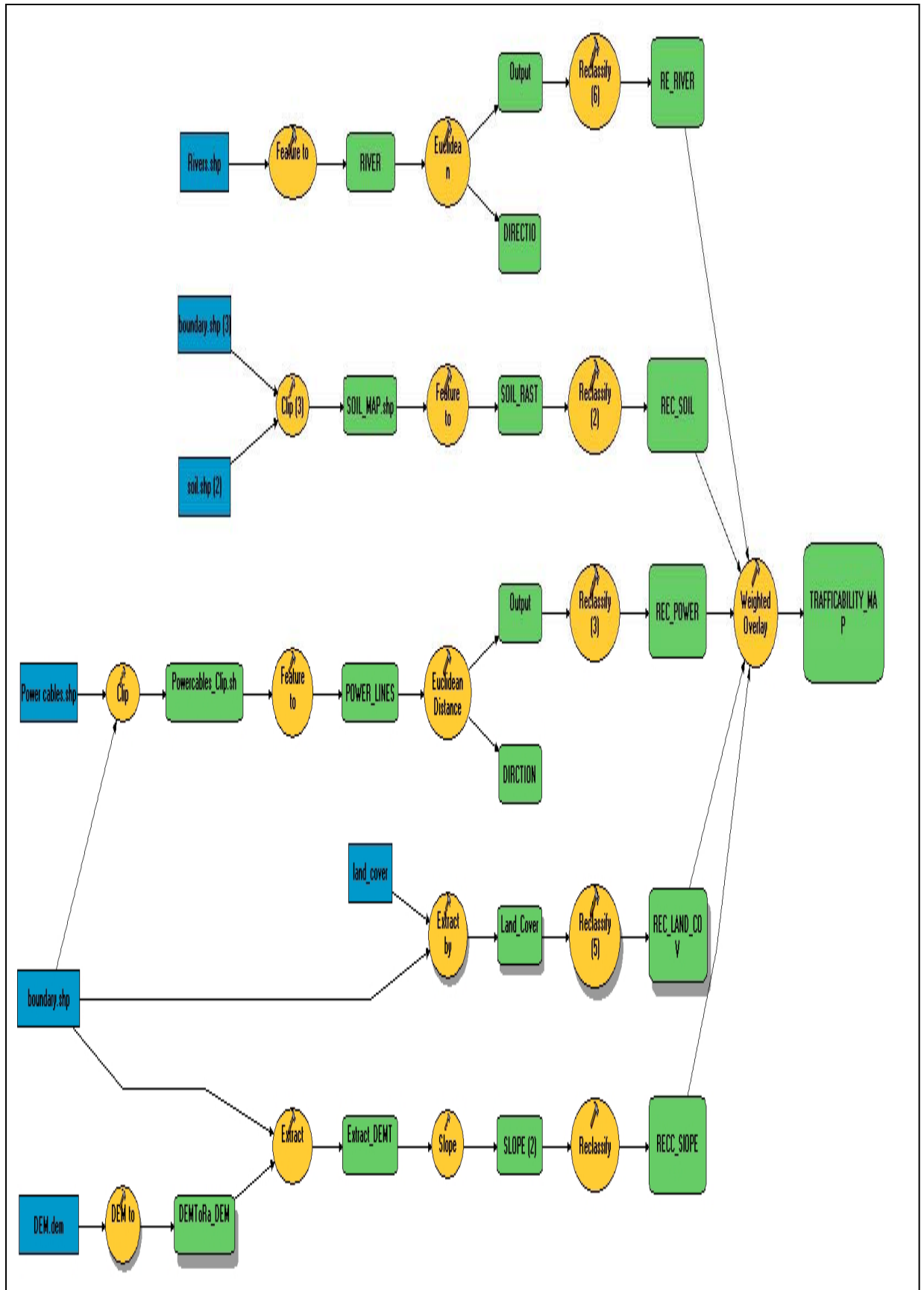


Figure 5.13. Model builder of the whole process of WOA.

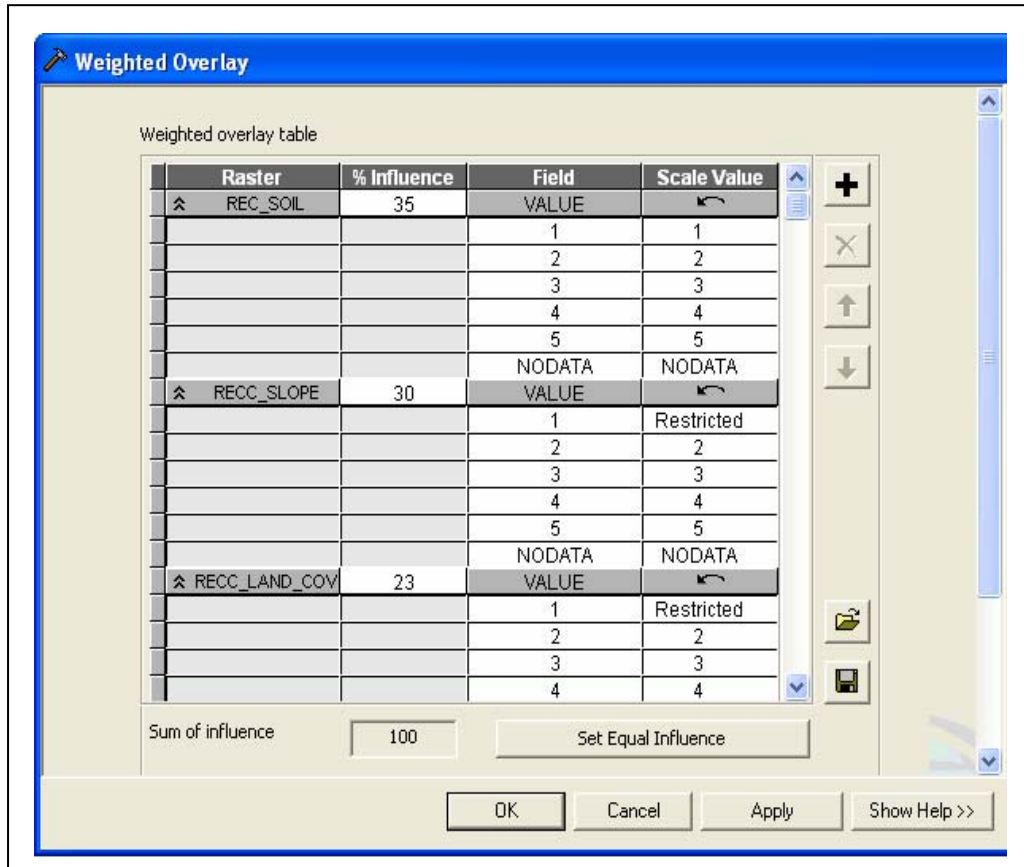
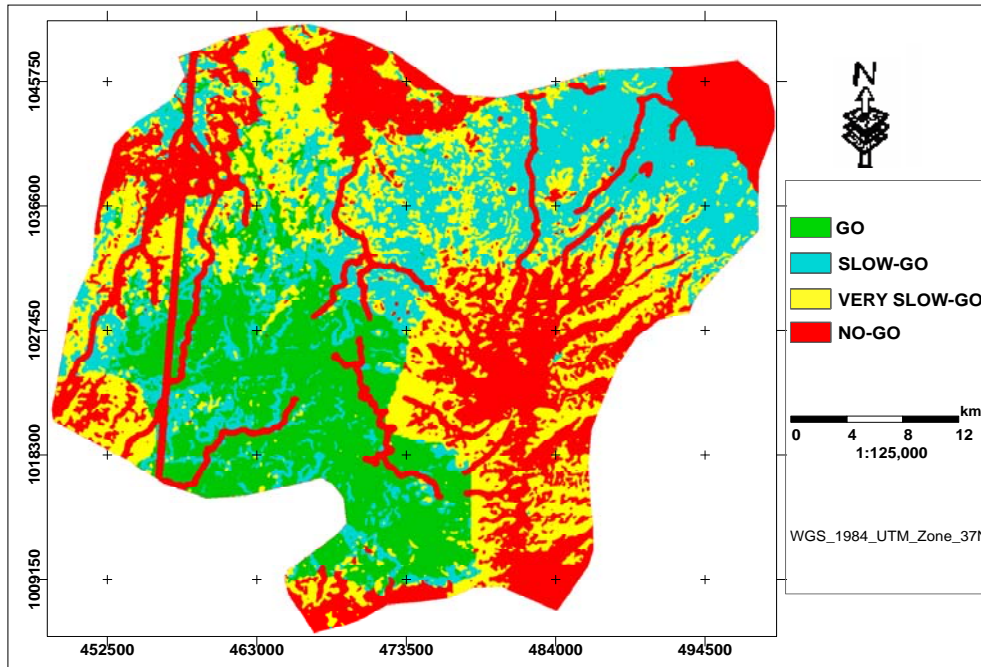


Figure 5.14. The WOA operation window

After the weights are assigned for each factor in IDRIS software using the analytical hierarchy process, the model for the whole process is constructed and the weighted assigned for each factor are encoded through the Weighted Overlay Analysis window. The window helps to tune the weights adopted from the Analytical hierarchy process. Since the experts were not stratified with the results obtained with the consistency ratio, the weighted overlay window was used to adjust the percentages obtained with in the framework of the consistency ratio obtained. By doing so, the conflicting opinions of the experts were resolved.

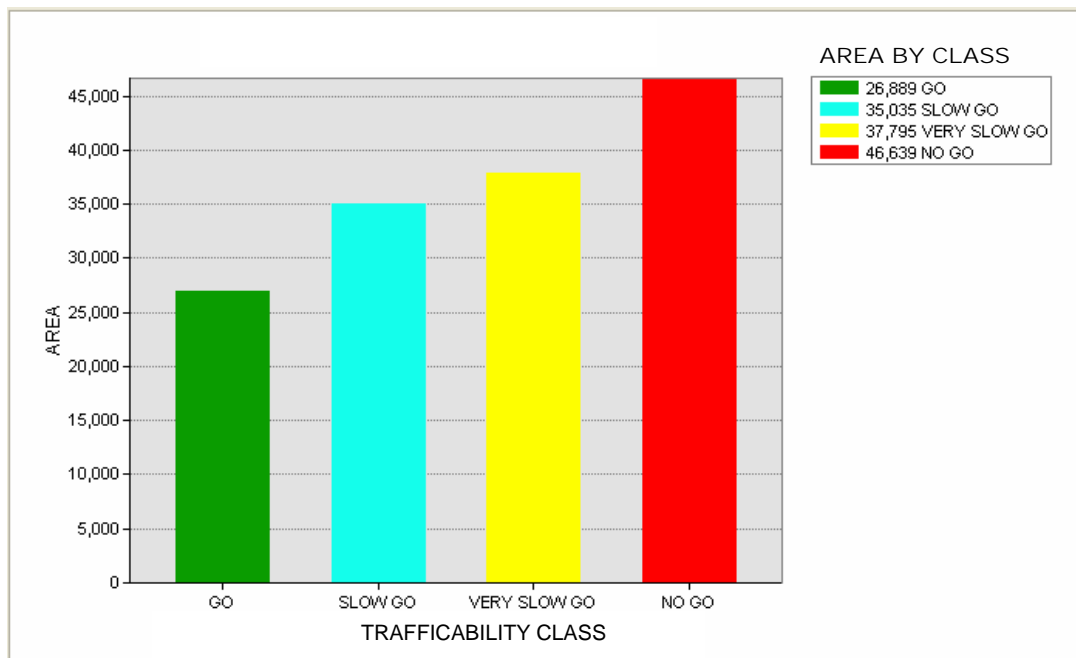
## CHAPTER 6. RESULTS AND DISCUSSION

### 6.1. RESULTS FROM THE EXPERT SYSTEM



*Figure 6.1 Off-road trafficability map output of Expert system.*

As it is indicated above, the off-road trafficability map generated using the Expert systems in GIS environment generates a map classified in to four suitability classes ranging from possibility to advance to impossibility to Advance. The knowledge and opinion of experts using informal assessment was used to create the knowledge base in the knowledge engineer. Accordingly, the area allocated for each suitability class is indicated in Figure 6.1. Each pixel was evaluated according to the rules enforced by the experts and classified to produce a thematic map of off-road trafficability. The results of each suitability class are represented in a bar graph indicating area coverage in hectares in Figure 6.2.



*Figure 6.2 Area of Trafficability classes in hectare*

The size of the trafficability class increases towards the untrafficable terrain conditions. The decision tree for the GO surface condition is less complex than any other class making the smallest number of rules in the knowledge base. As indicated above, the GO terrain conditions are the smallest trafficability class with an area of 26889 hectare and 18% of the study area. Land cover type of grass, agricultural over a Leptosol and Cambisol soil types and a slope gradient of less than 5 degree is designated as a GO terrain condition. Besides, all bare grounds in any soil type with a gentle slope gradient of less than 5 degree results a passable GO terrain condition as they have a good traction than any other land cover type according to judgment of the experts.

SLOW-GO terrain condition, the second smallest class occupies 35035 hectare of land which is 24% of the study area. These surface condition areas in Leptosol and Cambisol soil types with a slope gradient of between above 5 and 15degree and land cover type of grass and agricultural land are categorized as SLOW-GO because of the relatively steep slope. Mobility over a Nitisol (Moderately suitable) soil types through grass and agricultural lands in slope gradient between 5 and 10 degree is also categorized in this terrain condition. Besides, urban area over any soil type with a slope gradient of less than 10 degree is also categorize as a SLOW-GO. Moreover, bare grounds, which were the most suitable land cover type, were

passable slowly when the slope is greater than 5 and less than 15 degrees. Finally, SLOW-GO is possible over the above indicated terrain conditions if the river sections are affordable throughout.

The other trafficability class was the VERY SLOW-GO surface condition of the trafficability map. This was the second complex class in the knowledge base next to the NO-GO terrain condition. It is second largest one in area covering only 37795 hectare (26%) of the study area. If the soil type is either Leptosol or Cambisol over a slope of less than 15 degree, mobility through lightly stocked trees is possible very slowly. Grasslands and agricultural lands over soil types other than Luvisols and Vertisols where the slope gradient was steeper (between 20 and 25 degree) is categorized as a VERY SLOW-GO terrain condition. Besides, lightly stocked trees over in slope gradient of between 15 and 20 degree are passable very slowly if the soil type is also either Leptosol or Cambisol soil type. The lightly stocked trees are also categorized in this class if the soil type is Nitisol and slope gradient is less than 15 degree. Grasslands and agricultural lands over Luvisol soil type and slope gradient of between 0 and 20 degree. If the slope was greater than 20 the result would be NO-GO. The river sections must be affordable for VERY SLOW-GO terrain condition.

The NO-GO terrain condition makes the complex part of the knowledge base with greater number of rules than any other class. This was because rules of exception increase towards the NO-GO terrain condition. It was the largest in terms of area coverage with 46639 hectare (32%) of the total area. This class was characterized by extreme cases. The terrain was impassable if the slope is greater than 25 degree over any soil and land cover type. If the landcover type was forest and water bodies the result is a NO-GO terrain condition under any soil type and slope gradient. Lightly stocked trees were impassable in any slope range if the soil type was either Luvisol or Vertisol. Moreover, lightly stocked trees were impassable when the soil type was Nitisol and the slope gradient was over 20 degree.

## **6.2. RESULTS FROM THE WEIGHTED OVERLAY ANALYSIS**

The results obtained from the WOA were obtained in four trafficability classes as GO, SLOW-GO, VERY SLOW-GO and NO-GO. The classes names are similar to that of the

class names obtained from the Expert system for the ease of comparison. Figure 6.3 shows the off-trafficability map using the WOA method.

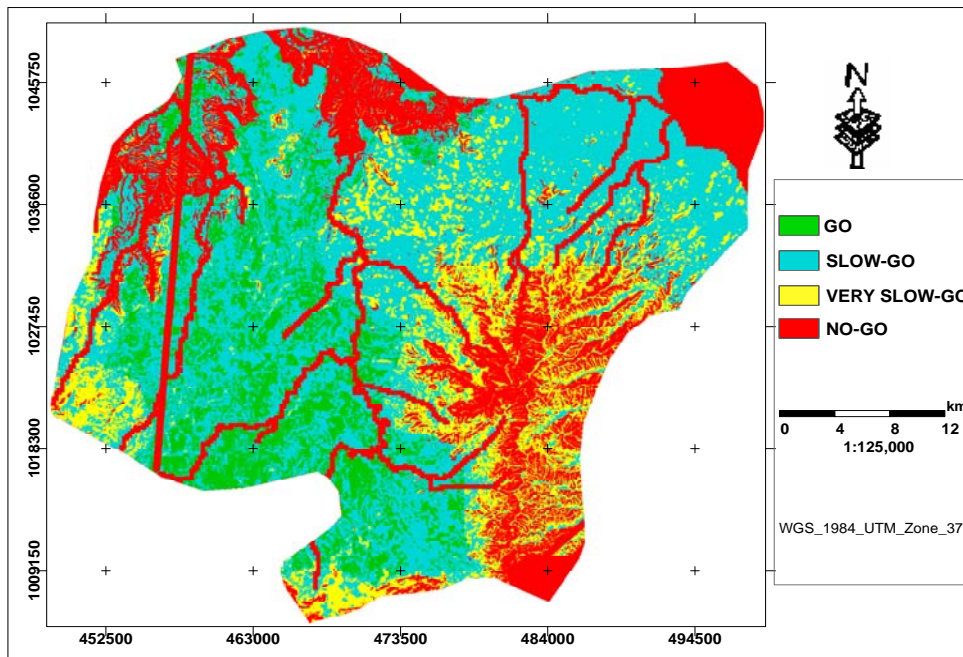


Figure 6.3 Off-road trafficability map output using WOA.

The off-road trafficability map generated using the Weighted Overlay Analysis in GIS environment generates a map classified in to four suitability classes ranging from possibility to advance to impossibility to Advance. The knowledge and opinion of experts was used to generate the factor weights and the AHP was used to resolve the conflict of factors and assign a factor weight to each factor. Accordingly the area allocated for each suitability class was indicated in the following figure 5.18.

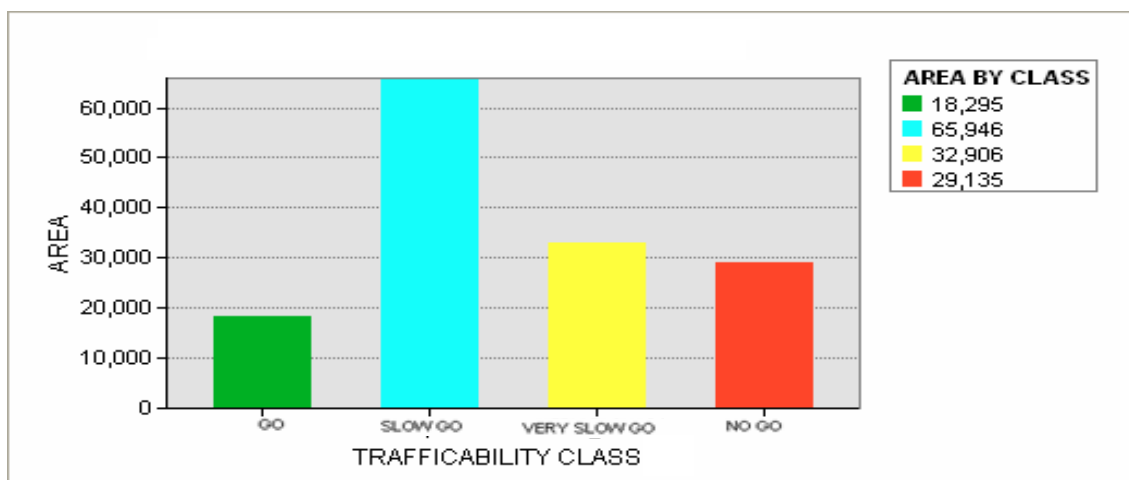


Figure 6.4 Area of Trafficability classes in hectare

The GO class of the trafficability was 18295 hectare. This covers only 12.5% of the study area. The area largely lays in Cambisol soil type and a landcover type of agricultural land in gentle slope. The grassland in the same slope gradient and soil type was not depicted as GO terrain condition and this is because the weight given to the land cover. The grassland over a Cambisol soil type is generalized to the SLOW-GO terrain condition despite the fact that the slope was very gentle over a soil type with high bearing capacity. Practically such surface conditions were judged by the experts as good for off-road mobility.

The largest class was the SLOW-GO class with 65946 hectare of land. This was 45.1% of the study area. The Nitosl soil types which are the third strongest soil types over a slope gradient of less than 5 degree and a land cover of grass and agricultural land was largely recognized as a SLOW-GO terrain condition. In addition, grasslands over a Cambisol soil type in a gentle slope of less than 5 degree was categorized as SLOW-GO. A landcover type of lightly stocked tress in a Leptosol soil type over a gentle slope was also identified in this terrain condition. This class was the second smallest in the Expert system method.

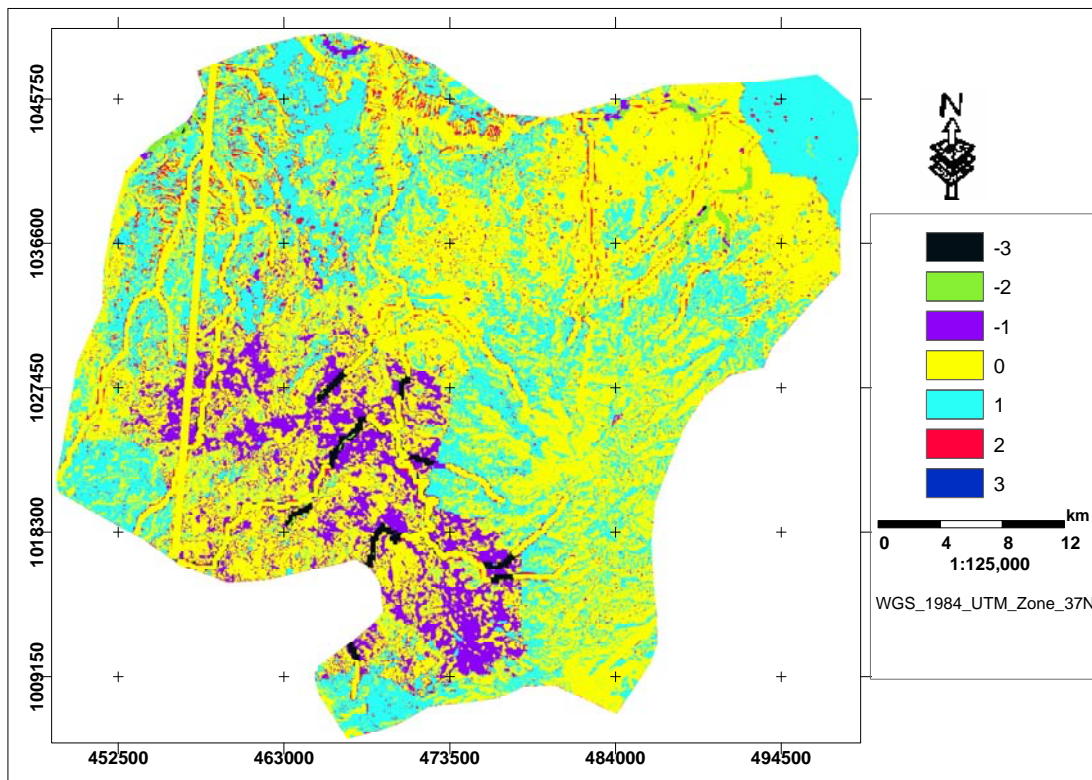
The VERY SLOW-GO trafficability class was the Second largest class with an area extent of 32906 hectare of the study area which is 22.5% of the total area. This class is found to be the second smallest one in the Expert system method. The lightly stocked trees over soil type of Luvisols are largely recognized as VERY SLOW-GO terrain condition. This was because the higher weight given to soil types. Practically, lightly stocked trees are not traversable over such soil types and in any of the soil types if the slope is greater than 15 degree, according to judgment of experts. Vertisol soil types (very unsuitable soil type) were unsuitable regardless of the slope gradient and land cover type except for bare grounds. However, the area which lay in this soil type was totally categorized as SLOW-GO in the WOA method including the bare grounds. This was mainly such exceptions were not possible to map in WOA method as it was generalized by the factor weights assigned and reclassification of the datasets.

NO-GO terrain condition was second smallest one in terms of area with area coverage of 29135 hectare and 20% of the total area. This terrain condition includes all restricted areas like power lines, rivers and forests. Slope gradient over 25 degrees in any soil type and are restricted for mobility in off-road fission. Forests also restrict mobility in off-road fashion and hence they were categorized as NO-GO terrain conditions.

## 6.3. COMPARISON OF RESULTS

### 6.3.1 DIFFERENCING MAP RESULTS

The out maps from the two methods of spatial modeling allow comparison as they are produced using the same data layers for the same purpose. Image differencing in ArcGIS 9.3 Raster calculator is used to obtain the difference map of the two methods. The thematic map obtained from the WOA method is subtracted from the map obtained using Expert system. The results are given in numbers ranging from -3 to +3 with 0 in the center. The difference in the results increase towards both sides while the 0 value means the area was classified similarly in both methods and hence no change. The Figure 6.1 shows the difference map of results from the two methods.



*Figure 6.5 Difference map of results*

The algorithm gives a difference map in seven categories with zero at the center indicating the no change area. The difference increases towards the negative and positive numbers both sides. The negative results indicate areas of change where the Expert system categorized them differently in a way that the WOA does not. For instance, the linear features with a

black colour are the affordable river sections where by a wheeled vehicle can traverse them. These areas are restricted in the WOA. This is because the WOA doesn't support such computation of exceptions unless they are superimposed after the final process.

Areas with a purple colour show that grasslands over a suitable soil class identified to be SLOW-GO surface condition in the WOA that were categorized as GO conditions in the Expert systems method. As a result there was a significant difference between the two outputs in the GO class. This is because the grasslands are underestimated or generalized by the weight given to soil. Similarly, the cyan colour in the difference map shows all areas where VERY SLOW-GO was possible in the WOA result map. This area was categorized as NO-GO in the Expert system output map. It includes the Vertisol soil types where mobility was restricted unless the land cover is bare ground. The bare grounds in Vertisol soil types were categorized as NO-GO where as practically, bare Grounds still favors offensive forces; forests still favor defense whereas sparsely covered, level terrain favors offensive maneuvers (Collins, 1998). Moreover, the red color in the difference map indicates areas with a combination of relatively steep slope and land cover other than grass and agricultural lands but they are negligible in size. These areas are restricted in the Expert systems while they are dominantly classified as a SLOW-GO in the WOA.

The NO-GO terrain surface condition were more or less similar in both outputs except in areas where the Vertisol soil type is categorized as NO-GO in the Expert system and this is indicated in yellow colour and zero value in the difference map. The Vertisol soil type is categorized as SLOW-GO in the WOA. All forests, water bodies and restricted areas like power lines and rivers (except the affordable river sections) are categorized as NO-GO terrain condition in both results. The over all similarity and correlation of the outputs was discussed in the following topics.

### **6.3.2. CROSS TABULATION OF MAP RESULTS**

The area of the resulting maps is cross tabulated using Zonal area tabulation in ArcGIS. Zonal tools take a value raster as input and calculate for each cell a function or statistic using the value for each cell and all cells belonging to the same zone. The Zonal tools are grouped by how the zones are specified, by a single input value raster, or by a second zone raster. The

Zonal tools in which the zones are defined by a single input value raster either calculate statistics or quantify the characteristics of the geometry of the input zones (ArcGIS Desktop Help).

The result obtained from the Expert system is taken as a dataset that defines the zones. The result from the WOA was the dataset that defines the classes that will have their areas summarized with in each zone. The resulting table is area in meter square tabulated for each cell value (Table 6.1). The area cover is converted to percent by dividing each class by the row total.

*Table 6.1 Cross tabulation of the results' covers (values in %)*

<b>WIGHTED OVERLAY ANALYSIS METHOD</b>	<b>EXPERT SYSTEM METHOD</b>			
		<b>GO</b>	<b>SLOW GO</b>	<b>VERY SLOW GO</b>
<b>GO</b>	53	40	4	3
<b>SLOW-GO</b>	9	86	2	3
<b>VERY SLOW-GO</b>	2	55	31	12
<b>NO-GO</b>	1	4	20	75

For the ease of analysis, the level of correspondence for each covers summarized with in similar zone in the cross tabulation table are categorized in to four level of correspondence as Low, Good, Very good and excellent. Table 6.2 shows the level of correspondence of the two methods for each covers summarized with in similar zones.

*Table 6.2 Llevel of correspondence from the cross tabulation table*

Above 75%	Excellent
<b>Covers Summarized with in Similar Zone in %</b>	<b>Level of Correspondence</b>
Below 50 %	Low
50-65%	Good
65-75 %	Very Good

Strong agreement in the cross tabulation table of results lays in the SLOW-GO class where 86 % from the WOA is summarized in the same class in the Expert system. Similarly, 75% the NO-GO class in the WOA generalized in the same class in the Expert systems. The most suitable class which is the GO surface condition is the other significant relationship where 53 % is summarized in both results. In this case, 40% is classified as a SLOW-GO terrain condition in the case of Expert system. The disagreement in the results of the two methods seems to be in the VERYS SLOW surface condition where only 30% of it in the WOA is summarized to be in the same class in the Expert system.

Excellent correspondence between the two outputs is observed in the SLOW-GO terrain condition where 86% of this class in the WOA was identified in the same condition in the Expert system. The very SLOW-GO terrain condition implies the case where there is a poor correspondence between the two methods. Only 30% is found to be summarized in the same zone in both methods. Rather, 55% which is much greater than the diagonal value is allocated to the SLOW-GO terrain condition in the Expert systems. The main diagonal of Table 5.3 shows the agreement between the two methods. Generally, most of the suitable terrain conditions for off-road mobility of wheeled military vehicles and the obstacles which are impassable were similarly classified in both methods except in the SLOW-GO terrain condition.

There is a considerable disagreement in the GO terrain condition where only 53% of the class in WOA is similarly summarized in the same zone in the Expert systems. The main difference between the two results is that the WOA uses the weight factors to emphasize or deemphasize the different factors of the off-road trafficability analysis. Where as in the Expert system method, the experts' opinion is freely exercised with out using any weights to combine the factors. As a result some of the terrain conditions are overemphasized and some were emphasized or deemphasized in the WOA to bring a different result from the Expert system approach.

The general spatial relationship of the two approaches is obtained from the Multivariate band collection statistics. This shows how the results spatially correlate to each other. Section 6.3 shows the overall spatial correlation of the results using a multivariate band collection statistics.

### 6.3.3. MULTIVARIATE BAND COLLECTION STATISTICS OF MAP RESULTS

The correlation matrix shows the values of the correlation coefficients that depict the relationship between two datasets. In the case of a set of raster layers, the correlation matrix presents the cell values from one raster layer as they relate to the cell values of another layer. The correlation between two layers is a measure of dependency between the layers.

Correlation ranges from +1 to -1. A positive correlation indicates a direct relationship between two maps, such as when the cell values of one map increase, the cell values of another map are also likely to increase. A negative correlation means that one variable changes inversely to the other. A correlation of zero means that two maps are independent of one another. The correlation matrix is symmetrical. Its diagonal from the upper left to lower right is 1.0000 since the correlation coefficient of identical maps is +1. A correlation matrix using the multivariate statistics shows how the pixels in each output spatially correlate as a result Figure 6.2 obtained shows the spatial correlation of the results.

MULTIVARIATE BAND COLLECTION STATISTICS OF RESULTS					
<Null>					
#	STATISTICS of INDIVIDUAL LAYERS				
<Null>					
#	Layer	MIN	MAX	MEAN	STD
#	-----				
1	1.0000	4.0000	2.7118	1.1000	
2	1.0000	4.0000	2.5921	1.0317	
#	=====				
<Null>					
<Null>					
#	COVARIANCE MATRIX				
<Null>					
#	Layer	1	2		
#	-----				
1	0.78082	0.57139			
2	0.57139	0.68669			
#	=====				
<Null>					
<Null>					
#	CORRELATION MATRIX				
<Null>					
#	Layer	1	2		
#	-----				
1	1.00000	0.78033			
2	0.78033	1.00000			
#	=====				

Figure 6.6 Multivariate band collection statistics of maps

According to the results obtained, the correlation of the two maps is 0.78. It is therefore suffice to deduce that the results spatially correspond to each other strongly as the ideal correspondence is +1. This shows that the results from the methods have strong spatial

correlation and hence the two methods have comparable outputs for this particular application.

## **6.4. SUMMARY OF EXPERTS' OPINION ON THE RESULTS OF ANALYSIS**

In the course of the study, experts have participated in deducing facts in the decision tree and assigning weights in the WOA. The experts have expressed their professional opinion about the outputs of the methods of off-road trafficability analysis. Their opinions about the whole process of the analysis and results is entertained and summarized as follows.

- There was a common understanding among them that the methods of off-road trafficability analysis adopted are effective for such applications in military terrain analysis than the counter techniques using paper maps manually as the earlier save time and improve accuracy.
- The expert system was convenient for them to depict their knowledge in terms of facts in the knowledge base than assigning weights in the WOA.
- During the field visit after the outputs are obtained, they have observed that some terrain configurations that are practically impassable are categorized in the trafficability classes in both methods. This is more exacerbated in the WOA. This was mainly because of the coarse resolution (90m) of the DEM data. It was also learnt in the field that such generalizations of the terrain can be identified using 1:100,000 topographic maps. They have also proposed that digitizing the topographic maps can yield better elevation data. This is because of the fact that the paper maps have more than a double finer resolution (40m) than the DEM data used.
- The experts preferred the WOA for faster and easier obstacle overlay. The Expert system was complex for the experts to understand although it yields better results using expertise who can effectively manipulate the system to deduce facts from their opinions and behaviors.

## CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

### 7.1. CONCLUSIONS

- Integrating of GIS and MCE techniques provides a powerful tool for decision-making procedures in military planning as it allows a coherent and efficient use of thematic spatial data.
- The similarity to point out from both methods is that there is Very good correspondence with 75% summarized in same zone for NO-GO trafficability class, which is relevant when the models are used to select only areas where trafficability is restricted. Besides, the two methods have excellent correspondence in the SLOW-GO trafficability class with 86% summarized in the same zone as shown in cross tabulation table.
- For the GO trafficability class, the two methods have good correspondence value in the cross tabulation result where 53% is summarized in the same zone. Low correspondence occurs in the VERY SLOW-GO trafficability class, where only 30% is summarized in the same zone. The disagreement between the two methods is mainly due to the use of factor weights ( $w_j$ ) used in the WOA method which cannot be employed in the Expert systems and the detail knowledge of experts in the Expert system which can't be entertained in the WOA.
- However, the spatial correlation result obtained from the multivariate band correlation statistics (0.78) showed an overall strong spatial correlation between the results obtained from the two methods.
- It is therefore suffice to conclude that the WOA method can be employed with factors measured in an ordinal scale, providing similar results to those obtained from the Knowledge based approach to model off-road trafficability analysis for wheeled military vehicles.
- It was learnt that the Expert system was more convenient to quantify and depict the detail opinion of experts more easily than the WOA. Besides, reclassifying datasets in the WOA method results generalization of facts affecting the output. While in the Expert systems reclassifying datasets in to suitability ranges was not necessary as the knowledge engineer supports float data type and this is also one of the causes that has resulted difference between results two methods.

- The ease and speed of modeling is very important question in military operation planning especially during the course of movement of armed force during war times. The WOA is computationally easier and faster as compared to the Expert system which demands expertise and the development of the knowledge base is complex and time taking task. The WOA can therefore be effective for faster Combined Obstacle Overlay (COO), which is usually manually done using paper maps. However, with a previously created expert knowledge base, a less experienced user may use the Knowledge Classifier to apply the knowledge base to data and perform a classification with the already deduced facts as deducing it may be difficult or take longer time for less experienced experts or decision makers.
- It was also learnt that group decision making which is common in military operations planning is convenient in the Expert System than in the WOA. This is because the constructing the hierarchical decision tree in the knowledge provides a platform where by experts and decision makers can develop the rules in group discussion than assigning factor weights which was found to be a spot of disagreement among experts.
- The off-road trafficability analysis was an ill-structured geographic problem where sufficient data with a desired quality was not available. Such problems can best be managed with systems that can support domain-specific knowledge of experts. The Expert system is the most convenient method to entertain precise knowledge of experts as compared to the WOA which provides generalized solutions leaving the decision maker with the role of the expert.
- The other advantage of using the Expert system is that rules of exceptions (The river sections for example) can be employed to bring about a more accurate output which is impossible in the WOA case. This is critically important as exceptions are common in decision making.
- Generally, the Expert system was more powerful tool that provides detailed expert level performance and decision making process than the very much generalized method in the WOA which prerequisites factors measured in ordinal scale.
- Finally, it is worth mentioning that speed and accuracy in military operations planning is important to evaluate a battle area for successful operations. GIS and remote sensing techniques are therefore very important for the Ethiopian Army to

revolutionize the manually combining terrain based information with the state of the art technology for efficient planning of military operations.

## 7.2. RECOMMENDATIONS

- Despite the fact that Geoinformatics and its vast application in military have gone hand in hand throughout the course of history, the military sector has been remained to be the most unresearched area in Ethiopia. It can therefore be a good research area in this field where there are several directions that should be explored.
- Military planners should promote GIS and remote sensing techniques in conducting terrain based decisions rather than relaying on paper maps that are inflexible and lack up to date information.
- The choice of the Decision making tools is very important since it has a significant effect on the final outcome in any application. A comparative study of the WOA and Expert system considered in this research shows that the two methods convey comparable results but with significant variations. These and other methods of MCDA have to be tested practically to use the appropriate methods both in the civil and military applications.
- The Expert system used in this research is designed for general applications in GIS and remote sensing. A more specialized prototype capable of answering questions like what type of vehicle to use in what type of weather and terrain conditions need to be designed. Such Expert system can help to have standardized off-road trafficability information which is free from personal judgments of military topographers.
- The off-road trafficability analysis in this research is conducted by considering five factors. However, in reality, other important factors like weather condition cover and concealment, line of sight, and location of enemy forces have to be included for real world applications and further researches are necessary to assess all terrain based tasks in military operations planning.

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## Signed Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been dully acknowledged.

Name: Gebreslasie Gebremedhin

Signature: \_\_\_\_\_

Place and date of Submission:

June 2009, Addis Ababa, Ethiopia.