EZEKIEL DANIEL

DEVELOPMENT OF A SYSTEM TO IDENTIFY OPTIMAL LOCATIONS FOR SAFE WATER WELLS IN AFRICA USING VP-EXPERT SYSTEM

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
EZEKIEL DANIEL

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechatronics Engineering

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Approval of Director of Graduate School of Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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To my family…

ABSTRACT

It was estimated that about 900 million of the world population do not have access to sustainable safe drinking water, 84% of this estimated population dwell in rural areas (WHO/UNICEF, 2010). The MDGs were established in 2000 by UN with the aim to address critical issues like poverty, children's education and health, sustainable environment, disease control, and economic development. One of the goals of the Millennium Development Goals is to reduce by 50% the number of the world population that does not have access to sustainable potable water supply by the year 2015. Africa as a continent is not on track to meet the MDGs target. In fact, Africa has the lowest potable water coverage when compare to other continents of the world. In this thesis an expert system using VP-Expert was designed to help improve the siting of water wells in Africa. The thesis explains major factors to consider before siting water wells in Africa.

In this thesis a system was developed to identify optimal locations to site water wells in Africa. The procedure of the knowledge acquisition in the design of this system was done through interviewing geology experts, text books, journals and various related sources and the knowledge was represented in the rule-based procedure. These rules identify the quantity and quality of water a targeted location is capable of producing. VP-Expert software was used for the design of the system and the system was validated by geologists from the Kaduna State Government of Nigeria.

The developed system can be used effectively by governments, non-governmental organizations and individuals to improve the supply of safe drinking water in Africa.

Keywords: Expert system; groundwater; vp-expert; aquifer; potable water

ÖZET

Dünya nüfusunun yaklaşık 900 milyonunun sürdürülebilir güvenli içme suyuna erişiminin olmadığı tahmin edilmektedir, bu tahmini nüfusun% 84'ü kırsal alanlarda yaşamaktadır (WHO / UNICEF, 2010). BKH 2000 yılında, yoksulluk, çocuk eğitimi ve sağlığı, sürdürülebilir çevre, hastalık kontrolü ve ekonomik kalkınma gibi kritik konuları ele almak amacıyla BM tarafından kurulmuştur. Binyıl Kalkınma Hedefleri'nin hedeflerinden biri, 2015 yılına kadar sürdürülebilir içme suyu kaynağına erişimi olmayan dünya nüfusunun sayısının% 50 azaltılmasıdır. Bir kıta olarak Afrika, Binyıl Kalkınma Hedefleri hedefine ulaşma yolunda değildir. Aslında, Afrika dünyanın diğer kıtaları ile karşılaştırıldığında en düşük içme suyu kapsamına sahiptir. Bu tezde, Afrika'daki su kuyularının yerleşimini iyileştirmeye yardımcı olmak için VP-Expert kullanan uzman bir sistem tasarlanmıştır. Tez, Afrika'da su kuyularına yerleşmeden önce dikkate alınması gereken ana faktörleri açıklar.

Bu tezde Afrika'daki saha su kuyularına en uygun yerleri belirlemek için bir sistem geliştirilmiştir. Bu sistemin tasarımında bilgi edinme prosedürü jeoloji uzmanları, ders kitapları, dergiler ve çeşitli ilgili kaynaklarla görüşülerek yapıldı ve bilgi kural tabanlı prosedürde temsil edildi. Bu kurallar, hedeflenen bir konumun üretebileceği suyun miktarını ve kalitesini belirler. Sistemin tasarımı için VP-Expert yazılımı kullanılmış ve sistem Kaduna Eyaleti Nijerya Hükümeti'nden jeologlar tarafından onaylanmıştır.

Gelişmiş sistem, hükümetler, sivil toplum kuruluşları ve bireyler tarafından Afrika'da güvenli içme suyunun tedariki için etkin bir şekilde kullanılabilir.

Anahtar Kelimeler: Uzman sistem; yeraltı; vp-uzman; akifer; içme suyu

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LIST OF ABBREVIATIONS

AI:	Artificial intelligence
CWR:	Cracked Weathered Rock
DEW:	Distance to Existing Well
DSC:	Distance to Source of Contamination
ES:	Expert System
KB:	Knowledge Base
KBES:	Knowledge Base Expert System
MDG:	Millennium Development Goal
NGO:	Non-Governmental Organization
PSS:	Permeable Subsurface Soil
RWSN:	Rural Water Supply Network
UI:	University of Illinois
UN:	United Nations
UNDP:	United Nations Development Programme
UNEP:	United Nations Environment Programme
WHO:	World Health Organization
WIT:	Water Indicator Tree
WRC:	Water Resource Center

CHAPTER 1
INTRODUCTION

It was approximated that about 900 million population of the world do not have continuous access to safe water sources because it is a luxury that only few can afford. Eighty-four percent of this population is rural dwellers (WHO/UNICEF, 2010). Although the whole world worked hard to attain the MDG target of "reducing by 50%, the percentage of the population without sustainable access to safe drinking water by 2015", this goal was not met, especially in Africa. Hand dug and drilled water wells are the major sources of drinking water in Africa. These source of water supplies many with drinking water because they are the closest source of water from residential homes. Groundwater is the most common natural resource on earth and is also cheap to develop. In general groundwater often has a lower capital cost and excellent natural quality than surface water. Groundwater is not easily contaminated because it has a natural cover protecting it against both animal and human activities. Since 1960s the technology of transporting water from one point to another is experiencing significant growth as a result of the growth, good quality pumps and water fittings are now available almost everywhere in the world. However, the art of siting safe drinking water wells is still a major concern in Africa.

Proper siting of safe drinking water well determines its productivity and sustainability. Identifying the appropriate location to site water wells requires consideration of some very important factors. The hydrogeology of the site is a critical factor to consider since it determines the yield of the aquifer. The use and the user of the water is another factor is another vital factor because it determines the place the water will be needed. Furthermore, the effect that the new well will have on an existing well is another fundamental factor. Lastly, how to access the groundwater is a factor that cannot be neglected.

Therefore to successfully site water wells, adequate knowledge of the procedures of well-siting is required because these siting procedures have both economic and environmental implications.

1.1 Groundwater

From the preliminaries stage i.e. planning stage, sufficient and specific information about the uses and dominant modes by which the groundwater occurs in the target area is required. This information is needed so that from the start of the design we can add into the programs the well siting capacity. Groundwater is normally held in cracks (or void pores or fractures) in rock formations (ARGOSS, 2010). Groundwater naturally occurs in two common modes and these modes of occurrence can be found in a single formation:

I. groundwater occurs in the empty pores between the grains unconsolidated rocks and sediments. This mode is known as primary porosity.

II. groundwater are also held in fractures or cracks, which may or may not be interconnected in consolidated and cemented hard rocks. This is known as secondary porosity.

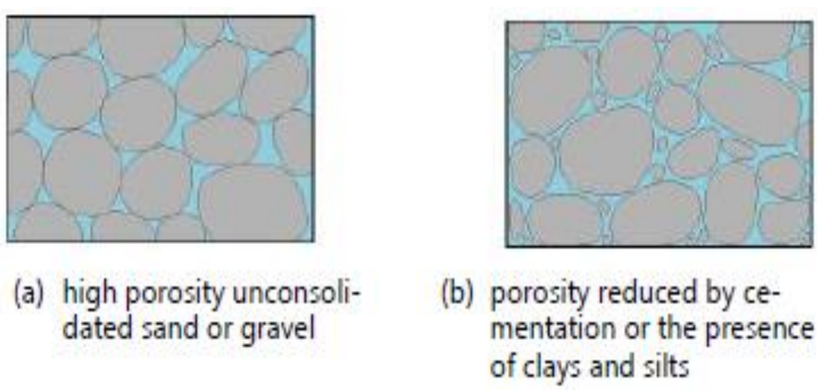

Figure 1.1: Primary Porosity

Source: MacDonald et al (2005)

(c) consolidated crystalline rock rendered porous by the presence of fractures (e.g. christiline basement)

(d) consolidated fractured rock with porosity in-creased by dissolution (e.g. limestones)

Figure 1.2: Secondary Porosity

Source: MacDonald et al (2005)

1.2 Aquifers

An aquifer is a water bearing formation. The siting process should show the dominant aquifer in the proposed location. This is a necessary requirement to strategically explore groundwater. Groundwater can be found under the following conditions, namely:

I. Water is held under pressure in aquifers covered by impermeable materials (such as clay). Under this condition, the water bearing formation is called a confined aquifer. The water found in this aquifer is usually under high pressure. The water level rises (see figure 1.2d) and sometimes over flow (see figure 1.1a) when struck during drilling because of the effect of the pressure acting on it.

II. The water table in an unconfined aquifer is constantly interacting with open space (i.e. the atmosphere). Therefore the water in unconfined aquifers is not under high pressure.

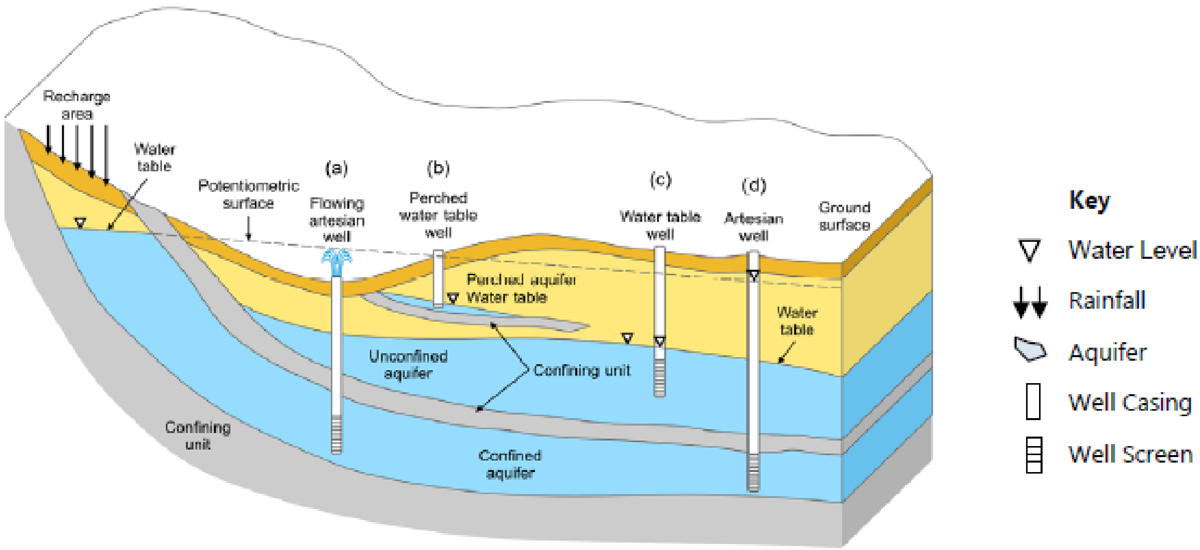

Figure 1.3: Schematic of Groundwater

Source: Todd et al (2005)

The Figure 1.3 above shows the various types of aquifers and how they are formed.

1.3 The Need for Sustainable Access to Improved Water

Sustainable access to improved water is a basic requirement to decrease poverty and mortality rates. Safe drinking water can prevent waterborne and sanitation-related diseases from spreading. Almost 2.2 million people die annually from water-related diseases according to a report by the World Health Organization (WHO) (2014). When people gained access to potable water, then the death rates due to water-related diseases such as cholera, diarrhea and malaria will reduce significantly (UNDP-UNEP, 2004).

As described above, safe drinking water can be a scarce resource in some parts of Africa and can require people to travel long distances away from their houses to access a safe source of water. It is common for people in Africa to wake up as early as 4:00 am in the morning to travel to get clean water because of the scarce nature of the resource. A village chief describes the situation, by saying “If you want safe drinking water, then you have to wake up as early as

4:00 a.m. and go to a borehole in the neighboring village" (Ariet village chief, 19 September 2008, conversation).

Women and young girls are primarily saddled with the responsibility of collection of water in Africa (UNICEF and WHO, 2012). Figure 1.4 shows a girl collecting water from an unprotected natural spring in Ariet village, 315 km northeast Kampala, Uganda. Women and young girls often fall victims of violence because of the distance they have to travel without security in order to discharge their duty of collection of water. This also poses a challenge to girls' attendance in school. Having sustainable access to safe drinking water can help to keep girls in schools (Faeth and Weinthal, 2012). Another of the MDGs, target is to attain gender equality. This goal includes addressing goals of eliminating violence against girls and women. Making progress in the availability of improved water will very likely provide benefits in this crucial area as well.

Figure 1.4: A Girl Collecting Water from an Unprotect Natural Spring

Photographed by Simon Peter Esaku

1.4 Contributing to Provide Safe Water

Though there is an increased access to potable water, there is still need for more work to be done in that regard. Governments and non-governmental organizations (NGOs) are partnering to provide clean drinking water to communities in Africa. Expert system offers great opportunities to help agencies improve clean water resource planning. While GIS-based models generally require large amounts of high-resolution data, the system developed in this thesis was designed to be applied in data-deficient areas in Africa. Organizations working in this area often lack funds to acquire commercial satellite data; therefore the system designed here focus on using data that is available at little or no cost to the public.

Finally to increase performance in achieving greater access to safe drinking water, the system developed here can be used to easily identify locations where there is high yield and safe groundwater. The result is an affordable solution to help individuals, governments and NGOs improve water wells siting and hence increase the quality of life of the communities.

1.5 Aim and Objective

The aim of this research is to develop an Expert System using VP-Expert that can be used in data deficient developing regions of the world like Africa to identify locations that will produce high yield and safe drinking water. When used, it will offer recommendations for optimal water well locations that minimize the risks to pollution and dry wells and thus maximize the benefits for people.

An aim for the project is that the system be easily implemented by interested individuals, governments and NGOs. This project is intended for use by both technical experts and non-technical experts in the field of hydrogeology.

1.6 Scope

Obviously, using information about groundwater is preferable when assessing locations for water wells. However, quality data on groundwater and sub-surficial geology are rarely available in Africa. Instead of developing a system suitable for regions with quality data such as United States and then apply it to data-deficient regions, a constraint was placed on the design to use data readily available for Africa. Therefore, it became necessary to design a system that does not use groundwater, geology or high-resolution commercial satellite data. To ensure that the system could be replicated globally, only publicly available datasets with global coverage were used.

CHAPTER 2
LITERATURE REVIEW

This chapter presents the condition of drinking water in rural Africa. The current water well siting practices is also reviewed in this chapter. Then a report outlining guidelines for siting surveys for water wells is evaluated for its applicability in the African context. Furthermore, a summary of previous research on risks to safe drinking water is presented. Finally, a review of the methods used for site suitability is also presented.

2.1 The Condition of Safe Drinking Water in Africa

A very high proportion of Africa's population gets its drinking water from groundwater sources. Many people prefer groundwater to surface water as a source of drinking water because of its high degree of natural protection from pollution and drought (MacDonald, Davies and Dochartaigh, 2002). On the other hand, surface water is often polluted, and infrastructure for water pipes is very expensive. Therefore, from the above discussion groundwater is more likely to remain a reliable source of drinking water than any other source of water for the African population.

However, sources like toilets, animal pens, cemeteries, garbage piles, can also contaminate groundwater aquifers (UNICEF, 1999). In addition, water wells can serve as a medium to transmit contamination from surface water into an aquifer. Therefore, there is an increasing need to site water wells in locations that are least prone to contamination.

The fundamental principle of an improved water well is that water is extracted with the help of a pump by drilling a hole into a groundwater source. There are three common types of wells use in Africa to access groundwater. The first type is a hand dug well and is the most common (WaterAid, 2008). Hand dug wells are the most easily contaminated because they are normally uncovered. Though these types of wells are not ideal, but when properly installed they can be effective. Because hand dug wells are often open, they require daily sanitation which unfortunately is not always regulated (Awuah et al., 2008).

The shallow well is another type of well that is commonly use in Africa. Shallow wells provide a more protected drinking water option than hand dug wells and are also more expensive to install than the hand dug wells. These types of wells are constructed by drilling holes through dirt and installing pumps. The installed pumps can be mechanized or manual. Generally in Africa and other rural contexts, drilled wells are usually 50 mm in diameter and their lengths range between 35 m to 300 m. A concrete slab is normally used to cover the well. These wells are always sealed and have higher protection against contaminants getting into the water supply. However, these shallow wells can be contaminated if a seal breaks or if there is a leakage in the pipes. Finally the third common type of well in use in the African context is the deep well. The deep well is the most expensive of the three types of wells. These wells can be over 270 m deep. These wells typically have mechanized pumps or pump houses and can cost up to $30,000 USD to construct (http://thewaterproject.org/).

Therefore, since shallow and deep water wells are least likely to be contaminated, this research identifies suitable locations to site shallow and deep wells to increase the production of safe drinking water. However, the system developed in the study can also be used to identify suitable locations for hand dug wells.

2.2 Selecting a Site for Water Wells

The Rural Water Supply Network of Illinois in 2010 published guidelines on best practices for siting of water wells. Despite the fact that the report was specific to Illinois and the geology and infrastructure referenced are different from the African context, the workflow and many issues it discusses are still applicable. The network describes a form of site selection for water well. The current standard workflow is outlined in Figure 2.1. This workflow highlights four components namely: (1) groundwater availability, (2) impacts and risks of a new well, (3) water use (requirements of a well) and (4) access to a source.

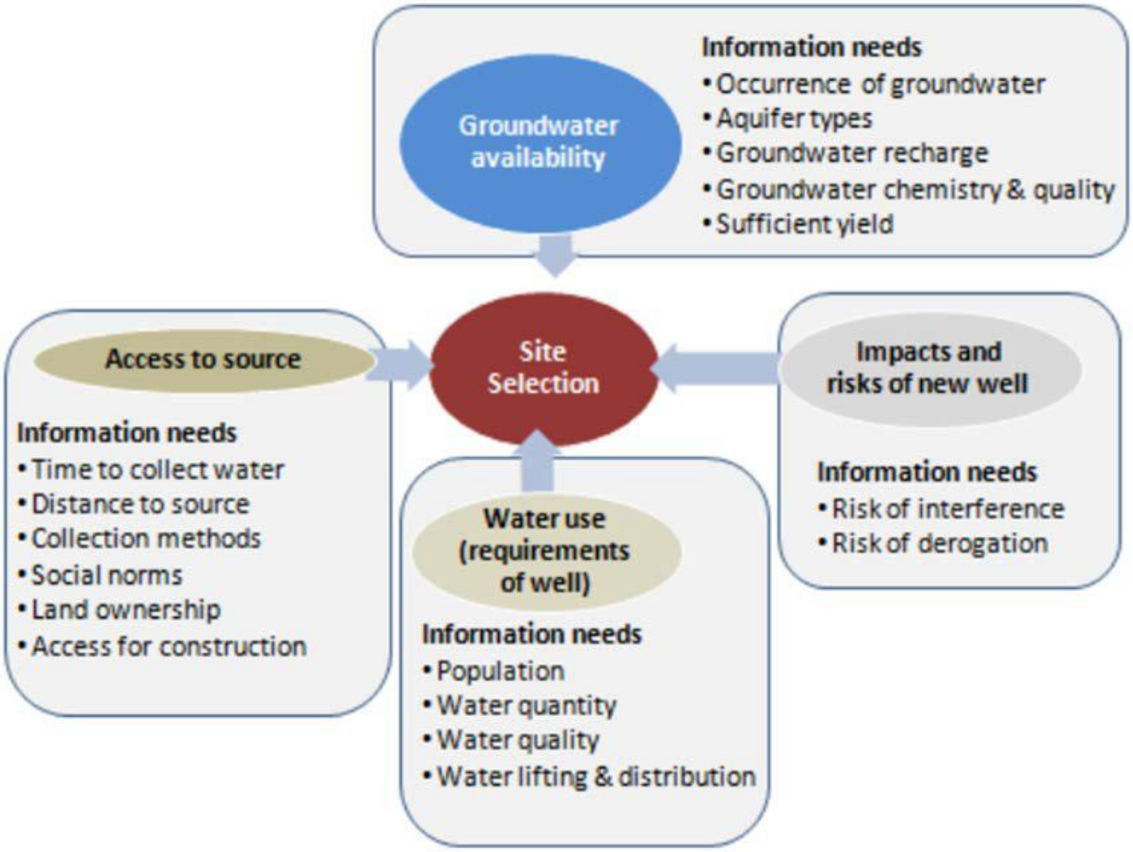

Figure 2.1: Components of Well Site Selection

Source*:* Rural Water Supply Network (2010)

Figure 2.1 denotes the various components involve in siting water well.

The system developed in this study is intended to be a precursor to the site surveying work. It will only supplements and increase the effectiveness of the existing techniques and not to replace them. When the general framework is implemented, it provides suggestions to siting survey teams of areas that have minimum risk and maximum potential benefits. Even with this information, geophysical data about groundwater depth, water quality and geologic formations is still required.

The first component of the site selection process deals with the availability of groundwater. In Africa there are a lot challenges involve to effectively complete this first step. The reason for these challenges is a lack of universal information about groundwater. In fact, Adelana and Macdonald observe that in many areas of sub-Saharan Africa, there is relatively little attention given to the systematic information gathering about groundwater resources (as cited in Danert, 2014). In areas were maps are available that identify sources of groundwater; the accuracy of the information is not sufficiently reliable (MacDonald, Davies, and Dochartaigh, 2002). However, the model can be used to identify sites that are likely to have minimal risks to the well. The siting team can then use the model to reduce the number of areas in which to do a physical siting survey. Therefore, this will result in a more efficient use of resources in terms of time and money.

The second component of the model addresses the potential impact of a well on a groundwater source. It answers the question to the potential problems a new well can cause to groundwater. It is worthy of note that this component of the workflow does not address actual risks to drinking water. Since this component does not address risks to drinking water, the framework developed in this study does not improve this component.

The third component evaluates the water at a site. The value added by the framework is the ability to evaluate a site for the contamination risk. The general framework improves this evaluation by pre-identifying risks to the clean water and identifying community needs for clean water (population and other factors).

The Rural Water Supply Network's guidance also highlights the need to avoid sources of contamination, for example toilets, septic tanks, animal pens, and garbage piles identifying risks on a micro level, one site at a time. Therefore, there is a need for a macro level decision support tool (i.e., the application of the framework developed here) that is able to identify high-risk areas more broadly. This ensures new wells not only avoid contaminants, but are also installed to achieve maximum coverage (i.e. within 1.5 km of households). As explained, the system does not replace the site suitability process developed by the Rural Water Supply Network—it supplements it. The system, when implemented in a specific context, can supplement local knowledge and help drilling contractors reduce the number of siting surveys that must be conducted. This improvement in efficiency is possible because the system pre-identifies the specific locations where there may be risks to water sources.

2.3 Previous Research on Risks to Drinking Water

To protect a water source from contamination, it should be sited upslope from a contamination source (UNICEF, 1999). As explained earlier, water wells can be contaminated at three areas: the opening on the surface, the piping from groundwater to surface, and the groundwater source. As discussed above, groundwater is a good resource to help provide more clean water coverage. However, groundwater is not infallible as a source of drinking water. Groundwater can be contaminated by chemicals and pathogens from organic and inorganic waste (Rural Water Supply Network, 2010).

Furthermore, a report from the UI at Urbana – Champaign WRC identifies some common water pollution sources. These pollution sources are salt from road, septic tanks, fuel tanks stored underground, animal waste, fertilizer, and refuse dump (1990). The report also provides recommendations for minimum distances between a well and a potential source of contamination. The recommended minimum distances offered an advice that a well should be placed far away from sources of contamination. llinois Water Resources Center.

Table 2.1 shows the minimum separation distances for common contamination sources using guidelines from the Illinois Water Resources Center.

Table 2.1: Minimum Separation Distances from Contamination Sources

CONTAMINATION SOURCE	MINIMUM DISTANCE
Sources and routes of Contamination	61m
Cesspools	46m
Leaching pits	31m
Septic Subsurface seepage tile or manure pile	23m
Septic Tank	15m
Surface water bodies	8m

These recommended separation distances helps in understanding the relative potency of a particular contamination source, but because the recommended distances are designed for a person installing a small well on personal property, the value of the specific recommendations is limited.

Finally, the University of Illinois WRC recommends that a well should not be sited on the same direction that groundwater is flowing from a source of contamination. This type of general consideration is included in the general framework.
Additionally, the U.S. Environmental Protection Agency (EPA) recommends that well owners have a zone of protection around a well to prevent contamination. The recommended distance designated to limit risk of groundwater contamination is 30 m (California State Water Resources Control Board, 2011). Both the guidance from University of Illinois Water Resources Center and the EPA are recommendations to prevent groundwater contamination as opposed to surface water contamination. Since surface water can travel faster than groundwater, a contaminant can travel further than the minimum distances recommended by both agencies. Therefore, the fundamental principle is that the greater the distance a well is located from a contamination source, the more suitable is the location.

2.4 Methods for Site Suitability Analysis

To find suitable locations to site water wells, a user can overlay different layers in a GIS. Ian McHarg was the first person to analyzed suitability by overlaying layers in GIS. In 1969 he presented a seminar titled, *Design with Nature*, he demonstrated how a set of transparent layers, one for each criterion can be superimposed, to develop a complete map of suitability. This method is considered the antecedent of modern overlay in GIS (Qiu et al., 2014). There is various suitability modeling methods. One method divides locations into two groups: those that are suitable and those that are not. This method is known as Boolean overlay and it evaluates whether a location meets each criteria, on a yes/no basis (Mitchell, 2012). This is a particularly useful method when boundaries or attributes of a criterion are crisp. Alternatively, where these are not crisp, there are two common methods that allow a user to rate locations on a scale from more suitable to less suitable. These two methods are weighted overlay and fuzzy overlay.

Weighted overlay permits the user to assign importance to a specific criterion. When a user assigns importance, a weight is assigned to the layer (Mitchell, 2012). This can also be referred to as the percentage of influence for each layer. When weighted overlay is applied in a raster context, the output of the raster is obtained from the result of the addition of the products of cells values of each input layer and their corresponding percentage of influence.
Fuzzy overlay on the other hand permits a user to rate suitable locations when criteria are hard to quantify or when the relationship between specific criteria and suitability are not well defined. Additionally, Mitchell points out, "fuzzy overlay is particularly good for creating a suitability model that attempts to capture the knowledge of experts in a particular field" (Mitchell, 2012). Fuzzy overlay has been used for suitability analysis for a wide range of applications such as finding the best locations for wind power systems, rice growing areas, and solid waste landfill (Demesouka et al., 2014; Kihoro et al., 2013). Examples of the use of fuzzy logic to model risks include groundwater vulnerability risk mapping (Nobre et al., 2007) and landslide susceptibility modeling (Chalkias et al,. 2014). In both studies, the use of fuzzy logic highlights how it can handle uncertainty where boundaries and attributes are difficult to define.

Tsiko and Haile in 2011, applied fuzzy logic to model water resources. They used fuzzy logic to archetype the most favorable locations of water reservoirs in Eritrea. That project is similar to this research develops a framework and then applies it to a real life situation. Tsiko and Haile used fuzzy logic for water resource planning because their resolve in respect to basis was accompanied by uncertainties. This meant there was ambiguity about the measurement of the criteria. The authors note, "This makes fuzzy logic a more natural approach to this kind of Multi-criteria Decision Analysis (MCDA) problems" (Tsiko and Haile, 2011,).

CHAPTER 3
EXPERT SYSTEM AND VP-EXPERT SHELL

3.1 Overview

An expert is someone having comprehensive or authoritative knowledge in a particular field. Therefore a computer system created to act as an expert to provide a solution to a problem in a particular domain is called an expert system**.** There are three individuals who take part in the design of the system; knowledge engineer, domain expert and the user. The domain expert is the person that has the required expertise to solve the problem that the proposed expert system is pre-planned to solve. The knowledge engineer acquires knowledge from the expert and transforms it into a format suitable for the system to use. The user is consults the system to solve her/her problem by responding to questions from the designed system. The knowledge engineer performs the major task of designing an expert system; he obtains the knowledge from the domain expert and presents it in a comprehensive format to the user.

3.2 Expert System

An ES is a subclass of AI developed to solve a specific problem in a particular domain. The designed computer system is able to simulate the conduct of a human expert to solve a problem in a particular domain. An ES is computer system that copycats a human expert.

The term Expert System or Knowledge Base System is used to refer to a computer system that has the same as a human expert in its knowledge base. The synonymous used of the two terms, Expert Systems (commonly called ES) and knowledge-based systems (also referred to as KBS), are frequently used. Expert systems are the greatest common types of artificial intelligence application. In an expert system, the area which human intellectual endeavor to apprehend is identified as the task domain (Mishkoff, 1985).

3.3 Architecture of an Expert System (ES)

Building an Expert System requires a combination of many components that result into the decision making viz. goals, facts, rules, inference engine, etc. (Dennis, 1989), thus we describe an expert system as a system, and not an ordinary computer program.

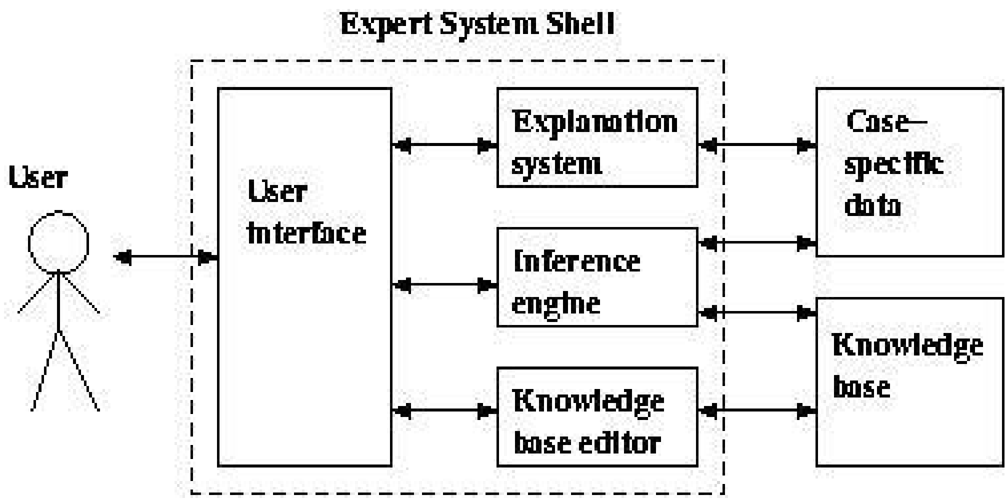

Figure 3.1: ES Architecture

Source: Mishkoff, (1985)

Figure 3.1 show the components of knowledge base expert system.

3.3.1 The Knowledge Base of ES

This is the heart of an expert system. Engineering problem solving uses heuristic knowledge, recognized scientific ideologies and computational algorithms. A heuristic knowledge is a rule-of-thumb that aids one to limit how to proceed. The domain knowledge of an expert system is saved in its KB and this module is very important that the successful application of the system relies on the excellence and dependability of the knowledge confined in it (Sayedah and Tawfik, 2013).

The knowledge base consists of stationary knowledge (situation, events and facts about objects) and dynamic knowledge that deals with the information about the sequence of action. There are various methods of representation and organization of knowledge and knowledge base. The If-Then production rules are used to represent the knowledge. The stationary and dynamic knowledge are also called declarative and procedural knowledge respectively.

3.3.2 Inference engine

Representing the domain expert's knowledge in the knowledge base is not enough and there must be an extra component that guides the execution of the knowledge. This component of the expert system is recognized as the control structure, the rule translator or the inference engine. The inference engine chooses the kind of search to be used to solve the problem. In fact, the inference engine runs the expert system, defining which rule is to be useful, executing the rules and defining when a suitable solution is attained. The kind of inference mechanism relies on equally the nature of the problem domain and the technique in which knowledge is represented in the knowledge base.

3.3.2.1 Forward Chaining

In designing an expert system to solve a particular problem, someone may choose to start with a preliminary state and then tries to reach the goal state. The method of shifting over different solutions to proceed from the preliminary state to goal state is termed search and the realm of all probable paths of search is the search space. There are two search methods broadly used in rule based systems, these are forward chaining and backward chaining.

As the name implies search in forward chaining proceeds in the forward direction. The forward chaining is a data driven search. The forward chaining is advantageous when goal conditions are minor in number when related to the initial state. Antecedent part is checked first and then goes to consequent part.

3.3.2.2 Backward Chaining

In backward chaining the system backs a goal state or suggestion by examining known information's in the framework. The system searches the state space working from goal state to the preliminary state by the applying the inverse operators. When there are rare goal states and many preliminary states, it may be better to start with the goal to work back towards the controller state. Backward chaining is a goal driven or ambitious search.

3.3.2.3 Hybrid Chaining

Hybrid chaining always starts with forwarding chaining and anywhere a fact is required from the operator, go into contrary to the leaf node of the knowledge and have it to proceed with forwarding chaining mechanism.

3.3.3 Working Memory

The working memory aims at the gathering of symbols or reliable information that mirrors the present condition of the problem which comprises of the data gathered during problem implementation.

3.3.4 Knowledge Acquisition

The methods involve in extracting, constructing and organizing information from the domain expert, so that it can be used in the building the system is termed knowledge acquisition. The success of expert system mainly depends upon the superiority, comprehensiveness, and accurateness of the information stored in its knowledge base. This permits one to obtain more knowledge about the problem realm from the expert (Patel, 2013).

3.3.5 User Interface

This is the component of the system which permits the user to interact with the expert system.

3.3.6 Explanation facility

Expert System is unique and special in the sense that it has the ability to explain to a user how a conclusion was reached and this is achieved through the explanation facility. This is one of the key benefits of the expert system.

3.4 Developing an Expert Systems

The development of any successful expert system involves so many important steps (Nilsson, 1998). These steps are:

• Identify the problem: Just like most compiler programs the expert system is an answer to a crucial problem. The development of an expert system can be validated when there is a problem it can solve.

• Study the alternatives: Though the identified problem in step one above may be suitable to the criteria for an expert system we would be cautious with simpler and cheaper alternative solutions.

• Feasibility: In this step we will try to study the practicability of the design system. The developed system should be practicable from all aspect such as procedural, economical and so on.

• Selection of design tools: There are so many expert system design tools available in the market. These design tools are computer software sets that allow us to key in the expert's knowledge inside the computer without having to program. Though most of these design tools are rule based, some tools allow the execution of the frames and semantic network but they are slightly expensive. Therefore, the selection of the right design tool is key to developing successful expert system.

• Execute the knowledge acquisition: The design of an expert system technically begins with the knowledge acquisition. In this step of the design of the expert system, we acquire relevant knowledge from field experts and other relevant sources such text books, journals, and so on.

• Design and complete the Expert System: Now that we have chosen the proper expert system design tool and have acquired the needed knowledge we may now begin with the design of the expert system. First, we desire to generate a plan for a hierarchical flowchart, matrix decision tree or other plans that will assist us in establishing and understanding the knowledge. By means of these assistances, we will be able to translate the knowledge into the "if-then" rule. Once the elementary design is achieved we can start to create a sample of one of the sections of the system. Once we are satisfied that the system is going to perform properly we can start to increase the sample into the final system.

• Testing and correcting: At this phase of the development of the expert system, we would test the designed system and make corrections where necessary as most expert systems are always faulty at the initial stage. The responses gotten from the users will show the places to make the corrections so that we may achieve the best execution.

• Maintenance: The knowledge base of an expert system can be modified. This provides the opportunity to consistently maintain, update the system with innovative knowledge and eliminate the knowledge that is no longer related. This is a very vital part in the development of expert systems.

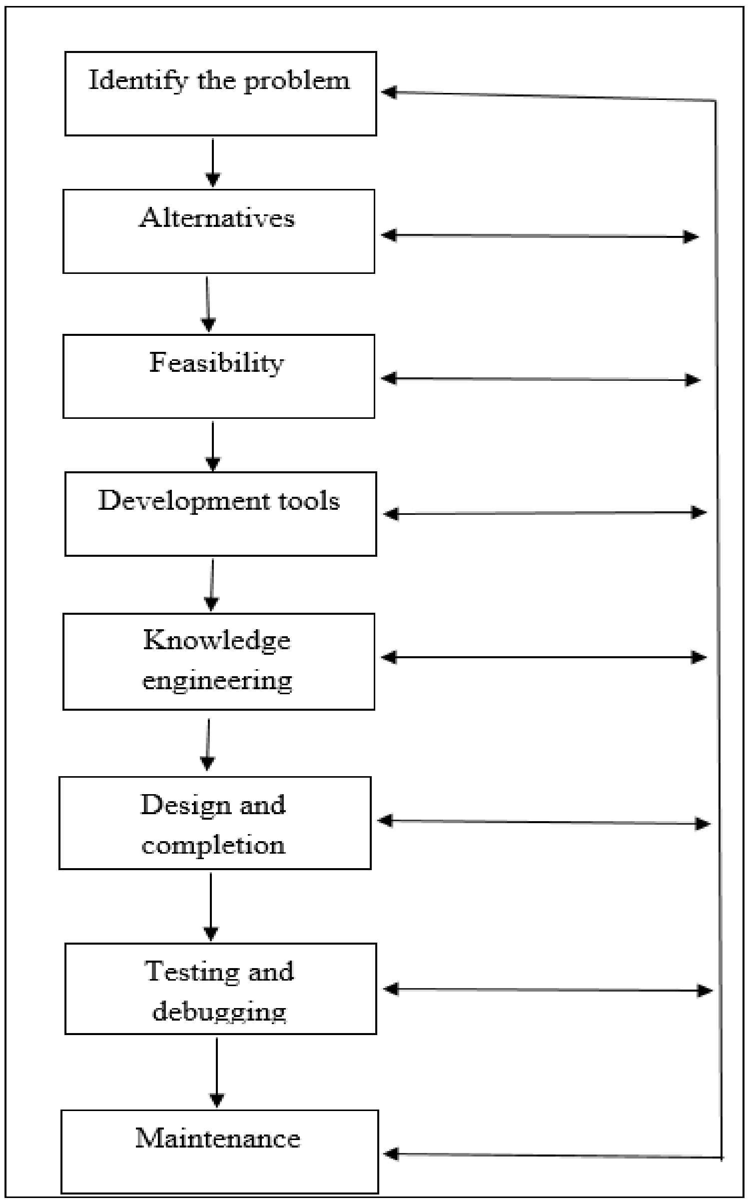

Figure 3.2: Development Cycle of Expert System

3.5 Features of Expert System

• Goal driven reasoning or backwards chaining: This is an inference method which frequently practices the if-then rules and breaks down the goal into easier verifiable minor sub-goals.

• Handling uncertainty: Expert system has the ability to handle uncertainty since it can think with rules and facts that are not surely identified.

• Data-driven reasoning or forward chaining: This is an inference method which infer a problem solution from original facts using the if-then rules.

• Data representation: Is the technique in which the problem precise data inside the system are kept and accessed.

• User interface: This is where the user interacts or communicates with the system.

• Explanations: ES has the potential to explain the procedures that were used to give a commendation.

3.6 Application of Expert System

Expert system has so many applications in our contemporary world. These applications are in various categories, viz. Knowledge domain which is used to detect faults in vehicles and computers. Expert system also finds application in finance and commerce to detect fraud, doubtful transactions, stock market trading, airline scheduling and cargo schedules. In addition it is applied in design domain where camera lens is designed and automobile design. It also applied in monitoring systems for equating data to monitor petroleum pipeline outflow. Another field where expert system is applied is the medical domain for diagnosis and treatment of various diseases. Furthermore it is also used in geology to identify locations that are suitable to drill for oil or water.

3.7 Advantages of Knowledge Based Expert System

1. ES is universal. This helps to solve the problem of scarcity of experts.
2. Human are not totally reliable.
3. Expert systems are economical.

4. Expert Systems are fast i.e. if a human expert has the capacity to attend to 100 clients per day then about 400 users can consult an expert system per day.

5. Reduced risk.

6. Can be used at different locations at a time.

7. The KB can be modified

3.8 Limitations of Expert System

1. Expert system has limited domain.
2. Experts needed to setup and maintain system.
3. They do not study.
4. An expert system cannot refine its own knowledge base.
5. They lack common intellectual and sensitivity.
6. They can't apprehend infrequent knowledge.
7. May have high development cost.
8. They are more appropriate for problems concerning inference.

3.9 Why Used Expert System

The human experts are not always available and also not 100% reliable. A human expert may not be able to explain choices and their cost effective. An expert system can be used anywhere and anytime. Therefore, considering the numerous advantages of expert system and the deficiencies of human experts, expert systems have turned out to be vital in our day to day life.

3.10 Some Expert System Tools

• PROLOG: This is a logic programming language which practices backwards chaining.

• CLIPS: A common domain software tool for constructing expert systems (C-Language Integrated Production System).

• OPS5: First AI language used for Production System (XCON used for configuring VAX computers).

• EMYCIN: Is an expert shell for knowledge representation, reasoning, and description.

• MOLE: A knowledge acquisition tools for obtaining and sustaining domain knowledge.

• ESPLAN: Is based on fuzzy explanation of antecedents and consequents in production rule.

• LIPS: Is used for answering linear programming problems (Linear program solver).

• VP-Expert: This design tool operates base on production rules.

To execute recommended implementation efficiently, a cautious choice of an ES shell for the precise domain purpose is very vital. VP-Expert was finally selected as the development shell for executing Water Well Location Site Expert System because of the virtuous performance of the interface and command menu of the shell.

3.11 VP-Expert

VP-Expert is a design tool that works base on production. It is made up of inference engine, the user interface, and every component needed to fully design an expert system. An expert system comprising of an empty knowledge base is called an expert system shell. When someone develops a knowledge base for a particular area then it becomes an expert system in that domain. By means of a shell, someone can design an Expert System in several domains. VP-Expert assists only rule-base knowledge illustration or representation, which is easy English similar to rule building (Sayedah and Tawfik, 2013).

VP-Expert works based on the inference method for backward reasoning. The inference engine is used to cruise around the knowledge base in order to answer questions, the rules of the knowledge base are written on the editor and a client's interfaces for supervising the questions, inquiring queries from the clients, and giving recommendations and clarifications, where desired. It also comprises restricted graphical proficiencies. Be warned that this version of VP- Expert is designed for students, therefore some selections won't be accessible and that the magnitude of your knowledge bases will be restricted.

3.12 Reason for Selecting VP-Expert

There are different types of ES shells, but VP- Expert presents a rich combination. It has an input command that robotically produces knowledge by the table confined in a text, database, and an inference engine which practices backward chaining and ideal design windows that makes it possible to detect what is going on behind the screen as the inference engine cruise around the knowledge base. VP-Expert posse's a confidence factor that allows one to justify the content of the knowledge base, an easier English language creation rule, a command that permits the VP-Expert to clarify its actions throughout the period of consultation and it also has a knowledge base chaining which permits one to construct knowledge bases and chain, else it would be too big to fit in memory. Finally, it creates question robotically and has the capacity to perform peripheral DOS programs.

3.13 Knowledge Base in VP-Expert

Using VP-Expert to design expert system requires inducing a KB which comprises of 3 stages; actions, rules and query statements.

3.13.1 ACTIONS block

This is the code that regulates the implementation of the inference engine. The ACTIONS block includes declarations that regulate the activities of the system. These declarations are performed inside the command in where they appear.

The key DISPLAY explanation guides the client on what to do. The FIND statement speaks the framework's aims. The final declaration presents the results.

3.14 Query Statements

Variables that don't seem as the result of some rule in the knowledge base are referred possible queries for the client. Uncertainty, the inference engine tries to locate such a variable and value drive the client. This process is complete by the ASK and CHOICES statements.

3.14.1 ASK statement

The method of the prompt for a variable is explained by the ASK statement. As with any further program, these prompts must be useful. It contains the subsequent procedure:

ASK variable: "prompt";

Example:

ASK TOPOGRAPHY: "Please take the location's TOPOGRAPHY, and enter it into the system?”

3.14.2 The CHOICES statement

If there is limited quantity of probable replies towards a query they might be found in a menu well-defined by a CHOICES statement. It contains the subsequent method:

CHOICES variable: list of values;

For instance:

CHOICES TOPOGRAPHY: High, Low;

This menu is published out once the query is enquired. Be informed that if there wasn't any CHOICES statement for a variable, the client must key in the value on the cursor later the prompt.

3.15 Production Rules

This is the domain knowledge written as If-Then rules. Dissimilar to the statements in the ACTIONS part, they aren't executed in the directive enumerated; as an alternative, they are accessed as desired through the course of backwards chaining. The directive of rules is vital only when there are multiple rules that might be utilized to give a variable a value.

3.16 VP-Expert's Consultation Screen

Consultation is the process of applying the system to solve a particular problem. The system solves problems by using rules from its knowledge base. In general, the client doesn't input questions straight to the system, this happened through the actions part of the knowledge base but does pass in responses to queries related to the question. To start consultation, select Consult found under the main menu, and hit Go.

There are three windows found in the VP-Expert consultation screen; Communication window, Rule Window and Values Window. The communication window is where data or information is inputted by the user, and results are revealed here. The Rules Window permits one to see the action of the VP-Expert's inference engine, as it interrelates with the knowledge base throughout the consultation. The values window records the middle and last resultant values throughout the path of the consultation. The values are shown as variable = value CNF.

3.17 Certainty Factors

Clients might also offer credence in the information they enter in answer to queries. This can be done as follow; press HOME, enter a value between 0 and 100 then hit the RETURN button and END.

The acronym CNF 100, which appears at the side of each variables task in the values windows, denotes the confidence factor. This is a number that shows the degree of certainty that a decision is valid. A confidence factor of 0 shows no confidence while a factor of 100 shows total confidence. Confidence factor can be inputted by the end user when responding queries throughout the consultation. Confidence is a personal method to give variable levels of certainty to declarations. If there is no confidence factor been stated explicitly, then 100 is assumed.

3.18 Main Menu in VP-Expert

The navigation keys, function keys, initial characters of option term and numbers are used to select choices in any menu. Submenu of the choice presently highlighted is display under the main menu. Vital choices in the main menu are shown in Table 3.1 below:

Table 3.1: Important Options of a VP-Expert Main Menu

Consult	For Executing the system on the present KB
Path	Change the current drive
Edit	Used to create and modify the knowledge base
File name	Choose extra knowledge base for erasure or consulting
Quit	Quit VP-Expert

The Escape button might at all times be applied to backspace, in precise, to escape a choice that was already selected.

3.19 VP-Expert Editor

This is a text editor found on both consult and main menu. The editor is also cited robotically where ever a grammar blunder is noticed in the KB. When the editor is cited at the main menu, it prompts the client to the folder name to be corrected. The client can select from the present menu or input a name. A new folder might be created by entering a new folder name.

All files name in the editor should always ends with KBS as extension.

3.20 Editor Command Menu

The editor commands are always found at the bottom of the screen (see Figure 3.3). These commands can be cited by applying the function keys.

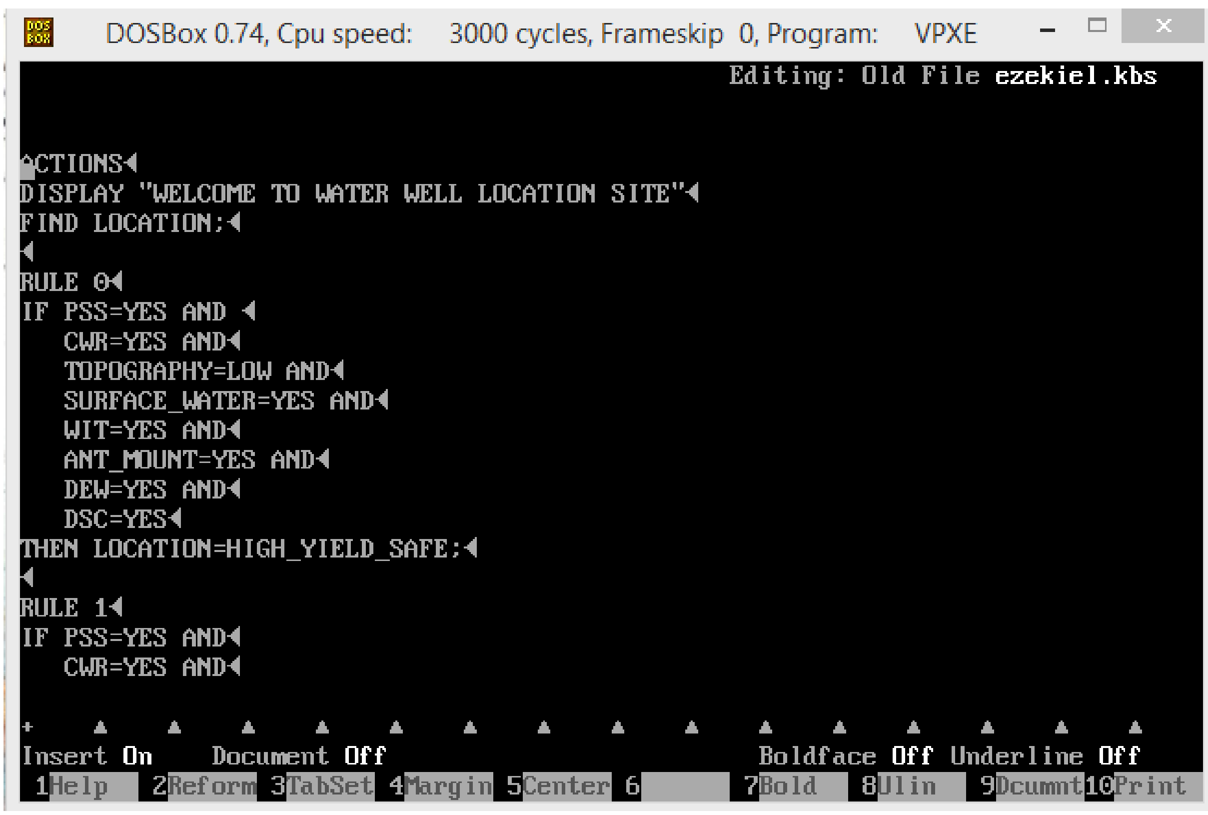

Figure 3.3: Command Menu in editing mode

3.21 Some Common Editor Commands

Table 3.2 shows the most common used editor commands.

Table 3.2: Editor Commands for VP-Expert System

F1	Invokes the help facility
F10	Print the file
ALT-F5	Save file without exiting
ALT-F6	Save file and exit the editor
ALT-F8	Quit editor without saving
Control-Enter	Input a new line
Delete	Delete character at cursor position
Backspace	Delete character to the left of the cursor position
Control-T	Delete from cursor position to the end of word
Control-Y	Erase the whole line
Page Up	Go up by one screen
Page Down	Go down by own one screen
Home	Move to the beginning of line
End	Move to the end of line

CHAPTER 4
DEVELOPMENT OF OPTIMAL WATER WELL LOCATION EXPERT SYSTEM

4.1 Preamble

The ability to identify the right location to site water well will determine the success or failure of the well construction. Whether the target is to find a water supply for domestic, agricultural or industrial purposes, relevant knowledge about groundwater occurrence and proper planning will help in identifying the appropriate location to site the well. This section of the research provides the necessary guidance and fundamental requirements for siting water wells.

4.2 Groundwater

The water cycle is the origin of Groundwater sources. These groundwater sources are held in aquifers (water bearing formations) under the surface of the ground. In order to produce safe water for drinking and other purposes these aquifers are penetrated by drilling wells.

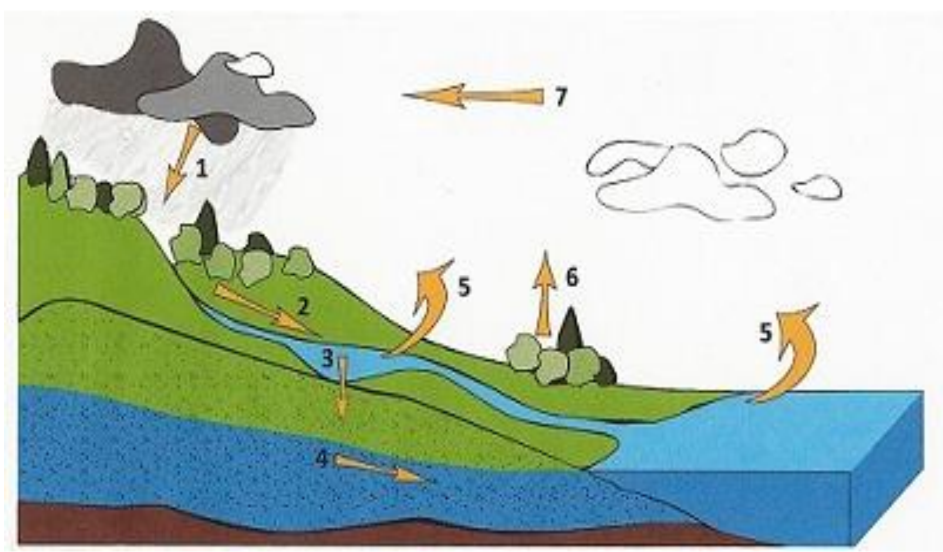

Figure 4.1: Water Cycle

Source: Lifewater International (2014)

In the above Figure 4.1 the numbers 1, 2, 3, 4, 5, 6, and 7 denotes precipitation (rain or snow), runoff, infiltration, groundwater, evaporation, transpiration and clouds respectively. Water drops from the sky when the clouds are saturated with water, this process is called precipitation. This water moves on the earth surface. The earth absorbs this moving water in a process known as infiltration. The infiltrated water is stored in the empty spaces of soil particles and in the cracks of rocks as groundwater. The only means of having access to this groundwater sources is drilling of wells into the ground where this water is held. An aquifer can be defined as a water bearing formation that has the ability to yield or produce a useable amount of water. The porosity and permeability of soil and rock formations determines the quantity of water that an aquifer can produce.

Though people often see groundwater sources as underground lakes or rivers moving under the earth surface, but groundwater is actually trapped in the void spaces earth materials. However, groundwater moves, but it flows very slowly. The flow rate ranges between two hundred centimeters in a day to about two hundred centimeters in a year. The permeability of the soil and rock formations determines the rate of flow of groundwater through it. Groundwater always flows from the recharge area (which is the area of infiltration), towards an area called discharge point.

The empty spaces found in the earth materials are known as porosity. It is result obtained when the volume of empty space is divided by total volume. Porosity is usually expressed in percentage.

The capability of water to move within the empty pores that exist between the earth formations is called permeability.

Table 4.1: Porosity and Permeability Table of Sediments

Sediment Type	Porosity	Permeability
Uniform size sand or gravel	25 - 50%	High
Mixed size sand and gravel	20 - 35%	Medium
Glacial till	10 - 20%	Medium
Silt	35 - 50%	Low
Clay	33 - 60%	Low

Error! Reference source not found. shows that clay is highly porous but has low permeability. While the permeability of gravel is very high, its porosity is relatively low. Groundwater moves within the empty pores of earth materials. Water moves more freely between earth materials that have high permeability. Gravel formations yield more water than clay layers because of their high permeability, so therefore gravel layers are good groundwater sources. Layers of bedrock can yield sufficient amount of groundwater if they are weathered and have enough fractures.

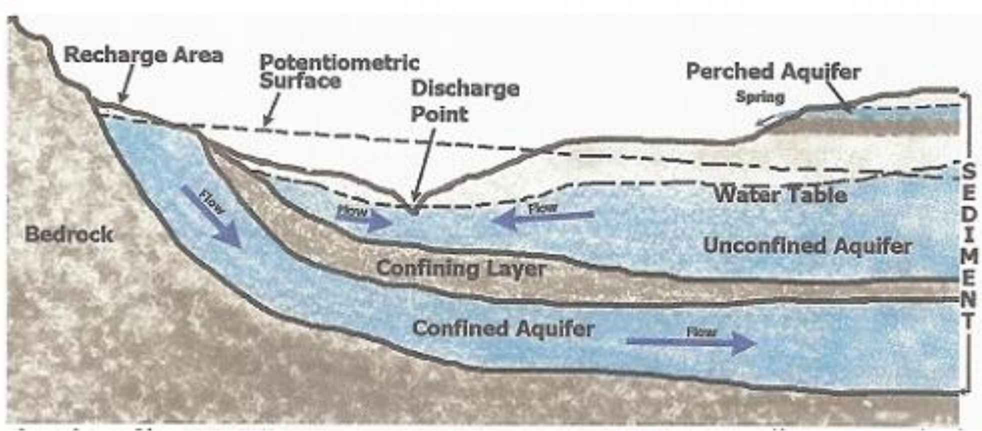

Figure 4.2: Groundwater Diagram

Source: Lifewater International (2015)

The water under a confining layer (Figure 4.2) can easily be protected from contamination because a confining layer normally restricts the movement of water within it. Therefore, clean sources of water are often found under a confining layer since the confining layer offers a cover from contamination for the water beneath it. A confined aquifer is bounded both above and below it by confining layers**.** Water rises above the top of the confined aquifer when a well is drilled into it because of the high pressure exerted on the water in confined aquifers. At a very high pressure the water can rise above the ground surface. A special type of well called artesian is formed in this manner. An unconfined aquifer on the other hand is not bounded above by a confining layer. In an unconfined aquifer, the top of the saturation point is called water table. Void spaces under the water table are usually full of water. A perched aquifer is a small unconfined aquifer found under a confined layer. This aquifer is not a good groundwater source because it has a very low yield.

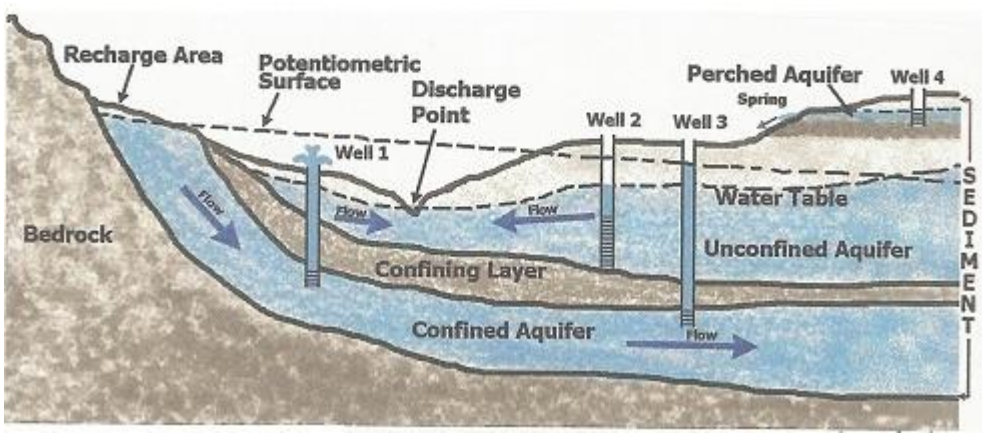

Figure 4.3: Groundwater Diagram Showing Different Positions of Wells

Source: Lifewater International (2015)

Figure 4.3 above illustrates the aquifer types and other factors that determine the depth to water from the ground surface. The level that groundwater is expected to rises in a well is called the potentiometric surface. The potentiometric surface is the minimum depth that must be reached before water can be found. For unconfined aquifers, water table and potentiometric surface are at the same level. In a confined aquifer, the water level is lower than the potentiometric surface. The static water level is the level of water in a well when the well is not been pumped.

4.3 Deciding Where to Drill

There is a very high temptation to start drilling water wells without proper planning when the required drilling equipment is available. However, the processes involved in drilling wells should be properly organized in order to increase the chances of success in siting water wells. Drilling reliable and sustainable wells are possible when they are carefully sited. Those involved in the projects of siting water wells must have relevant and adequate information about groundwater occurrence and how it got there in order to successfully site water wells.

Therefore, in designing the Expert System to identify optimal locations to site water wells, the following critical factors were given due considerations:

4.3.1 Types of Subsurface soil

The only way to accurately know the amount and quality of water that can be produced in a particular location is to sink a borehole in that place. However, we can have a rough estimation of the quantity of useable water that an aquifer can produce by having relevant knowledge about the kind of earth materials that form the water bearing formation. Significant amounts of drinking water are held in the layers of sand and gravel deposits. However, the yield of the aquifer depends on the thickness and permeability of these earth deposits. In general, thick deposits of large sizes of grains produce high yield of groundwater. On the other hand clay yields very small amount of water because of it low permeability. Therefore, it is not a wise decision to drill wells in clay soil because of its low yield.

In conclusion, high yields are produced at areas with thick deposits of cracked weathered rocks (Dijon, 1981).

4.3.2 Vegetation

During the dry season, ant mounds and some green vegetation can serve as good indicators of groundwater in an arid landscape. Good indicators of groundwater such as trees with broad leave usually grow at places where the water table is high. Baobao, Kapok and Daniella are examples of some water indicator trees found in Africa.

4.3.3 Topography

The water table normally flows along the ground surface. Groundwater always flows from a higher ground to a lower ground. Therefore, places such as the bottom of valleys are always good locations for water wells because water from the rain always stays there (Dijon,1981).

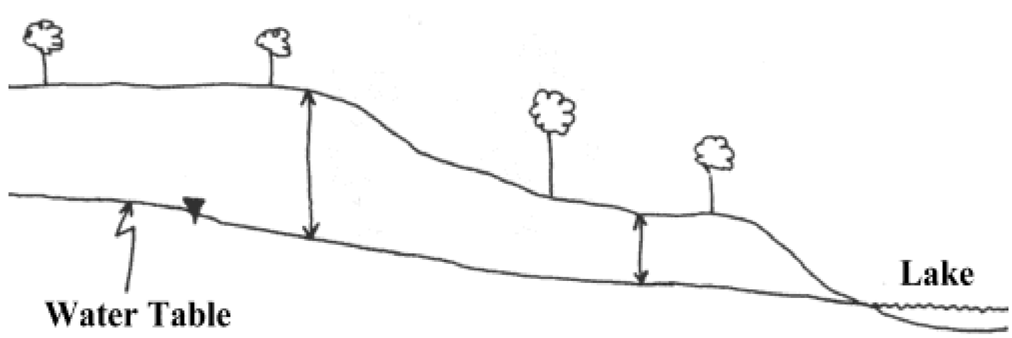

Figure 4.4: Direction of Groundwater Movement

Source: Dijon (1981)

4.3.4 Surface water Body

Water wells can be sited with high probability of success at a distance of about 15 m from a surface water bodies like rivers and springs. Even when the surface water bodies are temporarily dried, the aquifer may still yield some useable amount of water. Water wells located near riverbeds are known to be reliable (Dijon, 1981). The water taken from these wells are usually of better quality than the water from the river. Generally, springs indicate the presence of water bearing formation.

4.3.5 Distance to Existing Well

When a well is pumped, the groundwater in the aquifer normally moves toward the direction of the point at which the water is being tapped (see Figure 4.5). Pumping usually has an influence on the direction of movement of groundwater. But the water level will not be affected at a considerable distance (say 30m) away from the well even if the well is pumped for several hours.

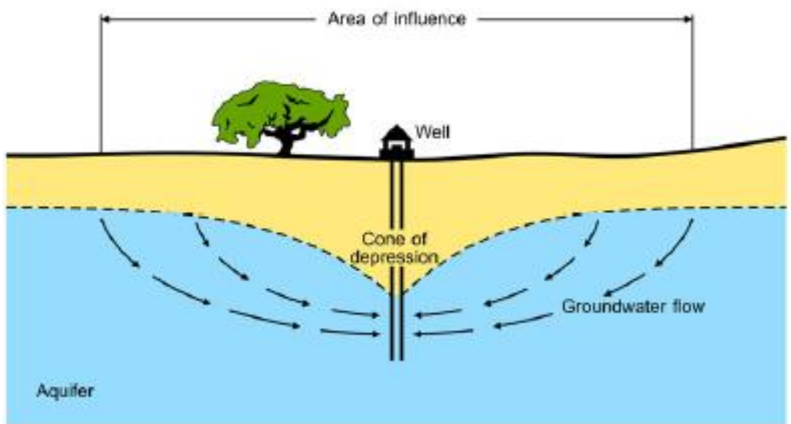

Figure 4.5: Area of Influence

Source: Amended from Oregon State (2010)

When two or more water sources such as wells are placed very close to each other, the water sources will be at risk of tapping water from the same aquifer and this will adversely affect the yield of the water sources as both wells will interfere with each other. This will eventually leads to dry wells.

4.3.6 Sources of contamination

It is a bad practice to drill water wells in places that the groundwater is polluted. Therefore, wells should be placed at a considerable distances from contamination sources. If a well is located far enough away from sources of contamination, the soil is able to filter out harmful organisms before they reach the well.

Table 4.2: Recommended Distances between Water Sources and Contamination Sources

Different Types of Contamination Sources	**Distance (m)**
Piles of garbage, fuel stations, industrial waste	100
Cesspool	50
Latrines, animal pens, barns, fertilizer	30
Surface water, septic tank	15
Ditch drain	7

Therefore it is advisable to adhere to the recommended safe distances as shown in Table 4.2 above when siting water wells. Wells should be sited up gradient from contamination sources.

4.4 Site Map

Identifying the most appropriate location to site water well can be very difficult. It often involves some kind of compromise between conflicting goals. Therefore, making a simple site map helps identify the most important factors to consider.

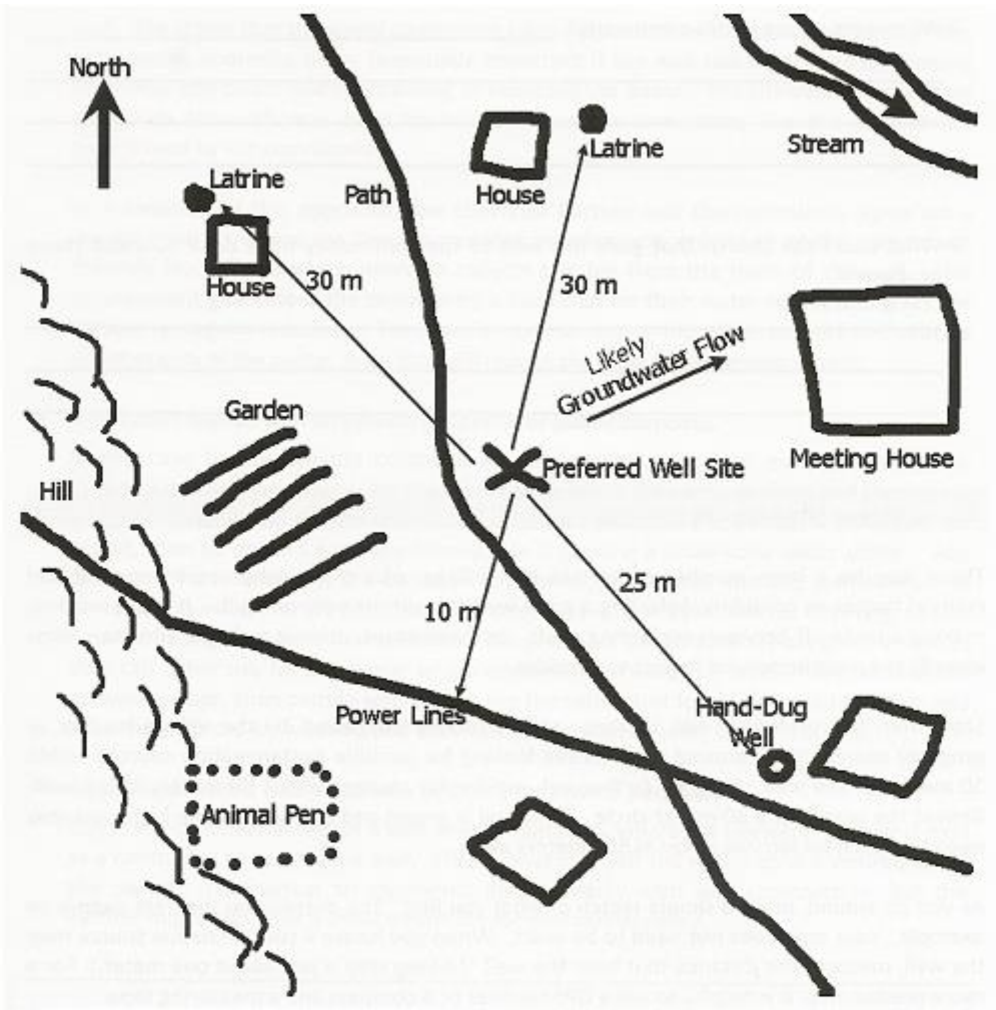

Figure 4.6: Water Well Location Site Map

Source: Lifewater International (2015)

The Figure 4.6 above is a site map showing the most preferred location to site water well.

4.5 Methodology

The designed system employs the acquisition of knowledge from domain experts (which are practicing geologists in this case), textbooks, articles and other relevant sources to create the production rules using expert system methodology for the actualization of VP-Expert system for identifying the optimal location to site water wells. The procedure for the development of the system is categorized into two stages; knowledge acquisitions and knowledge representation. The knowledge acquisitions involve the collection of data from domain experts, papers, books and other relevant sources. Knowledge representation explains how the knowledge acquired or data collected has been transformed into a format that is suitable for use by the computer and the coding in terms of IF-THEN statement. Running the system on VP-Expert design tool and finally loading the program for consultations.

4.5.1 Knowledge acquisitions

The knowledge used in the design of the system was acquired through consultations with geologists, textbooks, thesis, articles and other relevant materials. Also initiating elementary enquiries, adopting essential modifications in each stage and then the developed expert system is designed based on preceding phases.

4.5.2 Knowledge representations

The designed system is a rule-based expert system. The IF…THEN rules were used to represent the knowledge acquired, where IF demonstrate the condition and THEN provides the solutions.

4.6 Coding

The optimal water well location Expert system was coded through the use of a VP-Expert design tool; the shell is a precise tool for designing expert systems thus only expert's systems developers are acquainted with it. VP-Expert operates based on the backward reasoning method for inference. The tool has an inference engine for searching the knowledge base to respond to queries, an editor for writing and modifying the rules of the knowledge base, and a user interfaces where the user interacts with the system.

The production rules of the designed expert system consists of 8 attribute questions which serves as the input of the system and 6 possible outcomes for the location which describes the suitability of the targeted location to site water well. These input questions are shown below:

1. Is the subsurface soil permeable?

2. Is the rock type cracked and fractured?

3. What is the nature of the topography?

4. Is the location near surface water?

5. Is there a water indicator tree?

6. Is there an ant mound?

7. Is the distance to existing well greater than or equal to 30 m?

8. Is the distance to source of contamination greater than or equal to 100 m?

The possible variables of the location in the designed Expert System include:

1. High_Yield_Safe: This means that the location will supply high yield and safe drinking water.
2. High_Yield_Unsafe: This means that the location will produce high yield but unsafe (i.e. contaminated) water.
3. Moderate_Yield_Safe: This implies the location has a moderate yield and safe drinking water.
4. Moderate_Yield_Unsafe: This implies the location has a moderate yield and unsafe water supply.
5. Low_Yield_Safe: This means that though the location will have a low yield of water supply, but the water is safe for drinking.
6. Low_Yield_Unsafe: This implies that the location will have a low yield and unsafe water for drinking.

The sample of the developed expert system production rules is being demonstrated below for further explanation.

According to Rule 4;

IF PSS is equal to YES AND

CWR is equal to YES AND

Topography is equal to LOW AND

Surface water is equal to YES AND

WIT is equal to NO AND

Ant Mound is equal to YES AND

DEW is equal to YES AND

DSC is equal to YES THEN

Location is equal to High_Yield_Safe;

RULE 4
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=NO AND
ANT_MOUND=YES AND
DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

Figure 4.7: A Sample of the Production Rule

Figure 4.7 above shows how the inputs of the designed system were combined to create the production rules in the knowledge base of the system.

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CHAPTER 5
RESULTS, TESTING AND VALIDATION

5.1 Presentation of The developed System

The designed system was developed using the VP-Expert System design tool and the completed system is presented in this chapter. During the process of developing this system, all the production rules contained in the knowledge base of the system were tested and modifications were done where necessary. The designed system was validated and all relevant recommendations were included in the final designing stage.

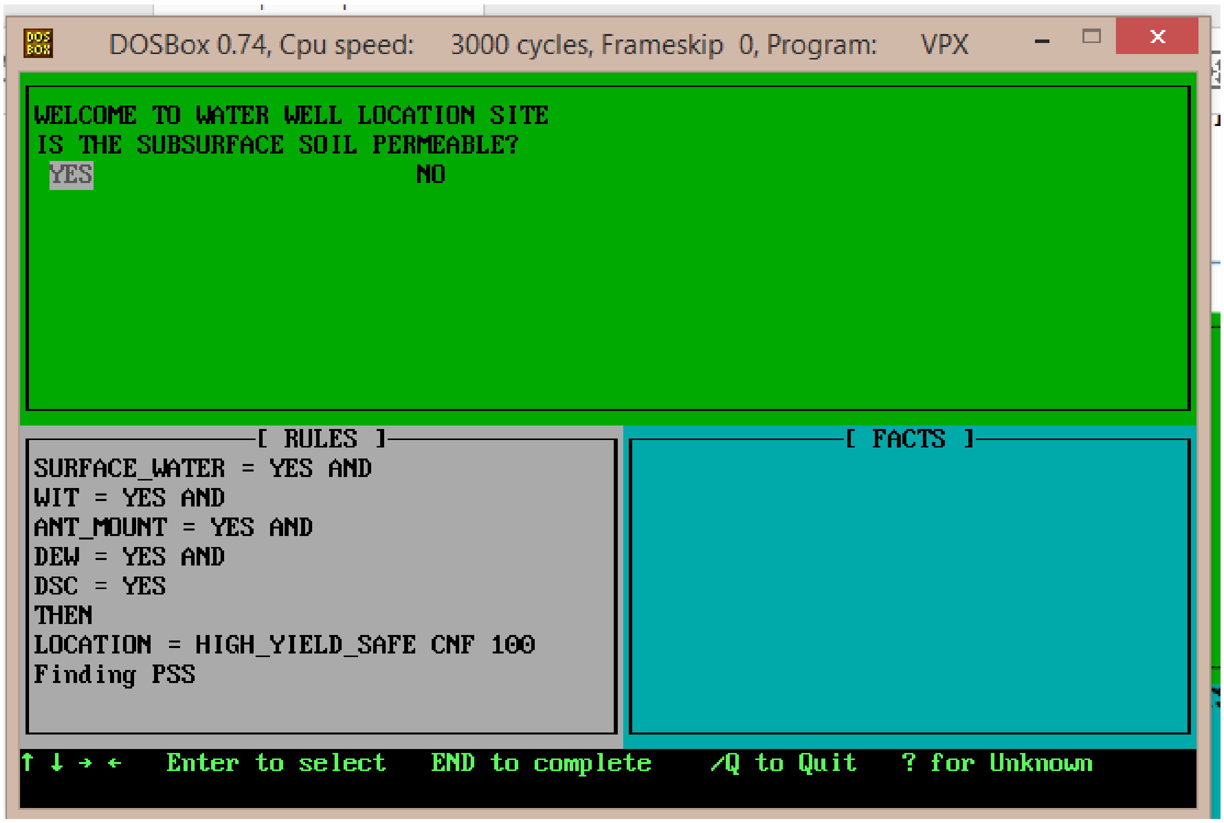

Figure 5.1: The Developed Expert System Ready for Consultation

5.2 Results and Discussion

At this stage, all relevant acquired knowledge (as discussed in the preceding chapter) has been inputted into the designed system. The user interface does the evaluation of the knowledge with the help of the rules and facts windows to determine the output base on the questions that the user answered. The system operates according to the backward chaining method of inference; this checks the memory to verify if the goal has been added, this is necessary because another knowledge base might have already proved the goal. The system searches the rules in its knowledge base, and if the goal has not yet been previously proved, it then looks for a rule or rules that contain the goal in its THEN part. The system then searches the memory to verify whether the memory contains the rule's goal premises. If the system cannot find the premises in its memory, then the premises is referred to as a sub-goal. This sub-goal will be proved and supported by corresponding rules. This process continues until the system finds unproved premises. The system queries the user when it finds a primitive. The system now proves both the original goal and the sub-goals using the information it gets from the user. The diagrams below show different stages of interaction between the user and the system.

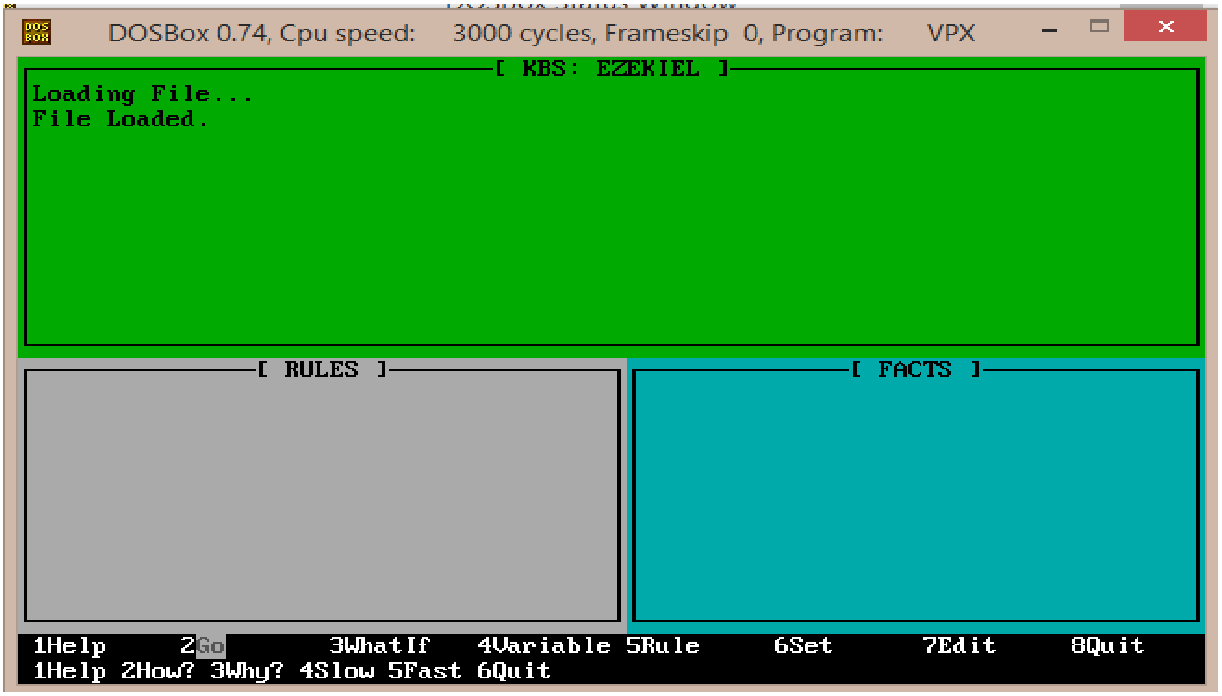

Figure 5.2: The System Loading its Knowledge Base

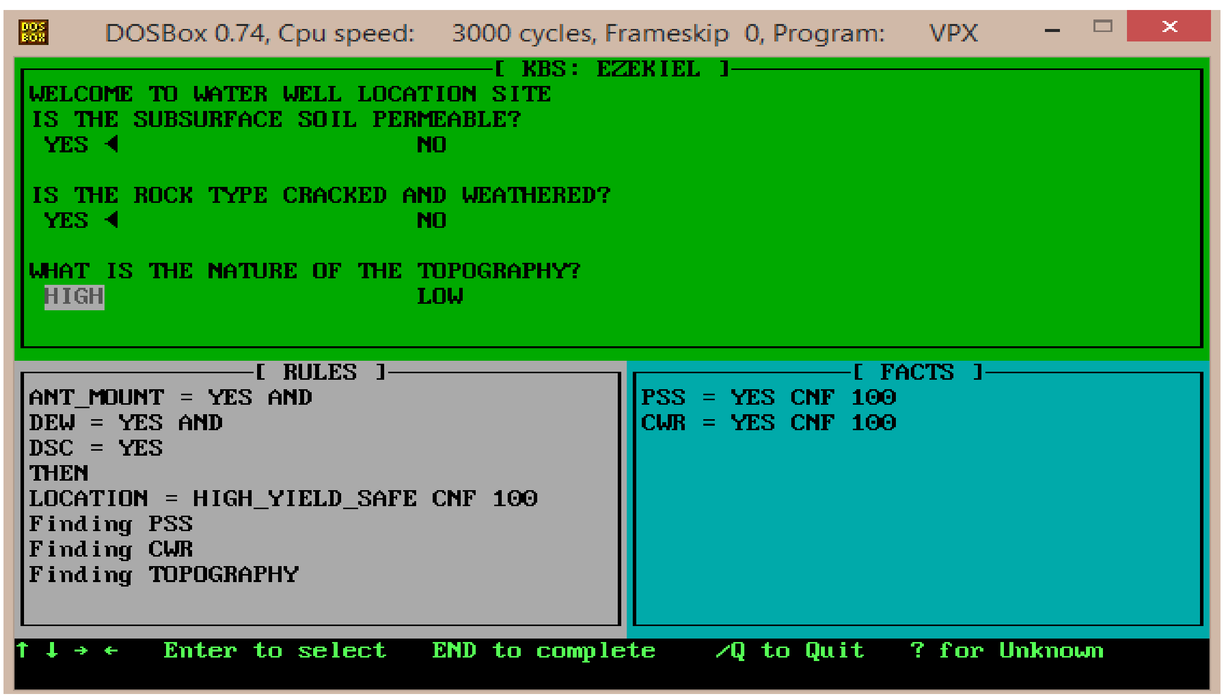

Figure 5.3: The User Responding to Questions

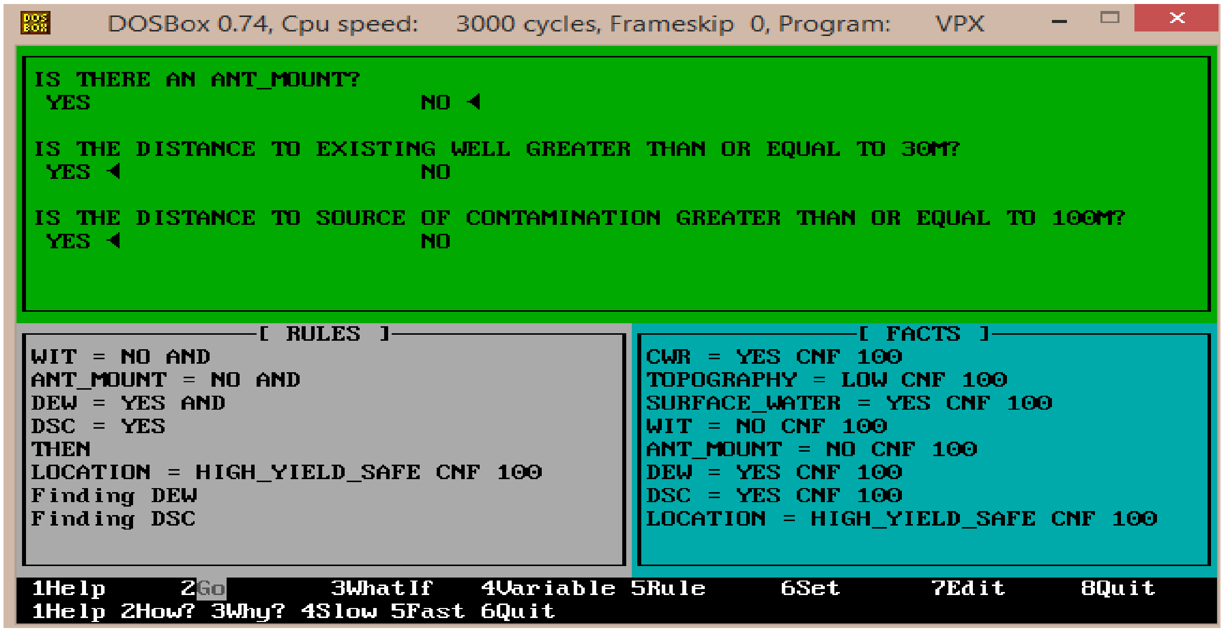

Figure 5.4: Result of Consultation

From the above illustration we can see that the system has performed intelligently and with a good performance like a human expert in that domain. It has performed intelligently since it was able to answer queries and give recommendations as though it was a human expert in the field of hydrogeology. The system was validated by domain experts. The result presented in Figure 5.4 illustrates the efficiency and usefulness of the designed system. It was confirmed by the experts that this system can be used as a very important tool to improve the supply of potable water in Africa since the region has limited number of experts who are always working under pressure because of the overwhelming workloads. The system is designed to be used by both experts and non-experts in hydrogeology.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this research a system was designed to identify optimal locations to site water wells where risks to failure and waste of resources are minimized and productivity and sustainability of clean water wells are maximized in rural Africa. The purpose of the thesis is twofold: improving the current research on the supply of potable water in Africa and designing a suitable system that could be implemented by individuals, governments and non-governmental organizations throughout Africa to improve the supply of safe drinking water.

The optimal water well location site system designed in this thesis was a rule-based system. The knowledge base of the designed system consists of relevant production rules on factors to consider before drilling water wells. The results obtained does not only show the feasibility of drilling successful safe drinking water wells through the application of expert system, but the results also shows that the subclasses of AI can be applied in different drilling projects.

The design of optimal water well location system has been presented. The knowledge acquisition and representation steps were adequately explained. The IF-THEN rules were chosen for the decision making in the developed expert system. The knowledge translated into the if-then rules were collected from experts and other relevant sources and from this acquired knowledge 134 production rules were created. The production rule consists of 8 input attributes and has 6 possible number of output results. The optimal water well location expert system was developed using VP-Expert System designing tool.

In conclusion, the developed expert system when implemented can increase the production of safe drinking water by offering advices on the best locations to site water wells. Both experts and non-experts can use the system as an assisting tool in the process of decision making.

6.2 Recommendation

The system developed in this thesis did not capture all the factors that should be considered before siting water wells. There are several political, cultural, and social factors that are involved in deciding where to site water wells that were not included in the knowledge base of the system. I therefore recommend that any person who is interested in carrying a further research on this area should include the above mentioned factors.

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APPENDIX

SAMPLE OF THE DEVELOPED SYSTEM KNOWLEDGE BASE

```
ACTIONS
DISPLAY "WELCOME TO WATER WELL LOCATION SITE"
FIND LOCATION;

RULE 0
IF PSS=YES AND
  CWR=YES AND
  TOPOGRAPHY=LOW AND
  SURFACE_WATER=YES AND
  WIT=YES AND
  ANT_MOUNT=YES AND
  DEW=YES AND
  DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 1
IF PSS=YES AND
  CWR=YES AND
  TOPOGRAPHY=LOW AND
  SURFACE_WATER=YES AND
  WIT=YES AND
  ANT_MOUNT=YES AND
  DEW=YES AND
  DSC=NO
THEN LOCATION=HIGH-YIELD_UNSAFE;
```

RULE 2
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=YES AND
ANT_MOUNT=YES AND
DEW=NO AND
DSC=YES
THEN LOCATION=MODERATE_YIELD_SAFE;

RULE 3
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=YES AND
ANT_MOUNT=NO AND
DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 4
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=NO AND
ANT_MOUNT=YES AND

DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 5
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=NO AND
WIT=YES AND
ANT_MOUNT=YES AND
DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 6
IF PSS=YES AND
CWR=YES AND
TOPOGRAPHY=HIGH AND
SURFACE_WATER=YES AND
WIT=YES AND
ANT_MOUNT=YES AND
DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 7
IF PSS=YES AND
CWR=NO AND

TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=YES AND
ANT_MOUNT=YES AND
DEW=YES AND
DSC=YES
THEN LOCATION=HIGH_YIELD_SAFE;

RULE 8
IF PSS=NO AND
CWR=YES AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=YES AND
WIT=YES AND
ANT_MOUNT=YES AND
DEW=YES AND
DSC=YES
THEN LOCATION=MODERATE_YIELD_SAFE;

RULE 9
IF PSS=YES AND
CWR=NO AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=NO AND
WIT=NO AND
ANT_MOUNT=NO AND
DEW=NO AND
DSC=NO
THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 10

IF PSS=NO AND

CWR=YES AND

TOPOGRAPHY=LOW AND

SURFACE-WATER=NO AND

WIT=NO AND

ANT-MOUNT=NO AND

DEW=NO AND

DSC=NO

THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 11

IF PSS=NO AND

CWR=NO AND

TOPOGRAPHY=LOW AND

SURFACE_WATER=NO AND

WIT=NO AND

ANT-MOUNT=NO AND

DEW=NO AND

DSC=NO

THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 12

IF PSS=NO AND

CWR=NO AND

TOPOGRAPHY=HIGH AND

SURFACE_WATER=NO AND

WIT=NO AND

```
  ANT_MOUNT=NO AND
  DEW=NO AND
  DSC=NO
THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 13
IF PSS=NO AND
  CWR=NO AND
  TOPOGRAPHY=LOW AND
  SURFACE_WATER=YES AND
  WIT=NO AND
  ANT_MOUNT=NO AND
  DEW=NO AND
  DSC=NO
THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 14
IF PSS=NO AND
  CWR=NO AND
  TOPOGRAPHY=LOW AND
  SURFACE_WATER=NO AND
  WIT=YES AND
  ANT_MOUNT=NO AND
  DEW=NO AND
  DSC=NO
THEN LOCATION=LOW_YILED_UNSAFE;

ASK PSS: "IS THE SUBSURFACE SOIL PERMEABLE?";
CHOICES PSS: YES,NO;
```

ASK CWR: "IS THE ROCK TYPE CRACKED AND WEATHERED?";
CHOICES CWR: YES,NO;

ASK TOPOGRAPHY: "WHAT IS THE NATURE OF THE TOPOGRAPHY?";
CHOICES TOPOGRAPHY: HIGH,LOW;

ASK SURFACE_WATER: "IS THE LOCATION NEAR A SURFACE_WATER?";
CHOICES SURFACE_WATER: YES,NO;

ASK WIT: "IS THERE A WATER INDICATOR TREE?";
CHOICES WIT: YES,NO;

ASK ANT_MOUNT: "IS THERE AN ANT_MOUNT?";
CHOICES ANT_MOUNT: YES,NO;

ASK DEW: "IS THE DISTANCE TO EXISTING WELL GREATER THAN OR EQUAL TO 30M?";
CHOICES DEW: YES,NO;

ASK DSC: "IS THE DISTANCE TO SOURCE OF CONTAMINATION GREATER THAN OR EQUAL TO 100M?";
CHOICES DSC: YES,NO;

RULE 15
IF PSS=NO AND
  CWR=NO AND
  TOPOGRAPHY=LOW AND

SURFACE_WATER=NO AND
WIT=NO AND
ANT_MOUNT=YES AND
DEW=NO AND
DSC=NO
THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 16
IF PSS=NO AND
CWR=NO AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=NO AND
WIT=NO AND
ANT_MOUNT=NO AND
DEW=YES AND
DSC=NO
THEN LOCATION=LOW_YIELD_UNSAFE;

RULE 17
IF PSS=NO AND
CWR=NO AND
TOPOGRAPHY=LOW AND
SURFACE_WATER=NO AND
WIT=NO AND
ANT_MOUNT=NO AND
DEW=NO AND
DSC=YES
THEN LOCATION=LOW_YIELD_SAFE;