ASSESSMENT OF THE POTENTIAL IMPACTS OF COAL MINING ON WATER RESOURCES IN MUI BASIN, KITUI COUNTY IN EASTERN KENYA

Submitted by

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Declaration

I hereby declare that is my original work and has not been submitted for a degree in any other university.

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Dedication

Dedicated to my late father Mathew Wamalwa from whom I derive my motivation every day. I love you Dad.

ABSTRACT

The venture into coal exploration has led to the discovery of over 240,000 tonnes in the Mui basin and hence plans to start mining are ongoing. However, the analyses of this coal by various researchers revealed that it has impurities like iron, sulfur, ash and other heavy metals which if improperly handled e.g. by discharging the wastes on an unstable or permeable ground can pollute water resources of an area when the ground collapses or when the content seeps to the water flow system.

This research has assessed the geology and geological structures augmented by a study on the soil properties like permeability, surface topography and water flow systems so as to determine their potential to transmit coal related pollutants from the coal zones to the water sources. The procedure in this case involves data acquisition i.e. gravity data for geology and geological structures, water strike and rest levels to enable generation of water flow maps, topographic map to study the topography of the area, soil samples to study the physical properties of soils in the area on addition to a chemical analysis for soils and water to establish the baseline physical-chemical conditions of the area. The results, inform of a map on the basis of chemistry of water and soils, indicate that the southern part of the Mui basin has the highest risk to pollution followed by the centre part while the north has the least risk to pollution.

The high vulnerability on the southern part of the study area is due to the thick sediments and presence of clay and silt that act as reservoir to pollutants. Other factors like the topography of the ground, trend of geological structures and water flow direction act to channel pollutants in this area. The research recommends a similar assessment to be carried out in the rainy season so as to factor in the role of the study area's climate which was not considered by the research. On addition, this study should be carried out from time to time when actual mining starts so as to ensure effective mitigation measures.

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List of Acronyms

MoE - Ministry of Energy

DEM- Digital elevation model

TDS- Total Dissolved Solids

TSS-Total Suspended Sediments

GoK- Government of Kenya

AMD-Acid Mine Drainage

CSIR- Council of Scientific Industrial Research

KPLC-Kenya Power and Lighting Company

WSL- Water Strike Level

WRL-Water Rest Level

NRC-National Research Council

CHAPTER ONE

INTRODUCTION

1.0 Background of the study

Kenya's population growth is one of the fastest growing in the world at a rate of about 2.7 per cent, posing a severe strain on development due to increasing costs of food, medical care, energy and infrastructure. The formulation of the energy policy, with respect to this population, is in the appreciation that the overall national development objectives of the Government of Kenya are accelerated economic growth and rising productivity of all sectors, equitable distribution of national income, alleviation of poverty through provision of basic needs, enhanced agricultural production, industrialization, accelerated employment creation and improved rural-urban balance (GoK, 2002). According to Balla (2005), the realization of these objectives is only feasible if quality energy services are made available in a sustainable, cost effective and affordable manner to all sectors of the economy ranging from manufacturing, services, mining and agriculture to households. The need for an integrated comprehensive national energy policy cannot therefore be gain said.

The need for improving access to energy in sub-Saharan Africa is of paramount importance as it offers significant opportunity for achieving sustainable development goals as envisaged in the millennium development goals agenda (World Bank, 2004 and 2006). Kenya through the Ministry of Energy, endeavours to secure affordable, reliable, clean and dependable power for provision of essential services such as lighting, heating, cooking, mobility and communication as well as driving industrial growth (GOK, 2002). This is fundamental to economic stability and development as interruption of energy supplies, for example power rationing between June and November 2006, can cause major financial losses and create economic havoc (World Bank, 2007). According to KPLC (2006) power outages in Kenya are as a result of immense pressure on existing indigenous power sources like hydro-power, thermal, geothermal and solar and high costs of importing additional power from neighboring Uganda, considering a total effective source utilization of 96% of the installed sources.

Though hydroelectric power, a renewable energy source, tops the list of energy sources in Kenya with 646.1 MW of the effective total output (AFREPREN, 2004 and 2005) it is not reliable due to its dependence on weather patterns and may also cause environmental degradation (Robins and Younger, 1996). For example, during rainy seasons, the seven hydroelectric power generating dams on river Tana, are silted making power generation difficult. On the contrary, during drought power rationing is occasioned by the reduction of water levels in these dams. According to Balla (2004), power step-up in such production periods is sourced from independent power producers who use thermal generation which is equally expensive. Geothermal power production on the other hand, though constant, is not feasible to step up at a short notice in addition to its high cost of equipment and in technology (AFREPREN, 2005).

In search for alternative sustainable energy, the Government of Kenya planned and carried out coal exploration in the Mui basin in Mwingi district, which covered an area of 400km^2 (Ndolo et al, 2003). So far, thirty three (33) wells have been drilled with depths ranging from 75 to 324 metres and coal seams encountered in twenty (20) of the wells (Ndolo, 2004). Coal samples were then analyzed and results revealed that the coal is sub-bituminous to bituminous in quality, with an average calorific value of 18MJ/kg. In general, coal exploration has reached a commendable stage as three (3) new wells with coal seams thickness of 13 metres, 5.37 metres and 4.20 metres having been encountered (MoE, 2002). Seventeen (17) wells previously sunk have coal seam thicknesses ranging from 0.3 metres to 12.6 metres. Further, these coal seams have been discovered at depths ranging from 20 metres to 320 metres below the ground and at the moment an area of about 20 km^2 has been delineated as a coal zone.

Coal is a dependable element of homeland security. This is in consideration that electricity is very difficult to store in significant quantities and so the system depends on generation being on call to meet the demand. However, coal can be stored at power plants and therefore provide an inherent "buffer" in case of supply interruption (AFRENPREN, 2005). In recent years, virtually all new power generation has been fueled by petroleum and natural gas. While gas can be stored, it is typically not stored at the power plant and can be interrupted more easily by infrastructure problems or terrorist acts. Increasingly, most countries' petroleum use is becoming more dependent on imports both through pipelines, while,for those mining coal like South Africa, all coal is domestic (AFREPREN/FWD, 2006). Therefore, continued emphasis on embracing coal as an alternative energy source is a clear goal of reducing our nation's dependence on imported energy.

Coal-based electricity is strategically critical to any country's environment and water resources though it provides economic stability via energy security. In the present world, over 50% of the countries, e.g. United States' derive electricity from the use of domestic coal. This is in view of the fact that no energy source is currently available that can provide a viable, low-cost alternative for electricity production. United States, for example, has a doubled coal production since 1970, increasing from 520 million tons in 1970 to over 1 billion tons in 2001(AFREPREN/FWD, 2006). The continued use of coal in a clean and environmentally acceptable manner is possible and supports the stated national energy strategy of maintaining fuel diversity to secure economic and security objectives. Furthermore, the security, stability and availability of coal reserves provide a mitigating effect against price swings of other fuels.

Despite all the advantages earmarked by the energy sector, the discovered coal deposits in Mui basin contain sulphur, iron, volatile matter, ash, carbon, nitrogen and trace elements like Cd, Se, Cr, Pb and Hg which are known to be environmental unfriendly if poorly handled especially where there is inadequate information on geology, geological structures, soils and groundwater flow systems (Rushton, 2003). Also both opencast and underground mining method can be a recipe for water pollution. In the process of exploration and mining, huge amounts of water are discharged to facilitate the operations. This water often contains high loads of total suspended solids (TSS), total dissolved solids

(TDS), hardness and heavy metals, which contaminate the surface and ground water regimes.

Mine water may be acidic or neutral depending upon the pyrite content in the coal as inorganic impurities (Salmon, 1999). Acid mine drainage occurs in those mines in which sulphur content is found in the range of 1–5% in the form of Pyrite (FeS_2). This degrades the water quality of the region in terms of lowering the pH of the surrounding water resources and increasing the level of total suspended solids, total dissolved solids and some heavy metals. In non acidic mines, water quality shows high hardness, TSS and bacterial contaminants. The high value of hardness of mine water reduces its utility in domestic purposes. Pollutants such as TSS, TDS, oil and grease and heavy metal are found in the coal mining waste effluents. Management of this liquid waste at the primary level and secondary level has always been suggested to control the pollution level at the source. These concerns threaten to scatter the whole idea of coal being used as an alternative power source.

This research therefore seeks to assess and understand the geology and geological structures, soils properties from geotechnical studies and groundwater flow systems in the basin via modflow simulations so as to minimize chances of potential transmission of coal- related pollutants. In addition, the study will explore for proper coal technologies to be employed during exploitation so as to reduce the release of the contaminants.

1.2 Statement of the research problem

Kenya's population is rapidly growing and therefore the need for affordable, reliable and dependable power for provision of essential services such as lighting, heating, cooking, mobility and communication as well as driving industrial growth is of paramount importance. This is in agreement that secure, reliable and affordable energy is fundamental to economic stability and development at household and national level. However, there are concerns in the sustainability of the energy resource base in supporting the needs as the high population pressure and industrialization has exerted pressure on already available energy sources.

The need to establish alternative and sustainable energy resources led to exploration of coal deposits in Mui basin, Mwingi district. Coal samples analyzed revealed that the coal is sub-bituminous to bituminous in quality, with an average calorific value of 18MJ/kg but also has ash, volatile organic matter, sulphur, iron and fixed carbon. These compositions besides a highly carbon-intensive have negative environmental impacts on a region's water regime including disruption of ecosystems particularly when mining; a concern that has well been documented in countries like United States who have embraced coal exploitation.

The high magnitude of pollution of water during coal activities is connected to poor knowledge, assessment or understanding of an area's geology, geological structures, topography, drainage systems and location of water sources (Dhar, 1993). For example in Mui basin there is no documented assessment of all these issues in relation to transmission of coal wastes since the discovery of coal in early 1950s and subsequent exploratory drilling and targeted mining. Such assessments would have kept in mind the permeability of the rocks, the character of the soils and the trend of the geological structures when designing the mining and the associated activities e.g. the sites of disposal (Kariuki et. al., 2008 and 2010).

Improving knowledge on the area's overall ground characteristic is paramount in planning during the preliminary design stage of any mine development. For example, mapping of an area's geology reveals the type of rocks and hence knowledge on their strengths, resistance to corrosion by acids and permeability to water. The same survey provides knowledge on the geological structures and their trend that acts as channels of transmission of pollutants. Specification of this information is needed to underpin the assessment of potential impacts that excavation, storage and backfilling of materials from coal sites can have on water quality. Consideration of topography enables the selection of ideal dumping sites as gentle slopes, valued at about15–20 degrees, reduces transmission of pollutants and allows vegetation to be established (Lodewijks, 2002).

Understanding the drainage systems and location of water bodies in the area is also handy as a prerequisite. This is achieved by setting out the assessment framework i.e. a site conceptual model which has a formal meaning in hydrogeology, having been defined by as a set of rigorously justified assumptions which represent ones simplified perception of a real system. These models describe how water enters an aquifer system, flows through and leaves hence creating an understanding of the transport and discharge of groundwater contaminants. This helps to assess the site behavior, any risk mitigation measures or firm plan for implementation at a more appropriate point in time and a long-term contingency plan incorporating proposals for monitoring. This study minimizes activities that can lead to dump instability, collapsing and eventual water pollution when wastes are released.

1.3 Research questions

This research sought to answer the following questions.

1. Does geology, geological structures, soils, surface and ground water flow systems have a potential to transmit coal related pollutants in Mui basin?
2. Is it possible to delineate areas vulnerable to pollution by the pollutants in Mui basin?

1.4 Aim of the study

To assess the potential impacts of coal mining on water resources in Mui basin area based on geology, geological structures and geomorphic characteristics of the area.

1.5 Objectives of the study

1. To determine the potential role of geology, geological structures, soils, surface and ground water flow systems in transmission of coal related pollutants in Mui basin.
2. To delineate areas vulnerable to pollution by the coal related pollutants like Fe^{3+}, S, TDS, hardness, carbon, heavy metals and TSS in Mui basin.
3. On basis of (1) and (2) above to design a plan for coal mining and handling that will protect water resources in Mui basin.

1.6 Rational and significance of the study

The significance of this study for Mui area was realized through the achievement of its main aim of assessing the geology, geological structures and geomorphic characteristic of the area which will be put into account during coal exploitation so as to enable minimized ground water pollution in the area. In realizing this, gravity surveys were carried out to study the areas geology in terms of their density and type and trend of the geological structures. Soils and water sampling and eventual analysis carried out help to indicate the likelihood of already existing pollution activities resulting from coal activities since their inception in 1996. Physical properties of soils, as determined during the study helps in explaining the trends of concentration of coal related pollutants in the soils and consequently water resources. Other properties like the soil strength, consolidation and permeability will help in designing the mine while swelling pressure will help to decide on areas where waste waters can be channeled to avoid areas which can easily be flooded. Water flow regime in Mui basin is also important in determining the points of location of the water and direction of flow hence helps to design the mine and points of disposal in attempts to minimize the likely impacts of coal exploitation to the water resources in Mui area.

1.7 Conceptual framework

All activities in coal exploration and exploitation, if not checked, degrade the quality of water of a region (Ghosh, 2003). This is through the huge amounts of water that are discharged on the surface to facilitate the mining and drilling operations. The discharged water often contains high load of TSS, TDS, hardness and heavy metals which contaminate the surface and ground water.

The multi sources of the pollutants like drainage from mining sites including acid mine drainage and sediment runoff from mining case of large opencast mine complicate efforts to pin point the discharge point and hence complicate efforts to pollution control. Therefore, efforts to control an imminent water quality crisis should embrace a systematic planning (Fig. 1.1), during the preliminary design stage of exploratory drilling activities and mine development. With that, much emphasis should be laid on the knowledge, assessment or understanding of the geology, geological structures, topography, drainage systems and location of water sources in Mui basin so as to minimize transmission of pollutants to water bodies or cause dump instability, collapsing and eventual water pollution when wastes are released.

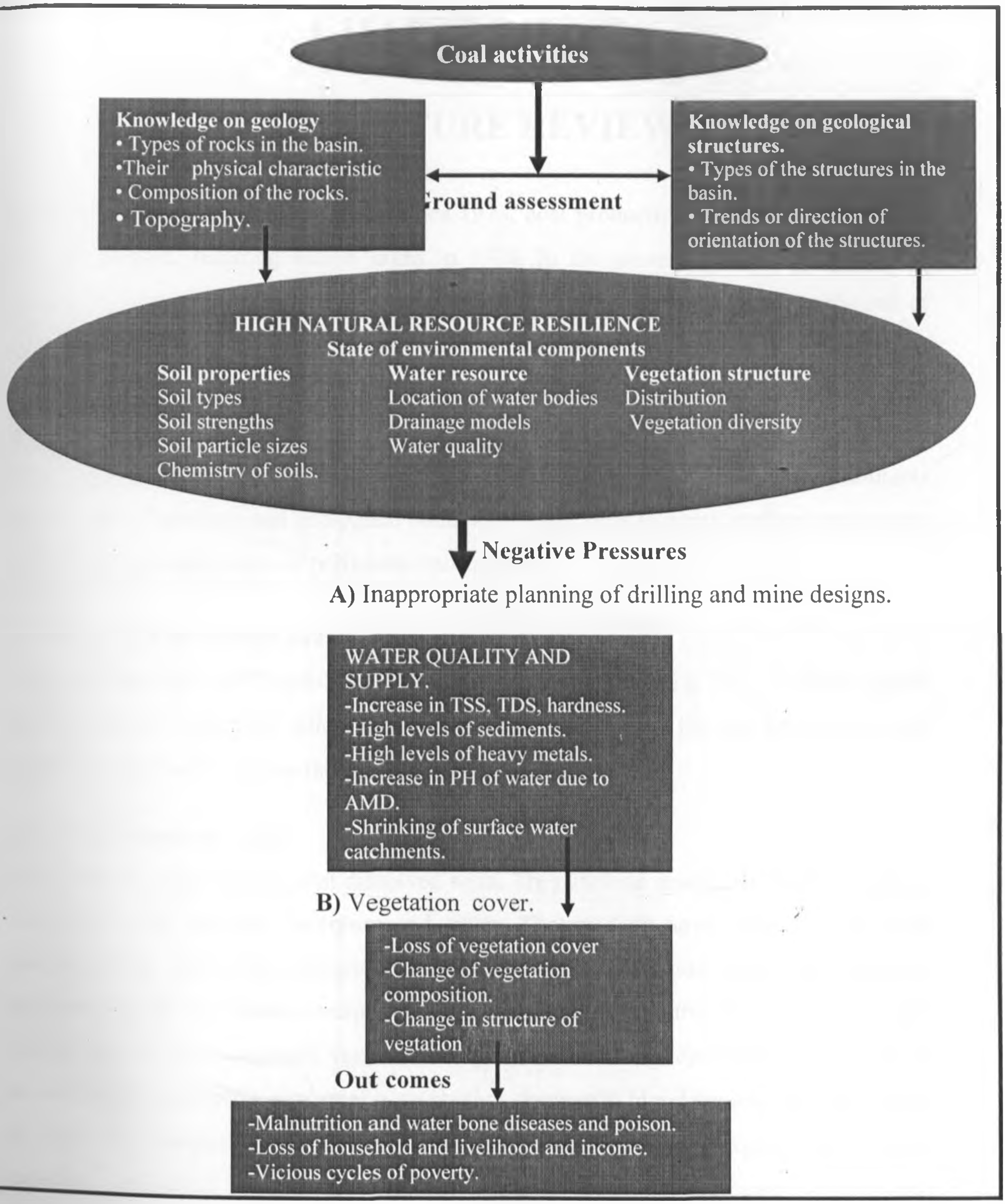

Fig. 1.1: The potential impacts of coal activities on water resources.

CHAPTER TWO

LITREATURE REVIEW

According to Krishnamurthy (2004), since 1973, coal production has increased by more than 80 percent, reaching record highs in 1998. In the present day, coal supplies 32 percent of the nation's total energy needs, mostly for electricity production. At the end of 2006, the world wide recoverable coal reserves amounted to around 800 or 900 gigatons (Loneragan et al., 1998). Loneragan (op. cit) added that China is the top producer with about 38% share followed by the USA and India. It is however noted that the economic utilization of coal resources needs an understanding of the effects of coal related pollutants on life, role of geology and geological structures, water flow systems, surface topography and soils as potential ways of pollutants transmission.

2.1 Effects of coal related pollutants on life

Adler and Rascher (2007) noted that every coal related pollutant e.g. Fe^{3+}, S, heavy metals like Pb, Cd and suspended solids like ashes has its own effect to life and hence concerted efforts are required to reduce their release when mining.

2.1.1 Total dissolved solids

Heavy metals comprise the total dissolved solid. They include arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver. Though they have other sources, coal burning release substantial amount of it and each has its own side effect. For example, inorganic arsenic is a known carcinogen and can cause cancer of the skin, lungs, liver and bladder. Lower level exposure can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels and a sensation of "pins and needles" in hands and feet. Barium on short term exposure can cause vomiting, abdominal cramps, diarrhea, difficulties in breathing, increased or decreased blood pressure, numbness around the face, and muscle weakness while large amounts can cause, high blood pressure, changes in heart rhythm or paralysis and possibly death (Adler and Rascher, 2007).

Cadmium and cadmium compounds are known human carcinogens. Severe damage to the lungs may occur through breathing high levels of cadmium while ingesting very high levels severely irritates the stomach, leading to vomiting and diarrhea. Long-term exposure to lower levels leads to a build up in the kidneys and possible kidney disease, lung damage and fragile bones. Lead can affect every organ and system in the body. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system, weakness in fingers, wrists or ankles, minor increase in blood pressure and anemia. Exposure to high lead levels can severely damage the brain and kidneys and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage while in men it can damage the organs responsible for sperm production.

With mercury, mercuric chloride and methylmercury are possible human carcinogens. The nervous system is very sensitive to all forms of mercury. Exposure to high levels can permanently damage the brain, kidneys and developing fetuses. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

2.1.2 Sulphur

In livestock, intake of large amounts of sulphur in form of sulfates leads to observable reductions in steers' performance (Kandylis, 1984) most likely due to either reduced water consumption or clinical polioencephalomalacia (sulfur toxicity). This was supported by NRC (1996), who added that sulfates may have been important in the observed reductions in water and feed intake encountered in a study conducted in the USA. Casgrande (1987) reported that sodium sulfate addition to drinking water of heifers reduced water intake and feed intake, but the addition of sodium chloride to the water did not cause the reductions.

2.1.3 Iron

It is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day (Banerjee, 2004). The average lethal dose of iron is 200–250 mg/kg of body weight, but death has occurred following the ingestion of doses as low as 40 mg/kg of body weight (National Research Council (NRC), 1996). Autopsies have shown haemorrhagic necrosis and sloughing of areas of mucosa in the stomach with extension into the submucosa. Chronic iron overload results primarily from a genetic disorder (haemochromatosis) characterized by increased iron absorption and from diseases that require frequent transfusions (Chapel and Mariz, 1999 and Coles et al., 1979).

2.1.4 Acid mine drainage

On the other hand, Acid Mine Drainage (AMD) related pollution loads include environmental, socio-economic, political and financial risks (Adler and Rascher, 2007). Environmental risks include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna (Pulles et al., 2005; Adler and Rascher, 2007). Such pollution has been linked with several health related consequences. Groundwater contaminated with AMD might unwittingly be consumed by individuals, with treatment often ineffective by the time the effects materialize (Cooke and Limpitlaw, 2003).

Acid mine drainage also has enormous direct and indirect financial implications for government and the mining industry and can raise constitutional issues under certain circumstances. According to a recent Australian report, the total costs of AMD in Australia were expected to reach approximately $80 million annually with an estimated cost. $1 000 million over 15 years. Similar expenses were also reported in Canada and the United States (Clescerial et al., 1998). The South African Department of Water Affairs and Forestry has spent more than R120 million over the last decade to investigate and clean up the historic pollution caused by abandoned or liquidated mines. This amount is only a fraction of the total amount that may ultimately be required (Schwab, 2002).

Mining operations substantially alter the hydrological and topographical characteristics of mining areas and subsequently affect surface runoff, soil moisture, evapotranspiration and groundwater behaviour (Schwab, (op. cit). Further, the interconnectedness of underground mine workings associated with different mining companies increases the liabilities associated with AMD, especially for those companies last in operation, since "the cumulative impact resulting from all the mines in a region could be imposed upon the last mine in the region to cease operations" (Pulles et al., 2005). The removal of highly acidic water from active mine workings may also have large cost implications, as the replacement of infrastructure such as pumps and pipelines due to excessive corrosion is extremely expensive and could reduce mine productivity over time (Colwel et al., 1999).

2.2 Impact of geology and geological structures in coal mining area on pollution and on life

The study of the impacts of coal mining on hydrology with respect to geology has been directed towards the repercussions of mining efficiency/economics, mine dewatering, ground control and safety (Brady et al., 1988). Throughout the history of coal mining, geology has been responsible for serious injuries and fatalities as they are routinely misidentified and frequently inadequately supported. Brady et al., (op. cit), therefore recommends studies on geology of an area to examine the physical characteristics of the geologic anomalies in order to make support and other mining recommendations which will help mitigate the problems associated with each feature and to determine methods to predict the hazards in advance of mining, if possible.

The study on geology considers the mineralogy and weathering of the rocks, dip of zone of coal occurrence, competence of the rocks and sediments (surface and near surface geology) (Callaghan et al, 1998). They are augmented by geologic discontinuities i.e. fractures and lineaments, surface topography, ground water (including water elevation and fluctuation), method of mining, rate of advance, backfilling, time and structural characteristics (Brady, 1998).

2.2.1 Mineralogy of the rocks

This is reflected in the drainage quality which is influenced by the type, amount and distribution of reactive minerals in the rocks in contact with the water (Caruccio and Geidel, 1984). Caruccio and Geidel (op. cit) added that there are two groups of minerals, sulfide and carbonates, which largely control mine drainage quality even though they usually constitute only a few percent of the rock mass. For example acid potential arises mostly from the sulfide mineral pyrite. In weathered rocks and soils, exchangeable acidity and metal sulfate minerals may also contribute to total acid production (Cravotta et al, 1990). Alkalinity is provided mostly by carbonate minerals especially limestone, calcite and dolomite which are the most important acid neutralizers (Ferguson and Robertson, 1994). The mineral siderite is problematic for testing and interpretation as it initially provides neutralization, but subsequent iron hydrolysis produces acidity hence difficult even in mitigation.

Silicate minerals also provide some acid neutralization but their rate of reaction is much slower than that of carbonates (Ferguson and Morin, 1991) hence ion exchange reactions of acidic water with clays, though they can also contribute alkalinity, this only occurs when the strata are saturated. Small amount of other elements are often contained in carbonates and can be released when the mineral dissolves e.g. a small percentage of manganese which can substitute for iron in siderite.

2.2.2 Geologic weathering

Weathering on the rocks can either be physical or chemical. Chemical weathering acts to remove the more soluble and reactive minerals like carbonates and pyrite from near-surface rocks and soils (Cravotta et al.1990). The weathered zone, for mine drainage prediction purposes, is inert and has little capacity to either generate or neutralize acidity. According to Ferguson and Morin (1991), weathered materials are often weakly cemented or partially decomposed and are often colored brown, yellow or red. Groundwater circulating through these weathered zones contains low amounts of dissolved solids and alkalinity, reflecting the relative lack of soluble minerals in the zone. Below the weathered zone, the rocks retain most of their original mineral assemblage, and may contain appreciable amounts of sulfides, carbonates or both (Ferguson and Morin, (op. cit).

Groundwater circulating in this zone generally contains more dissolved solids. For this reason groundwater from the weathered zone has low specific conductance, which indicates low dissolved solid content and little alkalinity. Colwel et al, (1999), added that groundwater from deeper strata has much higher alkalinity and dissolved solids. The deeper water could add significant buffering to acidic water in surface mine backfills or as recharge to flooding underground mines. The weathered zone groundwater would have little impact on mine water chemistry.

2.2.3 Dip of the zone of Coal occurrence

Coal mining is almost always done in flat-lying or gently dipping sedimentary rocks comprising sandstone, shale, claystone, siltstone, marls and hard-rock more often involving igneous or metamorphic rocks that may or may not occur in stratified layers (Salmon, 1999). Disturbance of these hard-rocks during mining activities reduce their strength increasing chances of subsidence leading to water pollution (Salmon, op. cit). Furthermore, hard-rock mineral deposits have extensive faulting due to physical weathering; such faults act to channel pollutants to water sources. Hydrothermal alterations of mineral deposits in the rocks caused by ore-bearing solutions are also important to be considered. For example, argillic, kaolinitic or sericitic alteration forms clays and clay-like minerals or sulfide ore bodies often being strongly weathered by acid generation leads to a subsequent reduction in rock strength thereby increasing chances of subsidence (Colwel et al., 1999).

2.2.4 Competence of the rocks and sediments

Roof falls, resulting from incompetent geology, continue to be one of the greatest hazards faced by not only by coal miners but also by hydrogeologists. The structural integrity of a coal mine roof is greatly affected by natural weaknesses, including bedding planes, fractures and presence of faults (Colwel et al, 1999).

Bedding is a factor that mostly causes roof problems in coal mines. According to Damberge et al, (1988), the most common examples are weak laminations in sedimentary rocks as a whole and thinly interbedded sandstone in case of sandstones. In both examples, it is not just that the bedding planes are closely spaced, but also that the bedding surfaces are very weak. In metamorphic rocks, occurrence of grain alignment create laminations along which slipping of rocks can occur. According to Damberge et al., (op. cit), such features are not easily identifiable particularly to untrained eyes but have profound effects as far as pollution is concerned.

Moisture sensitivity also lowers the competence of rocks through generating swelling pressures or compromising support effectiveness of especially sediments (Bennet et al., 1988). Movement of rocks caused by moisture changes are profound on slicken sides i.e. small scale (<2m) fault surfaces of highly aligned sedimentary rocks distinguished by glassy, grooved surfaces (Amyot and Vezina, 1997).

2.3 Importance of Ground water modeling in coal mining areas on pollution and on life

An aquifer is a water-bearing body of rock which stores and transmits water. The disturbance of the subsurface caused by coal mining creates substantial systems of inter-connected voids which, once flooded, typically display the storage and transmission functions characteristic of aquifers (Adams and Younger, 1997). However, because of the size and engineered connectivity of mined voids, the aquifer behaviour of flooded abandoned mine voids often has little in common with the Darcian laminar flow aquifers which account for most groundwater resources. Undoubtedly, coal mined systems do display marked behavioural similarities to karstified limestones and evaporites, although they are also distinguished from these closest natural relatives by the particular geometries of voids present and the lateral scale of interconnection.

In order to protect water sources from pollution in such a setting, modeling is used to brush over the fact that the system does not compare very well with a sand filter (the device for which Darcy's Law was after all devised) and apply a standard Darcian flow code (Di Pretoro and Rauch, 1988) such as MODFLOW (Dutta et al., 2002). In this, the model seeks no more than a regional water balance. According to Amyot and Vezina (1997) this approach is unlikely to disappoint, though it remains no more defensible as an algorithm than the simplest of "black box" calculations. As long as some detail required e.g. reproduction of the details of a well and the piezometric level record at a given point, then the formulating transfer coefficients is possible (Juwarkar, 2004).

The results of modeling consists of two continuum models, one representing the Technical Report (Teutsch and Sauter, 1990) relatively slow flow through small fractures while the other represents flow through the major conduits mostly characterized by changes in the flow direction. In order to consider cavities in area underlain by limestone like around Mui, CAVE (Carbonate Aquifer Void Evolution) model has been developed in which a single-layer MODFLOW model has a 2D pipe network routed through it representing caves and other large cylindrical conduits in which the flow can be represented as either laminar or turbulent according to ambient conditions (Juwarkar, 2004). This model also allows for simulation of the development of caves during coal mining. Moebs and Sames (1989) described a similar model in which the "fast flow" network is represented by a "parallel plate" fracture model using the Poiseuille equation.

According to Nuttal et al., (2002) interpretation of MODFLOW results help to simulate piezometric drawdown (during mining), flow direction and subsequent recovery (after mine closure) for strata surrounding a coal mine. Neymeyer (2003) recommended a collaborative geotechnical-hydrogeological during mining to investigate the changes in permeability arising from active subsidence above longwall workings. However, where the model must simulate flow in flooded voids, rather than (or as well as) in the surrounding strata, MODFLOW and similar laminar-flow models appear to be less applicable.

2.4 Importance of Clean Coal technologies in coal mining areas on pollution and on life

The clean coal technologies are technologies that ensure a clean coal use, by removing or preventing the formation of SO_2, NOx and particulates when coal is burned to generate electricity at conventional coal-fired power stations (Gunther et al., 2006), which lower the quality of water. These "clean coal" technologies extend from coal washing to combustion to end-of-pipe techniques. According to Gunther et al., (op. cit), coal washing reduces the amount of ash in raw coal to facilitate combustion and increase the energy content per ton. It also reduces the sulphur content in coal in order to decrease the production of sulphur dioxide when burnt. Coal blending and briquetting are also efficient fuel preparation methods so that at other end of the process, particulate control is generally the first step and often relies on electrostatic precipitators. Flue gas desulphurization units can remove 90% of the SO_2 or more and are widely adopted. Many NOx reduction technologies are employed at commercial plants: low-NOx burners, over-fire air, reburn, non-catalytic reduction techniques and selective catalytic reduction.

2.5 Coal prospecting in Mui

Shah (1950) started it all when he reportedly found lignite in a well at Mui trading center. Still in 1950, Hamilton and Thompson investigated the occurrence and confirmed that the lignite seam was 18 inch in thickness, having its base at a depth of 61 ft below the surface. Shah (1952) reduced the area from 140 to grids of 38 square miles and drilled ten further bore-hole sites in the locality; at a spacing of one mile intervals on the corners of each grid. This prospect failed to prove the presence of lignite. Sanders (1954) sited a well approximately 1 mile due south of the first prospect pit, by Shah (1950), and found it to contain 4ft seam of lignite at a base of 39ft hence much efforts of exploration. Both the prospect pit and the well had been dug through a river sand resting uncomformably on sandy clays.

Since early 1980s, the Government of Kenya (GoK) has partnered with the private sector in efforts to intensify exploration of coal in Mui (Ndolo et al., 2003). According to Ndolo (2004), as of December 2002, a total of 33 wells have been drilled and at average depths ranging between 17-135 m depths. Coal samples encountered were analysed for calorific value, ash content, carbon content, and then were coal ranked (Kariuki et al., 2008). Kariuki (op cit) added that the samples were found to have calorific values ranging from 3318 – 3980 cal/g and were ranked from bituminous to peat. The average ash content ranged between 25-50 % while the carbon content ranged between 40-48.5 % and therefore the coal may be exploited for power generation.

CHAPTER THREE

REGIONAL CHARACTERISTIC OF THE STUDY AREA

3.1 Geographic location and Description

The 131.5 km^2 area of study lies within the larger Mui basin situated in Mwingi East and Mutitu districts of Eastern province bounded by latitude 1°30'S and 1°1.03'S and longitudes 38°09'E and 38°17'E (Fig 3.1) and forming part of the Kamba native reserve. It is located on Map series Y731 (D.O.S 423), sheet 151/1.

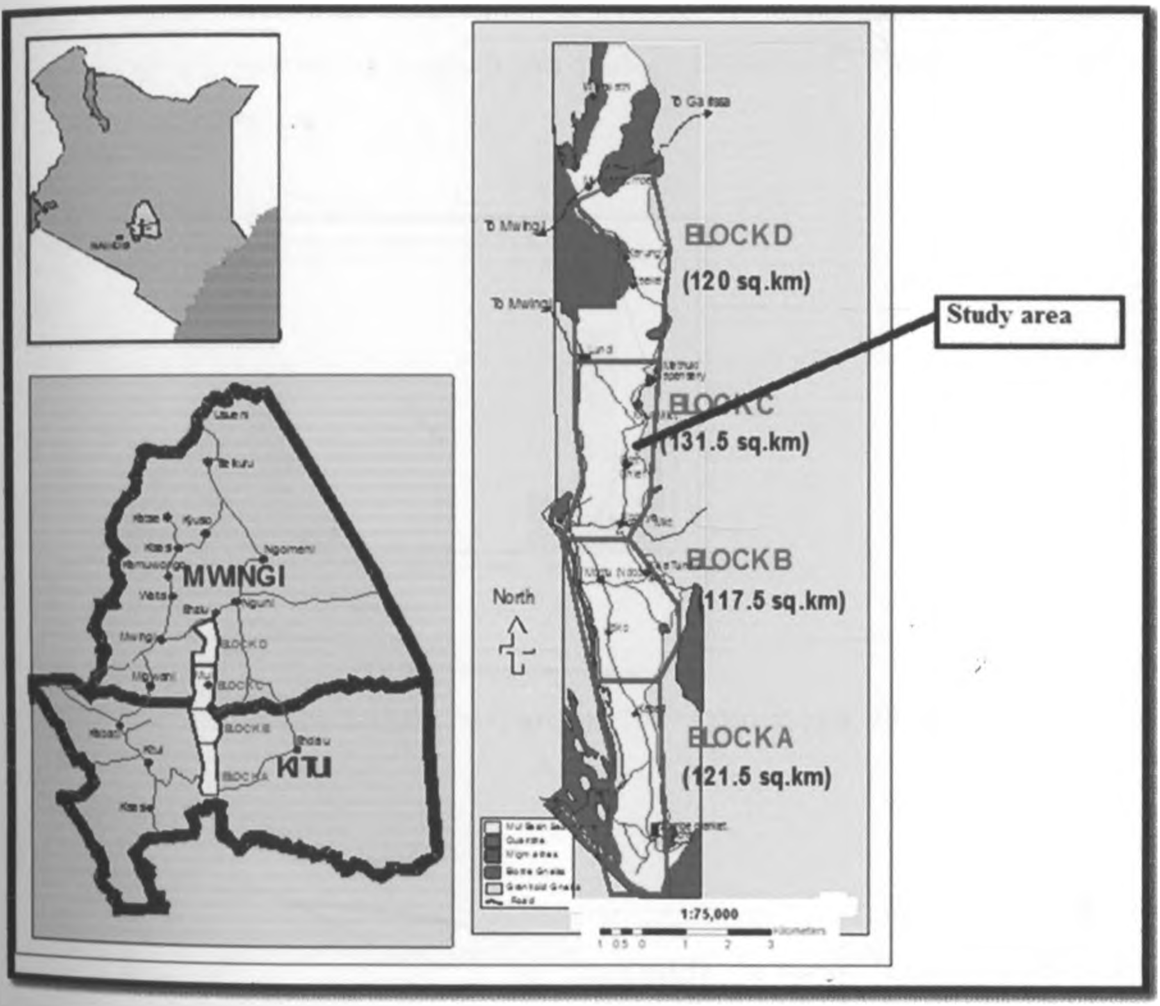

Fig 3.1: Geographic location of the study area.

3.2 Climate

The area is relatively dry, as indicated by values of rainfall and temperatures, with weather elements and climatic patterns following that of the larger Kitui district.

3.2.1 Rainfall

Rain falls in the area in two distinct seasons, in March and April and during October, November and December. The months of June to September are usually dry with almost no rains (Fig 3.2). The rains are mainly heavy convectional type falling in the evening and their amounts at any place are conditioned by elevation. Low lying areas tend to receive high amounts of rainfall than those on raised grounds. Therefore, there is an average of about 280 mm per year on the southern part at about 1200m and 125mm on the north at 1790m above sea level.

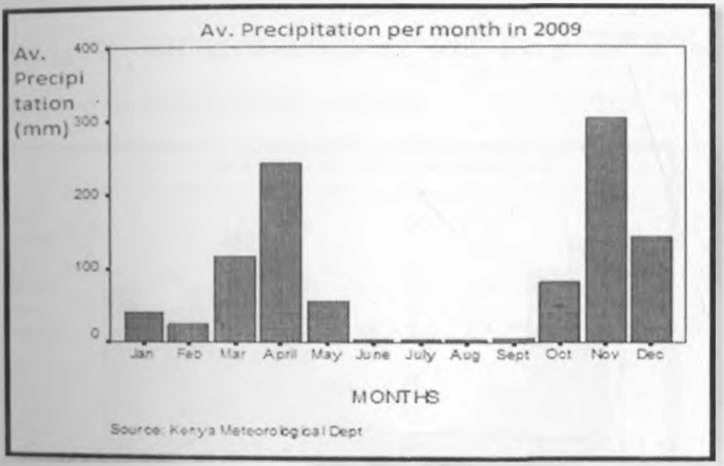

Fig 3.2: Mean precipitation of the Mui area in 2009 (Mukabana, 2009).

3.2.2 Temperature

The monthly mean maximum and minimum temperatures are 23.5°C in March and 19.8°C in July respectively on the average as was recorded in the period between January and December 2009 (Fig 3.3). Diurnal variations reach about 21.2°C in May.

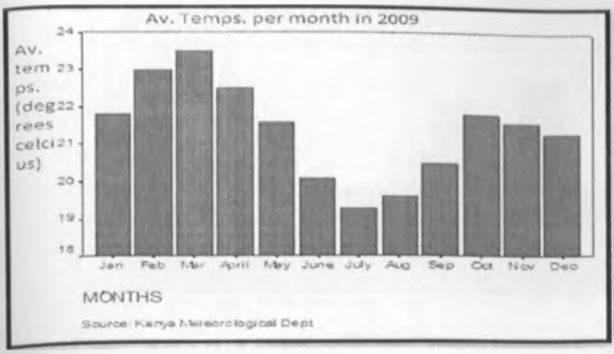

Fig 3.3: Mean monthly temperature of Muiarea in 2009 (Mukabana, 2009).

3.2.3 Evaporation

The maximum annual evaporation, measured as vapour pressure, is 20mm in the months of April and December, followed by an average of 18.5mm in the months like January, March and May. Minimum evaporation rates of about 14.5mm are experienced in the months of July, August and September (Fig 3.4). Notably, high evaporation rates occur during the wet seasons but are still disastrous as they exceed the amount of rainfall received in the particular months.

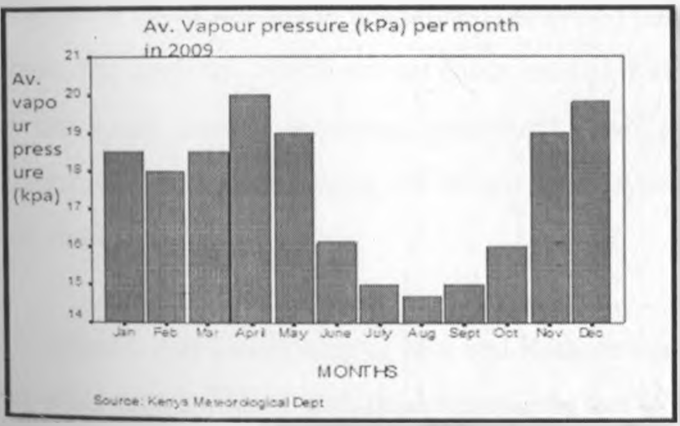

Fig 3.4: Average vapour pressure of Mui area in 2009 (Mukabana, 2009).

3.2.4 Wind Speed

Winds in the area are light throught the year having a maximum of 3.2 m/s in October and a minimum of 2.2 m/s in April (Fig 3.5). There are occasional dust storms in the entire basin especially on bare land characterized by strong winds mostly in August and September.

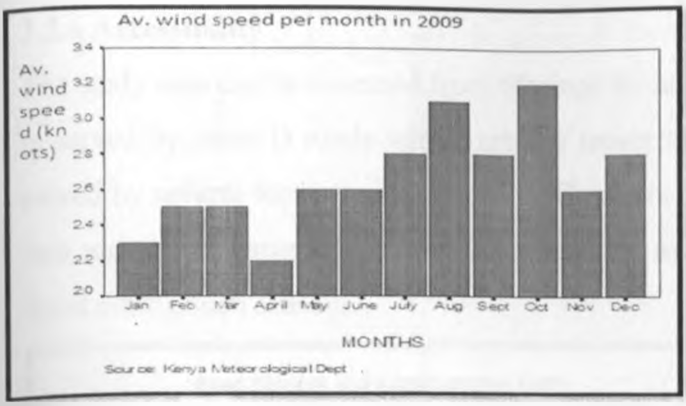

Fig 3.5: **Average wind speed of Mui area in 2009 (Mukaabana, 2009).**

3.2.5 Vegetation, Land use and Basin Environment

The distribution of vegetation in the study area is highly influenced by rainfall amounts, geology, soils and topography that control the availability of water in the dry seasons (Dixey, 1948). For example on the extreme north of the area, owing to the comparatively low rainfall and to the indigenous practice of overgrazing with both cattle and goats, the vegetation is mainly of the thick thorn-bush type with little grass. The lack of a good vegetation cover has led to abandoned cultivated patches due to serious gullying and soil-wash. The gneisses, which are not easily eroded, form high grounds that channel the water to the South thereby hindering vegetation establishment. On the account of soils, the central part of the area having red-brown sandy type has thin vegetation cover due to poor soil fertility.

The Eastern part comprising of Mui and Kathonzweni and Yoonye to the extreme south of the study area are lined with thick vegetation due to availability of water from R. Mui and ground water by virtue of topography. In addition, the presence of fertile sandy alluvium, provides suitable conditions for vegetation development.

On land use, the residents subsist by the cultivation of maize, beans and millet which are supported by irrigation during the dry season. In addition, there are small scale activities of mining limestone for cement manufacture at Mui center besides herding cattle and goats.

3.2.6 Accessibility

The study area can be accessed from Mwingi through Mathuki or Kitui through Yoonye. It is served by class D roads which are the major roads in the area. These roads are then served by several feeder roads (Fig 3.6). There are also several drifts constructed to enable free movement especially in the rainy seasons as most of the roads cross rivers which flood during such seasons.

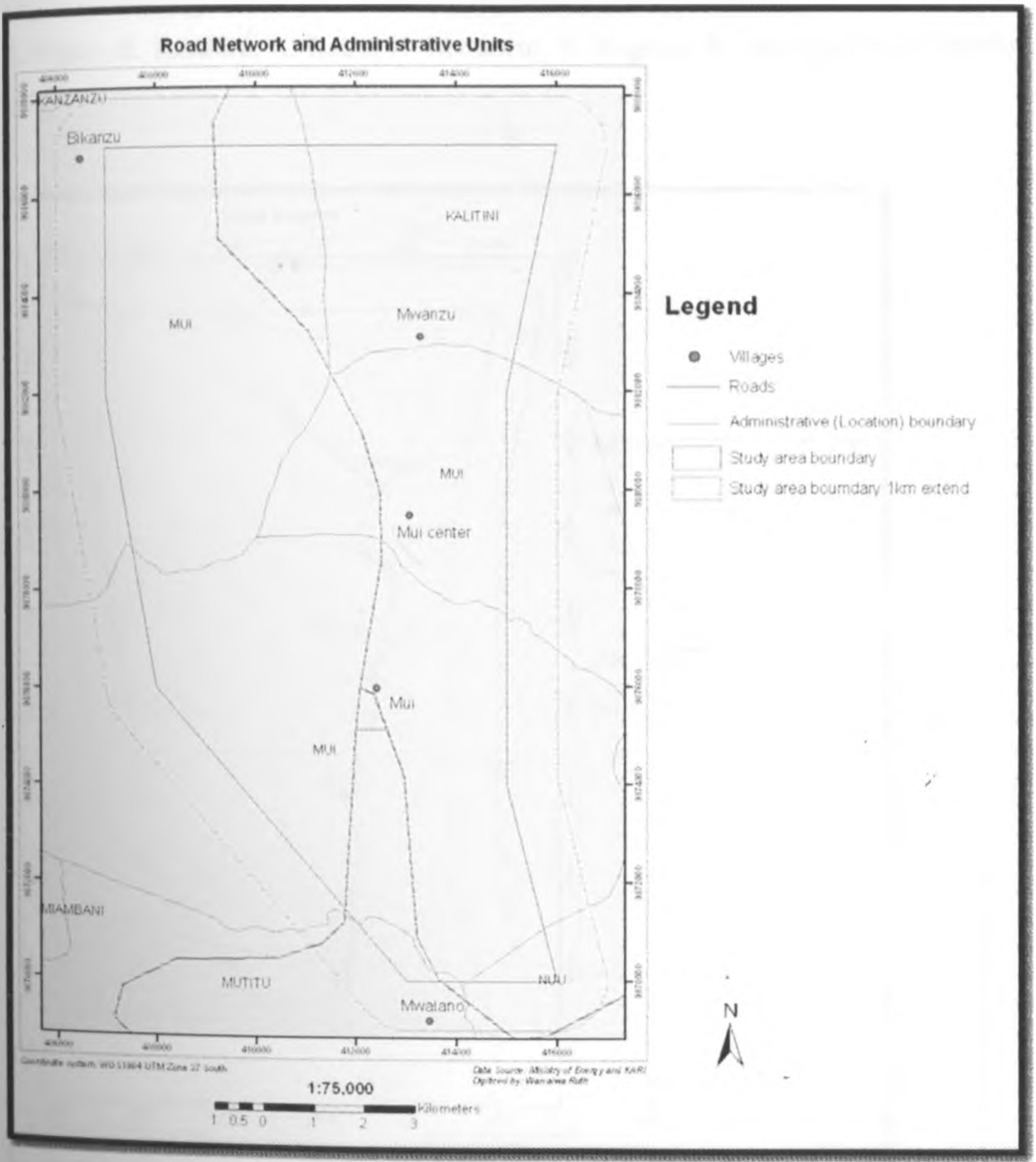

Fig 3.6: Transport network and villages in the study area

Administratively, the area lies in the yet to be developed Mwingi County but presently, is headed by a chief based at Mui center. In terms of communication, the area is well served by Safaricom and Zain companies. Electricity, however, remains a challenge in the area as only selected schools, dispensaries and market centers have electricity.

3.2.7 Hydrology

The area has one major river system i.e. R. Mui which is fed by six minor rivers namely R. Ngoo, R. Katiliku, R. Kathi, R. Mwanzui, R. Kagoue, R. Munyuni and R. Ithikwa (Fig 3.7).

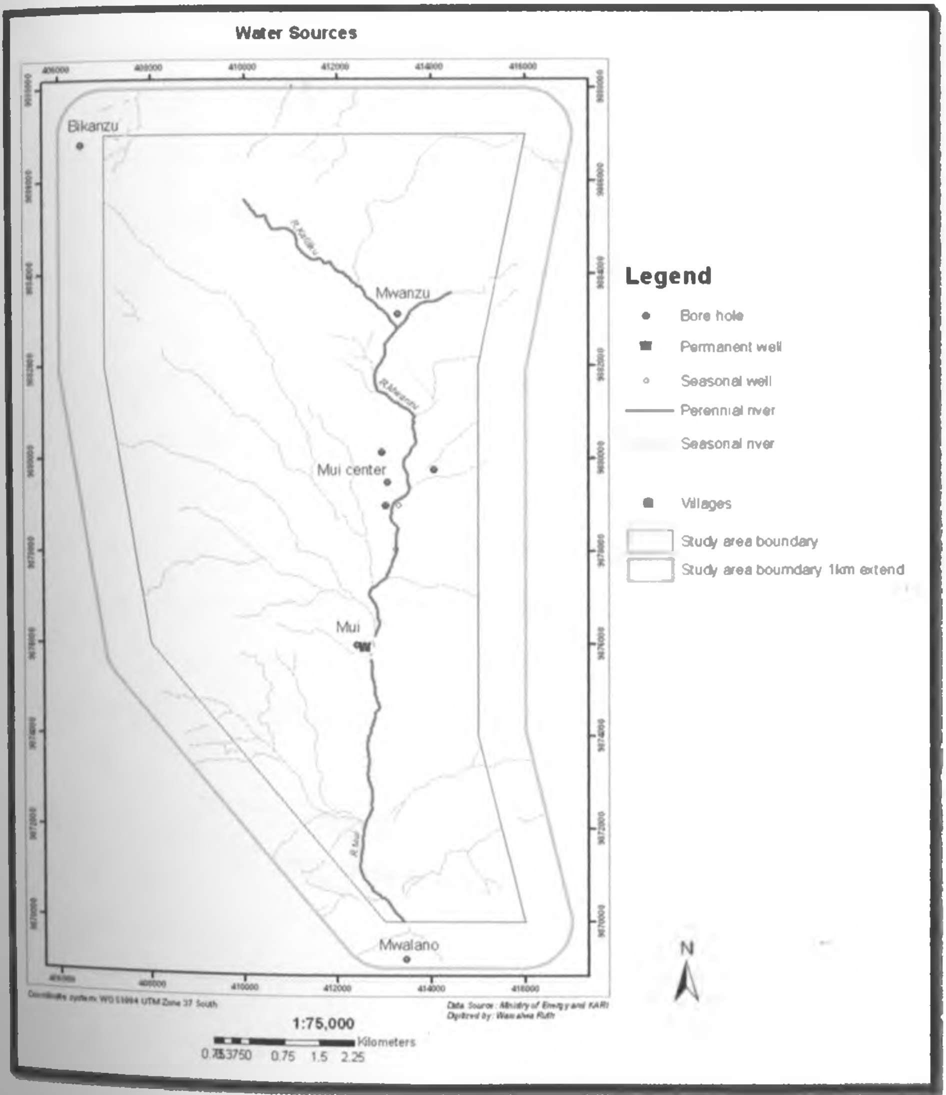

Fig 3.7: Water sources in the study area.

The relation of surface water with ground water is evident as most of the boreholes both dry and those containing water at the time of sampling, occur along the river beds or on the Eastern side where most of the rivers are flowing to.

3.2.8 Physiography of the study area

The country on the west has marked relief, the pattern of which is based partly on the predominant N-S strike and partly on the north-westerly trend of many of the rivers. It is a relic of a peneplain over 1970m high which now is most closely represented by the ground in the north corner of the area and by the summit levels which are the remainders having been eroded considerably below its original level. The erosion surface is an extension of the bevel that passes under the base of the lavas of the Yatta plateau and which Dixey, (1948) suggested is the sub-Miocene peneplain. In the northeast corner of the area around Ulaa, the area attains a height of nearly 2000m and their summits are considered to be relics of the end-Cretaceous peneplain of Saggerson (1962).

On the north at 1970m approximately, the ground slopes away eastwards as a pediment (Fig. 5.14) but in the eastern half of the area the lowlands slope eastwards at about 20 m. per kilometer. It is, therefore, believed that the peneplains and their residuals developed by a process of scarp retreat and pedimentation. In the course of time, the residuals on the end-Tertiary peneplain will be gradually removed by erosion, ultimately leaving a perfect plain. At the same time erosion will eat back into denuded remains of the sub-Miocene surface, gradually extending the end-Tertiary plain further west.

The oldest surface in the area mapped can be traced only on the tops of the highest hills. Subsequent to its maturity, presumably towards the end of the Cretaceous period, there was a general rise of the land and another cycle of erosion began.leading to the formation of a lower plain with residuals of the earlier surface standing up from it. This plain attained maturity in mid-Tertiary times. At the end of the Tertiary renewed uplift took place, when the older surfaces were tilted gently seawards and a new cycle of erosion and planation was initiated. The end-Tertiary peneplain resulted.

3.3 Geological setting of the study area

The geology of the area (Fig. 3.8) is complex, mimicking the hoisting Mozambique belt. It consists of a suite of highgrade paragneisses in which two characteristic facies are recognized (Sanders, 1963, Saggerson, 1962, Pohl and Horkel, 1980). The first facies comprise of a suite of dolomitic marbles with thin variegated intercalations of quartzites and various metapelites (kyanite-sillimanite gneisses) which grade laterally into thick sequences of banded biotite gneisses and biotite granulites. According to Ackermann (1977), these metasediments were deposited on gentle slopes around Mathuki and Miambani of the Mui area; the carbonate sequences developed on swells whilst thick sequences of impure pelites accumulated in intervening basins.

The second facies comprises a thick monotonous sequence of quartzo-feldspathic gneisses with intercalations of ortho-amphibolite (Almond, 1985). Towards the top, layers of banded biotite gneiss become more frequent. According to Biyajima et al., (1979) these metasediments in the entire Mozambique belt are thought to represent a thick sequence of ensialically derived arkoses and graywackes with intercalations of basic lavas or sills, deposited in a rapidly subsiding basin.

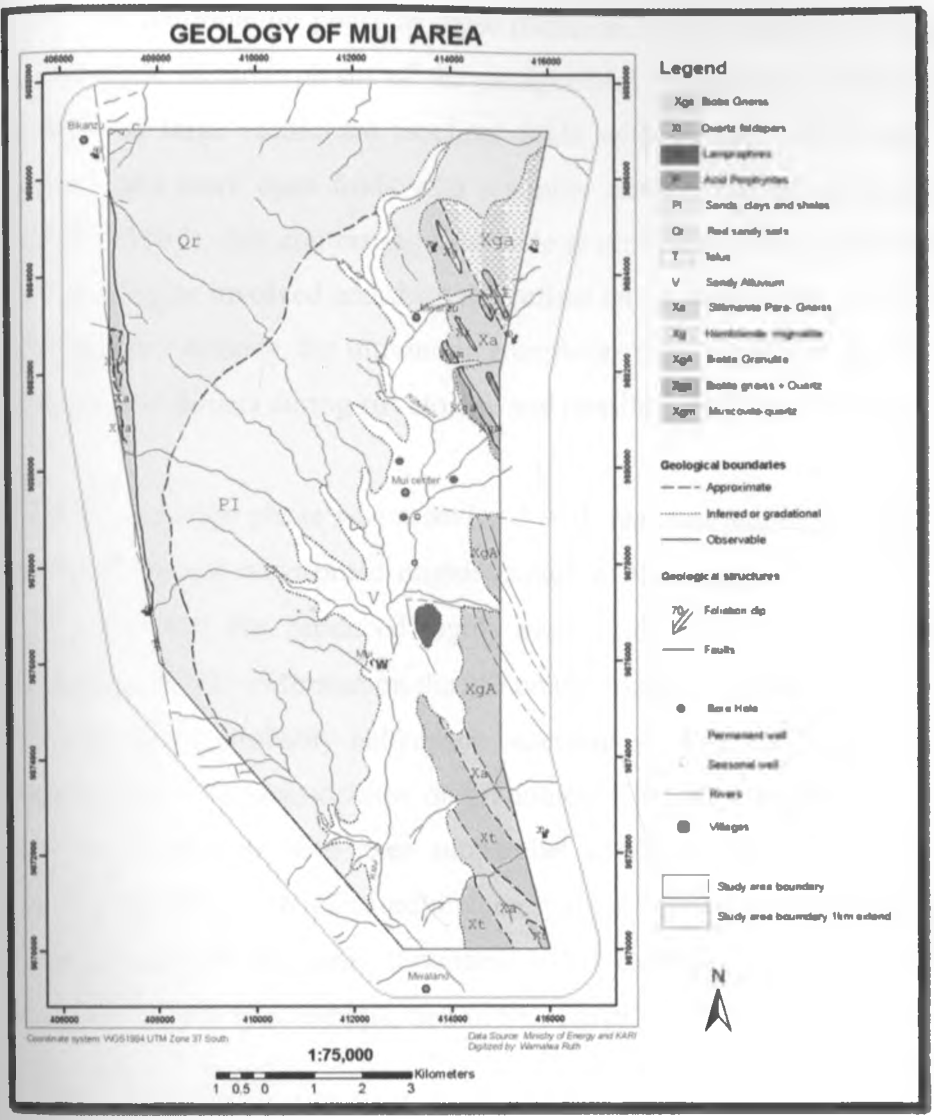

Figure 3.8: Geology of Mui area.

Little evidence exists on the nature of the original basement on which the sediments were deposited, as cover-basement relationships are generally obscured by intense deformation (Sanders, 1963). However, monotonous migmatite complexes underlying biotite paragneisses, cores of mantled gneiss domes (Biyajima et al. 1979), and also wedges of charnockites and granulites tectonically emplaced into the paragneisses (Pohl and Horkel, 1980) have the characteristics of a granitoid gneissic basement, reworked during the Mozambique orogeny. Small isolated complexes of ultramafic rocks (serpentinites and anthophyllite schists) occur as intensely tectonised lenses associated with amphibolites (Sanders, 1963).

The earliest deformation phase of these rocks i.e. Fl-deformation predates migmatisation and highgrade metamorphism of the paragneisses (Shackleton, 1979). It resulted in the formation of large recumbent isoclinal folds with general NNW axial trends in shelf sediments and more open folds with a similar trend in the rift sediments. According to UNESCO (1968), this contrasting fold style is attributed to the difference in competence of the lithologies involved and does not reflect an unconformity. UNESCO (1968) added that during this episode, the ultramafic complexes were emplaced as tectonic slices within major faults or thrusts during rift closure and possibly within transforms.

The F2-deformation phase was associated with regional amphibolite and granulite facies metamorphism and widespread migmatisation of the paragneisses (Walsh, 1977). Walsh (1977) added that this produced highly mobile slip and flow folds with NNE trending axes. During the F2- deformation the ultramafic rocks were intensely sheared (Shackleton, 1979), and small, probably anhydrous basement slices were transformed by high-grade metamorphism into charnockites or granulites. The concluding phase (F3-deformation) created open flexures with axes subparallel to F2-axes, and probably coincided with higher temperature - low pressure metamorphism, followed by retrograde metamorphism and post-crystalline cataclasis (Spooner, 1970) and it is this phase that terminated the cratonisation of the Mozambique belt in SE-Kenya.

3.4 Geological structures.

The area has in part complex structures due to the superimposition of minor folds and contortions on the major folds. The dips of foliation are high, averaging about 60° and strikes are in general essentially conformable with the regional roughly north-south strike.

3.4.1 Faults

In the Mutitu Ranges stretching through the entire blocks, most faults are normal faults Ministry of Energy, (MoE, 2004) and appear to have undergone a vertical movement. In all cases, MoE (2004) adds that the faults are deeply inclined between 65° and 90° and to the east. Their predominant vertical movement, with tens and sometimes hundreds of meters of down throw, produced cliffs or scarp features. On the eastern side of the study area, the faults are few and not pronounced. According to MoE (2004), conspicuous ones are along the Mui River plain from where they form an apparent drop of a step fault of a few tens of meters high.

3.4.2 Folds

There are no clear folds observed within the peripheral of Mui Basin basement rocks (MoE, 2004), however, localized subsurface intrusions resulted in the formation of localized ridges. These ridges are as a result of rocks that were intruded from the subsurface e.g. quartzites, granitoid and marble into the surrounding country rocks to form ridges of resistant rocks. In particular, quartzite ridges were observed on the southern part while the granitoid ridges form the hills on the north. Marble ridges are restricted to gentle slopping ridges at the central part.

3.4.3 Joints

In Mui basin, peripheral basement rocks have joints which vary in number from one rock type to another. According to Ndolo et al, (2003), their number increase in order from migmatites, pegmatites, quartzites, biotite gneiss and granitoid gneiss considering that the rocks exhibit considerable plastic deformation to form very few joints whereas brittle rocks are prone to joints. Joints in Mui Basin are considered to be young that the veins (MoE, 2004). Rose diagrams gathered from joints can be divided into three groups; single, double and triple/composites sets (MoE, 2004). According to Saggerson, (1962), single joint sets are caused by tensional forces and that these forces normally produce joint sets that are perpendicular to the direction of stress. He further points out that those joints occurring as two equally well-developed joint-sets that intersect at an angle of 80° are shear joints. Composite joint sets are a combination of the two.

Most single joint set roses are concentrated in the Mutitu ranges. From their orientation, perpendicular maximum stresses that caused their formation are directed SE-NW however, the one from eastern side appears to be oriented NE-SW. If these forces emanated from sedimentation then the loci of thick sedimentation (depo-center) is centered SE.

3.4.4 Veins

Veins in Mui basin are mostly of quartz and/or pegmatites and found occurring together with joints on the same outcrop (MoE, 2004). They represent molten rock injected in to former joints and hence their orientations (Appendix 2) are in line with those of former joints. Variation of veins' orientation from joints can be interpreted to mean that the principal forces that caused the formation of the two sets is not the same due to variation with time in the direction of the deforming forces. Some veins show some faulting hence a proof that deformational forces are still in progress.

3.4.5 Dykes

Dykes are noted around Ikoo (MoE, 2004). The dykes are mafic, fine grained and displays some pillow lava structures. Hydrothermal alteration is noted along the banks of Ikoo river 200m SE of this dyke. According to Saggersson (1962), the presence of pillow lavas implies that the dyke was intruded in a fluid and most likely in water within a river valley. The dyke trends at 312° within a miniature fault displacement of 1.5m at at trend of 314°. This fault trend is parallel to the Nzia faultline along which the Ikoo River flows before joining Mui River at an older Junction. Probably, it is a fissure that initiated and promoted the formation of the Nzia faultline, thereby directing the flow direction of Ikoo River into Mui's basinal channel.

3.5 Hydrogeological setting of Mui basin

Water occurrence in the basin is varied depending on the rock type. Igneous rocks like granites have primary and secondary fractures that are most important water bearing features. This means there are low groundwater yields that rarely exceed 2 liters per second and low storage capacity in fracture (UNESCO, 1968). According to WaterAid (2002) boreholes in these hard rock lithologies are often deep as a result of the poor groundwater yields. The weathered regolith above the volcanic rocks tends to be a lot thinner than the regolith above the Basement Complex, and it rarely exceeds 10m in thickness (UN, 1989) hence equally low water holding capacity,

Cretaceous sediments comprise of coarse textured arkosic sandstones, some being calcareous, as well as clays and carbonates with occasional conglomerate (WaterAid, 2002). The lithologies are highly indurated such that they are of low permeability and usually produce brackish water with a mineralization of up to 8500mg/l TDS (total dissolved solids).

Tertiary sediments mainly consist of limestone and medium textured sandstones that are found flanking the banks (UNESCO, 1968). The sandstones are generally calcareous but are ferruginous in some areas (WaterAid, 2002). In terms of groundwater potential this formation has a good water holding capacity while the carbonate deposits are good aquifers where they are karstic.

Quaternary and recent sediments, tend to be unconsolidated or weakly consolidated sand, clay, limestones and river alluvium; all have primary porosity (WaterAid, 2002 and UN, 1989). These sediments are generally thin and only relatively more pronounced in local depressions (Key, 1992). In terms of groundwater development potential, the sediments form by far the most productive aquifers in the basin (WaterAid, 2002).

Faults are of hydrological significance in the Mui basin especially in the southwestern areas since they provide the secondary fracture porosity that enhances groundwater flow. Two sets of faults are readily distinguishable in the basin therefore providing increased porosity and permeability at fault intersections (WaterAid, 2002).

CHAPTER FOUR

METHODOLOGY

4.0 Introduction

The research considered the integration of geochemical, geophysical and geotechnical techniques. Geochemical studies involved soil and water sampling later analyzed for coal related pollutants so as to give information on how far pollutants have been dispersed since the start of coal activities in Mui Basin and determine their potential role in transmission of pollutants. On addition, during water sampling, information on water strike level (WSL) and water rest levels (WRL) were collected to help model the flow regime of the basin which will be put into consideration during designing of the mine thereby averting pollutant transmission.

Gravity techniques, preferred over resistivity methods due to presence of resistive materials in the area that would interfere with the readings, were used to determine the geology in terms of density and mineralogy of rocks and trend of structures after modeling the data. Geotechnical properties of soils like particle size distribution, soil types and permeability were used to determine the likelihood of soil acting to transmit pollutants whereas shear strength to determine their ability to withstand heavy machinery associated with mining from which a mine design will be developed.

Field work began with water sampling as from 13th to 15th August 2010. This period was also used as a reconnaissance survey of the area to help design framework for soil sampling. Soil sampling was carried out in the entire month of October 2010 while gravity surveys in December, 2010 from 22nd to 30th.

FIELD METHODS

4.1 Positioning in the field

Positioning on the area was done using Global Positioning System (GPS) so as to exactly locate points for soil (Appendix 2) and water sampling (Appendix 3) such that once at a desired point, notes and data on sampling location, GPS reading, water depths and site name were recorded.

4.2 Gravity survey

This was achieved by the use of a CG-5 Auto gravimeter manufactured by Sintrex Company. Data acquisition began with the taking of the reading from selection of strategically placed base stations and proceeded to other points spaced at 500m on mortorable paths. Hidden areas especially around Kathonzweni were accessed on foot (Fig 4.1).

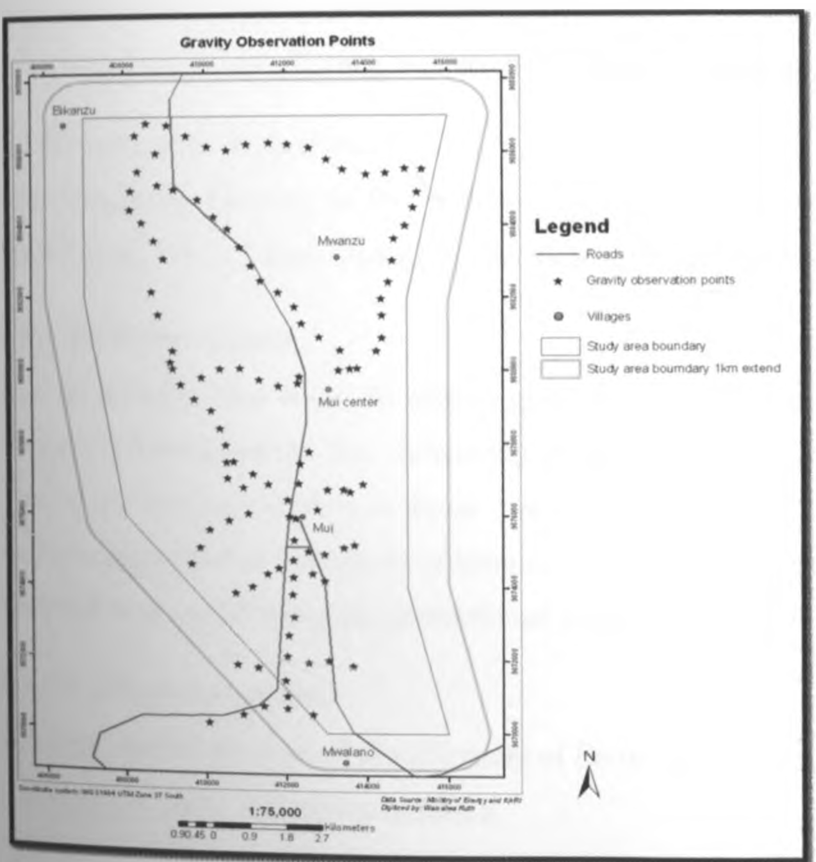

Figure 4.1: Gravity observation points superimposed on the road network of the area.

The first base station, used on day one of survey, was at Mui Boys High School and at AIC church on the second day. At every station, instrument was mounted on a tripod provided as it served to provide a stable base for the instrument in the field. Where the ground is generally uneven and of variable hardness a precise leveling of the gravimeter was achieved by rotating the foot screws. In setting it up, it was stabilized by treading on the frame next to each of the legs to push the steel tipped points into the ground. The base was then roughly leveled by using the bubble. Where the ground surface was very unstable, soft or difficult to reach, the standard tripod was attached to the optional surveyor's tripod.

The leveling of the instrument was by rotating the foot screws in the directions indicated by the icons on the top corners of the screen. The orientation was shown in arc seconds at the bottom of the screen and by the cross-hairs. Rotating continued until the intersection of the cross-hairs is within the small circle in the center (+- 10 arcsec) after which, using an RF Remote Transmitter, reading was taken in each station (appendix 5).

4.2.1 Gravity data corrections

Corrections were necessary to obtain the gravity anomalies that were the target of a survey (Telford et al, 1990). These were drift, elevation or terrain corrections.

4.2.1.1 Drift corrections

These corrections were achieved when a graph was plotted of measurements made at the base station throughout the day. According to Parasnis (1996), drift may be non-linear but it has to be assumed that it is linear between tie backs for most surveys. The drift correction incorporated the effects of instrument drift, uncompensated temperature effects, solid Earth and sea tides and the gravitational attraction of the sun and moon.

4.2.1.2 Latitude corrections

They were needed because of the ellipticity of Earth where g was reduced at low latitudes because of the Earth's shape and rotation.

4.2.1.3 Elevation correction

It was meant to correct for the variable heights of the stations above sea level, because g falls off with height while Bouguer corrections accounts for the mass of rock between the station and sea level (Reynold, 1997).

Notably, the corrections as they were done automatically with the SURFER 9.0 software that was used for interpretation.

4.2.2 Interpretation of the Gravity data

According to Keary and Brooks, (2000) methods for interpretation may be divided into two approaches i.e. the direct and indirect methods. In interpretation, the process involved the calculation of the nature of the body automatically by computer from the data. Because of the ambiguity problem, this was only possible with limits placed on variables e.g. density and the spatial nature of body so that the range of possible solutions were severely restricted. Using the SURFER 9.0 software, variation in the density, thickness of the assemblage of layers at varied co-ordinates were presented as contour maps with different color or shaded gray, shaded relief maps, side-illuminated and stereo-optical maps.

4.2.2.1 Soil Sampling

The chain survey method was chosen because it is simple and only requires a pair of compasses and a scale rule, easy to carry out and ensures a representative sample (Fig. 4.2).

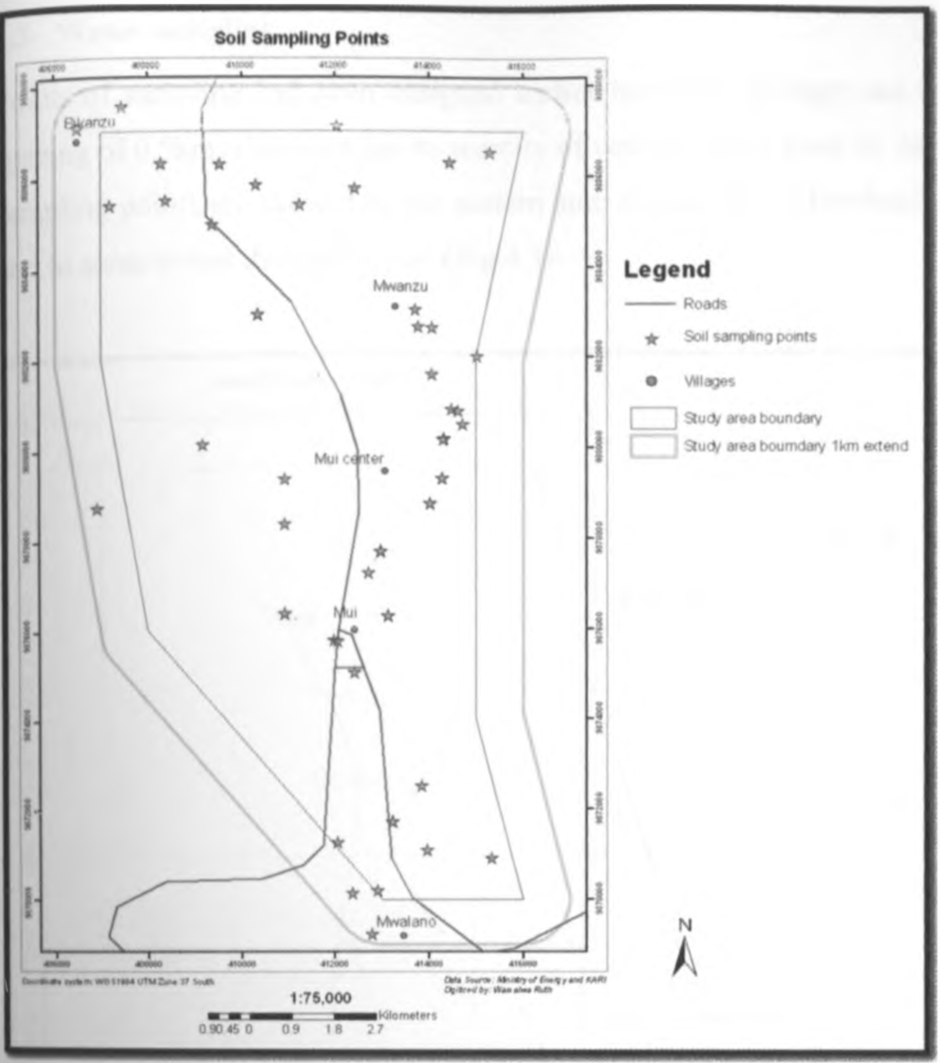

Figure 4.2: Soil sampling points.

4.2.2.2 Soil sample collection

This was achieved by the use of routine soil augering made with a hand auger to a depth of 1.5m deep where possible. Soil properties were then recorded on the Standard Soil Profile Description forms as per the standards applied for engineering purposes. Thereafter, sites for profile pits were selected and dug to a depth of about 2m deep. The trial pit method was used on the profiles as it is considered a satisfactory way of examining the ground in its virgin state. Using soil augers, the samples were taken packed in sample bags for testing in the laboratory.

4.3 Water sampling

Points of sampling had been designed earlier based on geology and at an approximate spacing of 0.5km. However due to scarcity of water in some parts of the study area, water sampling points are skewed to the eastern side around Mui, Miambani and Kathonzweni and to some extent the central part (Fig 4.3).

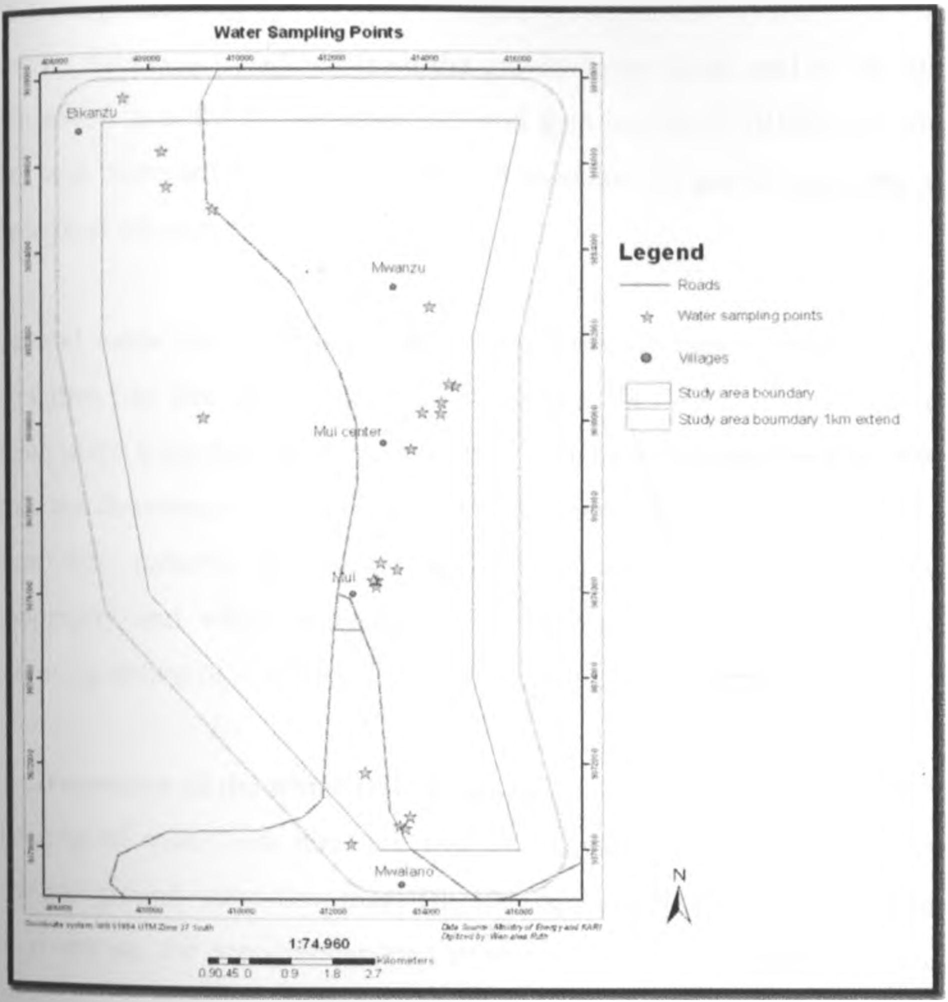

Figure 4.3: Water sampling points.

After sampling, the water was placed in plastic sample bottles and carefully sealed to ensure no entry of air which would otherwise affect the analyses procedures.

4.4 Laboratory methods

The analysis of soils and water was according to standards of chemical analyses available in the Foundation and Water laboratories respectively. Analysis of soil, for both chemical and physical properties, was according to the BS 1377: part: 1990 document while water analysis was according to the BS: 1377: part: 1991 document.

4.5 Data processing

Gravity data was transfered from the gravity meter flash card to the PC hard drive and then saved as a dbf IV file while in Excel then into the SURFER 9.0 software. Here, the data was corrected for drift, latitude and elevation for gravity anomaly and modeling for geological structures.

Soil and water data were in put in separate sheets in excel and checked for any incorrect entry then just like gravity data, was saved as a dbf IV file compatible with ArcGis 9.2 in which maps were generated. Water levels were modeld using MODFLOW 9.0 software to show the direction of ground water flow. The result map was overlaid on digitized surface water flow patterns to generate a general flow direction map. Data values for soils, topography and water analyses were coded and in put in the interpolation distance weighting option of ArcGis 9.2 to generate pollution vulnerability map

4.6 Generation of the water flow map

The map of water flow direction was a combination of two maps i.e. the surface water flow and ground water flow map. The surface water flow map was generated by digitizing the rivers on the topographic map of the study area in ArcGis 9.0 software. Using a technique of feature classification in the same software, the rivers were distinguished between the dry ones and those containing water at the time of water sampling. The ground water model was generated using the MODFLOW 9.4 software, which considers the difference in the water rest level and water strike level. The result maps obtained from the two procedures were then overlaid in ArcGis to produce the direction of water flow.

4.7 Vulnerability map

This was generated using ArcGis 9.2 by interpolation distance weighting technique. The technique works by first identifying each obtained value of concentration of the pollutants both in the water and soils, then assigning them a given feature, in this case colors, with the intensity equivalent to the value of concentration from which, the area was classified on its potential to vulnerability. The software, during the interpolation, assumes that the shorter the distance from the reservoir of a pollutant, the higher risk of pollution.

4.8 Results and interpretation

The results are in form of maps drawn on a scale of 1: 75,000. Results on soil analysis are distributed all over the study area. However for water data, to prevent extrapolation, the map is concentrated on the eastern part of the area which had water at the time of sampling.

4.9 Data quality

The results of this research are reliable. This was achieved through ensuring that the samples collected are availed to the respective laboratories within twenty four hours after collection. Water samples were chemically preserved using nitric acid while in the field to hinder decomposition and oxidation of the elements of interest. While in the lab, the instruments used were first of all calibrated according to the manufacturer's instruction before analysis commenced. Several analyses were then carried for the same sample and parameter to compare the reliability of the analysis. As for gravity measurements, quality was achieved by ensuring that the gravity meter is powered for 48 hours, to bring the instrument to the required internal temperature mark before observations were made. The water data may not be reliable as first and foremost is scarce and therefore not a true representation of the area both in terms of water quality and flow direction.

CHAPTER FIVE

RESULTS

5.1: Gravity distribution of Mui area

The study area has the low gravity values on the eastern side with the NE corner recording the least. The values steadily increases westwards hitting highs of between -51.9mgals and -34.9 mgals on the south of the study area. With the surfer 9.0 software, used after the data had been corrected, the southern part recorded the highest gravity anomaly of -34.9 mgals while the central-eastern section has the lowest of -51.3mgals (Fig. 5.1). the structures, as shown by thick continuous lines, have a general trend of N-S direction.

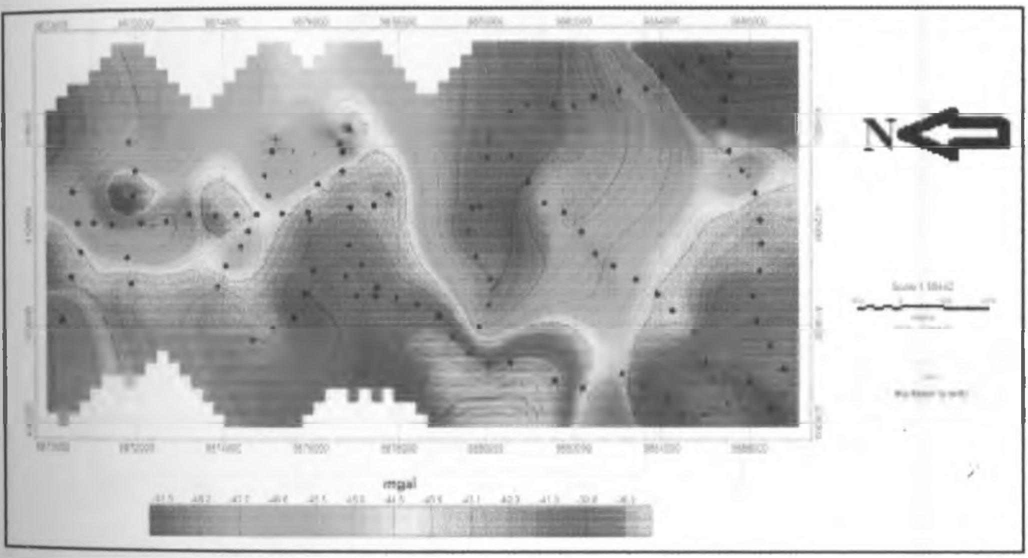

Fig.5.1: Gravity anomaly map of the study area.

5.2 Soil sample analyses

The series of 1:75,000 scale soil maps have been used as a basis for the work. These maps represent a simplification of the complex pattern of soil physical and chemical characteristics shown on individual collective farm maps, generated using ArcGIS 9.2 software, hence maps have been allocated a soil leaching potential.

5.2.1 Physical characteristic of soils

5.2.1.1 Soil types

The area is defined by sand, clay, silt and a mixture of sand and clay (Fig 5.2).

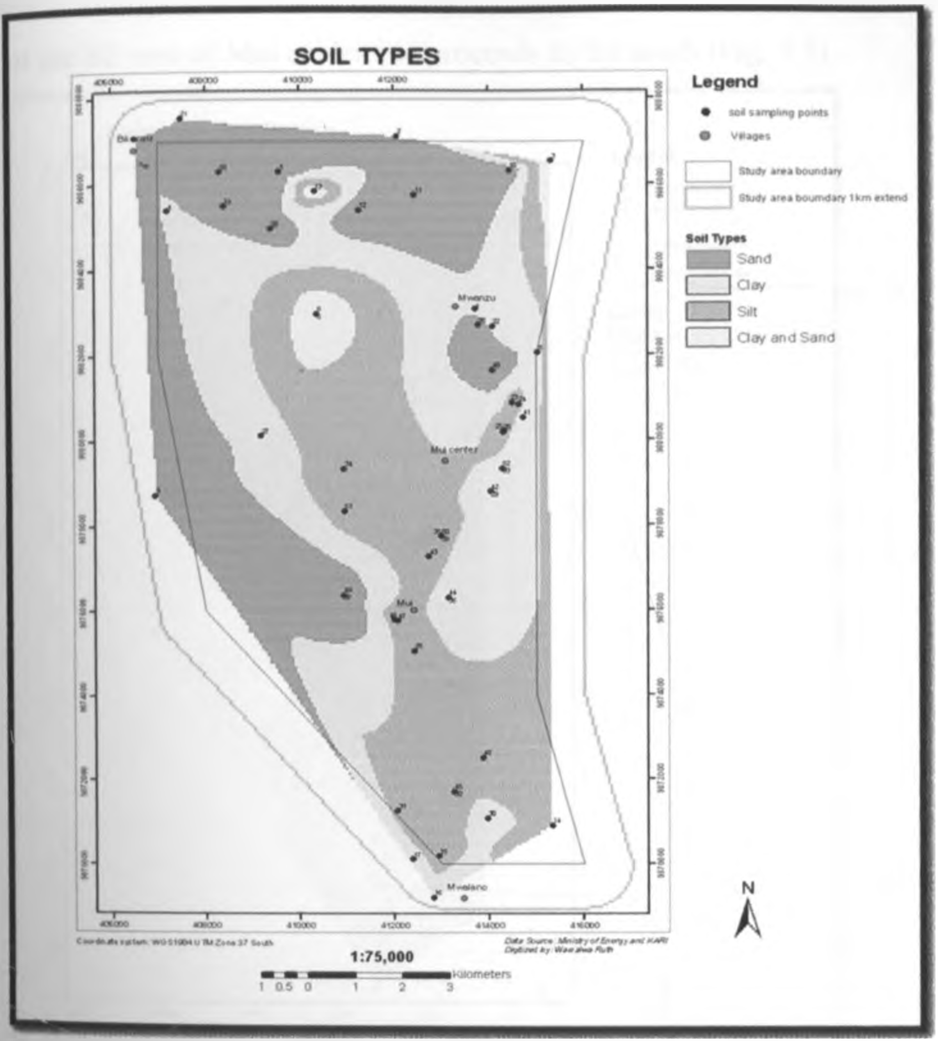

Figure 5.2: Soil types in the study area.

On the north of the study area, sandy soils dominate. They then stretch along the margins on the west towards the south and on the northeast area around. On the northeast of the study area, clay soils appear to boarder the sands and then the silt on the periphery. Clay soils just like the sandy soils stretch from the north through to the south sandwiching silt all through.

5.2.1.2 Grain size distribution

Grain size distribution follows the trend of the soils. In this case, the northern part covered predominantly with sand has coarse grains that measured approximately 1cm. This is then followed by medium sized soil particles, in areas overlain by clay soils, stretching to the south through the western side making a curve around fine grained soils, in silt rich area, on the SE area of Mui center and proceeds to the south (Fig. 5.3).

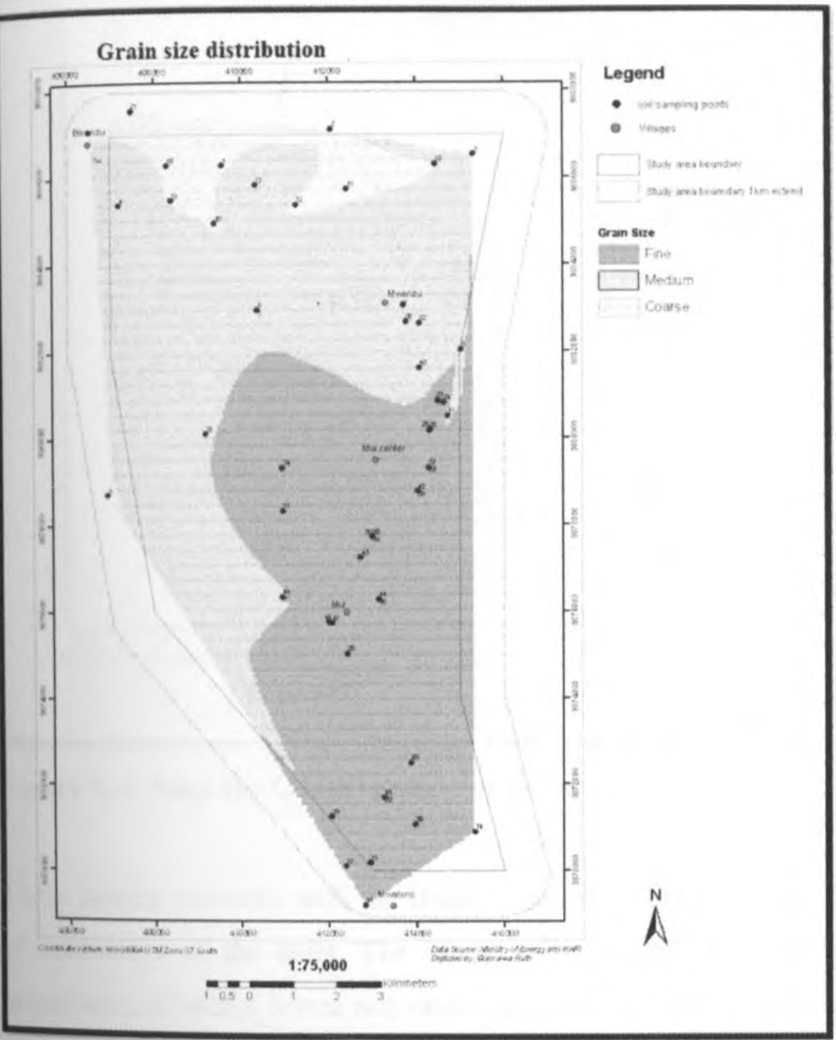

Figure 5.3: Grain size distribution of the study area.

5.2.1.3 Consolidation of the soils

The consolidation of soils is high on the south of the study area, with values ranging between 2.11-2.4kN/m^2 and reduces steadily northwards where the least values are recorded between 1.00-1.14kN/m^2 on the NW area (Fig. 5.4).

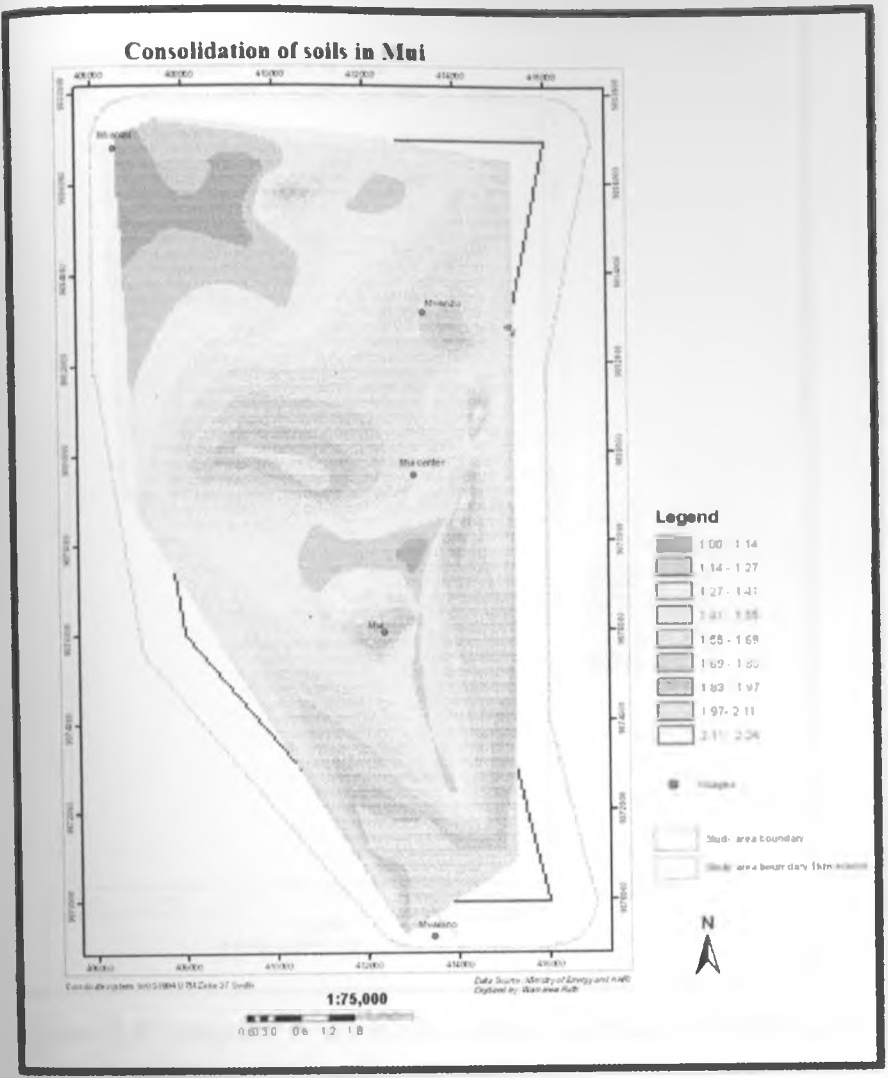

Figure 5.4: Map for Consolidation of the soils.

These results coincide with the trend of soil distribution in the area and are an indication of settlement of the soils. The sandy soils, on the north of the study area, have less consolidation values hence not easily compressed under heavy loads compared to the silt overlying the southern part of the study area.

5.2.1.4 Permeability of the soils

The high values of permeability, ranging between 8.00-10.00mm/sec are recorded around the NW of Mui area as values between 7.00-8.00mm/sec dominate the central parts. Least values between 6.00-6.8mm/sec are scattered in the central part and some southwards (Fig. 5.5).

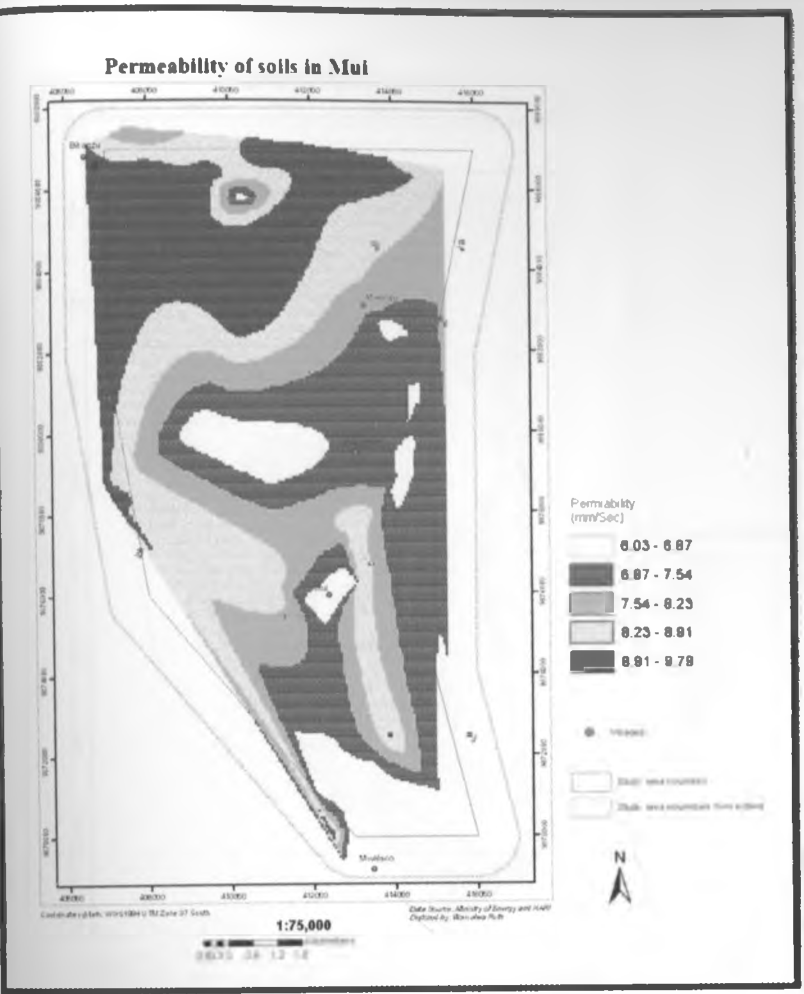

Figure 5.5: Map for Permeability of the soils in the study area.

The high permeability values characterize the sandy soils on the north of the study area which have low water holding capacity while the least values represent high water holding capacity, a property of silt and clay soils.

5.2.1.5 Shear strength of the soils

The shear strength of the soils is low, ranging between 1.50-1.58 kN/m^2 on the south and increases through the central part with the NW part recording the highest values between 2.11-2.18kN/m^2 (Fig. 5.6).

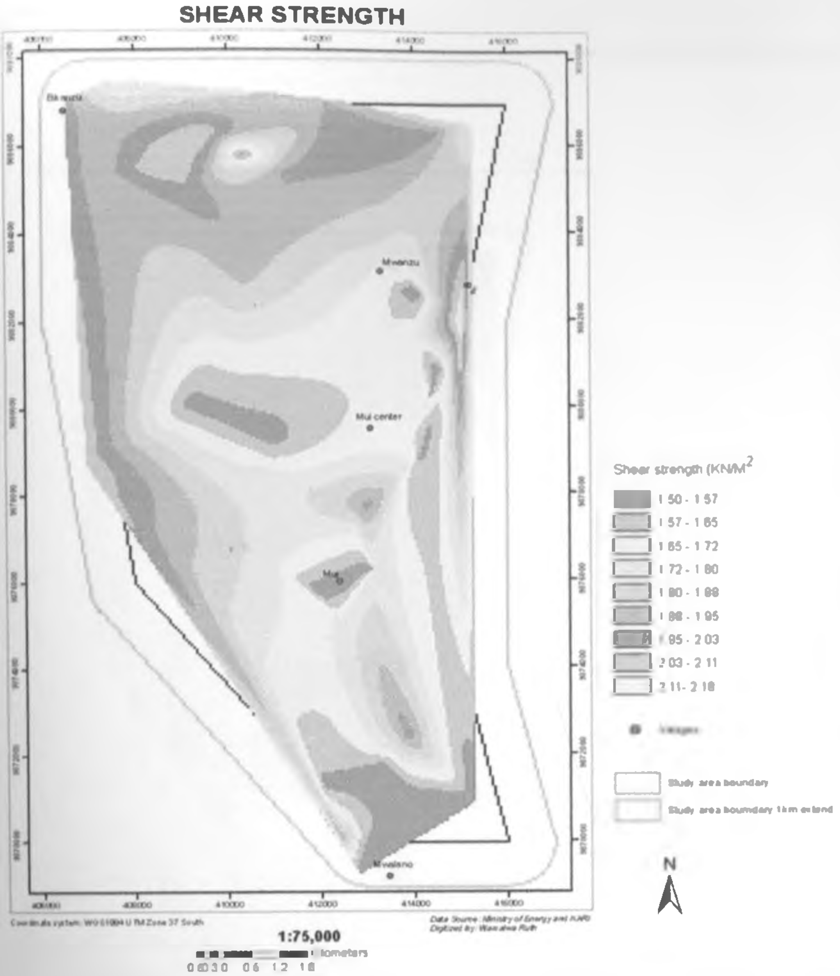

Figure 5.6: Map for Shear strength of the soils in Mui area.

The shear strength measures the amount of shearing that can be applied on a soil sample before it fails. High shear strength on the north of the study area indicate that the soils (sandy soils) cannot easily fail unless when heavily loaded as compared to the soils on the south of the study area (silt) which have low shear strength values.

5.2.1.6 Specific gravity of soils

The specific gravity of the soils is lowest, with values ranging between 1-1.38g/cm^3 on the north stretching through the western part southwards. The highest values between 2.54-

2.94g/cm^3 are recorded on the south, the central area and some patches on the north (Fig. 5.7).

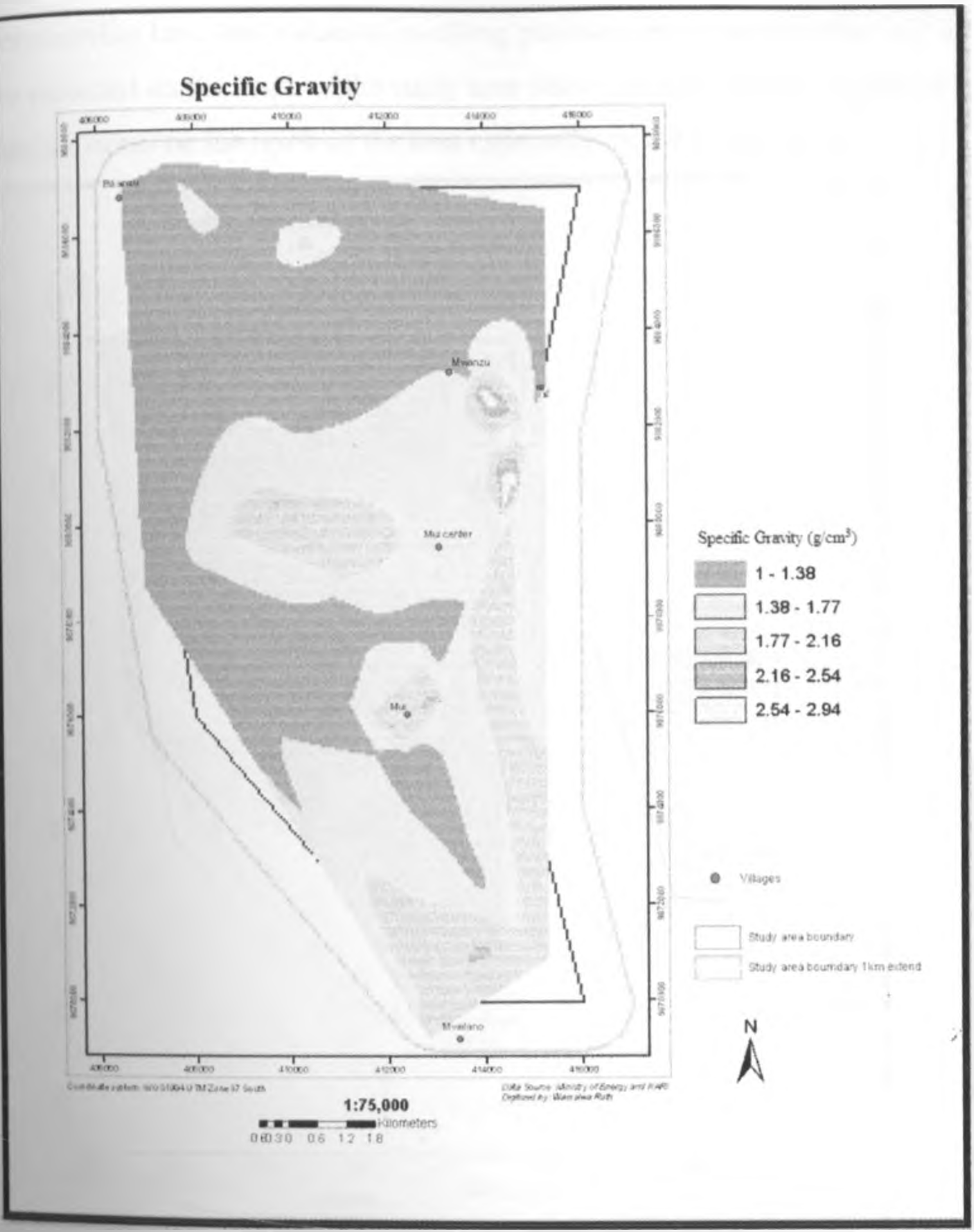

Figure 5.7: Map for Specific gravity of the soils.

Specific gravity measures the number of times a sample is heavier than water. The results indicate the distribution of soils in the study area, with high gravity values, is a characteristic of silt soils due to their closely packed grains that tend to elliminate air molecules giving them a compact structure unlike sandy soils.

5.2.1.7 Swelling pressure

Its values and distribution is the opposite of permeability in that the areas with high permeability have low values of swelling pressure. High values between 8.97-9.34mm/sec are recorded on the south of the study area while the least values ranging from 5.58 to 6.35 mm/sec occur on the north of the area especially on the NW (Fig 5.8).

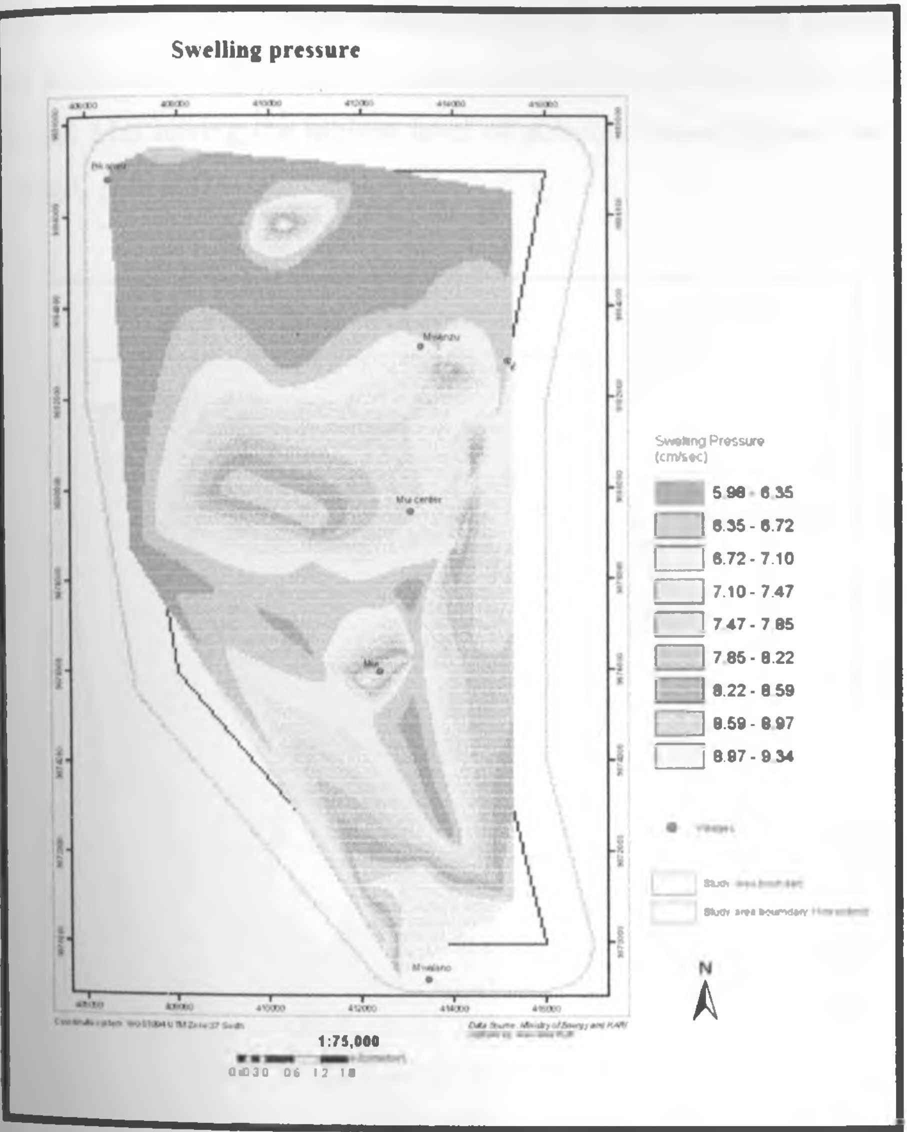

Figure 5.8: Map for Swelling pressure of the soils.

The variation in the swelling pressure indicate the varied chances of soils to flood. That is, the soils on the southern part of the study area, having high swelling pressure, are more likely to be flood upon down pours or when waste waters are directed there during the mining processes. The northern part has the least potential of flooding due to the high permeability that aloows no retention of water hence the low swelling pressure.

5.2.2 Chemical characteristic of the soils

5.2.2.1 Sulphur content

The value of sulphur ranges between 1mg/L to 11mg/L. Areas on the NW of the area have the least values. The values increase southwards with the area on the central section, around Mui having the highest level of pollution from sulphur that ranges from 9mg/L-11mg/L (Fig.5.9).

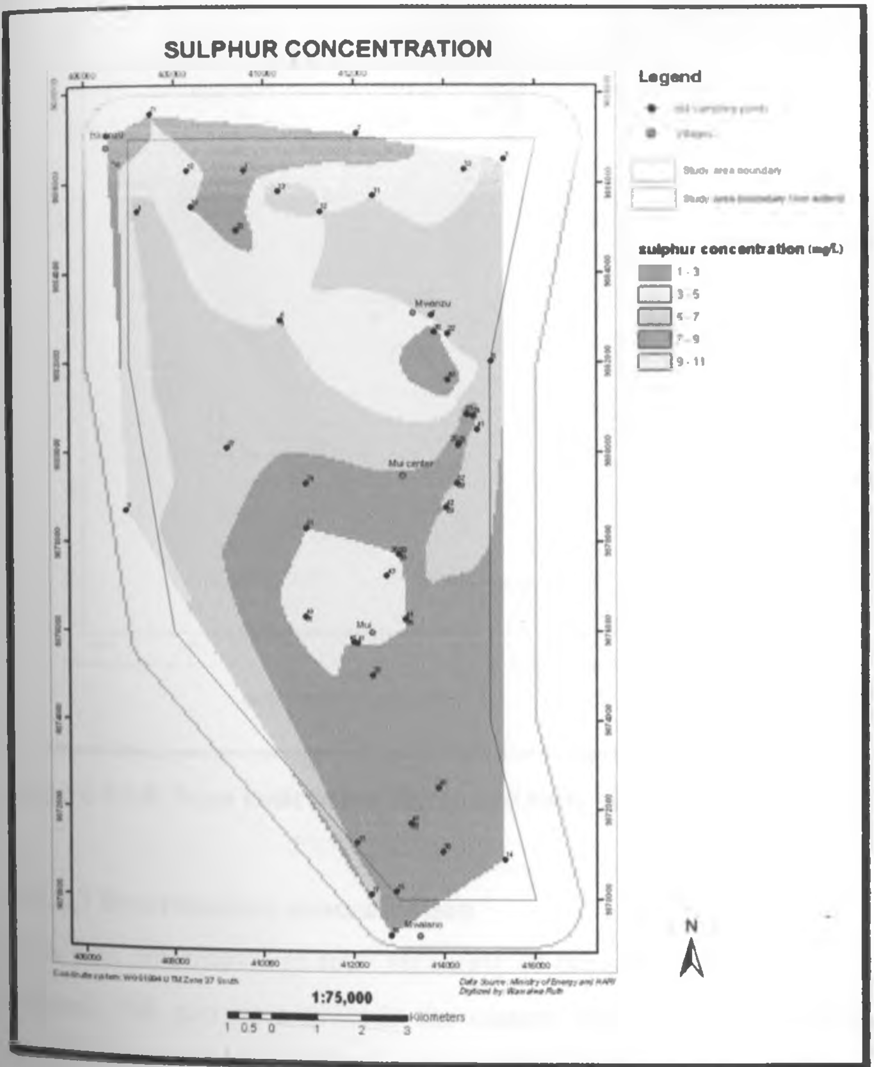

Figure 5.9: Sulphur concentrations in the area.

5.2.2.2 Iron concentration

The trend of iron is almost the same as that for sulfur i.e. the NW end has the least. The value steadily rises southwards with the highest recorded in areas around Mui i.e. on the southern part (Fig. 5.10).

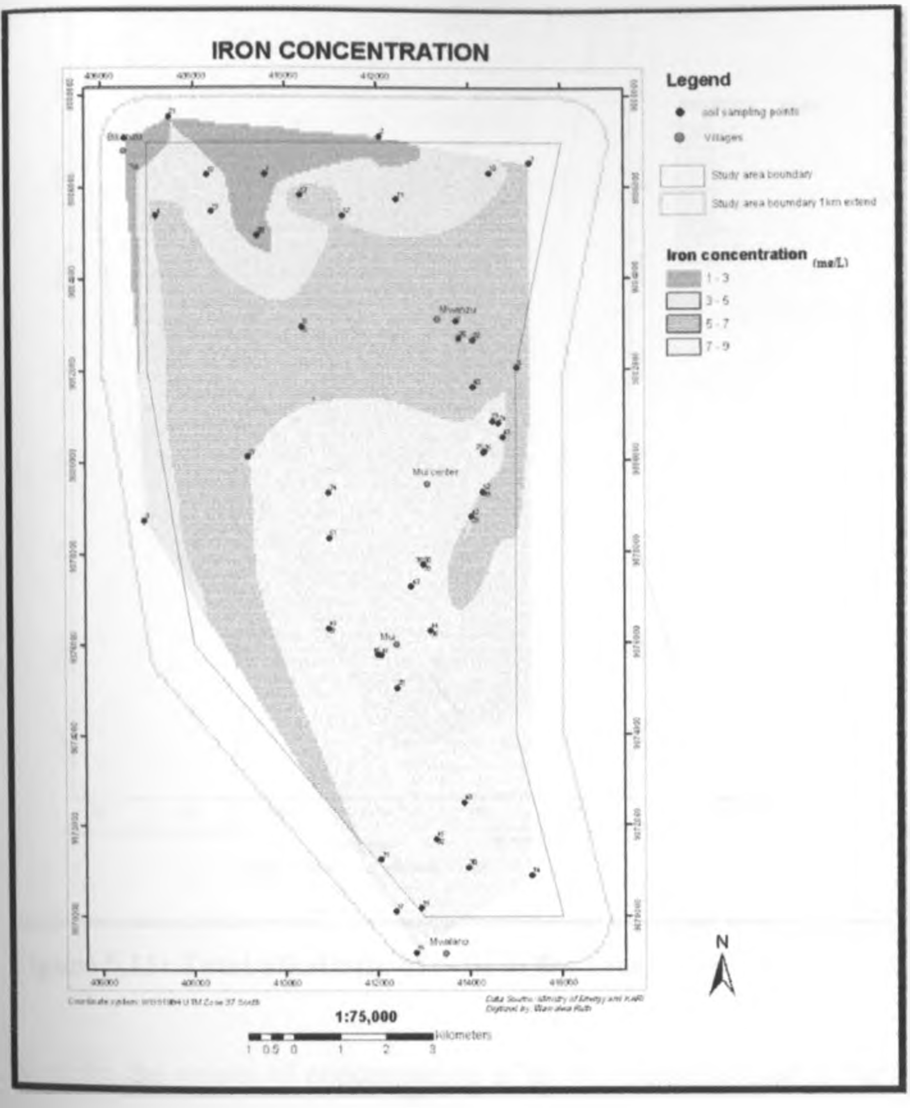

Figure 5.10: Iron concentration in the soils of the study area.

5.2.2.3 Bicarbonates concentration

This was determined as total alkalinity of the soils. The least values were recorded at the extreme NE and rises towards the eastern and southern. Highest values are recorded at Mui area and the extreme south. (Fig 5.11).

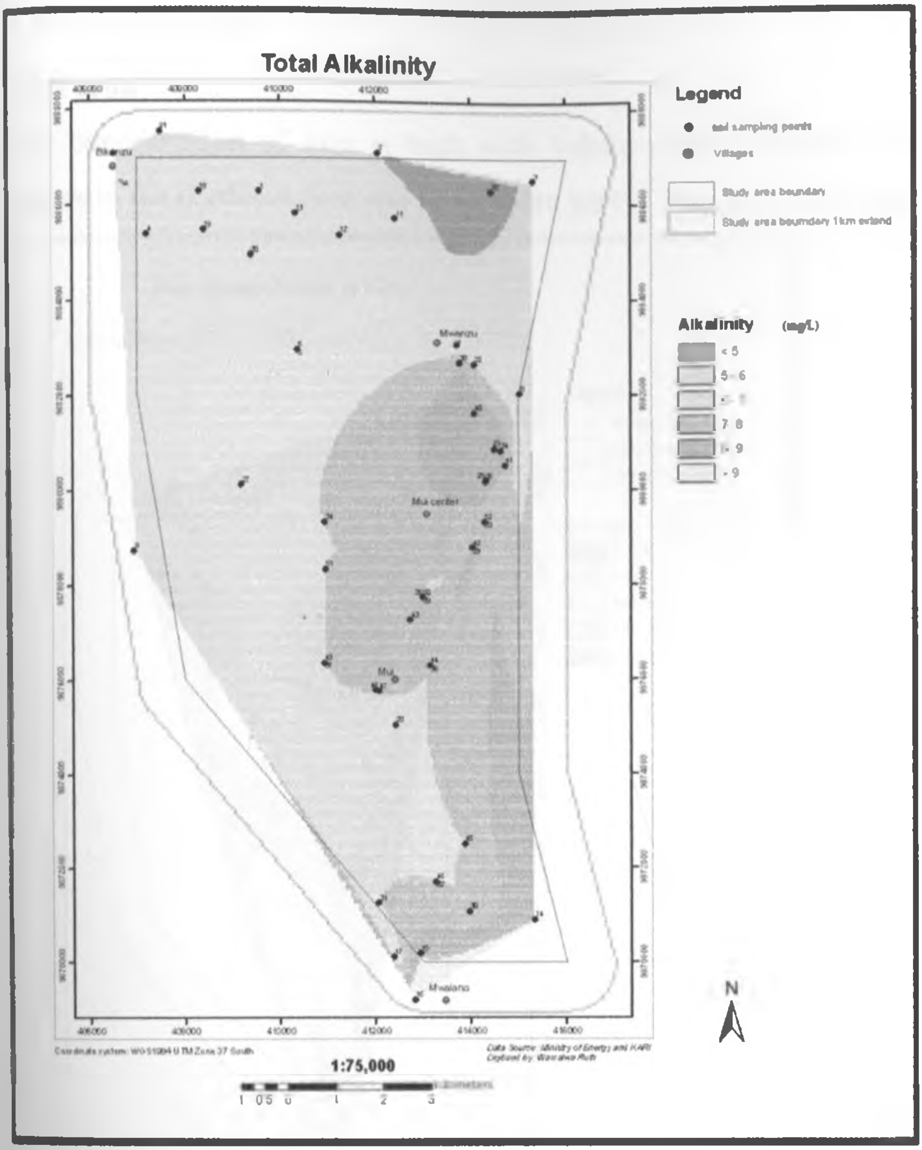

Figure 5.11: Total alkalinity of soils in the area.

Notably, the values of concentration of all the elements tend to vary with the soil type in that areas overlain by sandy soils tend to have lesser concentration compared to those overlain by clays and silt. This can be attributed to the fact that pollution resulting from the accumulation of the coal related pollutants is depended on the residual time of water in the soils. Sandy soils being highly permeable have poor water holding capacity hence no allowable time to concentrate the pollutants unlike the silt.

5.3 Water analyses

5.3.1 Iron

The concentration of iron is high with values ranging between 2.41-3.99mg/L in the waters in the northeast area and in southern part of the study area (Fig.5.12).

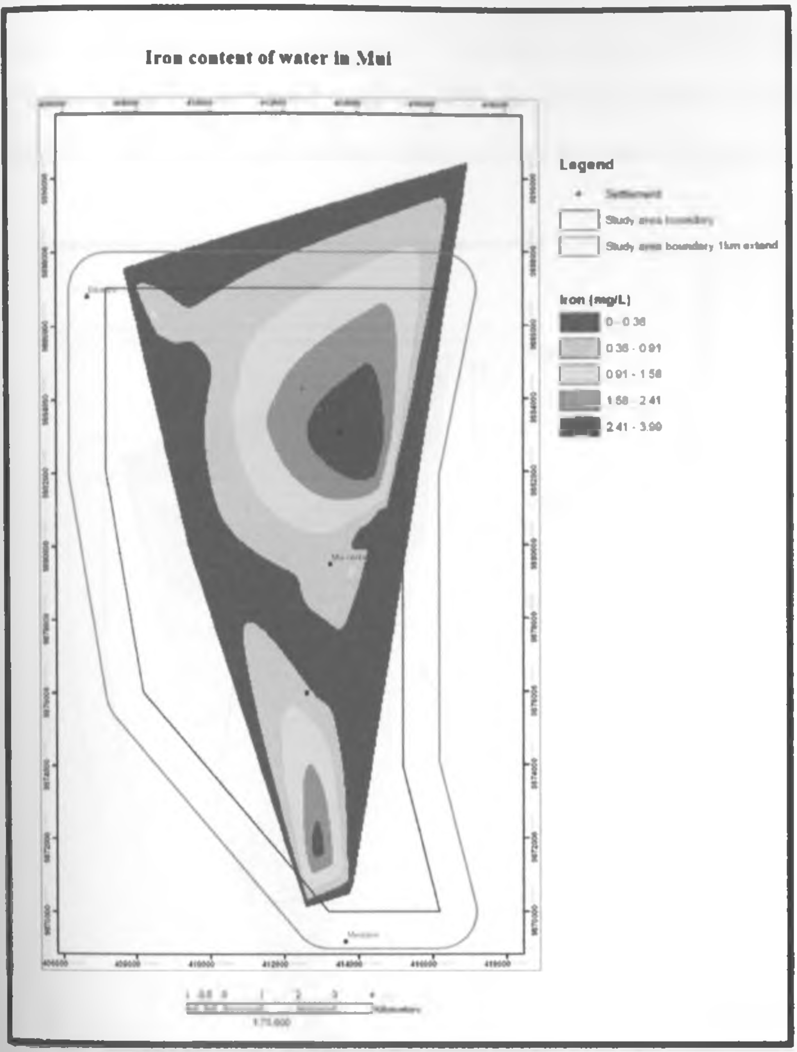

Figure 5.12: The concentration of Iron in the water.

Around the area of high concentrations, the values reduce outwards such that areas to the northwest of the study area record the lowest values between 0-0.38mg/L followed by the mid part of the study area. This is so because, considering that much of the coal deposit is concentrated towards the central part of the study area and stretching southwards, the water in this region is highly concentrated in the compositions of the coal. In addition the high concentration on the south can be attributed to the direction of trending of structures (N-S) thus tend to channel the water carrying pollutants to the south.

5.3.2 Total hardness

Highest values of total hardness between 918.74 to 2145.26mg/L are recorded on the east and northwest of the study area. The least values of 288.65mg/L are noted almost in the entire southwest and mid northern half of the study area (Fig.5.13). Areas around the south have recorded medium values followed by the northern part.

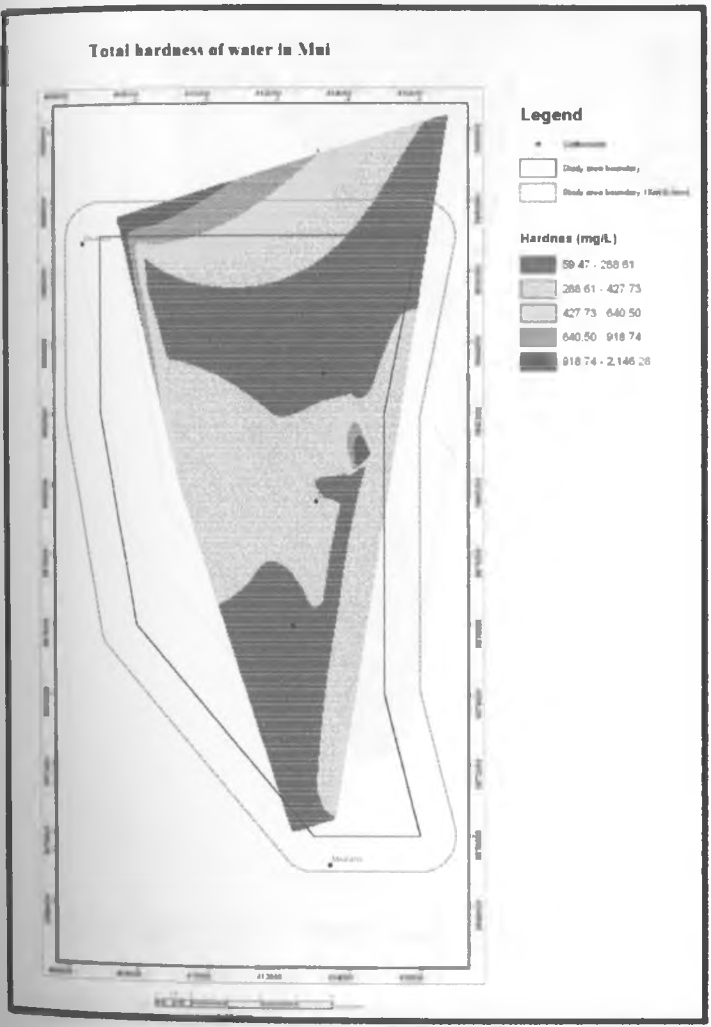

Figure 5.13: Distribution of total hardness.

5.3.3 Sulfur concentration

The entire middle strip recorded high concentrations with values ranging between 191-338mg/L, the values steadily reduces outwards to the least values of <4.16-73mg/L on the northern and southern parts of the study area (Fig. 5.14).

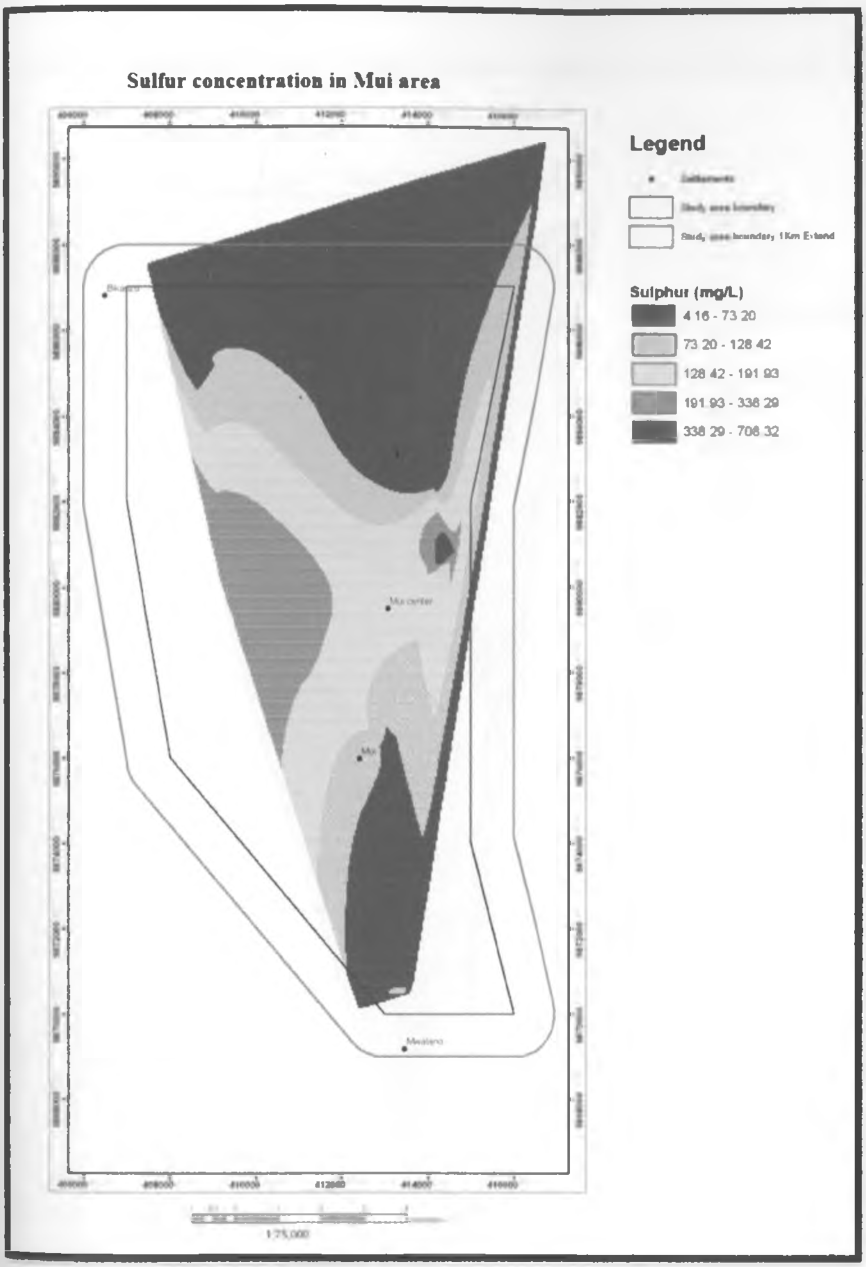

Figure 5.14: Sulfates concentration.

5.3.4 Total dissolved solid distribution

Just like the sulphates, high values between 2885-6249mg/L are recorded at the central part and steadily reduces towards the north, recording lowest values of 208-824m/L on the northeast and on the south (Fig. 5.15).

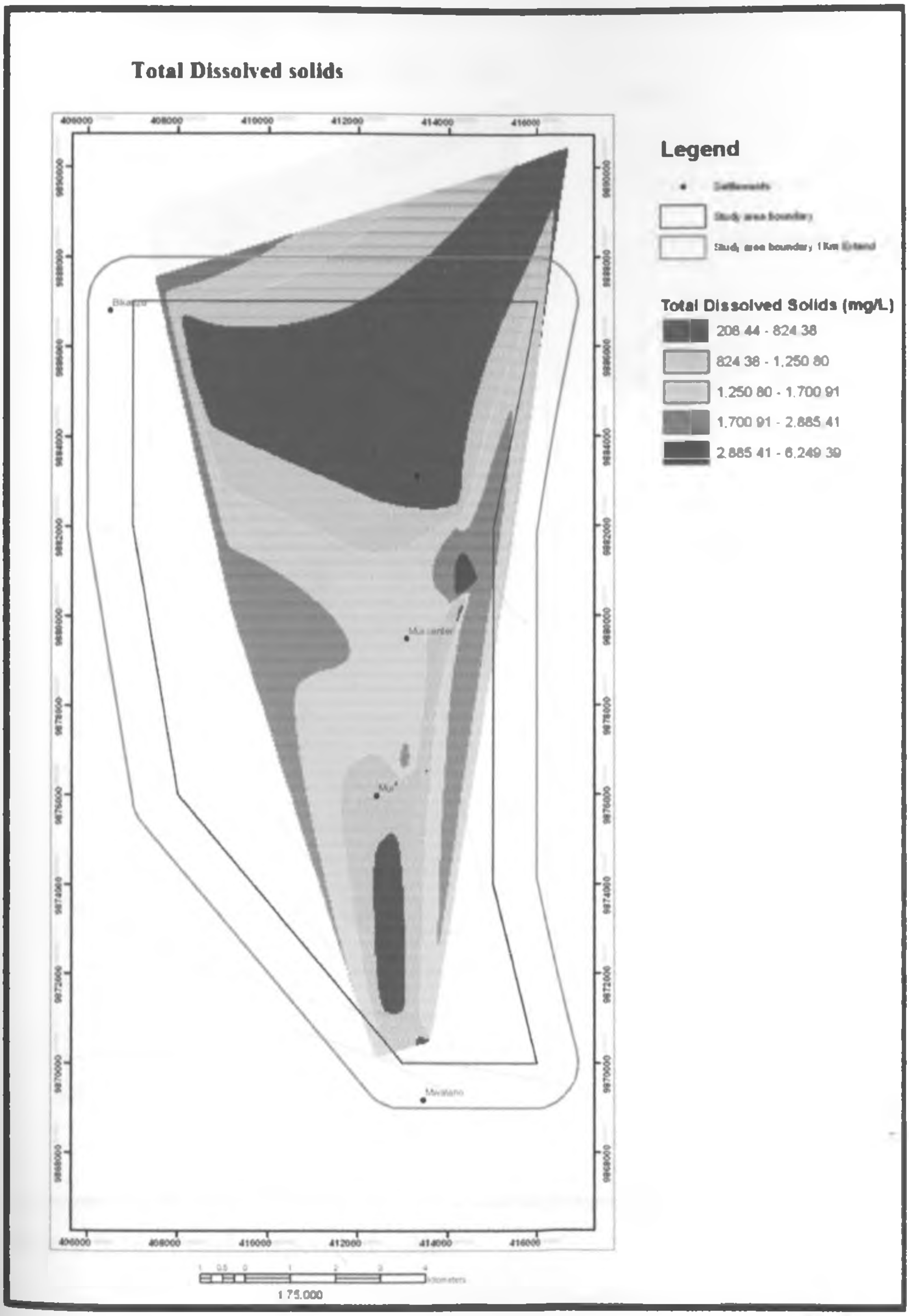

Figure 5.15: Total dissolved solids distribution.

5.3.5 Total suspended solids

Highest values of total suspended solids, ranging between 168-209mg/L, in the water are recorded on the mid northeast quadrant while areas on the northwest, east and southern part recorded the least values ranging between 0-20.43mg/L (Fig.5.16).

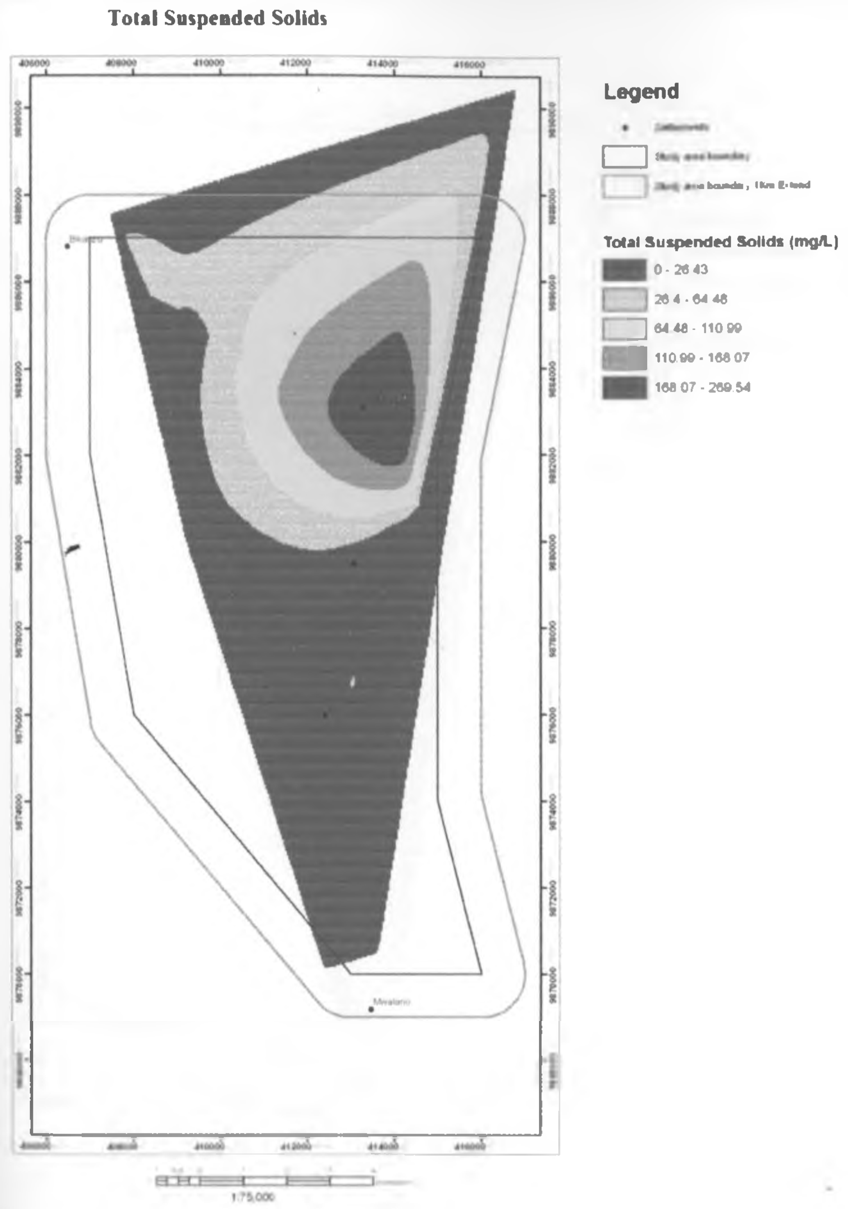

Figure 5.16: Total suspended solids.

5.3.6 Total alkalinity of the water

The values of total alkalinity,measure of bicarbonates, were highest between 609-881mg/L on the south followed by the eastern side of the area. Average values were recorded towards the north as the northeast area recorded the least values between 85-241mg/L (Fig 5.17).

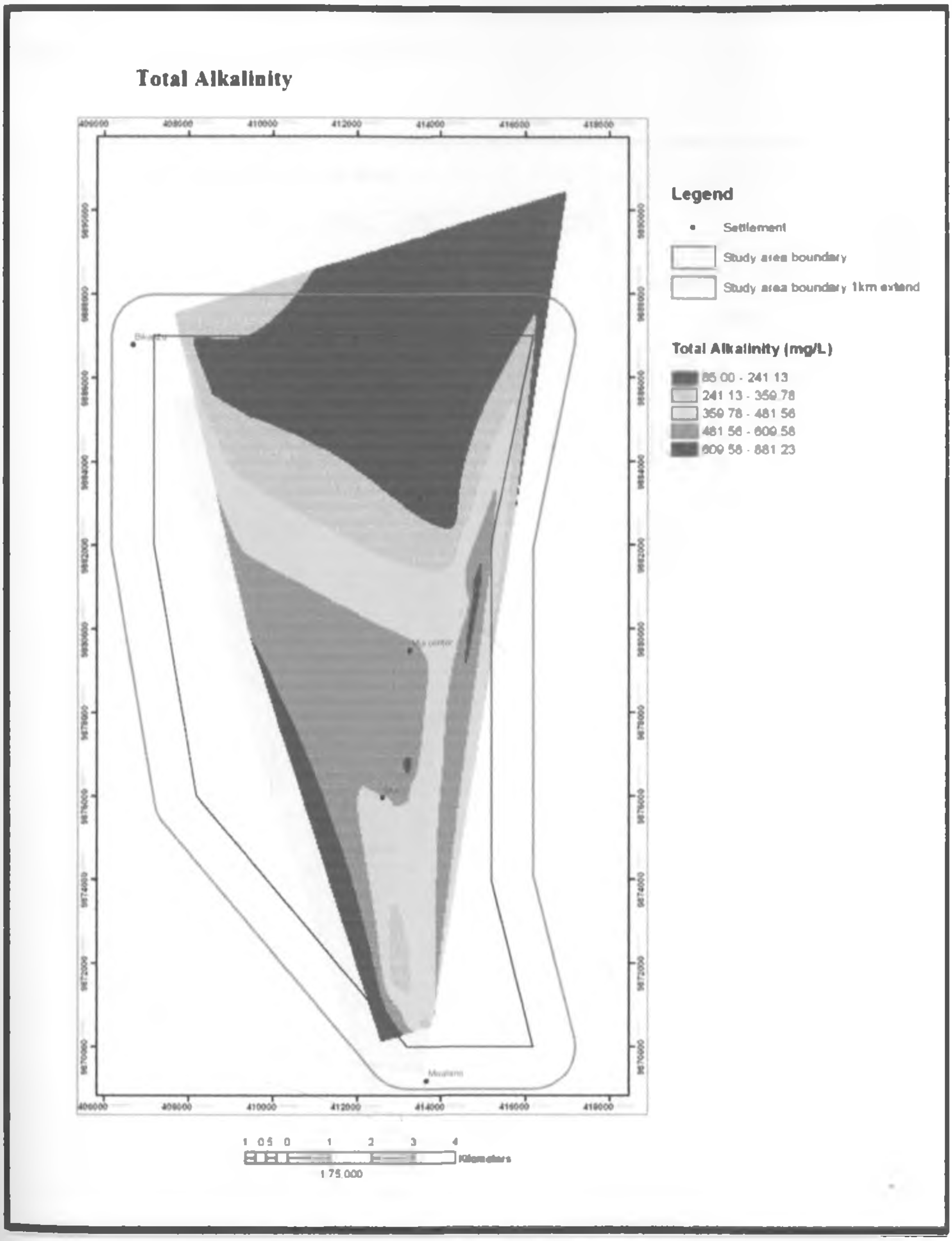

Figure 5.17: Total alkalinity of the water.

The values of total alkalinity indicate that the southwestern part is highly concentrated in bicarbonates, originating from coal in the study area.

5.3.7 pH of the water

Just like total alkalinity, high pH between 7.89-8 were recorded on the south followed by the western and northeastern parts of the study area. The eastern part has the low water pH ranging between 7-7.32 (Fig. 5.18).

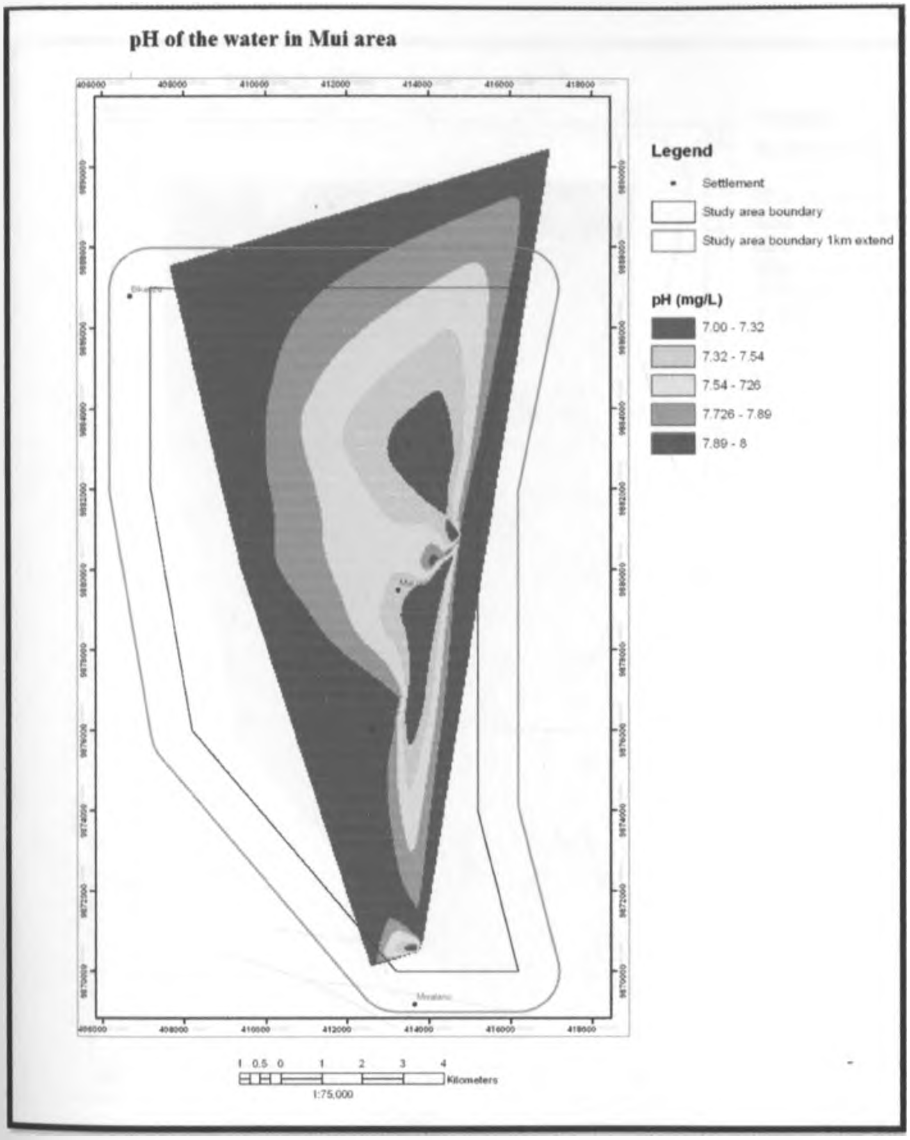

Figure 5.18: pH of water in the study area.

Notably, though the pH of the water in the study area is still in the basic range, the pH value on the eastern part is tending towards being acidic. These results correlate with the concentration of sulfur in the water indicating that the low pH is due to sulfur, which is acidic.

5.4 Topography of the area

This is represented on the Digital Elevation Model (DEM) (Fig. 5.19) that was generated using ArcGis 9.2.

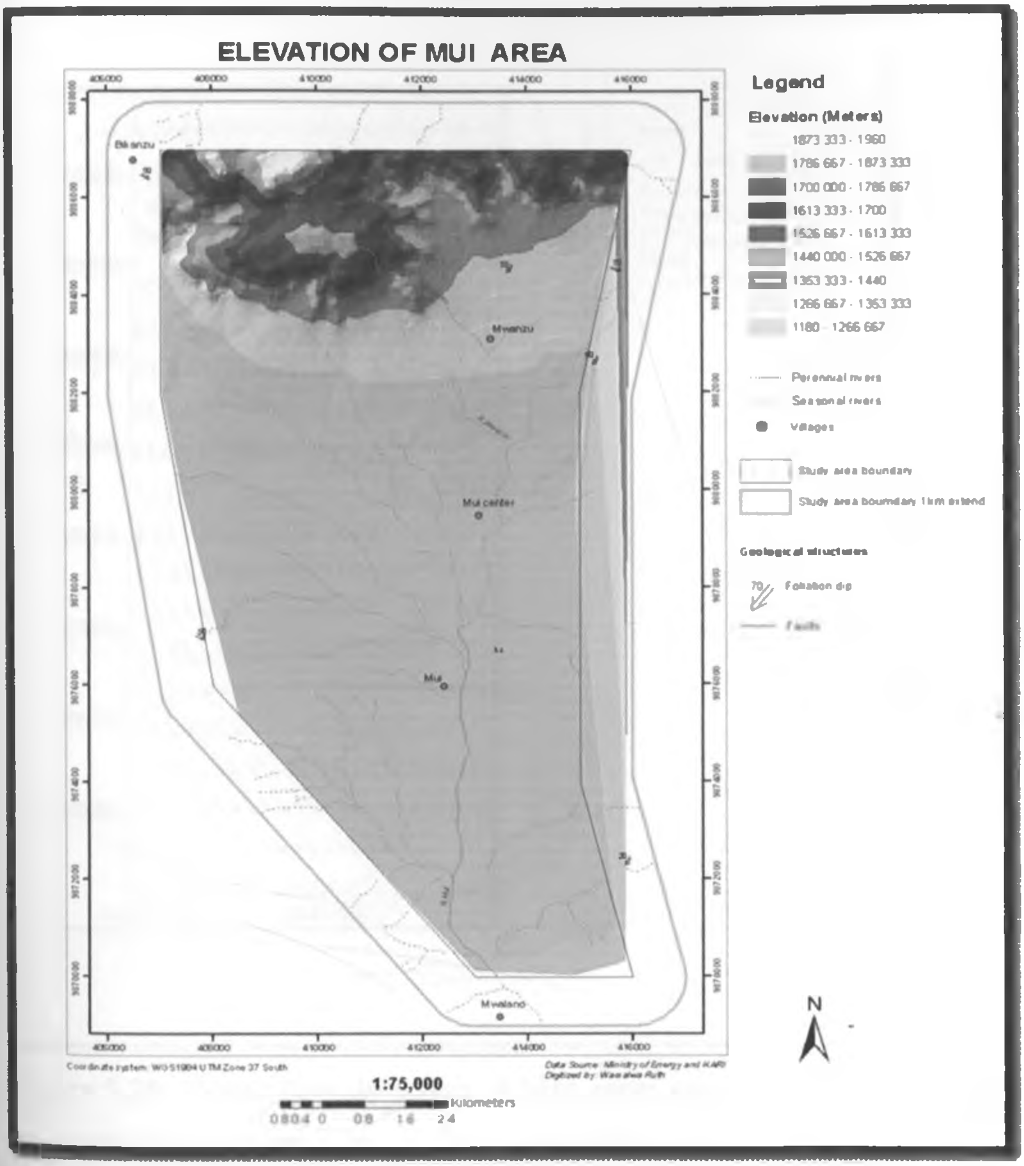

Fig. 5.19: Digital Elevation Model of the study area.

The highest grounds occur on the northwestern corner with height ranging between 1786-1873m above sea level. The values steadily reduce southwards to 1180-1266 metres above sea level.

5.5 Water flow direction

The area has a dominant north-south flow trend with divertions due to geological structure interference (Fig. 5.20).

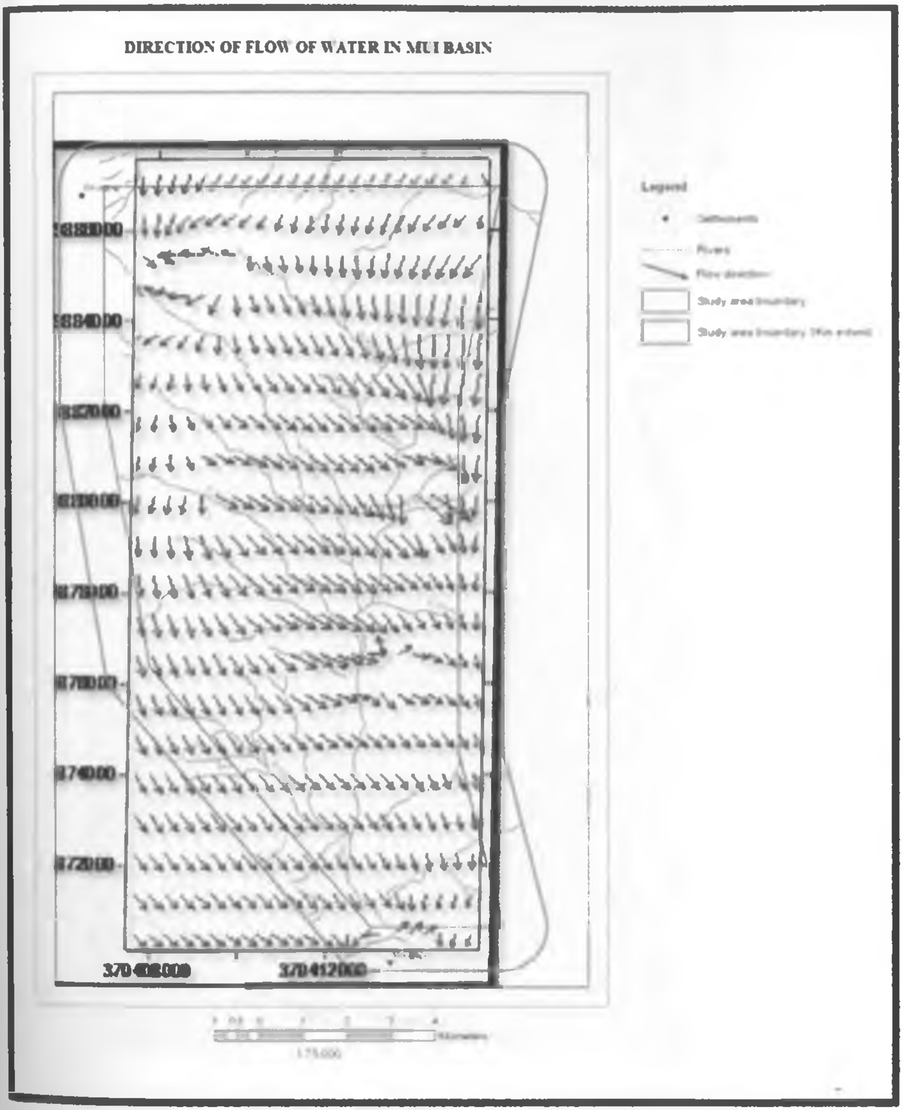

Figure 5.20: Water flow direction of Mui area; ground water flow superimposed on the surface water flow.

5.6 Potential vulnerability to pollution of the study area.

The area has varying vulnerability potential. The vulnerability maps which were generated based on soil chemistry (Fig 5.21) and slope (Fig 5.22) indicate that the northern part of the Mui area has the least potential, followed by the central part. The southern part of the study area has the highest risk to pollution.

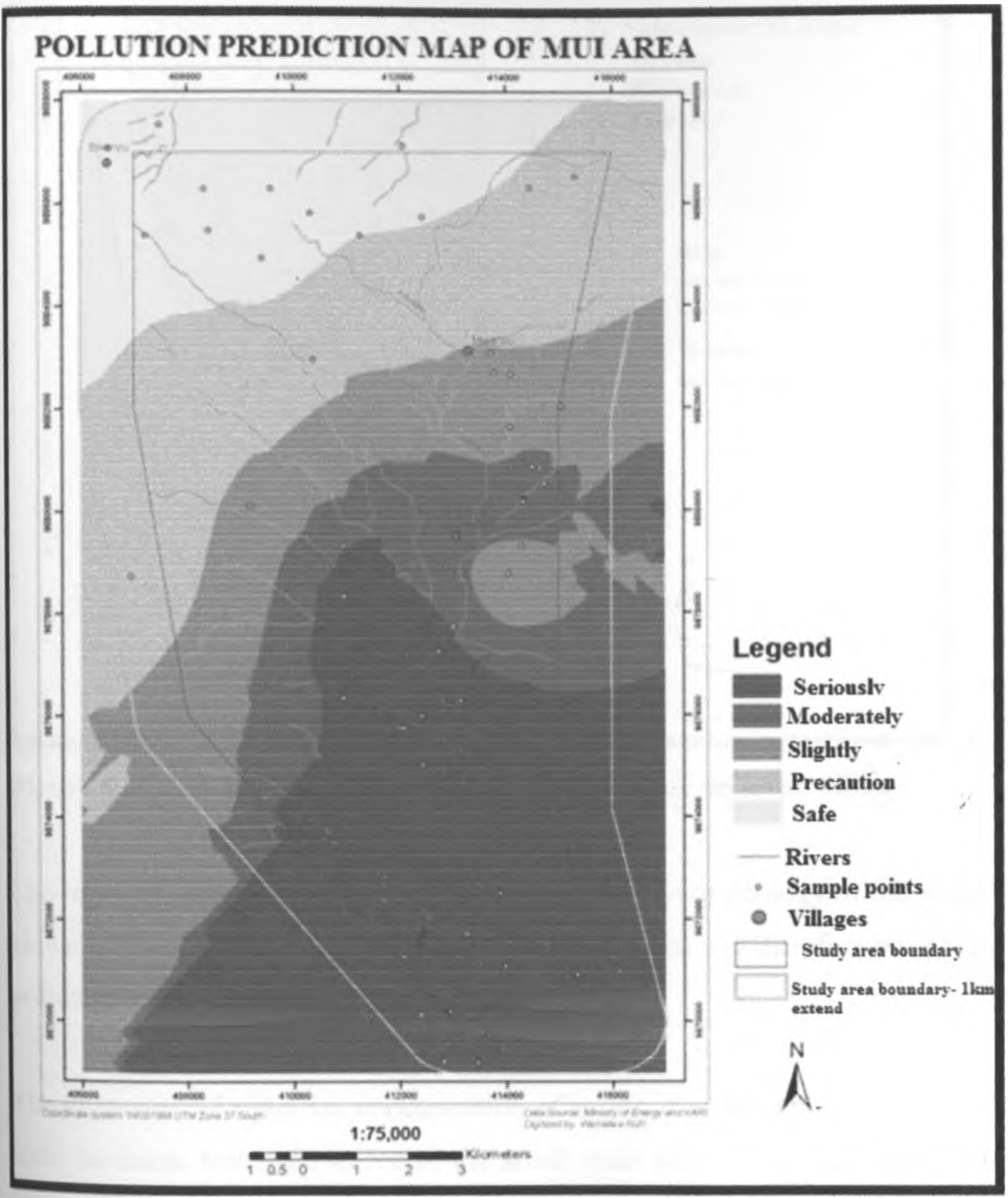

Figure 5.21: Pollution vulnerability map of Mui area.

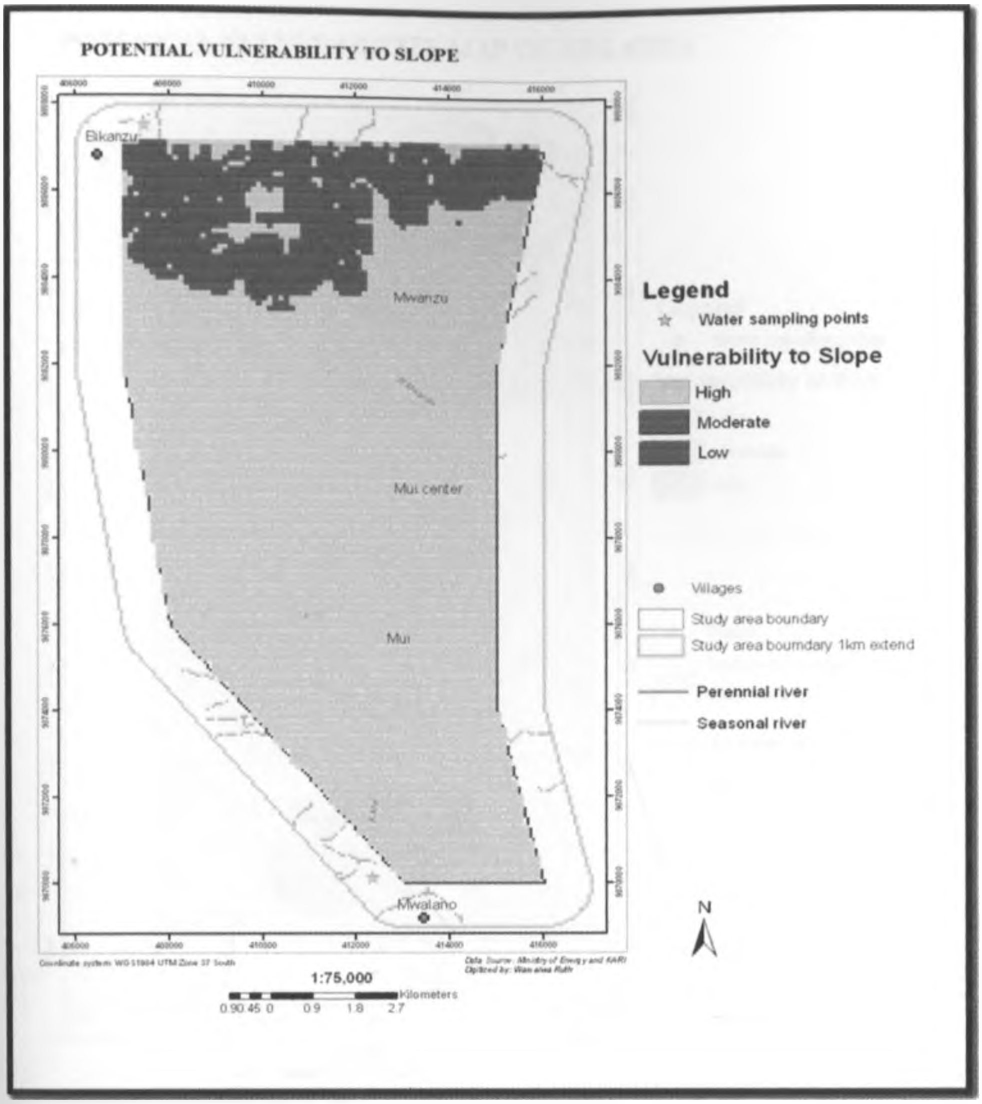

Figure 5.22: Potential vulnerability of Mui area due to slope factor.

The input of slope is vital as it indicates the influence of geology of the study area i.e. the elevated ground on the north are underlain by gneisses and therefore have less potential to polluttion due to poor water holding capacity.

The chemistry of water i.e. concentration of sulfur, iron, bicarbonates, TDS, TSS, pH and total hardness, was used to reveal the small scale potential of pollution. In this case the eastern and southern sides of Mui area have the highest potential to vulnerability (Fig. 5.23). Notably, the data leading to these results is derived from rivers hence a conclussion that water sources in Mui area are at the highest risk to pollution.

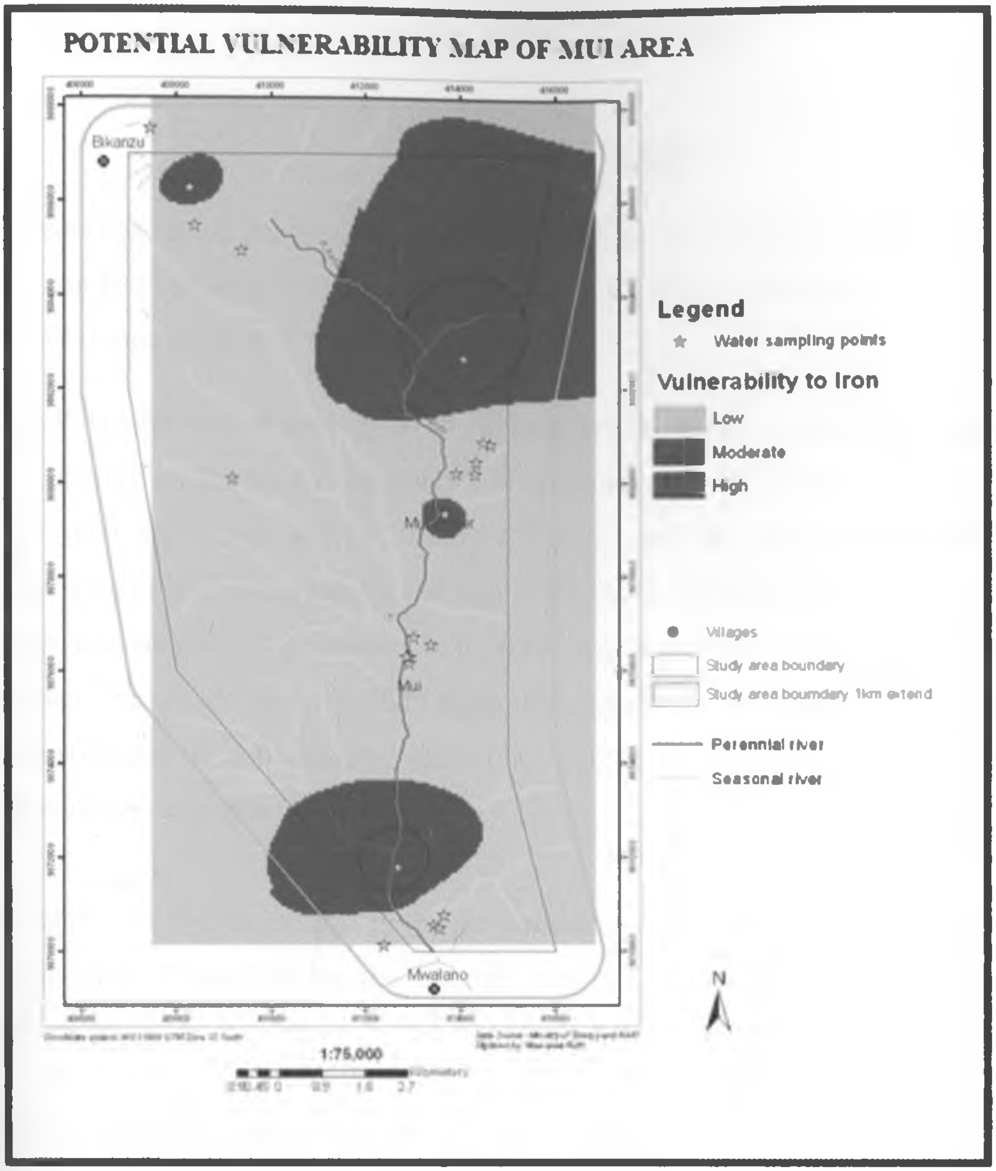

Figure 5.22: Potential vulnerability of Mui area based on water chemistry.

CHAPTER SIX

DISCUSSION

The area has varied concentration in the coal related pollutants both in the water and soils. This can be explained in terms of variation in the geology, geological structures, character of soils, topography and water flow regimes.

6.1.1 Potential role of geology of the area in transmission of coal related pollutants

The geology as shown by the gravity distribution map (Fig 5.1), the eastern part of the study area has lesser gravity values indicating the presence of the basement rocks; comprising of gneisses, granites and quartzites (MoE, 2002). This zone is characterized by lesser concentration of pollutants both in the water and soils. The south of the study area has less value of gravity indicating the presence of thick sediments which are unconsolidated like limestone, sandstone, clay and silt and is characterized by high concentration of pollutants.

The ability of the rocks to concentrate pollutants relates to their water holding potential which varies depending on the internal structure, mineralogy and ease of undergoing weathering.

6.1.1.1 Basement rocks

a. Gneisses

These are the oldest formation of the basin (Mathu and Tole, 1984). They are comprised of quartz and biotite predominantly (Plate 6.1). Being heterogeneous in a relatively hot weather of Mui basin, these rocks readily undergo insolation as evidenced by numerous fractures i.e. high secondary porosity. This ability makes them unable to retain water, both surface and underground hence low pollution risk as the water has low residual time in them to allow for contamination.

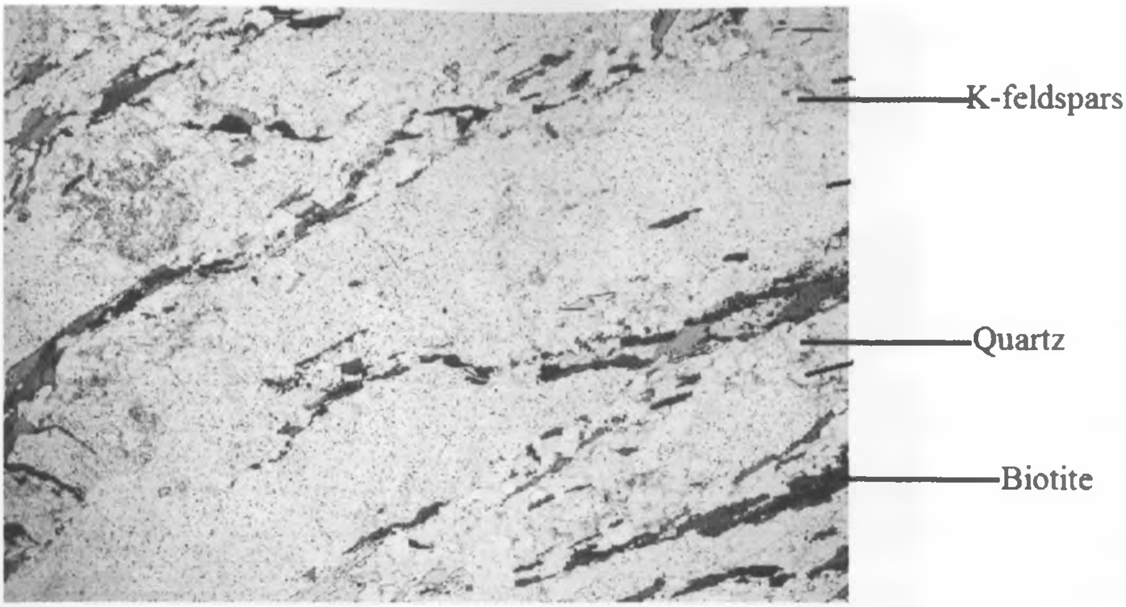

Plate 6.1: Photomicrograph of biotite gneiss; matrix has flakes of biotite and feldspars.

Additionally, due to their resistance to erosion, these rocks occupy the elevated grounds in the area ranging in altitude from 1700-1800 m above sea level (Key et al., 1989). This forces southward flow of water due to high specific yield consequently low pollution risk.

b. Granites

Granite is an equigranular rock with grain sizes of 2mm-7mm (Saltikoff et al., 1991). It consists of minerals like k-feldspars, plagioclase, mesoperthite and quartz with minor amphiboles and biotite. Furthermore, the interlocking textures (Plate 6.2) of the mineral grains and small flakes of biotite around the grain boundaries and shear planes hinders seepage of water in these rocks accounting to their low water potential as they form an impermeable face along which the water flows. Though essentially soils overlying such rocks need to have high concentration of pollutants, the reverse is true because these rocks weather to give rise to sandy soils which are also permeable hence no room for accumulation of water and by extension increasing risk of pollution.

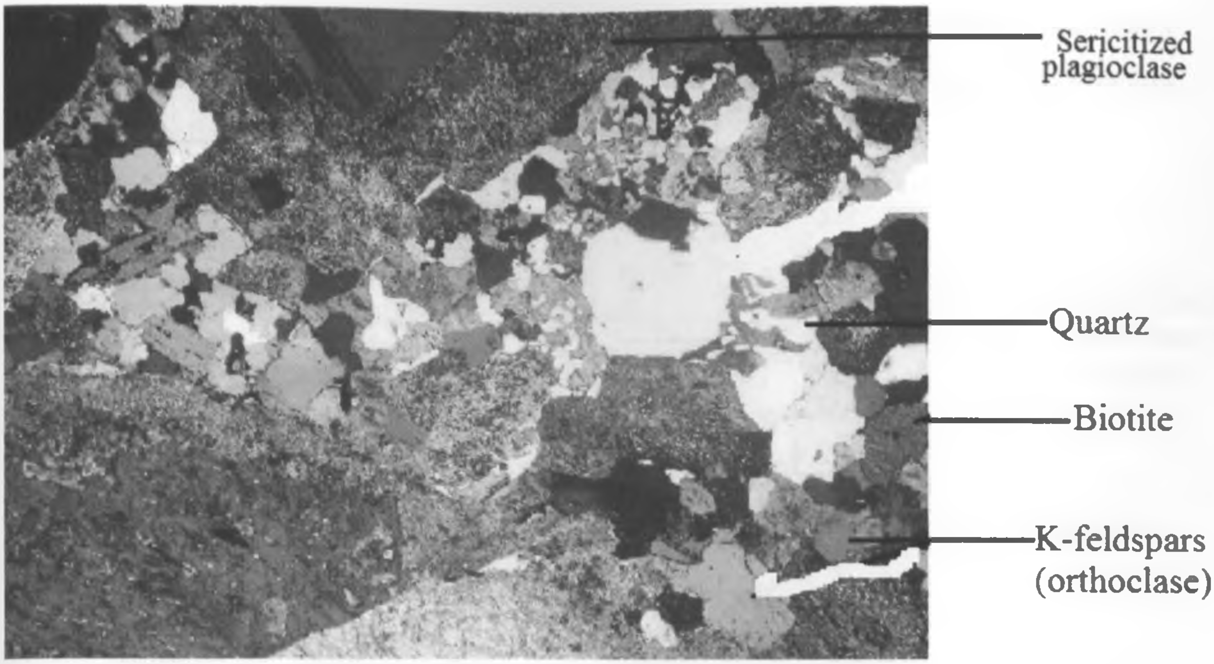

Plate 6.2: Photomicrograph of granitic rock consisting of k-feldspars, biotite and quartz.

c. Quartzites

These are metamorphosed rocks consisting of almost entirely quartz grains. The quartz having a hardness of 7 (Mohr hardness scale) are not easily eroded and hence have poor water storage capacity therefore low pollution rate as there is no humble time for water and pollutant interaction.

6.1.1.2 Sedimentary rocks

a. Sandstones

Sandstones, clastic in origin, underlay the entire central part of the study area. Their framework consists of quartz grains whose size range from 1/16 to 2mm. Their matrix consists of very fine material (Plate 6.3) with interstitial pore space between the frameworks of the grains. The pore space in a rock has a direct relationship to the porosity and permeability of the rock. Thus due to high porosity and permeability, these rocks tend to exhibit properties of sandy soils i.e. poor water retention capacity leading to a short residence time for pollutants meaning lesser risk of pollution. Though it is expected that the central part have low risk potential, this is not so due to cementing by secondary mineral, which forms after deposition and during burial of the sandstone, hence trapping the pollutants thereby increased chances of pollution.

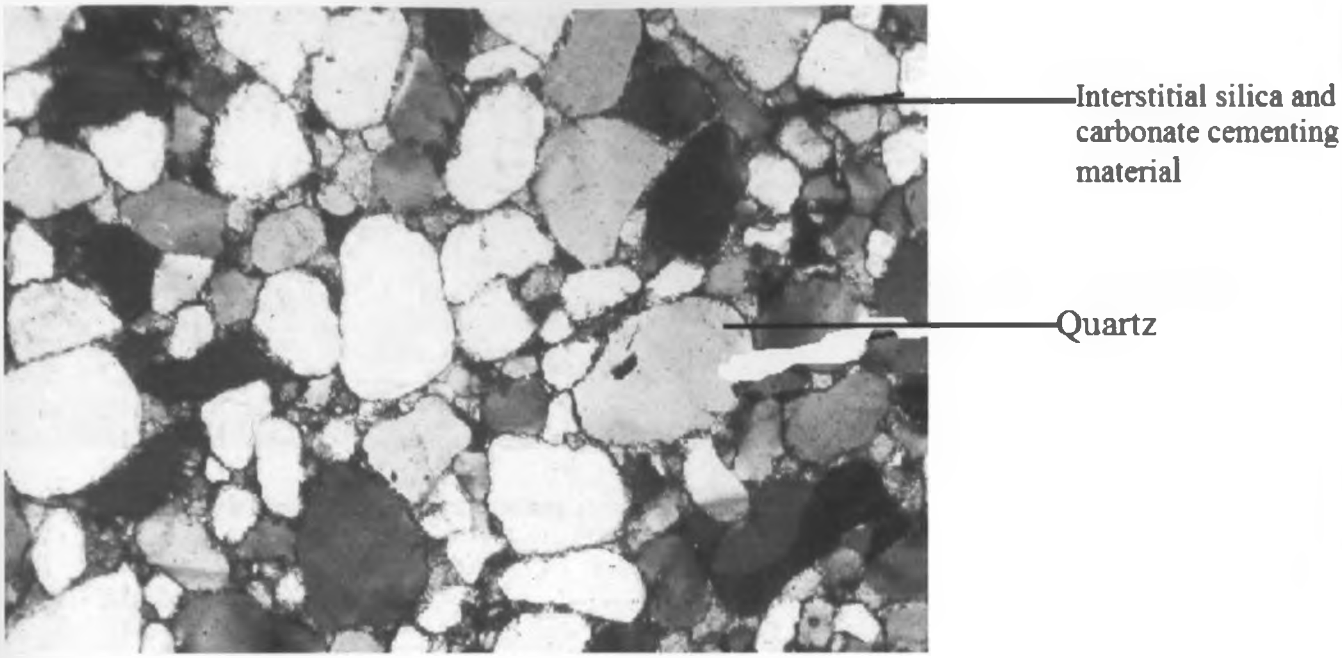

Plate 6.3: Photomicrograph of a poorly sorted sandstone.

b. Limestone

Limestone, a sedimentary rock composed largely of the minerals calcite and aragonite (Plate 6.5), characterize the area on the southwest of the Mui center. The solubility of this rock in water and weak acid solutions has lead to high permeability as surface water easily drains downward through joints in the limestone therefore channeling pollutants on the extreme south. This is a continuous process such that while draining the organic acid and pollutants through the soil slowly (over thousands or millions of years) these cracks will become enlarged due to dissolution of the calcium carbonate and carrying it away in solution thus tendency to transport large volumes of fluid carrying pollutants. In this case an immediate mitigation plan is needed in this area.

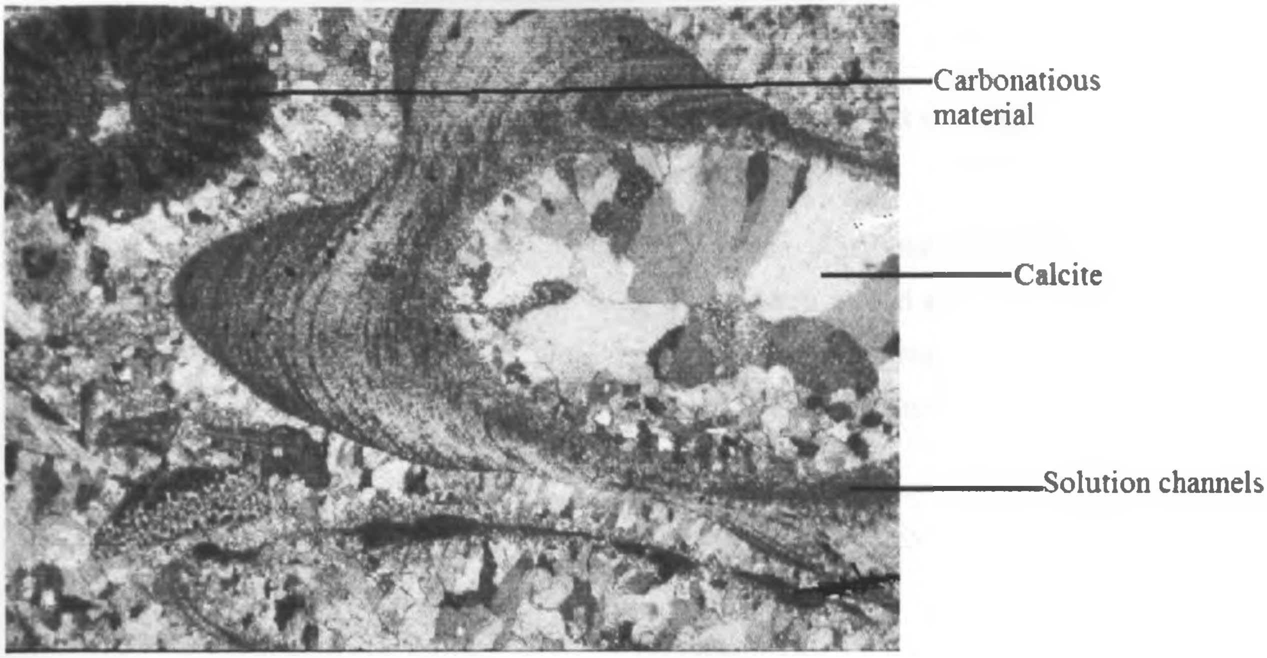

Plate 6.5: Photomicrograph of limestone.

c. Mudstone

Mudstone is a sedimentary rock whose original constituents are clays or muds. In the study area it under lays the entire extreme south (area with highest vulnerability). Their effect on pollution is in three sections i.e. its fine grains, fissility or parallel layering and presence of cracks or fissures. The fine grains (up to 0.0625 mm) provide a larger surface area for adsorption by pollutants. With increased pressure over time the platey clay minerals may become aligned with a subsequent appearance of fissility or parallel layering. These layers act as reservoirs for pollutants and shield them from harsh weather conditions (both chemical and physical) that could otherwise facilitate their oxidation to less harmful compounds. On the other hand, mudstone looks like hardened clay and depending upon the circumstances under which it was formed, it may show cracks or fissures, like a sun-baked clay deposit. However, these cracks are not continuous but just act as a cap reservoir for storage of fluid carrying pollutants.

6.1.2 Potential role of geological structures in transmission of coal related pollutants

The structures noted to contribute to transmission of coal related pollutants comprised of joints and fractures. Majorly, these structures occur on the gneisses and are interpreted to have resulted from tectonic stresses and strain in the rocks. These structures are observed as linear patterns on the gravity anomaly map and generally tend to have a trend in the north-south direction (Fig 6.1).

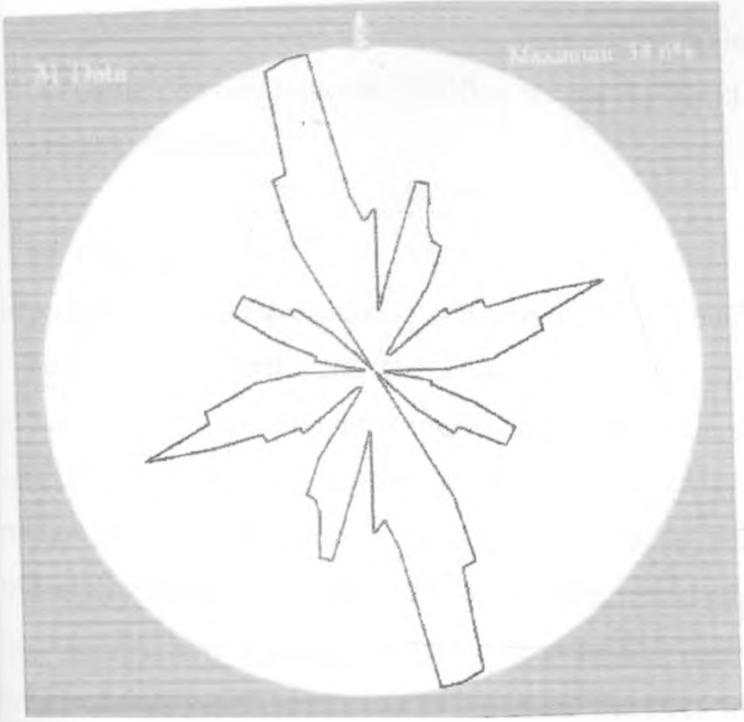

Fig 6.1 Rose diagram for trend of joints in the study area (MoE, 2002).

The figure reveals a dominant trend of the overall fracture system in the study area in the north-south, northeast-southwest and northwest-southeast direction. This is an indication of dominance of longitudinal joints that strike parallel to the strike direction of the rocks. In relation to dispersion of pollutants, these lineaments majorly direct the water to the south and as it is transmitted through the coal rich middle part it drains more coal related pollutants and hence high vulnerability of the southern side.

6.1.3 Potential role of soils in transmission of coal related pollutants

Mui basin is characterized by four soil types i.e. sandy soils, clay soils, silt and a mixture of clay and sand.

a) **Sandy soils**

The area overlain by them has the least potential due to them being coarse grained (particles diameter of about 0.0625mm) hence a small surface area for adsorption by the pollutants. High permeability gives them an almost zero water holding capacity i.e. water has a short residence time; not sufficient time to pose risks. Other properties like low consolidation and low shear strength makes them not vulnerable to collapse under heavy loads e.g. when overridden by machines used in large scale mining. On the other hand, the low swelling pressure indicates that they do not rapidly change volume on wetting hence not prone to flooding.

b) **Clay soils**

They characterize the area having vulnerability values ranging from medium to high. This is due to their properties like the ability to exchange ions which relates to the charged surface of clay minerals that comprise them. Here, all types of ions including organic molecules in solution get attracted to the surface of a clay particle or taken up within the structure of these minerals hence the high risk to pollution. Additionally, the low permeability hinders the higher rates of flow that would otherwise attenuate the pollutants. Clay minerals have a great affinity for water leading high swelling pressure. This makes them swell easily and may double in thickness when wet therefore vulnerable to flooding.

c) **Silt**

The silts have fine grain sizes of about 0.04mm hence have high surface area for adsorption by pollutants. It has the least permeability and highest swelling pressure thus prone to flooding. Its highest shearing and consolidation makes them very vulnerable to collapse and subsidence.

In this research, a simple classification of soil leaching potential was also used which involved three classes and seven subclasses. The low leaching potential soils were those with least capacity to attenuate pollutants and high leaching potential soils had the greatest potential (Table 6.1).

Table 6.1: Soil Leaching Potential classes of the study area.

Soil Leaching Potential	Category	Pollutant Transmission Characteristics	Classification of the area
High	H1	Readily transmit liquid discharges.	Northern part
	H2	Readily transmit a wide range of pollutants.	
	H3	Readily transmit non-adsorbed pollutants and liquid discharges and have some ability to attenuate adsorbed pollutants.	
	H4	Assumed to be readily transmit a wide range of pollutants.	
Intermediate	I1	Possibility to transmit a wide range of pollutants.	Central part
	I2	Possibility to transmit non-adsorbed pollutants and liquid discharges but are unlikely to transmit adsorbed pollutants.	
Low	L	Unlikely to transmit any pollutants	Southern part

The amount of pollutants noticeable in soils and their eventual degradation to other components is dependent upon the residence time within the soil zone which in turn is determined by the speed of pollutant movement through the soil and by how much of the pollutant remains in the non-mobile phase. These are determined by depth, duration and type of water logging, soil texture, permeable horizon and organic matter content.

The risk of water, in this case, to pollution is directly proportion to the depth, duration of stay of pollutants in the soil and water logging. Thick soil layers act as reservoirs for the pollutants, retaining them long enough and hence humble time to interact with the water. Seasonal soil water logging, caused by fluctuation in groundwater levels within the soil profile, tends to carry the pollutants through the depth and depositing pollutants in the water at different levels. Such soils are rated as having the highest risk and are classified as High (H_1) leaching potential (see Table 6.1).

Soil texture on the other hand influence the volume of water retained by the different types of soils (Adams and Foster, 1992). For example sandy soils, which dominate the northern part of the study area, have relatively small amounts of water held in them and most pollutants in them are in the mobile phase. With that, the pollutants are likely to leach quickly out of the soil profile due to the naturally high permeability. As a result, a subclass (H_2) (see Table 6.1) has been established in the High Leaching potential class to cater for sandy soils (Addiscot et al, 1991). Conversely, soils with a high silt and/or clay content are able to retain relatively large amounts of water, most of which is non-mobile. Water and pollutants leach through the soil slowly, giving more time for degradation to occur or retained in their original form. These soils are grouped as Intermediate (I1) Leaching potential (Alley, 1993).

Low permeable subsoils, which are clay-rich, act as significant barriers to vertical water movement and hence causes seasonal water logging and consequent accumulation of pollutants in the soil layers above. Where these subsoils extend below 1m depth the downward movement of pollutants is strictly limited (Chapel, 1993). Such soils are classified as Low Leaching potential (L) as shown in Table 6.1.

Organic matter content affects the ability of a soil to adsorb pollutants. According to Alley, (1993), this depends upon its cation exchange capacity which, under temperate soil forming conditions, depends mainly on organic matter and clay contents. Thus, the lower the soil organic matter and clay contents, the lower the ability of the soil profile to attenuate pollutants leading to high concentration of the pollutants in the water sources ike around the central part of the study area.

5.1.4 Potential role of surface topography in transmission of coal related pollutants

Slope of this area of study is characterized by minor hills, gentle slopes and flat terrain. The hills, located on the north, leads to undulations that tend to channel the water outhwards hence low water retaining capacity accompanied by low pollution potential. The central part is gentle slopping i.e. slope at about 5%. This implies that the area has adequate hydraulic gradient that just like the extreme south, it channels the water south wards. However due to reduced gradient, the water tend to move at a much lower velocity hence allowing for enough time for pollution to occur bearing in mind that this is the coal zone. On reaching the extreme south, there is drastic reduction in the hydraulic gradient hence no further movement but rather accumulation of water together with the pollutants herefore much pollution.

5.1.5 Potential role of surface water flow system in transmission of coal related pollutants

The surface flow system has a general north- south although tectonic fracture complicate groundwater flow patterns. This general movement of water is fairly typical of an upland setting within a plateau. Stress relief fracturing near the surface establishes a relatively shallow water table aquifer that responds quickly to precipitation events and directs water flow laterally towards the adjacent gentle slopping areas on the south of the study area. This flow tend to carry with it pollutants from the north of the study area through the center. Due to the flat terrain characterizing the southern part of the study area, the water carrying the pollutants have lesser chance of moving hence concentrating pollutants in the south of the study area.

6.1.6 Potential role of ground water flow system in transmission of coal related pollutants

Just like surface water, ground water has a general flow in the north-south trend. On the northern part (weathered zone), the rapid movement of water leads to a short residence time of pollutants hence minimum interaction with both soils and water thus lesser risk of pollution than does groundwater within the southern part of the study area.

Although groundwater within the weathered zone generally flows in accordance with topography, there is significant vertical leakage to the underlying strata, primarily through joints. This vertical leakage is further enhanced by the presence of faults and major fracture zones. Where these percolating rivers reach strata of contrasting vertical conductivities, additional flow zones are established at depth. Flow within this deeper aquifer is again directed laterally but is more controlled by structural features like joints, faults and fracture zones. A stratigraphic variation in the geology also influences the flow i.e. each of these rocks that are established at depth will leak to the underlying strata, but the volume of such leakage will gradually diminish as well the occurrence of joints through which the groundwater flows.

6.2 Coal mining and handling plan

It is evident that both open cast and underground mining will be used in the area; with the former preferred where coal seams are close on the surface while the later where seams are deeper.

In designing an open cast mine, the reservoir for coal washery fines (which are often significantly enriched in pyrite compared to the coal itself) must be buried deeply on the extreme north, an area with massive and strong basement rocks. The reservoir should be however be lined with an impermeable material resistant to chemicals so as to hinder seepage of the contents of the washery considering that these rocks are prone to faulting. Furthermore, the water level in this area being low (averagely at 15m below surface) the reservoir must be emplaced low down in the void, below the eventual mining water table level. In case where the water level falls sharply after emplacement of a reservoir, artificial pumping of the water must be done to ensure a high water table position within the backfill so as to prevent water pollution when water flows from the reservoir to the surrounding.

Basing on the value of the shear strength, it is apparent that the southern soils are more likely to fail. In this case when setting up a reservoir on this site, ground stability requirements should be met by deliberately plugging any connections with mass concrete plugs when starting to mine or by leaving un mined pillars of rock between the highwall and any nearby old workings as mining progresses.

Opencast sites should be 'advance dewatered' by means of pumping boreholes especially around Mui center where water levels are as low as 10m below the surface. This will be towards minimization of water contact with recently-oxidized materials within the site and avoidance of entrainment of suspended solids in the water. Owing to the low gradient in this area, sump pumping within the site will be the only realistic option, but here again area on the southwest of the Mui center is recommended as the possible site for the sump due to the presence of massive rocks i.e. the gneisses but should be lined with an impermeable sheet possibly a water proof nylon paper to prevent seepage.

In highly permeable soils especially on the entire north of the study area, compaction of backfill should be done to reduce permeability. In case of the presence of solution channels in areas with limestone e.g. on the southeast of Mui center, the backfill should be capped with clay to help minimize infiltration, thus arresting pollutant transport. During mining, a follow up by partial capping of pyritic spoil, where pyrite oxidation is known (from borehole sampling) to be occurring, should be done so as to reduce the overall pollutant load leaving a body of coal mine waste. If the backfill is predicted to decant at surface, it ought to be manipulated to the final restoration contours so that a passive treatment wetland system can be located strategically where it can easily capture toe leachates. After the entire process of establishing a mine is over, precautionary monitoring of post-restoration water table recovery and associated changes in water quality (surface and subsurface) in the entire area be undertaken during the after-care period (and beyond, in the event that residual risks emerge rather than vanish).

Underground mining targets deep seated coal seams. The process of mining has no direct effect on land surface as it is underground and also is much deeper than the level of existence of the water. However, the major task is to ensure stability of the overlying ground to prevent subsidence resulting from removal of materials below. The description of interim and permanent stabilization practices should including site-specific scheduling of the implementation of the practices. The initial site plans should ensure that existing vegetation, for example on the entire southern part, is preserved where attainable and that disturbed portions of the site are stabilized. Methods like temporary seeding, permanent seeding, mulching, geo-textiles, sod stabilization, protection of trees, preservation of mature vegetation are appropriate considering the low gradient in this area. Where the ground continues to show instability even with all natural methods of stabilization, artificial pillars from the roof to the floor of the mine should be constructed.

Throughout the process of underground mining, flow of water to faults e.g the Ikoo fault on the southwest and minor ones on the southeast of Mui center should be avoided but instead it should be stored at proposed sump that is properly lined with an impermeable sheet on the southeast of Mui area. The channel to the sump should be equipped by practices like silt fences, earth dikes, drainage swales, sediment traps and check dams to prevent siltation and eventual filling of the sump before being fully utilized. Subsurface drains, pipe slope drains and level spreaders should be installed to aid in the movement of materials owing to the fact that this area is low lying.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The present study has enabled an assessment of potential vulnerability of water resources to pollution from coal mining in Mui basin (sedimentary area) through a Geological and structural assessment. This is in recognition that the chemical data of soils and water provided a baseline physical-chemical conditions to map areas that are vulnerable. This was further augmented by the analysis of the geology through gravity method, geotechnical study of the physical properties of soils, analysis of the DEM and hydrogeological regime of the area which helped to discern factors that can enhance transmission of the coal related pollutants.

Geology, geological structures, slope of the ground and water flow system has proved to influence the direction of flow of water hence the pollutants. Pollution in this case is depended on the amount of time the water interacts with the pollutant. Geology i.e. the rocks, impart the influence through their textural structures and mineralogy which influences their ease to weathering and dissolution. For example, intergranular structures as in granites make the rocks impermeable hence hindered percolation. The gneisses, on the other hand, being coarse grained and occupy elevated grounds have high specific yield hence faster southward movement of water under the influence of gravity. With mineralogy, rocks with high percentage of quartz and feldspars are hard; not easily eroded by water (e.g. granites) hence no percolation but water movement on their surface southwards. Geological structures act as channels for passage for water. The observed structures have a general trend of north-south and northwest-southeast, which allow the water to be directed southwards and as a consequence carry with it the pollutants.

On soils, sandy soils, which result from the weathering of basement rocks, have properties that expose them to low risk of pollution resulting from short periods of water storage. On the contrary, the silts have the highest potential due to their physical properties that favor storage of longer period and the risk to collapse on heavy weights. Clay soils have a lesser potential risk second after sands as their properties are a little bit favorable to storage of water compared to sands. The properties of a mixture between clays and sand have properties intermediate between sandy and clays soils.

Topography in the study area is characterized by hills, gentle slopping and flat areas. The flat areas on the south tend to receive water that move through the coal zone which carries with it the pollutants hence high risk. The gentle slope (about 5%) have a moderate potential as the water don't reside there long enough due to the sufficient gradient that channels it southwards. The hills on the north have low water retaining capacity hence low residual time by pollutants hence low risk. The topography also influences ground water flow pattern where there is a general north- south flow.

7.2 Recommendations

The research has shown that the water resources in the study area are at risk of pollution. Considering that the research didn't consider input of weather conditions (sampling only during the dry season) such like a study should be conducted during the rainy season in the area so as to recommend for variation in the design if any. Besides that, with the start of actual mining, a similar study should be conducted from time to time in order to establish any changes due to changing ground conditions considering that the coal located area is highly unstable.

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APPENDICES

Appendix 1: Length and direction of orientation of joints (after MoE, 2004).

Length of joints (m)	Direction of orientation
0.5	11^0NE
1.0	6^0NE
5.0	15^0NW
4.0	7^0NE
4.0	11^0NW
1.0	VERTICAL
2.0	50^0NW
2.0	60^0NW
3.0	11^0NW
0.2	9^0NE
0.5	18^0NE
0.3	20^0NW
0.1	30^0NE
1.0	VERTICAL
0.5	VERTICAL
1.0	40^0NW
1.0	35^0NW
3.0	18^0NE
0.3	VERTICAL
0.1	30^0NE
1.0	40^0NW
1.0	50^0NW
0.1	VERTICAL
1.2	VERTICAL
0.5	18^0NW
0.1	24^0NW
0.4	35^0NW
1.0	40^0NW
0.2	58^0NW
1.1	35^0SW
0.4	30^0NW

APPENDIX: 2: Soil data

Station No.	Eastings	Northings	Soil types	Grain sizes	Sulfur(mg/L)	Iron(mg/L)	pH
1	406510.00	9887085.00	Sand	Coarse	1.00	1.00	9.00
2	409563.00	9886284.00	Sand	Coarse	1.00	1.00	9.00
3	412065.00	9887110.00	Sand	Coarse	1.00	2.00	9.00
4	415318.00	9886534.00	Clay and Sand	Medium	6.00	6.00	9.00
5	407211.00	9885383.00	Clay	Medium	6.00	6.00	8.00
6	410364.00	9882956.00	Clay and Sand	Medium	5.00	6.00	9.00
7	410364.00	9882956.00	Clay	Medium	7.00	6.00	8.00
8	413717.00	9883056.00	Clay	Medium	6.00	7.00	8.00
9	415043.00	9882030.00	Clay	Medium	6.00	6.00	8.00
10	406939.00	9878728.00	Sand	Coarse	4.00	4.00	9.00
11	414452.00	9886308.00	Sand	Coarse	4.00	4.00	9.00
12	412432.00	9885733.00	Sand	Coarse	5.00	4.00	9.00
13	411259.00	9885374.00	Sand	Coarse	5.00	5.00	9.00
14	410324.00	9885820.00	Clay and Sand	Medium	7.00	7.00	8.00
15	415343.00	9870910.00	Silt	Fine	9.00	9.00	8.00
16	412933.00	9870193.00	Silt	Fine	9.00	9.00	7.00
17	412820.00	9869216.00	Clay	Fine	9.00	9.00	7.00
18	412391.00	9870122.00	Clay	Medium	6.00	7.00	8.00
19	408305.00	9886286.00	Sand	Coarse	4.00	4.00	8.00
20	408400.00	9885478.00	Sand	Coarse	3.00	4.00	8.00
21	409399.00	9884944.00	Sand	Coarse	2.00	2.00	9.00
22	407478.00	9887552.00	Sand	Coarse	3.00	3.00	9.00
23	414086.00	9882652.00	Clay	Medium	6.00	6.00	8.00
24	414502.00	9880856.00	Silt	Fine	9.00	9.00	8.00
25	414639.00	9880820.00	Silt	Fine	8.00	9.00	7.00
26	414331.00	9880204.00	Silt	Fine	8.00	9.00	7.00
27	414317.00	9880174.00	Silt	Fine	8.00	9.00	7.00
28	409193.00	9880102.00	Clay	Medium	6.00	7.00	8.00
29	412429.64	9875027.67	Silt	Fine	8.00	8.00	8.00
30	414044.21	9878772.67	Clay	Fine	4.00	3.00	8.00
31	413973.49	9871080.57	Clay	Fine	8.00	8.00	8.00
32	412070.86	9871256.91	Silt	Fine	8.00	8.00	9.00

APPENDIX 2: Cont.

Station No.	Eastings	Northings	Tt-Alkalinity(mg/L)	Permeability(cm/sec)	Shear strength(kN/m2)	Consolidation(1/100mm)
1	406510.00	9887085.00	5.00	9.00	2.00	1.00
2	409563.00	9886284.00	5.00	9.20	2.10	1.00
3	412065.00	9887110.00	5.00	9.70	1.96	1.40
4	415318.00	9886534.00	6.00	8.30	1.70	1.70
5	407211.00	9885383.00	6.00	9.50	1.90	1.10
6	410364.00	9882956.00	6.00	9.60	1.90	1.30
7	410364.00	9882956.00	6.00	7.90	1.70	1.78
8	413717.00	9883056.00	6.00	7.80	1.73	1.70
9	415043.00	9882030.00	6.00	7.30	2.20	1.30
10	406939.00	9878728.00	5.00	9.10	2.10	1.40
11	414452.00	9886308.00	3.00	9.00	2.00	1.40
12	412432.00	9885733.00	6.00	9.00	2.00	1.20
13	411259.00	9885374.00	6.00	9.50	1.97	1.30
14	410324.00	9885820.00	6.00	6.40	1.56	2.00
15	415343.00	9870910.00	9.00	6.50	1.50	2.10
16	412933.00	9870193.00	9.00	6.30	1.59	2.00
17	412820.00	9869216.00	10.00	6.30	1.50	2.00
18	412391.00	9870122.00	6.00	9.60	1.97	1.30
19	408305.00	9886286.00	6.00	9.80	2.00	1.20
20	408400.00	9885478.00	6.00	9.80	2.10	1.10
21	409399.00	9884944.00	5.00	9.70	2.00	1.10
22	407478.00	9887552.00	5.00	7.50	1.69	1.30
23	414086.00	9882652.00	7.00	6.60	1.50	2.00
24	414502.00	9880856.00	9.00	6.60	1.53	2.20
25	414639.00	9880820.00	9.00	6.60	1.59	2.10
26	414331.00	9880204.00	9.00	6.70	1.53	2.00
27	414317.00	9880174.00	9.00	7.30	1.77	1.34
28	409193.00	9880102.00	7.00	6.30	1.54	2.00
29	412429.64	9875027.67	7.00	7.20	1.76	1.40
30	414044.21	9878772.67	9.00	6.50	1.59	2.30
31	413973.49	9871080.57	7.00	6.20	1.53	2.00
32	412070.86	9871256.91	7.00	6.30	1.56	2.10

33	413253.90	9871710.45	7.00	6.90	1.57	2.00
34	414295.86	9879319.58	7.00	6.20	1.52	2.00
35	410946.77	9879315.05	7.00	6.10	1.53	2.10
36	412996.37	9877723.81	8.00	6.90	1.55	2.00
37	413146.96	9876281.29	7.00	8.90	1.79	1.20
38	410940.12	9876343.26	7.00	8.90	1.76	1.30
39	413773.95	9882679.88	8.00	6.50	1.56	1.99
40	412996.37	9877723.81	7.00	9.00	2.00	1.00
41	414078.31	9881620.64	9.00	7.40	1.70	1.30
42	414733.16	9880517.17	8.00	7.50	1.73	1.40
43	414043.77	9878772.34	7.00	7.30	1.72	1.33
44	412736.80	9877244.65	8.00	7.50	1.76	1.36
45	413145.07	9876281.29	7.00	6.00	1.50	2.00
46	413253.90	9871710.45	7.00	6.20	1.50	2.10
47	412001.08	9875757.68	7.00	6.20	1.50	2.01
48	412073.40	9875737.47	7.00	6.30	1.53	2.00
49	413871.19	9872508.29	7.00	9.00	2.02	1.20
50	410940.12	9876343.26	7.00	6.10	1.54	2.00
51	412996.37	9877723.81	7.00	6.20	1.55	2.30
52	410950.71	9878323.83	7.00	7.40	1.78	1.20
53	414295.86	9879319.58	8.00	7.40	1.75	1.40

APPENDIX 3: WATER DATA

Sample No.	Eastings	Northings	pH	Tt. Alkalinity(mg/L)	TSS(mg/L)	Turbidity(mg/L)	TDS(mg/L)	Sulfates(mg/L)
693	412391	9870122	8.31	892.00	10.00	0.20	1624.40	54.40
694	408400	9885478	7.98	256.00	10.00	1.70	449.50	21.11
695	408305	9886286	7.71	156.00	70.00	116.30	197.78	22.28
696	407478	9887552	7.61	328.00	0.00	1.10	2281.60	39.89
697	409399	9884944	7.91	248.00	10.00	0.30	460.66	104.86
698	409193	9880102	7.79	602.00	0.00	0.10	2188.60	296.57
699	413452	9870540	7.49	254.00	10.00	0.20	720.44	94.86
700	413574	9870482	7.53	296.00	0.00	0.40	587.14	55.29
701	413671	9870766	7.83	482.00	10.00	0.20	1612.00	13.71
702	412692	9871790	7.66	256.00	20.00	2.10	368.28	9.08
703	412940	9876285	7.67	624.00	0.00	0.10	1098.02	47.49
704	412888	9876284	7.66	562.00	30.00	9.40	1207.76	38.29
705	412933	9876144	8.00	548.00	0.00	0.90	1000.68	45.11
706	413693	9879336	7.46	464.00	10.00	18.80	1144.52	140.86
707	413921	9880204	7.50	460.00	10.00	0.60	1401.20	144.28
708	414317	9880174	7.34	362.00	0.00	0.30	749.58	156.57
709	414639	9880820	7.59	674.00	0.00	0.20	2721.80	211.43
710	414331	9880434	7.71	310.00	0.00	1.00	905.82	112.43
711	414502	9880856	7.29	504.00	60.00	12.00	6497.60	740.00
712	414086	9882652	7.36	202.00	270.00	137.30	545.60	4.14
713	416806	9890454	7.86	84.00	0.00	0.30	582.80	54.71
714	412867	9876276	7.71	480.00	10.00	2.70	777.48	129.28
715	413391	9876542	7.25	366.00	10.00	2.50	884.12	81.71
716	413038	9876704	7.62	656.00	30.00	20.10	1984.00	72.43

APPENDIX 3: Cont.

Sample No.	Northings	Eastings	Elevation(m)	WSL(ft)	Tt.Hardness(mg/L)	Iron(mg/L)	Sulfur(mg/L)
693	370412391	9870122	663.00	30.00	56.00	0.03	10.88
694	370408400	9885478	763.00	65.00	220.00	0.27	4.22
695	370407478	9887552	778.00	32.00	222.00	1.44	4.46
696	370409399	9884944	777.00	65.00	1300.00	0.03	7.98
697	370409193	9880102	758.00	62.00	236.00	0.03	20.97
698	370413452	9870540	667.00	40.00	416.00	0.03	59.31
699	370413574	9870482	667.00	60.00	258.00	0.03	18.97
700	370413671	9870766	663.00	65.00	206.00	0.03	11.06
701	370412926	9876292	685.00	35.00	474.00	0.03	2.74
702	370412940	9876285	693.00	33.00	168.00	2.86	1.82
703	370412888	9876284	685.00	33.00	226.00	0.03	9.50
704	370412933	9876144	688.00	22.00	176.00	0.25	7.66
705	370410841	9876630	713.00	63.00	196.00	0.03	9.02
706	370413693	9879336	697.00	35.00	298.00	0.73	28.17
707	370413921	9880204	718.00	33.00	226.00	0.03	28.86
708	370414317	9880174	698.00	35.00	228.00	0.03	31.31
709	370414639	9880820	705.00	45.00	348.00	0.03	42.29
710	370414330	9880482	707.00	35.00	234.00	0.03	22.49
711	370414331	9880434	708.00	68.00	2250.00	0.08	148.00
712	370414502	9880856	708.00	40.00	248.00	3.67	0.83
713	370414086	9882652	727.00	30.00	216.00	0.03	10.94
714	370415510	9885442	788.00	70.00	142.00	0.03	25.86
715	370412867	9876276	686.00	35.00	222.00	0.03	16.34
716	370413391	9876542	685.00	30.00	390.00	0.25	14.49

APPENDIX 4: GRAVITY READINGS

Station No.	Time(Hrs)	Northings(m)	Eastings(m)	Altitude(m)	Observed Gravity(mGals)
Mui BST1	8.26	412047	9876454	698.00	1055.18
1	8.38	412251	9875924	693.00	1057.18
2	8.44	412218	9875342	687.00	1058.15
3	8.49	412204	9874768	690.00	1059.17
4	8.54	412194	9874302	691.00	1059.18
5	8.59	412177	9873818	695.00	1058.79
6	9.06	412208	9873212	683.00	1061.37
7	9.10	412068	9872692	676.00	1062.21
8	9.17	412031	9872108	676.00	1062.47
9	9.20	411994	9871436	677.00	1063.12
10	9.27	412038	9871012	674.00	1061.80
11	9.33	412035	9870658	682.00	1061.52
12	9.40	412674	9870516	671.00	1067.89
BST1	9.53				1055.22
13	10.06	412332	9876902	698.00	1057.55
14	10.12	412367	9877444	693.00	1057.83
15	10.19	412591	9877774	698.00	1058.85
16	10.30	412795	9876160	685.00	1061.66
17	10.38	413051	9876714	691.00	1062.28
18	10.47	413445	9876720	679.00	1065.90
19	10.53	413597	9876662	685.00	1066.49
20	11.02	413915	9876874	691.00	1067.46
BST1	11.30				1055.21
21	11.41	412563	9875022	683.00	1061.08
22	11.53	412970	9874934	681.00	1063.93
23	12.05	413453	9875108	680.00	1067.83
24	12.14	413706	9875200	684.00	1069.94
25	12.42	411842	9874568	685.00	1058.08
BST1	12.52				1055.20
26	13.12	411560	9874396	684.00	1057.44
27	13.24	411174	9874040	683.00	1058.64
28	13.37	410757	9873862	697.00	1057.90

BST1	14.07		
29	14.15	412101	9875982
30	14.27	412581	9871930
31	14.35	413074	9871988
32	14.42	413669	9871833
33	14.55	411455	9870716
34	15.00	410953	9870494
35	15.05	410085	9870256
36	15.19	411329	9871794
37	15.27	410808	9871880
BST1	15.45		
38	15.55	411079	9876068
39	16.00	410611	9875868
40	16.05	410121	9875606
41	16.11	409896	9875124
42	16.17	409667	9874666
43	16.29	410954	9876786
44	16.35	410569	9877048
45	16.42	410555	9877476
BST1	16.50		
46	16.55	411575	9876882
47	17.00	411199	9877166
48	17.04	410720	9877494
49	17.09	410526	9877944
50	17.14	410395	9878414
51	17.19	410160	9878912
52	17.24	409746	9879234
53	17.27	409410	9879618
54	17.33	409207	9880068
55	17.40	409207	9880546
56	17.44	40913	9881032
57	17.53	408860	9881554
BST1	18.09		
BST2	7.57	409161	9880232

	1055.17
698.00	1056.05
717.00	1064.63
676.00	1066.78
670.00	1066.28
691.00	1057.93
692.00	1055.39
679.00	1051.95
684.00	1059.69
695.00	1055.86
	1055.15
703.00	1053.96
709.00	1052.30
700.00	1052.80
697.00	1053.86
700.00	1052.27
715.00	1051.24
708.00	1049.67
713.00	1049.42
	1055.15
707.00	1053.96
706.00	1053.33
712.00	1050.29
703.00	1050.86
711.00	1050.17
712.00	1048.25
723.00	1046.76
725.00	1045.48
712.00	1044.86
731.00	1054.72
730.00	1044.35
736.00	1043.63
	1055.19

58	8.05	408695	9882184	738.00	1044.07
59	8.10	408996	9883092	739.00	1042.21
60	8.15	408762	9883602	750.00	1040.17
61	8.20	408464	9884090	756.00	1039.17
62	8.25	408164	9884440	757.00	1038.72
63	8.29	408174	9884956	767.00	1037.87
64	8.35	408369	9885492	761.00	1036.40
65	8.40	408829	9886006	766.00	1035.65
66	8.45	408296	9886486	768.00	1035.69
67	8.48	408576	9886828	775.00	1033.26
68	8.54	409092	9886768	766.00	1033.41
69	8.58	409572	9886464	768.00	1035.28
BST2	9.17				1044.56
70	9.30	410086	9886168	760.00	1036.94
71	9.37	410563	9886079	764.00	1039.43
72	9.40	411066	9886228	748.00	1042.23
73	9.45	411612	9886272	748.00	1043.20
74	9.48	412076	9886230	748.00	1045.15
75	9.54	412611	9886132	740.00	1048.12
76	9.58	413057	9885824	729.00	1051.91
77	10.02	413444	9885534	742.00	1054.84
78	10.07	414024	9885398	744.00	1058.52
79	10.12	414504	9885432	763.00	1057.81
80	10.16	414977	9885554	776.00	1054.64
81	10.21	415386	9885534	780.00	1054.44
82	10.27	415268	9884910	769.00	1056.51
83	10.32	415179	9884484	767.00	1056.79
84	10.39	414967	9883992	743.00	1061.88
BST2	10.59				1044.62
85	11.06	409939	9879830	721.00	1046.03
86	11.10	410387	9880060	712.00	1048.86
87	11.15	410886	9880074	712.00	1050.33
88	11.20	411355	9879764	711.00	1051.87
89	11.25	411833	9879574	701.00	1052.95

90	11.29	412321	9879668	706.00	1053.91
91	11.39	412349	9879848	699.00	1056.39
92	11.46	413332	9880012	703.00	1057.87
93	11.51	413786	9880073	703.00	1058.81
94	11.59	414259	9880548	705.00	1063.02
95	12.10	414401	9880914	702.00	1064.34
96	12.15	414400	9881532	711.00	1064.16
97	12.20	414380	9881988	714.00	1062.80
98	12.25	414556	9882450	717.00	1063.21
99	12.28	414666	9883032	727.00	1062.56
100	12.33	414699	9883636	726.00	1063.06
BST2	12.50				10444.64
101	13.03	408866	9885118	757.00	1037.03
102	13.10	409256	9885008	773.00	1037.71
103	13.15	409848	9884730	746.00	1039.34
104	13.19	410254	9884246	743.00	1041.85
105	13.23	410594	9883904	742.00	1043.52
106	13.28	410883	9883416	736.00	1044.95
107	13.33	411163	9882902	735.00	1046.49
108	13.37	411397	9882486	726.00	1047.72
109	13.43	411833	9882162	728.00	1049.40
110	13.47	412242	9881772	714.00	1051.17
111	13.51	412409	9881316	735.00	1051.90
112	13.56	412846	9880940	711.00	1054.26
113	14.02	413371	9880570	702.00	1056.93
114	14.07	413606	9880064	705.00	1058.26
BST2	14.25				1044.64
BST1	14.38				1055.31
115	14.47	412670	9874390	684.00	1062.25
116	14.55	412971	9874209	679.00	1064.14
BST1	15.09				1055.29