Spatial Multi Criteria Based Landfill Site Selection for Disposal of Petroleum Waste in the Shama Ahanta Area of Ghana

By

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(BSc. (Hon.) Geomatic Engineering, UMaT)

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Thesis submitted to the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana in partial fulfilment of the requirements for the degree of Master of Science in Environmental Resource Management,

DECLARATION

I hereby declare that this submission is my own work towards MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Disclaimer

This document describes work undertaken as part of a programme of study at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi – Department of Materials and Metallurgical Engineering. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

Shortage of land for waste disposal and inappropriate landfill site is one of the biggest problems in most of large urban areas. Therefore more efforts are needed to overcome this problem. Most of the landfill sites are selected randomly, and waste is burned and not treated, which impacts nature and human. The main aim of this research is to determine a suitable Petroleum Landfill Site (PLS) with less impact on environment. In this research, a potential site for an appropriate area for the Shama Ahanta Area was determined by using Geographic Information System (GIS) as a tool to aid the decision making process. To achieve this purpose, thematic layers and different tabular data such as topography, land use, roads network, ground and surface water, infrastructure, and urban areas were collected from different institutions and governmental agencies. Thematic maps were used to create the suitability map for the area and the result was compiled to the buffer zones around sensitive areas. By using multi-criteria analysis, a candidate site was allocated taking into consideration the sensitive areas in order to find out the best location for the anticipated PLS.

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CHAPTER 1

INTRODUCTION

1.1 Background

The petroleum industry, which conducts all exploration and production activities, provides essential petroleum products that are used as transportation fuels, electrical power generation, space heating, medicine, and petrochemicals. These uses of petroleum are major contributors to our present standard of living. The activities of finding and producing petroleum, however, can impact the environment, and the greatest of these arises from the release of wastes into the environment. Wastes are generated from a variety of activities associated with petroleum production. These wastes fall into the general categories of produced water, drilling waste and associated waste (Reis, 1996).

Produced water virtually always contains impurities, and if present in sufficient concentrations can adversely impact the environment. These impurities include dissolved solids (primarily salt and heavy metals), suspended and dissolved organic materials, formation solids, hydrogen sulphide, and carbon dioxide (Reis, 1996). Drilling wastes include formation cuttings and drilling fluids. Water based drilling fluids may contain viscosity control agents (e.g., clays), density control agents, (e.g., barium sulphate, or barite), deflocculants, (e.g., chrome-lignosulfonate or lignite), caustic soda 5(sodium hydroxide), corrosion inhibitors, biocides, lubricants, lost circulation materials, and formation compatibility agents. Oil-based drilling fluids also contain a base hydrocarbon and chemicals to maintain its water-in-oil emulsion. The most commonly used base hydrocarbon is diesel, followed by less toxic mineral and synthetic oils. Drilling fluids typically contain heavy metals like barium, chromium, cadmium, mercury, and lead. These metals can enter the system from materials added to the fluid or from naturally occurring minerals in the formations being drilled through. These metals, however, are not typically bioavailable. Associated wastes are those other than produced water and drilling wastes. Associated wastes include the sludge and solids that collect in surface equipment and tank bottoms, pit wastes, water softener wastes, scrubber wastes, stimulation wastes from fracturing and acidizing, wastes from dehydration and sweetening of natural gas, transportation wastes, and contaminated soil from accidental spills and releases.

In an evolving climate of environmental, legislative and financial pressures, the industry has had to adopt new principles and implement stricter controls in environmental management systems. At the same time, pressure from public opinion and environmental groups have slowly brought waste management to the attention of oil companies as a serious issue separate from the environmental damage caused by spills. It was not until the 1990s that waste management became a key environmental issue of concern within the oil and gas Exploration and Production industry (Webster, 2012).

Effective and responsible waste management may be accomplished through hierarchical application of the practices of source reduction, reuse, recycling, recovery, treatment and responsible disposal. After all practical source reduction, reuse, recycling, recovery and treatment options have been considered and incorporated, responsible disposal options for the residual is determined.

Engineered landfills serve as a disposal option for oil and gas Exploration and Production (E and P) wastes. They are specifically constructed and monitored facility designed to accommodate burial of large volumes of waste. Landfill may be constructed in a manner that makes it an appropriate disposal for certain toxic wastes. A key consideration in the operation of an engineered landfill site is the need to ensure long term containment. In the construction of such a landfill site certain requirement are needed such as lining the landfill content with an impermeable material like clay, plastic sheeting and/or multi-layer lining with integrated drainage system. It also requires monitoring boreholes or leachate collection system to provide a means of regular inspection of the containment. (Owens *et al*., 1993).

The location of the landfill site is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. Proper landfill site selection determines many of the subsequent steps in the landfill process, which, if properly implemented, should ensure against nuisances and adverse long-term effects. For example, a well-selected landfill site will generally facilitate an uncomplicated design and provide ample cover material, which would facilitate an environmentally and publicly acceptable operation at a reasonable cost.

The criteria involved in landfill site selection include environmental, economic and sociopolitical criteria, some of which may conflict. With increased environmental awareness, new legislation and certain other developments over time, the landfill site selection process has become much more sophisticated, as new procedures and tools have been developed.

Landfill siting has become one of the problems being confronted by the waste management planners due to the current permitting and siting requirements and its operations. Besides that, an escalating environmental degradation and awareness, increasing cost, community and political opposition, increasing of population densities, shortage of land availability and public health concerns also contribute to the difficulty of choosing suitable land for landfill (Daneshvar *et al*., 2005, Mahini *et al*., 2006, Sene *et al*., 2006 and Siddiqui *et al*., 1996). Therefore, in a landfill siting process there are many factors that must be taken into consideration and carefully evaluated. As a result, the most suitable site to be selected should cause minimum adverse impacts to the environment, society and economy as well as conforming with the regulations and generally accepted by the public. However, it would be time consuming and tedious to implement such a complex procedure by using manual processing approaches (Kao *et al*., 1996). In addition, there are numerous data to process and sometimes processing the data might be repeated for several times till the best site is found.

Site selection analysis can be improved by using Geographical Information System (GIS). GIS has the capability to manage large volume of spatial and non-spatial data that comes from various sources. GIS provides the decision maker with a powerful set of tools for the manipulation and analysis of spatial information. Kao *et al*., (1996) pointed out that large volume of spatial data can be processed using GIS technology within a short period of time. The ability to geoprocess data is what separates GIS from being simply a tool to visualise data. Geoprocessing allows for the aggregation of data based on various tabular and spatial relationships. GIS allows in-depth spatial analysis by manipulating data in order to highlight the area of interest. GIS can help to reduce remarkably the areas that have to be examined on the site, although the final decision has to be taken after field studies (Din *et al*., 2008).

1.2 Problem Statement

The absolute amounts of waste disposed of worldwide have increased substantially reflecting changes in consumption patterns. Consequently worldwide commercial, industrial and household waste is now a bigger problem than ever. Despite an increase in alternative techniques for disposal of waste, landfilling remains the primary means of waste disposal.

In Ghana, oil and gas production started in 2011 making it difficult to assess the impact of E and P waste disposal to the environment. In the near future more E and P waste will be generated and problems related to their disposal will begin to manifest. Improper disposal of these wastes would result in several environmental problems such as contamination of water bodies, ground water pollution, air pollution, shortage of land for waste disposal and potential financial liabilities. Proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. The Shama Ahanta area serves as the catchment area for the disposal of E and P waste in Ghana due to oil and gas exploration and production at Cape Three Point. In view of this, this research seeks to use GIS to select the most suitable site for the disposal of petroleum waste in the Shama Ahanta Area.

1.3 Research Objectives

The following subsections states the objectives of the study.

1.3.1 Main Objective

The main objective of this research is to identify areas suitable for a landfill site for petroleum waste in the Shama Ahanta Area of the Western Region of Ghana.

1.3.2 Specific Objectives

The specific objectives are as follows:

i. to determine spatially the factors for selecting landfill site;
ii. to determine areas suitable for constructing a landfill; and
iii. to obtain an area equivalent or greater than 1 hectare for the above stated purpose.

1.4 Thesis Report Organisation

The thesis report is structured into five chapters. The first chapter gives a background to the thesis, problem statement, objectives and organisation of the thesis report. The second chapter is the literature review on Petroleum Waste, the effect of Petroleum Waste, management of Petroleum Waste, landfill and an Overview of Spatial Multi-Criteria Decision Analysis. The chapter three gives an account of the study area, materials and method used for the project. The results of the project work are discussed in chapter four. Finally chapter five concludes the thesis with some recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Petroleum Waste

This thesis seeks to address petroleum waste and its disposal. Petroleum waste includes waste generated or associated with the following activities;

- drilling, operation, and plugging of wells associated with the exploration, development, or production of oil and gas including, oil and gas wells, fluid injection wells used in enhanced recovery projects, and disposal wells;
- separation and treatment of produced fluids in the field or at natural gas processing plants;
- storage of crude oil before it enters a refinery;
- underground storage of hydrocarbons and natural gas;
- transportation of crude oil or natural gas by pipeline;
- solution mining of brine; and
- storage, hauling, disposal, or reclamation of wastes generated by these activities (RCC, 1998).

These wastes fall into categories of produced water, drilling wastes and associated wastes. Produced water makes up about 98% of all oil and gas wastes. In Texas, it was estimated that 98% of these produced waters are injected in wells regulated under the federally approved underground injection control program administered by the Railroad Commission(RCC, 1998). Drilling fluids and other associated wastes make up about 1.6% and 0.4% of oil and gas wastes, respectively (Orszulik, 2008).

2.1.1 Effect of Petroleum Waste

Ghana's oil and gas exploration and production comes with many operational discharges including drill cuttings, drill fluids, air emissions, water and solid waste discharges. These result in the release of toxic and obnoxious materials into the coastal water. Although some of these discharges and emissions are injurious to the recipient ecosystem and biodiversity, their effects may not be immediately conspicuous as witnessed in huge oil spillage. Underwood and Peterson (1988) noted that when chronic long-term disturbances act through sub lethal effects on organisms, the population abundances of valued species and the ability to sustain provision of ecosystem goods and services into the future, becomes especially problematic.

Typical contaminants in oilfields are heavy metals, chloride salts and organics. Studies showed that soluble chloride salts and excess exchangeable sodium cause harmful effects on soil and plant growth (Moseley, 1983 and Miller and Honarvar, 1975). High levels of soluble salt lower the amount of water in the soil available to plants and reduce plant uptake of required nutrients (Murphy and Kehew, 1984 and Miller *et al*, 1980). High levels of exchangeable sodium cause loss of soil structure, resulting in low water and air infiltration and excessive compaction of soil. Heavy metals in soil can become incorporated and accumulated in the food chain or contaminate local sources of drinking water if leaching and migration occur from oilfield pits. Migration of metal ions from a pit site is usually limited by their attenuation in clay minerals and the formation of insoluble complexes in the soil. For drilling reserve pits, for example, researchers found little or no migration of metal ions from drilling muds because of clay attenuation and complexing (Whitmore, 1982 and Henderson, 1982). Attenuation and migration are affected by the type of soil; it is more extensive in porous soils than in clayey soils (Murphy and Kehew, 1984).

Incorporation of metals into the food chain takes place through several possible pathways of exposure from soil to an individual. Research indicated that the exposure pathway may be different for each metal (API, 1995).

Drill cuttings that through the years have been discharged from installations on the Shelf are today located on the seabed. Basically, two types of drill fluids are used in Ghana's oil and gas exploration and production: Water Based Fluids (WBFs) and Non-aqueous drilling fluids (NADFs). The usual practice with the WBFs is to discharge the drilling mud unto the seabed. Normally, drill fluids especially the NADFs are often reconditioned and reused in the wells until such a time that it cannot be continuously used. The NADFs are then treated and discharged onshore. During the drilling process these fluids eventually mix up with the drill cuttings which are discharged onto the sea bed. Consequently, the cuttings and residual muds typically are considered sources of pollution. When the mud volume used to dilute the drill solids that are retained in the active system exceeds the available storage capacity of the drilling rig, the excess mud is disposed as waste. Addressing the issue of drilling solids removal is a constant problem every day on every well. Most of these drill fluids especially the NADFs contain aromatic compounds, which are very injurious to the recipient ecosystem and biodiversity. The advantage of using the NADFs lies in its ability to give fewer drilling problems and efficient drilling.

Despite the fact that most oil industries do not associate toxicity with WDFs, Patin (1999) argues that the WDFs can still damage the marine life. Leaving aside the question of toxicity, water based mud (WBMs) deposited on seabed sediments may smother benthic animals and where they are in the form of very fine particles suspended in the water, can interfere with respiration in small marine animals and pelagic fish. It can also cause disturbances at the ecosystem level. According to Shparkovski (1993), a short-term increase in concentration of pellet suspension (particles with a size of 0.005-0.01mm) above the level of 2-4 grams per litre caused quick adverse effects and death to fry of salmon, cod and littoral amphipod. Ocean discharges of WBMs and cuttings have been shown to affect benthic organisms through smothering to a distance of 25 metres from the discharge and affect species diversity to 100 metres from the discharge Shparkovski (1993).

One of the potential impacts identified with the oil and gas exploration in Ghana is the release of toxic and obnoxious materials into the environment. Heavy metals from the drilling and production activities contaminate the marine ecosystem leading to a possible accumulation in marine organisms. By bioaccumulation, the toxic chemicals enter into the food chain and their effects may not be immediately conspicuous but chronic in humans. Wild (1996) and Population Reports (2000) indicate that the most dangerous heavy metals with serious human ill-health include lead, mercury, cadmium, arsenic, copper, zinc and chromium. Cadmium and arsenic, for instance, are reported to cause cancer whilst exposure to lead was reported in a study in Thailand, to possibly cause about 70,000 children to lose four or more points of intelligences Quotient (1Q) (Population Reports, 2000).

Like the drill muds, produced water discharges contain a significant amount of hydrocarbons, heavy metals and arsenic which can affect the marine ecosystem. For instance, Neff (1987) described the produced water for ocean discharge as containing up to 48 parts per million (ppm) of petroleum, because it had usually been in contact with crude oil in the reservoir rocks. There were also elevated concentrations of barium, beryllium, cadmium, chromium, copper, iron, lead, nickel, silver and zinc, and "small amounts of the natural radionucleides, radium 226 and radium 228 ("very little" of which became attached to nearby sediments) and "up to several hundred ppm of non-volatile dissolved organic material of unknown composition". He added that "in shallow, turbid waters, elevated concentrations of hydrocarbons may be detected in surficial sediments up to about 1,000m from the discharge"; and that the aromatic hydrocarbons and metals in produced water were toxic; "the toxicity of the soluble organic fraction of produced water is not known". It is apparent that the organic fraction of produced water can induce eutrophication and thereby affect the Biological Oxygen Demand (BOD). Such a situation can gradually but eventually turn from a local problem to a regional, national and Trans boundary problems especially when the project field is close to the coastal boundary of La Cote d'Ivoire.

Additionally, an obvious pollution associated with maritime traffic is the release of ballast water into the coastal ecosystem. These waters usually contain animals and plants that accidentally hitchhike along with the vessel from one part of the world to another. The transported plant and animal species usually do not have natural enemies at their new locations hence they multiply rapidly and can become ecological pests. With the oil and gas production and exportation, maritime traffic on Ghana's coastal waters is bound to increase with such problems. A typical example is the Eurasian zebra mussel (*Dreissena polymorpha*) in the North American Great Lakes, resulting in expenses of billions of dollars on research, control operations and the treating of fouled underwater structures and water pipes (Kloff and Wicks, 2004). Considering such huge expenses in the control of such pests, the ability of Ghana to deal with this threat is woefully inadequate. This implies more adverse effects on the functioning of coastal ecosystems. The situation can also have indirect effects on other sectors of the economy since money spent on controlling these pests could better have been spent to strengthen other sectors.

Atmospheric issues are attracting increasing interest from both industries and government authorities worldwide. This has prompted the oil and gas exploration and production industries to focus on procedures and technologies to minimize emissions. The principal emission gases include carbon dioxide, carbon monoxide, methane, volatile organic carbons and nitrogen oxides. Emissions of sulphur content of the hydrocarbon and diesel fuel, particularly when used as a power source. In some cases sulphur content can lead to odour near the facility.

The nitrogen oxides emissions contribute to eutrophication, acidification, and the formation of ground-level ozone, and result in higher background concentrations of NO_2. Non-methane hydrocarbons emissions combined with nitrogen result in the ozone formation, while CO_2 and methane can contribute to global warming. The sulphur oxides and nitrogen oxides can undergo chemical reaction in the atmosphere to generate several secondary contaminants, such as sulphuric and nitric acids. These contaminants come down as acid rain into the soil and the ocean, thus affecting the fauna and flora of the region.

The effects of the acid rain would not only be felt in the marine ecosystem but also, the onshore ecology particularly the Ankasa conservation area which comprises the Nini-Suhien national park and the Ankasa resource reserve. The reserve occupies an area of about 500 km^2 and it is within the pollution deposition distance of the Jubilee Field's oil and gas exploration.

The Jubilee Field project is expected to generate both hazardous and non-hazardous solid waste. According to Amoasah (2010) about 100 tonnes and 200 tonnes respectively of hazardous and non-hazardous wastes are expected to be generated per annum. The hazardous waste comprises oily wastes, lubricants, supply vessel tank sludge clean out, chemicals, glue, paint, thinner, paint tins, batteries, rubber, fluorescent tubes, filters and medical waste. The non-hazardous solid waste may consist of plastic packaging, kitchen waste, paper and cardboard, glass, wood, cabin domestic waste. These wastes are expected to be transported ashore for proper treatment and disposal. However, currently there are no hazardous waste landfill facilities, no chemical waste treatment facilities and no thermal treatment facilities other than basic combustors for medical waste at some hospitals in Takoradi and in Ghana as a whole. If these industrial wastes end up at the municipal dumping places then they may get drained and contaminate surrounding ecosystems. The risks include acidification of crop lands, ground and surface water contamination, human exposure to harmful pollutants, flora and fauna contamination and a possible bioaccumulation of obnoxious pollutants in these flora and fauna.

2.2 Management of Petroleum Waste

Good environmental management practices not only protect health and the environment but also help protect E&P operators from potential long-term liabilities associated with waste disposal. Proper waste management begins with pollution prevention. This refers to the elimination, change or reduction of operating practices which result in discharges into land, air or water.

If elimination of waste is not possible then waste management must be accomplished through application of series of measures; source reduction, reuse, recycling, recovery, treatment and responsible disposal. Responsible disposal options for the residual is determined after all practical source reduction, reuse, recycling, recovery and treatment options have been considered and incorporated (E&P, 1993).

E&P waste can be disposed by using appropriate method such as; Underground Injection, Land Spreading, Surface Discharge, Landfilling or Burial. The potential ecological sensitivity of the location of operation is key to the selection of an appropriate management practice for a specific waste (E&P, 1993).

2.2.1 Underground Injection

Injection refers to the pumping of waste fluids down a well into suitable underground formations for disposal. Disposal well are designed to provide an avenue or wellbore to transport fluids into underground reservoirs in a manner that will not adversely affect the environment. The most important environmental concern for all injection operations is the protection of the groundwater. The target formation should be geologically and mechanically isolated from usable sources of water and must also not contain commercial quantities of oil and gas (Orszulik, 2008). The highest volume of fluid that may be handled by E&P disposal injection wells is *produced water*. Others wastes suitable for injection may include; process water, blow down liquids, cooling water, dehydration and sweetening waste liquid and waste drilling fluids

According to the E&P Forum (1993), injection is an expensive process requiring extensive planning and control. In most cases, an injection well and system will require considerable E&P activity in a particular area to justify the investment in drilling a well or converting an existing producing wellbore to injection service.

2.2.2 Land Spreading

Land Spreading is a method of treatment and disposal for low toxicity waste. It involves the application of the waste to the upper soil zone of the designated land area. It minimises the impact to current and future land use. Characteristics of this method are such that contamination of soil, groundwater and run-offs should not occur (E&P, 1993).

There are two potential problems with waste disposal to land that may limit future applications. First, land treatment provides little control over migration of the mobile (leachable) fractions that may eventually enter the food chain of animals or humans. Second, spreading of oily wastes results in emissions of volatile organic compounds resulting in violation of some local laws and regulations controlling air pollution (Orszulik, 2008).

2.2.3 Surface Discharges

Offshore discharges of treated solids, such as drill cuttings and produced water are permitted in some areas. Offshore discharges, however, are prohibited within three miles of shore in the United States, and the discharge of oil-based drilling mud wastes are prohibited in all United States waters. Where offshore discharges are prohibited, waste solids must be transported to shore for disposal (Arnhus and Slora, 1991). This is generally more expensive than offshore treating and discharge.

Surface discharge is regulated in most areas, however, and permits for such discharge are required. When wastewater is discharged offshore, the water is typically treated to remove only the hydrocarbons. Although the dissolved solids (salt) concentrations of most produced waters are high enough to be toxic to even marine life, the rapid mixing and dilution of the discharged water makes the resulting environmental impact negligible (ODCE, 2012).

For near-shore discharges in shallow water, there is less opportunity for mixing and dilution of the discharged water and a toxic plume can exist for some distance away from the discharge point. Such toxic plumes are of particular concern when discharging a dense, high-saline, oxygen-deficient brine because it can be trapped in subsurface topographic low areas. Because this trapped brine can significantly impact the local marine life, permits to discharge high-salinity brines near the shore may be difficult to obtain, even if the hydrocarbon content is low (Orszulik, 2008).

When wastewater is discharged into onshore freshwater locations, both the hydrocarbon and dissolved solids concentrations must be low. Because of the high cost of removing dissolved solids, surface discharge of wastewater is generally possible only if the initial dissolved solids concentration of the water is low. Surface discharge into dry stream beds is a common way to dispose of treated water in arid areas like Wyoming (Reis, 1996).

Surface discharge into percolation ponds is also used in some areas. In percolation ponds, the water is allowed to percolate into the under saturated (vadose) zone, where it eventually evaporates back into the atmosphere. Because of the lack of control over where the water goes, this disposal method is being phased out. Discharge into evaporation ponds is also an option in many arid areas, particularly if a liner is used to prevent leaching of dissolved solids (Orszulik, 2008).

2.2.4 Landfill or Burial

Landfills serve a key role in the management of solid wastes and are likely to continue to be an important component of the waste management system. The implementation of the waste management hierarchy of waste avoidance, waste reduction, waste reuse, waste recycling and finally waste disposal has resulted in significant diversion of waste from landfill. This will continue, however, landfills will continue to underpin our waste management strategies until waste disposal is replaced by these measures (BPEM, 2005).

Landfills are used throughout the world for disposing of large volumes of municipal, industrial, and hazardous wastes. In landfills, wastes are placed in an engineered impoundment in the ground. At the end of each day or on some other cycle, the waste is covered with a layer of clean soil or some other inert cover material. Modern design standards require clay or synthetic liners, although, in some areas, unlined landfills continue to operate. Landfills can be used for disposing of drilling wastes and other oil field wastes. In some circumstances, these are offsite commercial operations established to receive wastes from multiple operators in an oil field (e.g., the West Texas region). In other cases, oil companies with a large amount of drilling activity in an area may construct and operate private landfills. For example, Total Company designed and built a controlled landfill to dispose of inert wastes at a remote site in Libya, where other management alternatives were not readily available. At this landfill, a bottom liner overlaid by a geological barrier was developed to prevent contamination of the soil. A top liner, which is drawn over the waste during non-active periods, will be installed permanently after the landfill is closed. Two collection pits collect rainwater and subsequent leachate (Morillon et al. 2002).

In the interest of inter-generational equity, today's landfills should not leave an environmental legacy for future generations to address. Furthermore, for as long as landfilling remains part of our waste management strategy, best practice measures must be adopted to ensure that landfills are managed acceptably (BPEM, 2005).

The environmental impact of petroleum waste is often negative, because it is toxic to almost all forms of life. Landfills play a significant role in the success of the waste disposal process. The current strategy for waste disposal suggests that landfills should be located as far from civilization as practically possible.

A sustainable waste disposal project requires increased consideration of the social and geologic aspects of the proposed site. In order to optimize waste disposal, more resources should be spent siting the landfill, and less spent trying to make a poor site work. Thus, this thesis seeks to capitalise on the advantages of GIS to spatially select a suitable landfill site considering all the necessary factors required for petroleum waste management. There are, however, certain factors that must be considered when siting a landfill.

2.3.1 Factor to Consider when Siting a Landfill

Appropriate siting of a landfill is a primary environmental control, so preliminary investigation of all possible landfill sites should be conducted to identify those sites with the best potential to be developed (BPEM, 2005).

The aspects to be considered when screening for potential landfill sites is:

- Buffer Zones
- Groundwater Vulnerability

Buffer Zones

To protect sensitive land uses from any impacts resulting from normal and upset landfill operating conditions, such as offensive odours, noise, litter and dust, an adequate separation (buffer) distance should be maintained between the landfill and sensitive land uses such as settlement, surface water bodies, roads and natural reserves.

Buffer zones should be provided between the landfill and sensitive areas or other land uses for example; at least 300 m from public roads, at least 400 m from industrial developments, at least 500 m from urban residential or commercial area, at least 1000 m from rural residential areas. For the case of Malaysia, land use types such as grassland, forests and cultivated land were considered appropriate for dumping except marshland and swamp type (Gaim, 2004). For this study, grassland and bush land areas were considered appropriate for a landfill site.

Since leachate can be toxic to aquatic organisms and cause eutrophication of the waterways, it must be managed so that it cannot escape to surface waters. Accordingly, landfills should not occur in:

- Wetlands;
- Marine and coastal reserves;
- water supply catchments;
- land liable to flooding if determined to be so liable by the responsible drainage authority; and
- Within 500 metres of surface waters.

Geschwind *et al* (1992) investigated the risk of congenital malformations in the vicinity of 590 hazardous waste sites in New York State. A 12% increase in congenital malformations was found for people living within 1.609km of a site for malformations of the nervous system, musculoskeletal system, and integument (skin, hair, and nails), higher risks were found. Some associations between specific malformation types and types of waste were evaluated and found to be significant. A dose-response relationship (higher risks with higher exposure) was reported between estimated hazard potential of the site and risk of malformation, adding support to a possible causal relationship. The study did report an increased risk of central nervous system defects for those living near solvent or metal emitting industrial facilities.

Hall et al, (1996) used the same method of exposure assessment to study renal disease near 317 waste sites in 20 counties in New York State. Increased risks were found for associations between renal disease and residential proximity to a site (within 1.609km), the number of years lived near a site, and a medium or high probability of exposure, although the associations did not reach statistical significance. A study by Croen *et al*,

(1997) based exposure measurement on both residence in a census tract containing a waste site and distance of residence from a site. Risks of neural tube (2-fold) and heart defects (4- fold) were increased for maternal residence within 402.25m of a site, although numbers of cases and controls were too small (between 2 and 8) for these risk estimates to reach statistical significance.

The development of landfills may impact on the natural reserve such as water bodies and flora and fauna of the local area. The potential impacts on flora and fauna are:

- clearing of vegetation;
- Loss of habitat and displacement of fauna;
- Loss of biodiversity by impacts on rare or endangered flora and fauna;
- Potential for spreading plant diseases and noxious weeds;
- Litter from the landfill detrimentally impacting on flora and fauna;
- Creation of new habitats for scavenger and predatory species;
- Erosion; and
- Alteration of water courses.

Particular areas where landfills should not occur are:

- Critical habitats of taxa and communities of flora and fauna; and
- Areas where a landfill is likely to have a significant impact on threatened species and ecological communities.

Groundwater Vulnerability

Pollution of groundwater by leachate is very difficult to remediate, and accordingly, landfills should be sited in areas where impacts on beneficial uses of groundwater are minimised. Landfills below the regional water table are not generally considered to be best practice because landfills below the regional water table increase the infiltration rate of groundwater by contaminants. An extremely deep water table region is suitable so that underground water is not contaminated by the leachate of the waste. According to North Dakota Department of Health (2002), the bottom of disposal trench should be at least four feet above the water table.

Geological formation in areas of potential landfill plays very significant role in minimizing the spread of leachate naturally, both at the time of moving into ground water or when moving laterally along the ground water. This situation therefore requires that landfill area selection studies that do not have bedrock with the formation of sandstone, limestone or hollow rock (Alesheikh, 2008). As the decomposition and stabilisation of waste may take many decades, landfills should be constructed in areas where the land on which the landfill will be placed is stable, thereby enabling the long-term integrity of the landfill cap and liner system to be assured. According to James (1997) result shows that there are significant effects of the faults and weathering on groundwater movement and that landfill site should be operated outside fault prone areas.

Soil with rapid permeability assessed to have a low value to a potential landfill site because it provides small protection against groundwater and require special additional technology. Soil type also affects the permeability of water into the ground (Alesheikh, 2008).

2.4 Overview of Spatial Multi-Criteria Decision Analysis

Decision Analysis is a set of systematic procedures for analyzing complex decision problems. These procedures include dividing the decision problems into smaller more understandable parts; analyzing each part; and integrating the parts in a logical manner to produce a meaningful solution (Malczewski, 1997). Multi-criteria Decision Analysis (MCDA) techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities.

The actual process of applying the decision rule is called evaluation. To meet specific objective, it is frequently the case that several criteria will need to be evaluated. Such procedures are called Multi-Criteria Evaluation (MCE). In the advent of GIS and its continuous development over the last decade including incorporation of decision making support into it makes it an ideal tool for site selection or facility allocation problem (Hasan *et al*, 2009).

The multi criteria decision analysis (MCDA) method has been integrated with two methods, namely; the analytical hierarchy process (AHP) and Weighted Linear Combination (WLC).

The AHP method which is developed by Saaty, (1980) is an effective approach to extract the relative importance weights (RIW) of the criteria. It is based on the pairwise comparisons which are used to determine the relative importance of each criterion. The pairwise comparison method involves three steps:

(1) Development of a pairwise comparison matrix: The method uses a scale with values range from 1 to 9. The possible values are presented in Table 2.1

(2) Computation of the weights: The computation of weights involves three steps. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made which includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared (Saaty, 1980).

Empirical applications suggest that pairwise comparison method is one of the most effective techniques for spatial decision making including GIS-based approaches (Eastman *et al*, 1993; Malczewski *et al*, 1997)

Table 2.1 Scale for Pairwise Comparison

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

(3) Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves following operations:

a) Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows,

b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously,

c) Compute lambda (λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$CI = (\lambda - n) / (n-1)$,

Where n= number of criteria

d) Calculation of the consistency ratio (CR) which is defined as follows:

$CR = CI / RI$

Where RI is the random index and depends on the number of elements being compared. If CR< 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if CR = 0.10, the values of the ratio indicates inconsistent judgments (Saaty, 1980).

The advantages of this method can be summarized that only two criteria have to be considered at a time, it can be implemented in a spreadsheet environment (Kirkwood, 1997) and it is incorporated into GIS based decision making procedures (Eastman *et al*., 1993 and Janskowski, 1995).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

Shama Ahanta Area consists of Sekondi Takoradi Metropolitan, Shama, Ahanta West, Mpohor Wassa East and Mpohor district which form part of the twenty-two districts in the Western Region of Ghana (Anon., 2012a). The Shama Ahanta Area as shown in Fig. 3.1 is located in the south western part of Ghana approximately 201 km by road west of Accra between latitudes 4°43'57.43" N and 5°01'03.08" N and longitudes 2°05'25.04" W and 1°37'29.53" W (Anon., 2012b). It shares boundary with Wassa West, Nzema East, Komenda/Edina/Eguafo/Abriem and Twifo/Hemang/Lower Denkyira districts. It has a land area of about 3080 square kilometres (Anon., 2012c).

3.1.1 Topography and Drainage

The Shama Ahanta Area lies within the low-lying areas of the country. The landscape is generally undulating with an average height of about 70 metres. The highest elevation ranges between 150 and 200 metres above sea level. The drainage pattern of the Area is largely dendritic. There are medium and small rivers as well as streams. Most of them originate from the Akwapim ranges and flow southwards towards the coast. The main rivers are the Pra, Subri, Butre, Brempong, Suhyen, Abetumaso, Hwini, Whin and Tipae. While most of them overflow their banks in the rainy season, majority virtually dry out in the dry season leaving behind series of dry valleys and rapids (Anon., 2013a).

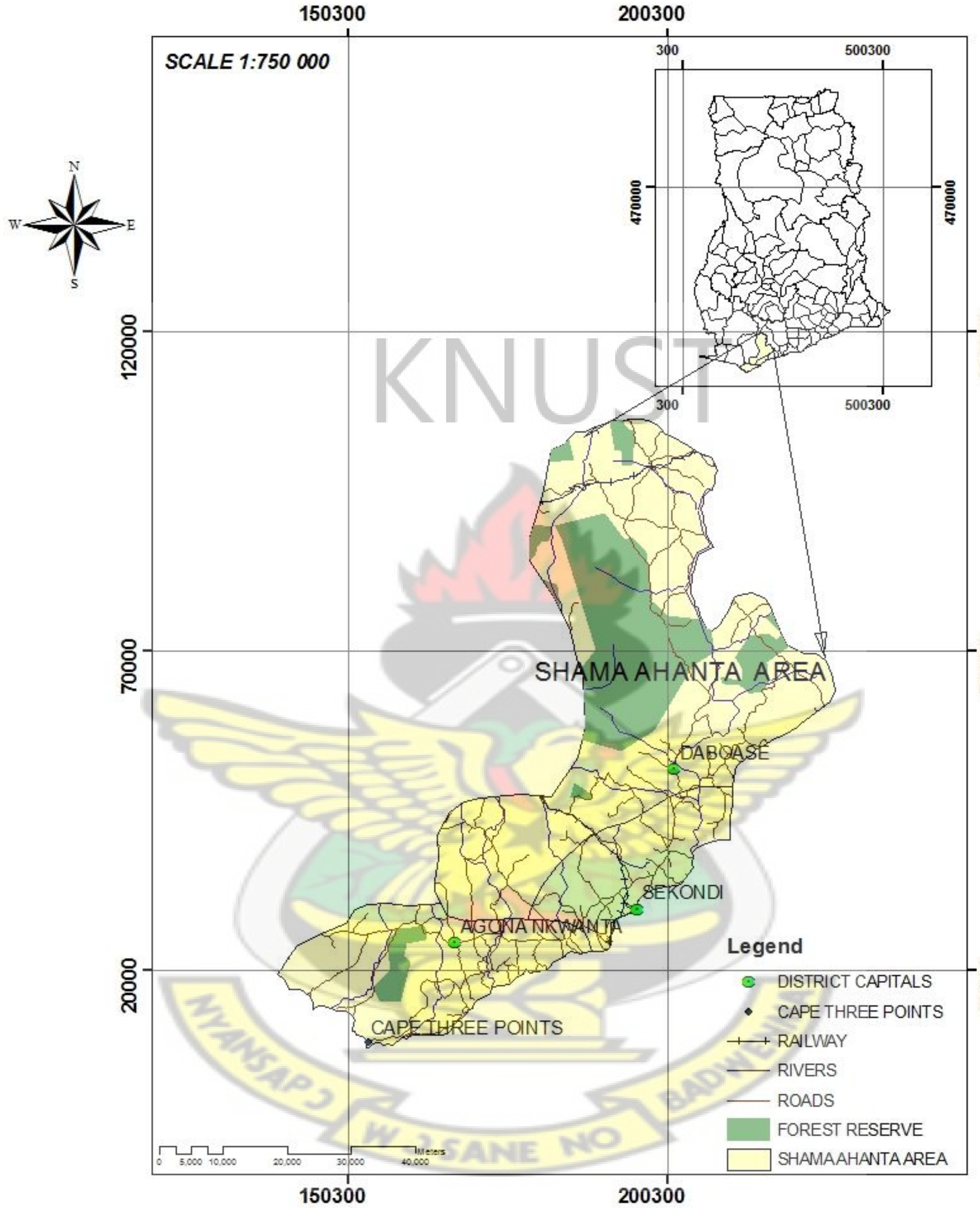


Figure 3.1 Map of Study Area

3.1.2 Climate

The Shama Ahanta Area is found within the South-Western Equatorial Climatic Zone of Ghana, with an average temperature of 24°C and records its highest mean temperature as 34°C between March and April and its lowest mean temperature of 20°C is experienced in

August. It has a mean annual rainfall of 1700 mm. Heavy rains are experienced between the months of May and June with the minor rains occurring between September and October (Anon., 2013b).

3.1.3 Geology and Soil

The main categories of rock and soil types which underlie the Shama Ahanta Area are namely Dahomeyan, Birimian Volcanic, Birimian Sediment and Tarkwaian. More than half of the soils in the area are Acrisols and the other portion are Ferralsols and Lixisols. There are some Luvisols in very small areas and some Fluvisols along the rivers in the Area (Anon., 2013b).

3.2 Materials

3.2.1 Software

Geospatial analysis was done in the ArcGIS environment using ArcGIS 9.3.

3.2.2 Data

Data used were mainly secondary data which included geological formation, district boundary, built-up area, natural reserves, settlements, major roads, local roads, land use, springs, wells, ground water, soil type, and topography.

3.3 Methods

The methods adopted in this study is summarised in the flow chart shown in Figure 3.2. It is divided into three steps which include Determination of spatial factors, Determination of Area suitable for PLS and Determination of Best location of a PLS.

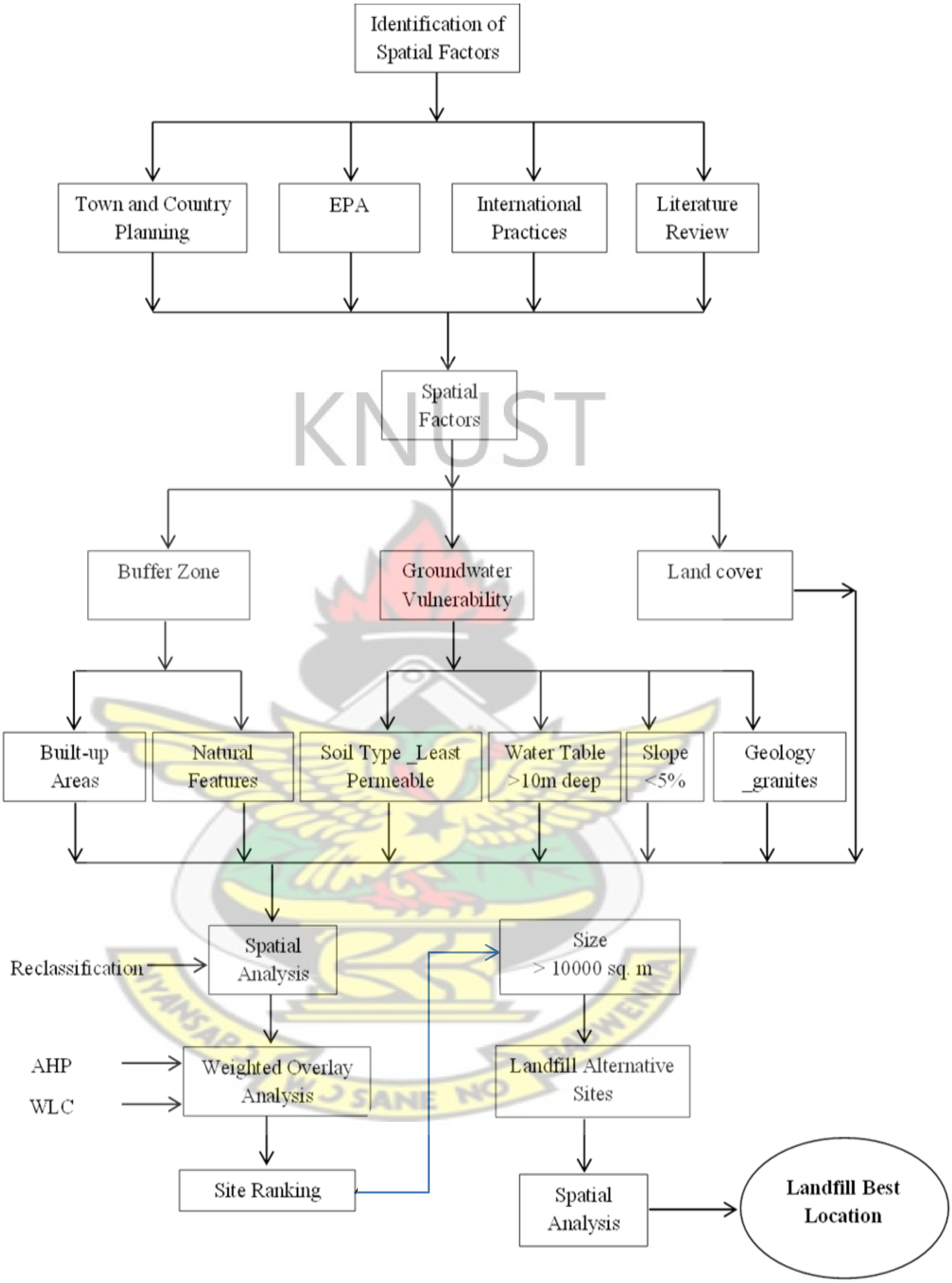


Figure 3.2 GIS Spatial Analysis Flow Chart

3.3.1 Determination of Spatial Factors for Landfill site

The presented method starts with the identification of evaluation criteria or parameters needed for landfill siting. All these parameters have been identified based on the local guidelines such as Town and Country Planning Department (TCPD) guideline for waste disposal siting as well as guidelines from the Environmental Protection Agency (EPA). Besides, the related information about landfill siting has also been reviewed from the international practices.

3.3.2 Determination of Suitable Areas for Disposal of Petroleum Waste site

After the identification of spatial factors for a landfill site, it was identified that potential landfill site should be considered based on its buffer zone from built-up areas and natural features, groundwater vulnerability and land cover.

Buffer Zones

As mentioned in many literature reviews such as Tagaris *et al*, 2003 and Chang *et al*, 2008, a landfill site should not be located very close to urban area. It should be situated at a significant distance away from urban areas due to public concerns, for example aesthetic, odour, noise, and health concerns. The landfill site should not be located within 2 km from sensitive areas *i.e.* settlements, roads, surface water and natural reserves. Euclidean distance of 10 km with 1 km interval was created around the sensitive areas in the Shama Ahanta Area.

The Euclidean distance maps of the sensitive areas were reclassified and given new field values as shown in Table 3.1. This was done in order to rate areas suitable for landfill site because the further the area is from sensitive areas the more suitable it is for a PLS. Based on the new field values given to the areas, scale value ranging from 1 to 9 or ‘Restricted’ was assigned to the area indicating that the larger the scale value of an area the more suitable it is for PLS, based on distance from sensitive areas.

Table 3.1 Scaling of Euclidean Distance

Euclidean Distance	New Field Value	Scale Value
0-1000	1	Restricted
1000-2000	2	Restricted
2000-3000	3	2
3000-4000	4	3
4000-5000	5	4
5000-6000	6	5
6000-7000	7	6
7000-8000	8	7
8000-9000	9	8
9000-1000	10	9
No Data	No Data	10

Groundwater Vulnerability

From an Engineered geological map as shown in Appendix A, reclassification was done and new field values and scale values were assigned to areas based on their vulnerability to groundwater. The Tarkwaian and Dahomeyan are rock formations suitable for landfill due to their characteristics of having low permeability. As a result they were given higher scale values compared to Birimian sediments and Sekondian series. Areas prone to fractures, faults and weathering were restricted because fractures, faults or weathering in the least permeable formation could result in high vulnerability to groundwater.

Aquifer level represents the depth from the ground surface to the water table. The depth to water table was determined using the inverse distance weighting (IDW) interpolation technique of the water level data, which was obtained from existing wells in the study area (provided by the CSIR-Water Research Institute).

Areas with aquifer level below 10 m deep are unsuitable for siting a landfill because the vulnerability of groundwater to pollution is high. Aquifer level map as shown in Appendix B was converted to raster data and reclassified for new field values and scale values to be assigned as shown in Table 3.2.

Table 3.2 Scaling of Aquifer Level

Euclidean Distance	New Field Value	Scale Value
0 -10	1	Restricted
10 - 12	2	1
12 - 15	3	2
15 - 18	4	3
18 - 21	5	4
21 - 24	6	5
24 - 27	7	6
27 - 30	8	7
30 - 33	9	8
33 - 36	10	9
No Data	No Data	Restricted

Landfill area should not be located on a hill with an unstable slope. An area is judged to be good if located in the sloping area with high topography. Very steep areas are considered to have smaller values because it was feared that a fatal avalanche could occur, especially when there is rain or high water seepage. The slope map shown in Appendix C was reclassified and new field values and scale values were assigned to sites based on how steep they were. Areas of slope greater than 6% were restricted.

Two stages of analysis were conducted. The first stage was an elimination process of unsuitable parcels of land for siting a landfill. Suitable parcels of land resulted from the first stage then went through a second stage of analysis. Here AHP and WLC were employed.

MCDM problems involve criteria of varying importance to decision makers and information about the relative importance of the criteria. This is usually obtained by assigning a weight to each criterion. The derivation of weights is a central step in defining the decision maker's preferences. These weights were derived through AHP analysis in which an individual criterion was compared to every possible pairing and entered the ratings into a pairwise comparison matrix or ratio matrix using pairwise comparison scale in Table 3.3. Since the matrix is symmetrical, only the lower triangle actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangle as shown in Table 3.4.

Table 3.3 Scale for Pairwise Comparison

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

The principal eigenvector of the pairwise comparison matrix was computed to produce the best fit set of weights for the individual criterion. Since the complete ratio matrix contains multiple paths by which the relative importance of criteria was assessed, the calculated weight was used to determine the consistency ratio (CR) of the pairwise comparison. The CR was determined as 0.08. Per the calculation the weights assigned to each criterion was as shown in Table 3.5.

Table 3.4 Pairwise Comparison Matrix

Factor Criteria	Slope	Geology	Water Table	Soil Type	Road	Land Cover	Surface Water	Settlle-ment	Forest Reserve
Slope	1	1/3	1/2	2	2	2	1/3	1	1
Geology	3	1	2	3	3	3	2	2	2
Water Table	2	1/2	1	3	3	3	1/2	1	1
Soil Type	1/2	1/3	1/3	1	1	1	1/3	1/2	1/2
Road	1/2	1/3	1/3	1	1	1	1/3	1/2	1/2
Land Cover	1/2	1/3	1/3	1	1	1	1/3	1/2	1/2
Surface Water	3	1/2	2	3	3	3	1	2	2
Settlement	1	1/2	1	2	2	2	1/2	1	1
Forest Reserve	2	1/2	1	2	2	2	1/2	1	1

Table 3.5 Weighting Value of Factor Criteria Computed using AHP

Factor criteria	Weight
Slope	10
Geology	21
Water Table	12
Soil_Type	6
Road	5
LandCover	5
Surface Water	20
Residents	10
Forest Reserve	11

Finally, WLC method was applied to compute the suitability index value of the potential areas based on the following equation;

$$S_i = \sum_{j=1}^{n} w_j \times x_{ij}$$

Where S_i is the suitability index for area i, w_j is the relative importance weight of criterion j, x_{ij} is the grading value of area i under criterion j; and n is the total number of criteria. Suitability index values obtained from the WLC method were used to determine areas suitable and unsuitable for siting a landfill in the study.

The suitable areas were queried to obtain areas equal or greater than one hectare. This was done in order to create enough space to accommodate large volume of waste and also have space for establishing monitoring and other facilities. A spatial analysis was further carried out to determine suitable area closest to the origin of waste transportation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The results of the research are stated in the following sections.

4.1.1 Spatial Factors for Landfill Siting

The results of the spatial factors for selecting petroleum Landfill site are presented in this section. The spatial factors identified for the selection of a petroleum landfill site (PLS) includes; Built-up areas, natural features, soil type, slope, geology and landcover.

Built-up Area

The Euclidean distance maps of the built-up areas in the study Area yielded two maps. Figure 4.1 shows the Euclidean distances from settlement indicating the suitability of the areas in siting a landfill per their distance from settlement areas whiles Figure 4.2 also shows the Euclidean distances from major roads indicating the suitability of areas by distances from road. Critical examination of the Euclidean distance maps revealed that there are a lot of settlements within the study area making the area unsuitable for PLS increase by about 33% of the study area. Maps also revealed that the settlements and the roads shared similar areas since the roads mainly connected the settlements making about 82% of the area unsuitable.

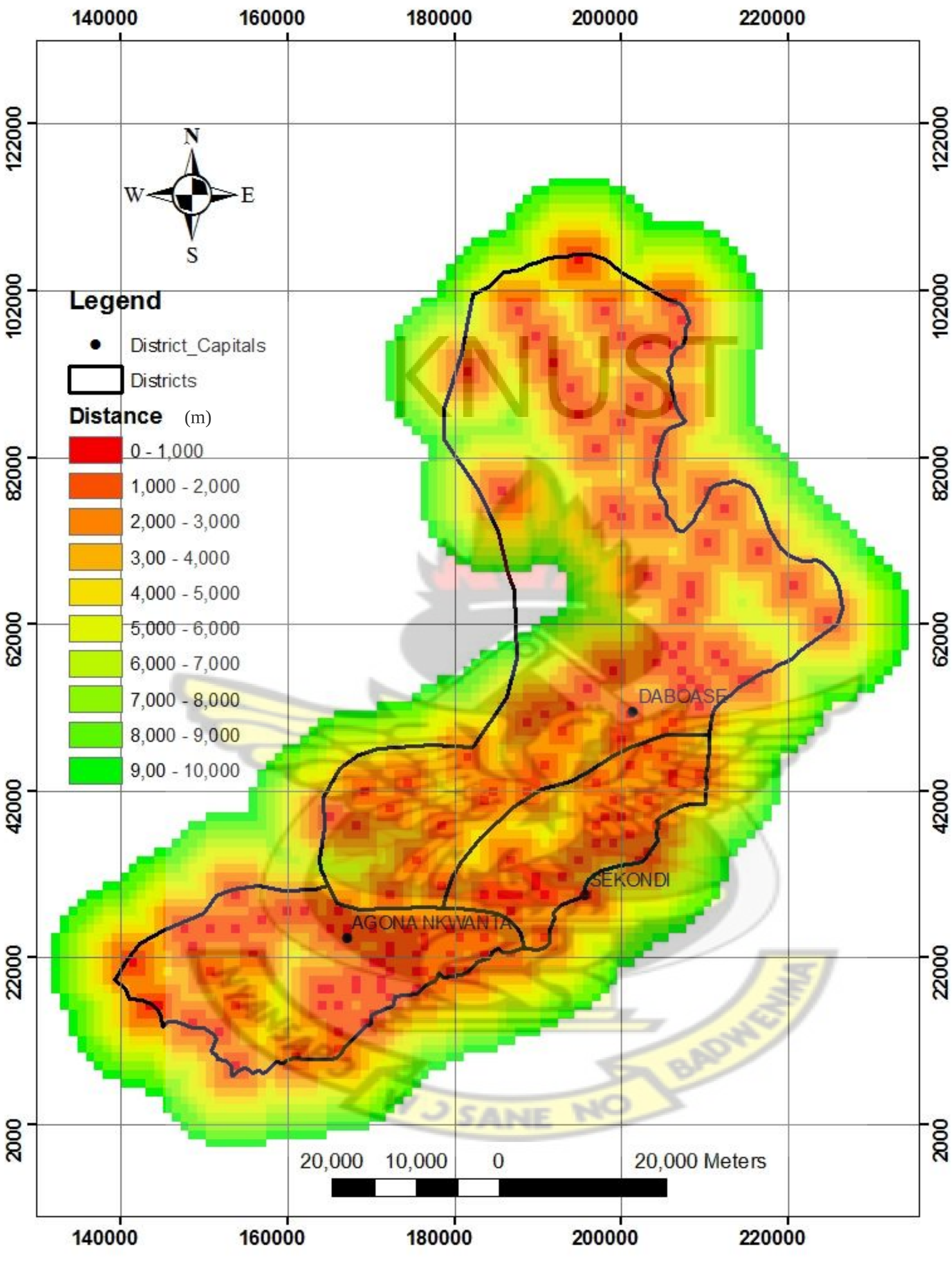
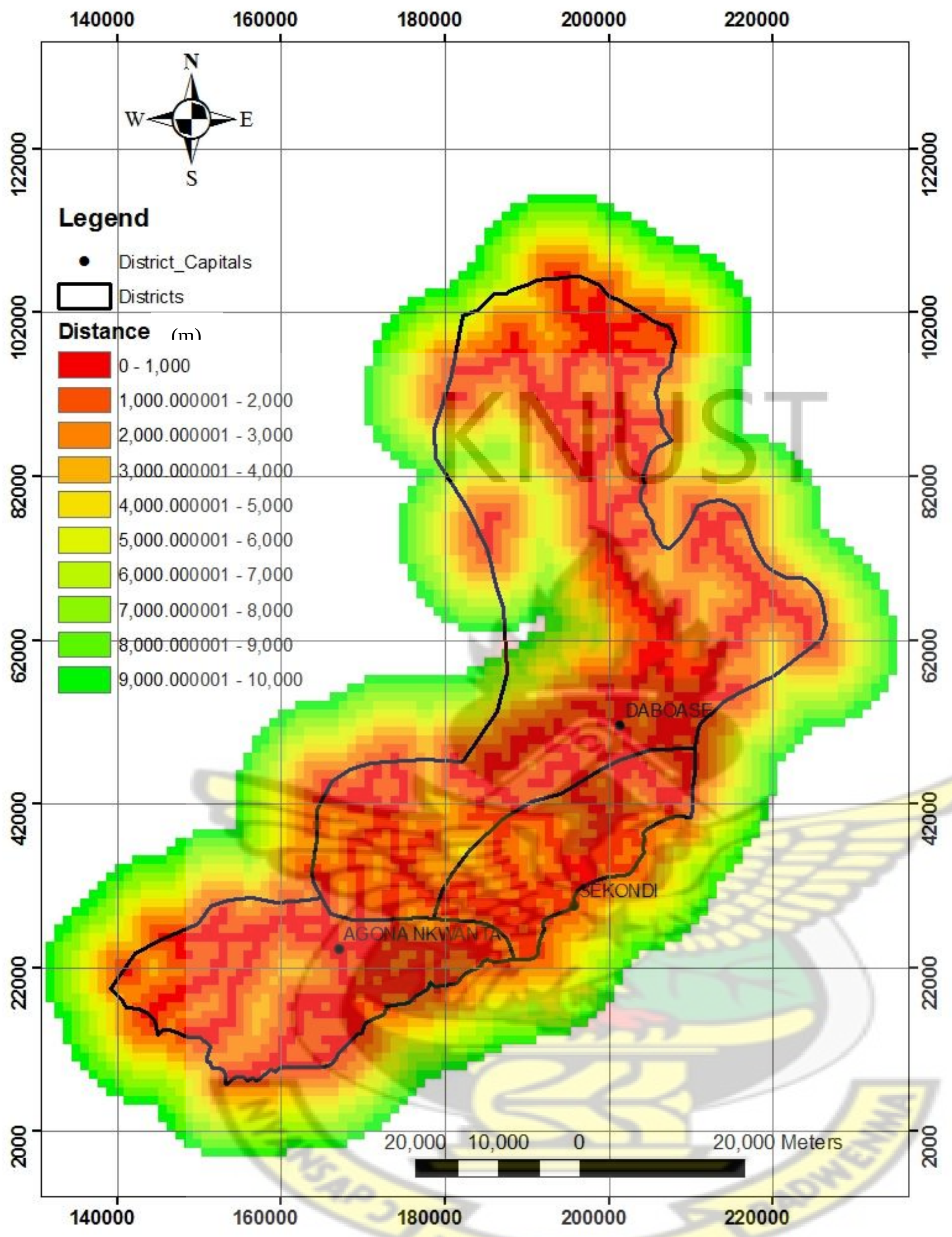


Figure 4.1 Map showing Euclidean Distances from Settlements in SAA



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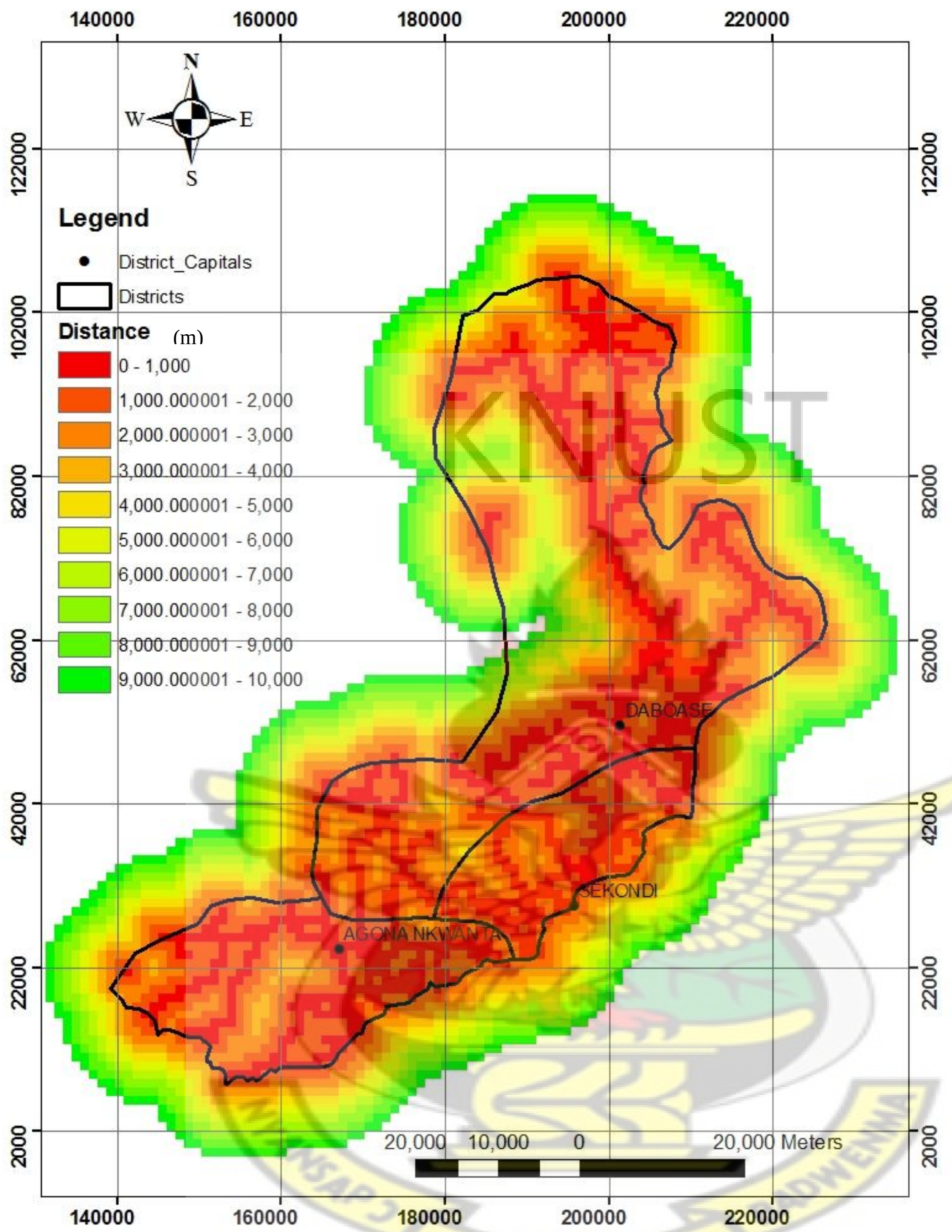

Figure 4.2 Map showing Euclidean Distances from Major Roads in SAA

Natural features

The suitability of areas for siting a landfill due to distance away from water bodies within the Shama Ahanta Area is shown in Figure 4.3. Figure 4.4 shows the suitability of areas for siting landfill per distance from forest reserve in the study area.

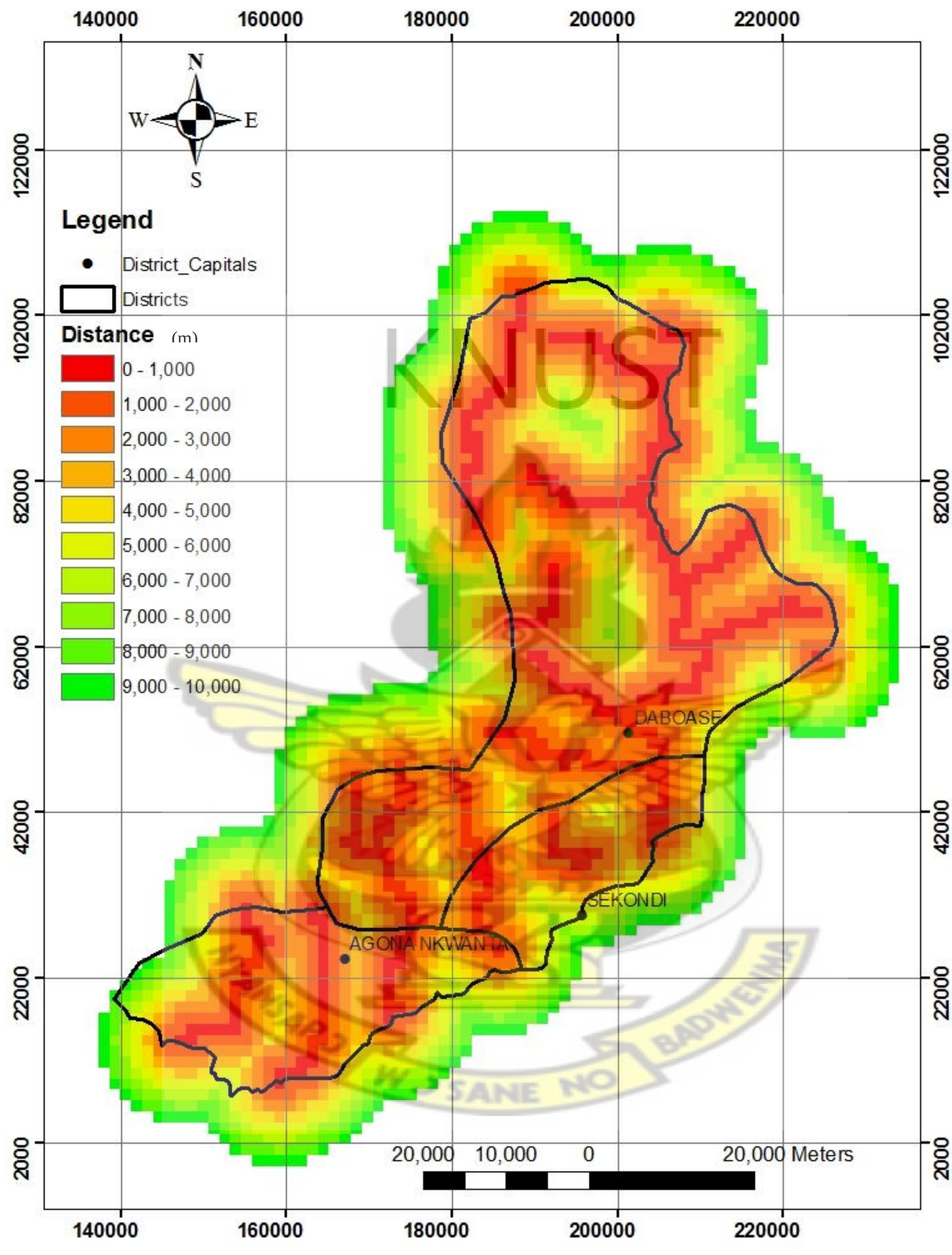

Figure 4.3 Map showing Euclidean Distances from Surface Water in SAA

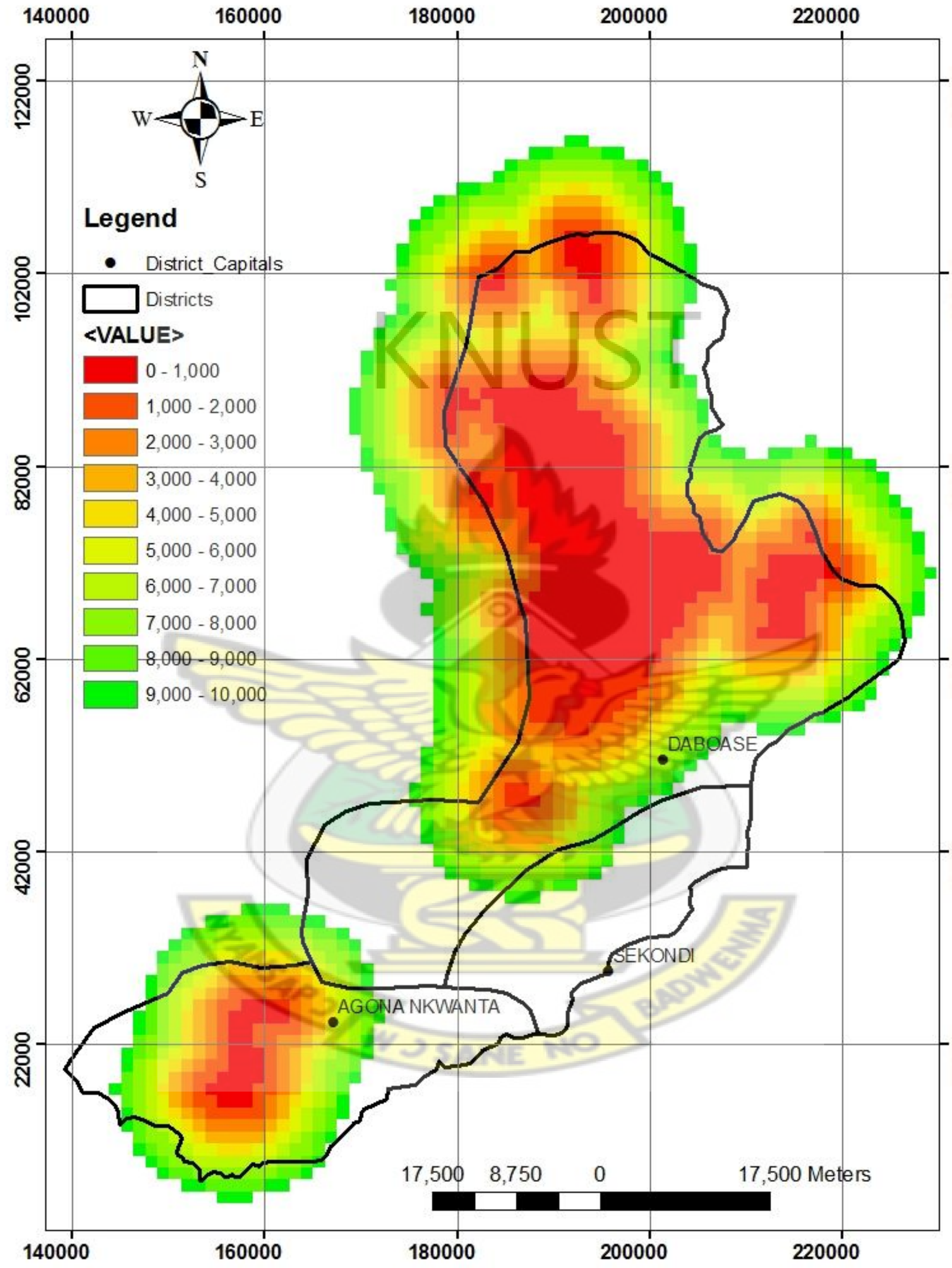

Figure 4.4 Map showing Euclidean Distances from Natural Reserves in SAA

4.1.2 Suitable Area for Siting a Landfill

Figure 4.5 shows the land suitability map for selecting the best possible landfill sites within the study area after taking into consideration buffer zoning of sensitive areas, slope, landcover and groundwater vulnerability. The land suitability map was divided into five classes: most suitable, suitable, moderate suitable, poorly suitable, and unsuitable.

Table 4.1 shows that 2.1% of the study area has a “moderately suitable” class of landfill site selection, whereas a total of 5.5% of the study area has “most suitable” and “suitable” classes. The “poorly suitable” and “unsuitable” classes for land-fill site selection occupied a total of 93.3% of the study area.

Table 4.1 Statistical Analysis for the Landfill Site Suitability Map

Class	Area(km2)	Area (%)
Most Suitable	35.45	1.15
Suitable	104.11	3.38
Moderately suitable	65.01	2.11
Poorly suitable	22.86	0.74
Unsuitable	2852.98	92.62
Total	3080.41	100

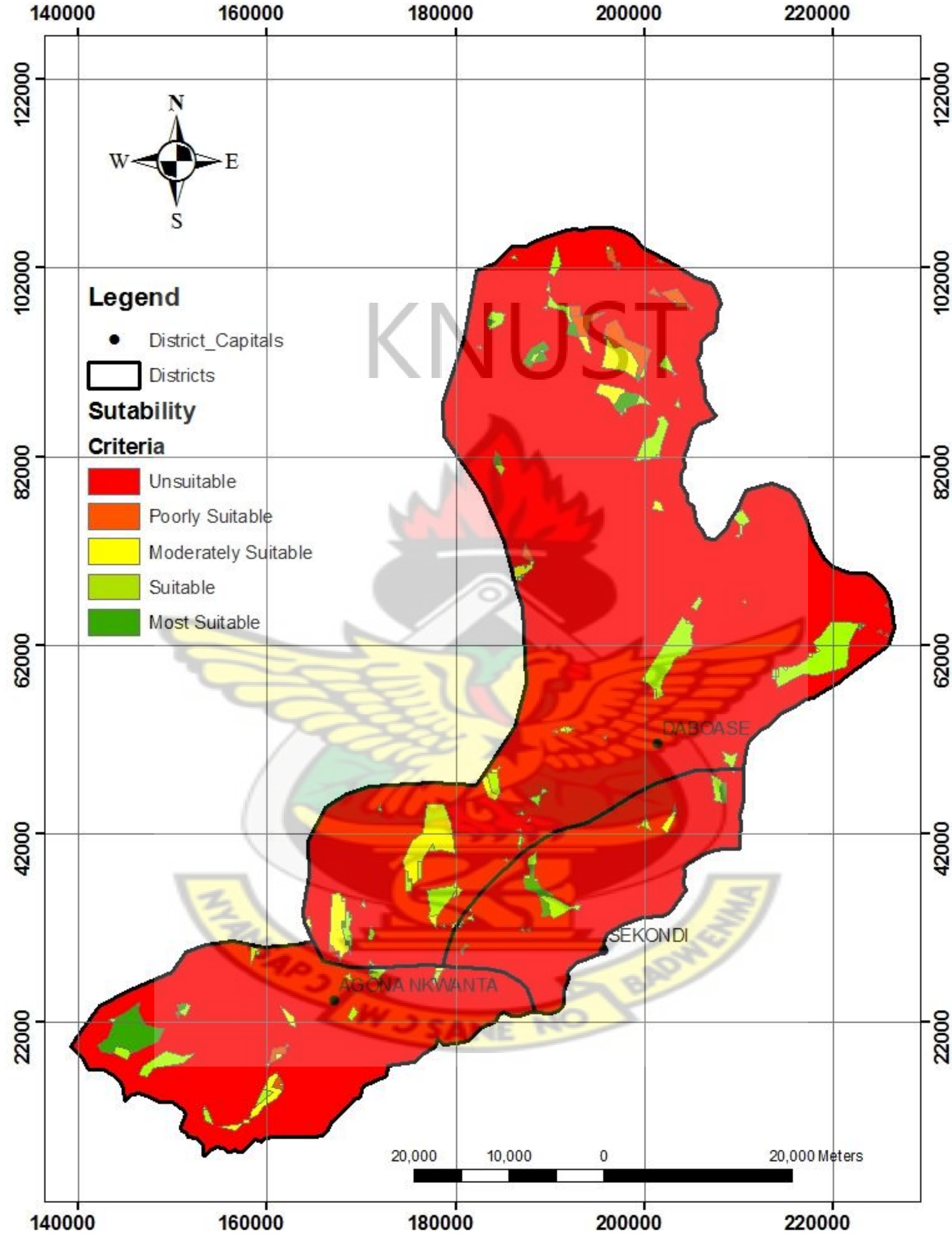

Figure 4.5 Map showing Landfill Site Suitability of the Study Area

4.1.3 Area Equivalent or Greater Than One Hectare for Siting Landfill

In order to have a size with the full complements of facilities, areas less than 1 ha were masked out within the most suitable class in the study area as shown in Figure 4.6. The major locations were identified in the area under study.

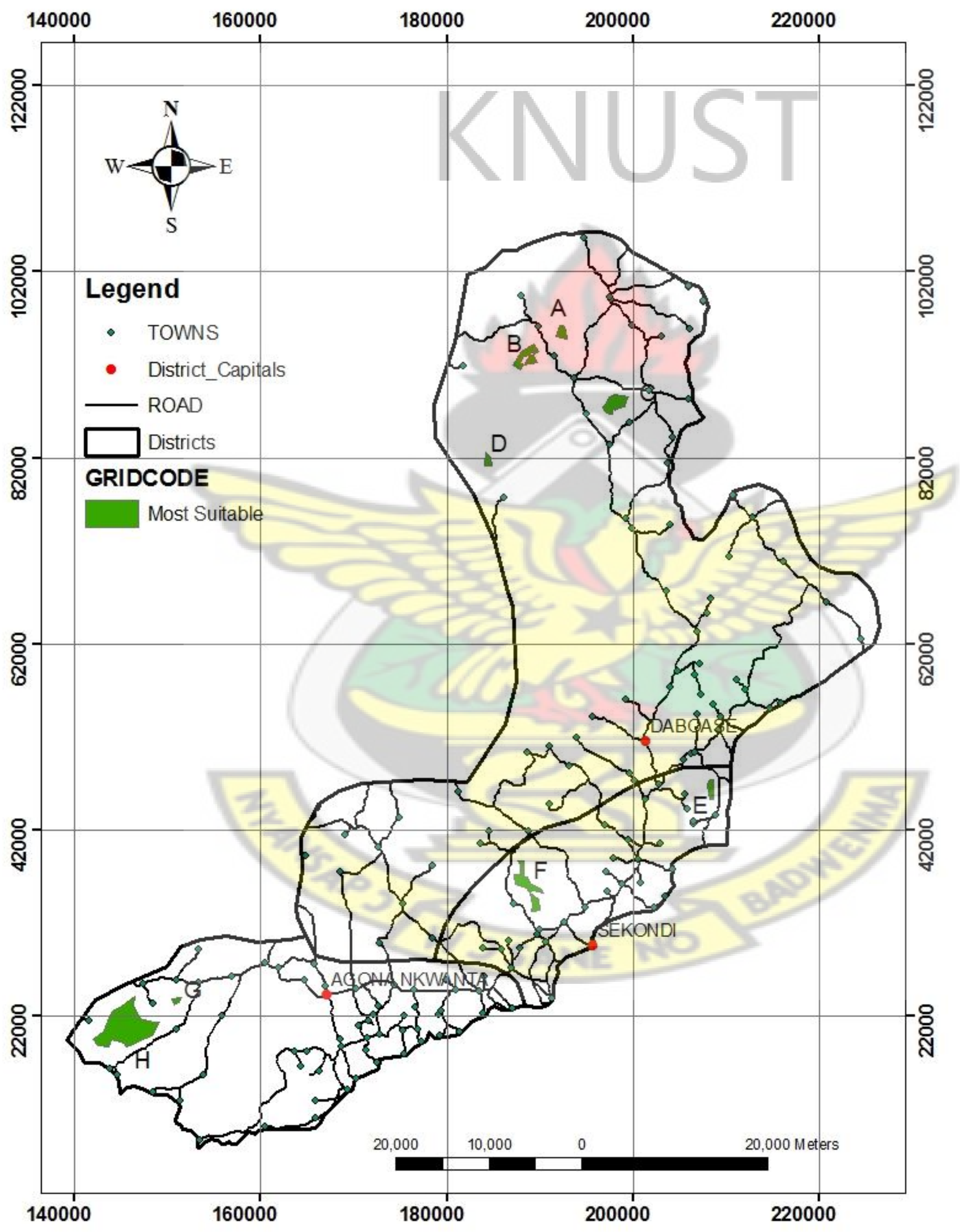

Figure 4.6 Map of most Suitable Alternative Locations for Landfill Site greater than one Hectare

Table 4.2 indicates the spatial attributes of the various alternative sites for landfill with respect to its area and distance from Sekondi which serves as the assemble point of petroleum waste.

Table 4.2 Statistical Analysis for most Suitable Alternative Locations of Landfill Site

Site	Area(km^2)	Distance (km) from Sekondi
A	1.10	65.77
B	3.24	63.25
C	3.43	57.81
D	0.75	52.91
E	1.00	20.87
F	4.79	7.94
G	0.38	45.45
H	18.20	48.27

4.2 Discussion

4.2.1 Spatial factors for Petroleum Landfill Site

Built-up areas are characterized by higher population density and vast human features in comparison to areas surrounding them. They may be cities, towns, villages and hamlets. Other sensitive features are natural structures which include forest reserves, wetlands, surface water and wells. According to Moseley (1983), Miller and Honarvar, (1975), most oilfields wastes contain heavy metal, metalloids, chloride salts and organics. Studies showed that soluble chloride salts and excess exchangeable sodium cause harmful effects on soil and plant growth. Humans are exposed to heavy metals and metalloids by ingestion (drinking or eating) or inhalation. Working or living near landfill sites increases the risk of human exposure, so does the nearness of water bodies and other sensitive features.

The EPA stated in its requirements that a landfill site should be 300 m from public roads, 400 m from industrial developments, at least 500 m from residential areas and 500 m from surface water. According to Geschwind *et al* (1992), however, people living within 1.609 km of a hazardous waste sites in New York State had a 12% increase in congenital malformations in the nervous system. These called for an increase in the buffer distance to 2 km.

4.2.2 Suitable Areas for PLS

PLS suitability in the Shama Ahanta Area resulted in about 83% of the area being unsuitable. These could be attributed to the fact that there are about 150 villages and towns in the study area which had 1 km buffer zone restriction. This made an area of about 600 km^2 unsuitable for siting a landfill due to settlements. Another reason is that there are several water bodies and major roads in the study area which also had 2 km buffer thereby increasing the restricted areas. The area covered by the forest reserves, wet lands and faults were equally considered in the buffer. The faults were mainly found at the south-western part of the study area. All these put together meant 83% of the study area was being restricted or unsuitable for siting a petroleum landfill.

The aquifer level distribution of the study area indicated that the south-western part had deeper depths of aquifer level compared to the north-eastern and central parts. The central part had the least depth of aquifer level making this area unsuitable for siting a landfill. The slope of the study area had an even distribution of elevations but the north eastern part of the study had the preferred slope for PLS (i.e. 6% and below) occurring mostly within forest reserves which are restricted zones for siting a landfill for petroleum waste. The south-western and central parts of the study area had large portion of them being underlain by the Dahomeyan rock formation which is the preferred formation in the study area due to its ability to have a low permeability, whereas the north-eastern part of the study area had large portion of it being underlain by the Birimian sediment which is highly permeable compared to the other formation in the study area. This is why the south-western part of the study area had most of the area being most suitable for PLS (See Figure 4.5)

4.2.3 Area Equivalent or Greater Than One Hectare for Siting Landfill

In this research seven locations were obtained as areas most suitable for siting a landfill for petroleum waste disposal. In Figure 4.6, all the sites are not close to any village or residential area but Sites A, B, C, D, G and H are very far from Sekondi from which the petroleum waste would be transported. The problem related to the distance from Sekondi is that the further the distance the higher the transportation cost. Despite these sites being very suitable for landfill they will be ignored due to their distance from Sekondi.

Site (E) is also located within the most suitable class for landfill site, and it is located near to Sekondi but further than site (F) which might be acceptable. The only problem with this site is that it has eight villages within 3- 4 km around it. Due to the ability of these villages to expand with time, these expansions could interfere with the restricted zone from residential area with time making the landfill site fall short of its requirement, which can also have adverse effects on habitants within the restricted or buffer zone.

Site (F) on either sides of the nearby existing road is highly recommended among the other sites. This site is not located too close to any village or residential area, which may provide the opportunity to operate this site for a long period. Furthermore, there is a wide area of most suitable class for landfill site, which can help the engineers to choose a preferred location. It is also the closest to Sekondi.

A field survey was conducted to check the conditions of the suggested landfill sites. From environmental point of view, it was found that all the suggested sites could be suitable for a new PLS.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.1.1 Spatial factors for PLS

From this study it can be concluded that petroleum landfill sites should be located 2 km from sensitive areas such as residential areas, water bodies, natural reserves etc. It was also determined that PLS should be located at area of aquifer level above 10 m and areas that would reduce the vulnerability of groundwater.

5.1.2 Suitable Area for PLS

The most suitable area determined for PLS constituted 1.15 % of the total area of SAA as a result of dense residential area and water bodies in the study area.

5.1.3 Area Equivalent or Greater Than One Hectare for Siting Landfill

This study enabled the determination of seven locations equivalent or greater than One hectare and most suitable for siting a landfill for petroleum waste in the Shama Ahanta Area. Due to transportation cost and future repercussions Site (F) is consider as the best location for siting a Petroleum Landfill in the Shama Ahanta Area.

5.2 Recommendation

It is recommended that stakeholders should be included in the landfill site selection decision-making process. That will lead to incorporation of preferences of several stakeholders (for example Ministry of lands, landowners and community among others) in the landfill site selection decision-making exercise, and therefore minimize conflict. Such analysis will eventually yield the most suitable sites for waste disposal in the entire country.

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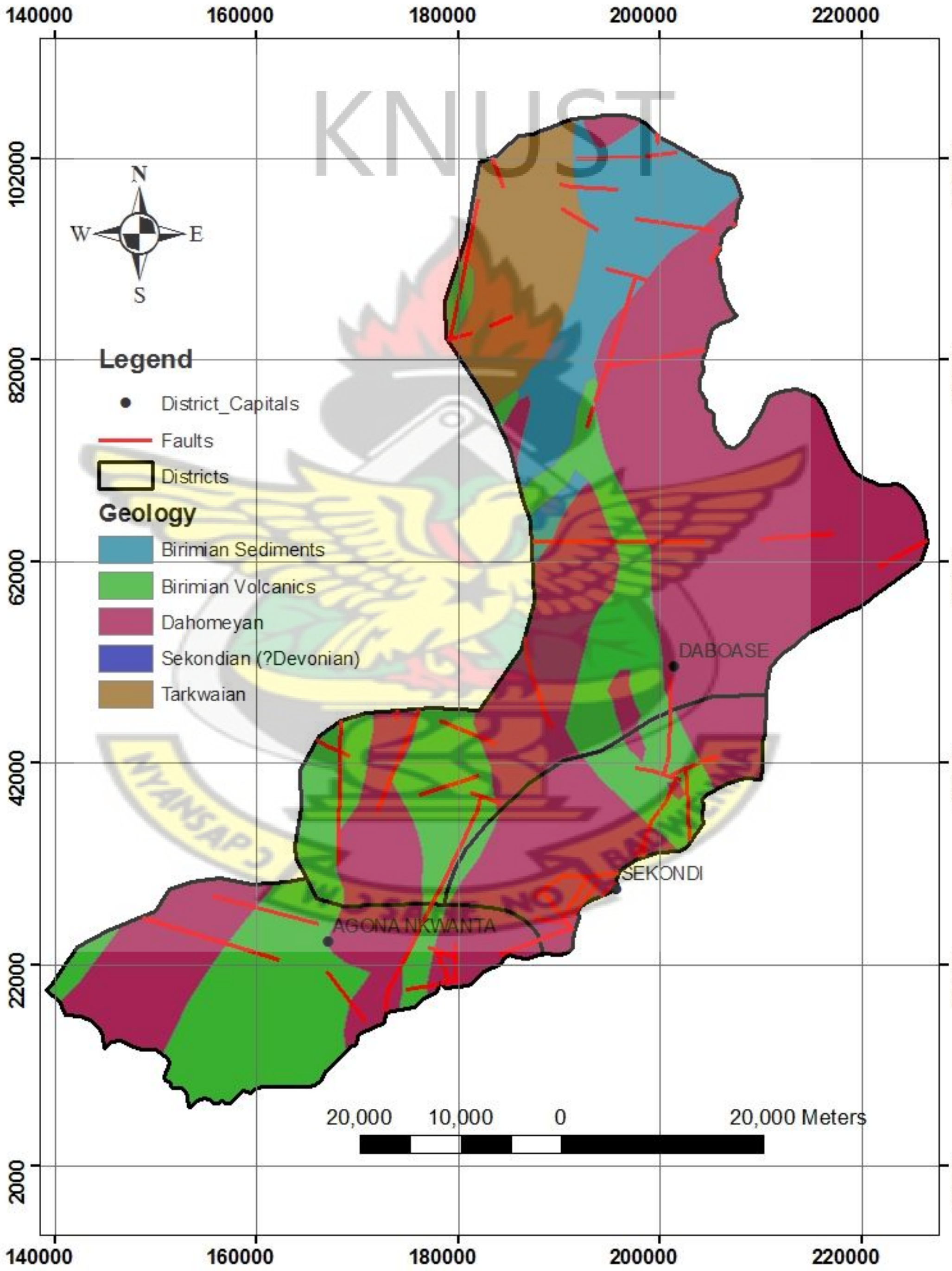
APPENDICES

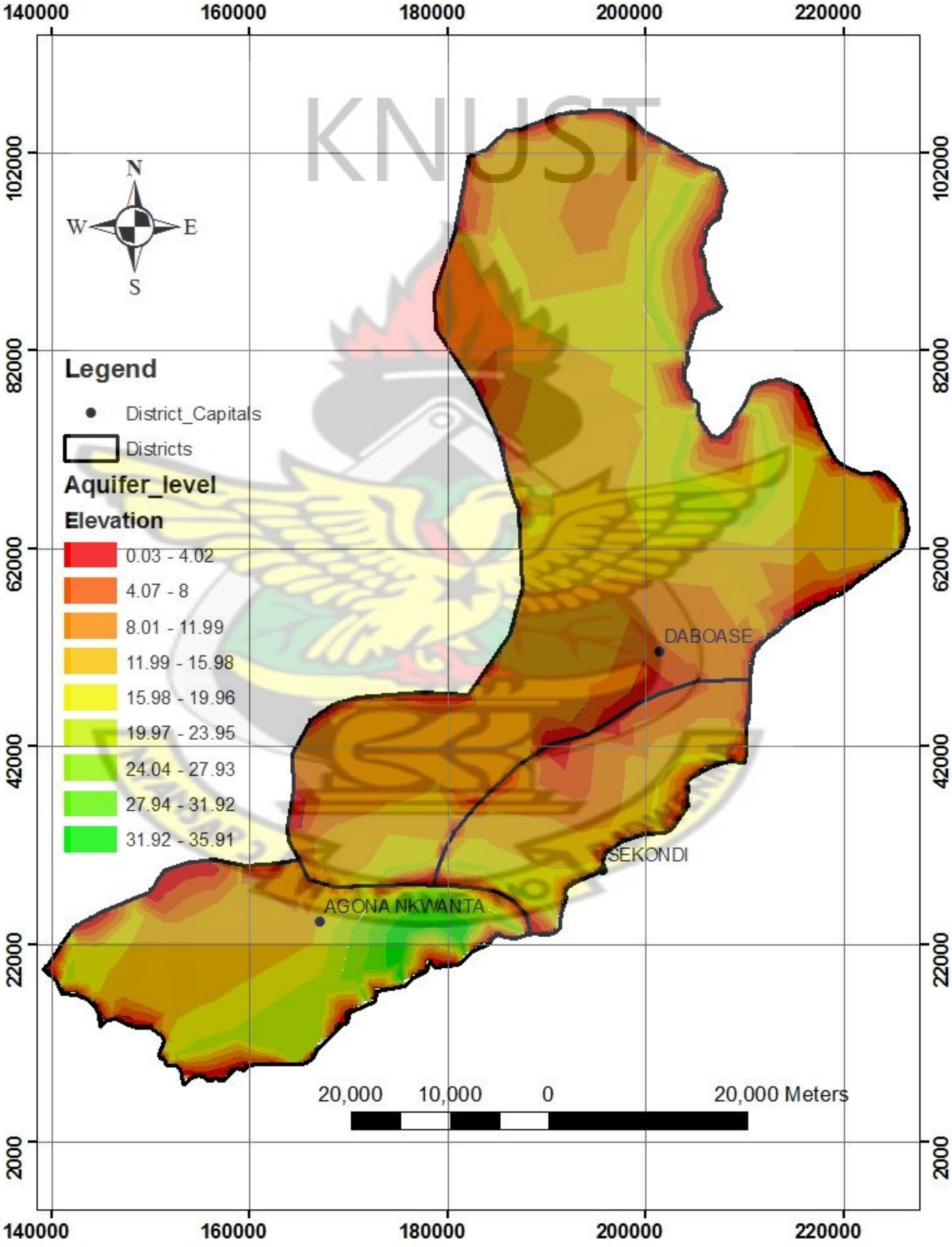
Appendix A

Geological map of the Study Area



Appendix B

Aquifer level map of the Study Area



Appendix C

Slope map of the Study Area