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Wind Farm Site Selection Assessment in the Greater Accra, Volta and Eastern Regions of Ghana: A GIS Spatial Multi-Criteria Assessment

Norwegian University of Science and Technology

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ABSTRACT

Global temperatures have increased since preindustrial times and will continue to do so unless practical measures are taken to halt the emission of carbon and other ozone depleting substances. Wind energy alone has the potential to supply energy in greater magnitudes to a significant percentage of the world's population with emissions of 0.02 to 0.04 pounds equivalent of CO_2 per kilowatts hour per year as compared to coal's emission of 1.4 to 3.6 pounds equivalent of CO_2 per kilowatts hour. Wind is a naturally occurring resource that has been the source of energy for mankind since time immemorial. Generating electricity from the power in the wind is however relatively recent. Wind is spatially and temporally variable and so tapping the wind power for producing electricity requires location specific analysis for wind installation. This study aimed at finding suitable locations for wind farms in South Eastern Ghana in West Africa. The study area covers three administrative regions. A ten year daily records of wind run data was collected from ten stations from the Ghana Meteorological Agency in Accra, and a ten year average wind speed was assessed for them. The study area has variable wind speed records, the lowest in the Volta region and the highest in the Greater Accra region. An SMCA was used to select the suitable factors for the study and the AHP was used to apply weights to all the factors in order of importance. A weighted overlay analysis in ArcGIS 10.2 was used to produce a map of the suitable areas using land use data, power grid lines, road networks and slope calculated from Digital Elevation Model (DEM) 30m resolution. The best location with best wind speeds are in the Greater Accra region covering some 86288 hectares of land. The second objective of this study was to find the initial estimate of electricity that can be produced from the selected areas. The wind speed of the selected areas was extrapolated to hub heights of 80m. The new wind speed used for estimating the electricity production is 3.6m/s. The Power law was applied using a swept area diameter of 100m, a hub height of 80m and 3.6m/s wind speed. The total initial estimate of power that can be generated is 10551MW, 1.2MW per turbine. The country can see economic transformation if this energy is added to the power grids and the surplus can be exported to countries in the sub region. The study shows that Ghana has capacity for wind energy which needs to be developed. Future studies must consider site specific measurement of wind speeds at the selected areas in the other regions as they are more spatially variable than the Greater Accra region since so the meteorological data cannot reliably interpolate wind speeds across those regions. Ground measurements at hub heights need to be conducted at the selected best sites in the Greater Accra region to ascertain the true wind conditions.

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Thirdly, I am sincerely thankful to Ola Fredin (PhD) for accepting to supervise my thesis, his comments, suggestions and encouragements have been of immense value to this study.

Lastly, I acknowledge my colleague students and staff at the Department of Geography and the Faculty of Science for their comments and critiques, it all added substance to my work. My wife and my daughter who endured during this period when I was often absent, I appreciate their patience and love. To God be the glory!

DEDICATION

To the memory of my beloved father, the pillar of my pursuit for knowledge

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List of Abbreviations

AHP	Analytical Hierarchy Process
CERGIS	Centre for Remote Sensing and Geographic Information System
CI	Consistency Index
CR	Consistency Ratio
DEM	Digital Elevation Model
EC	Energy Commission
ESRI	Environmental System Research Institute
GDP	Gross Domestic Product
GIS	Geographic Information System
IDW	Inverse Distance Weighting
IEA	International Energy Agency
IPCC	Inter-governmental on Climate Change
kW	kilo Watt
m/s	meters per second
LU	Land Use
MCA	Multi Criteria Analysis
MW	Mega Watt
NEC	National Energy Commission
NREL	National Renewable Energy Laboratory
SMCA	Spatial Multi-Criteria Analysis
SWERA	Solar and Wind Energy Renewable Assessment

UNCED	United Nations Conference on Environment and Development
UNEP	United Nation Environment Programme
USGS	United States Geological Service

CHAPTER ONE

INTRODUCTION

All over the world the interest and the need for renewable energy is increasing rapidly because oil and fossil fuel deposits are being depleted (Aleklett et al., 2010). Moreover, fossil fuel resources cause considerable amount of air pollution, acidic precipitation, ozone depletion (Dincer, 2000) and they ultimately lead to climate change and its associated impacts (Stocker et al., 2013). Concerns over global warming and climate change have grown over the last two decades and anthropogenic factors have been attributed as the lead cause other than just natural causes (Crowley, 2000; Liverman, 2007; Vitousek, 1994). Emissions from coal, oil and natural gas with active elements such as carbon dioxide are the lead causes of global warming. Several global conferences, notable among them, the United Nations Conferences on Climate Change (UNCCC) sought to mitigate global warming and adopt adaptive measures against climate change. The Intergovernmental Panel on Climate Change (IPCC) publishes a periodic working group report on the subject of global warming and climate change.

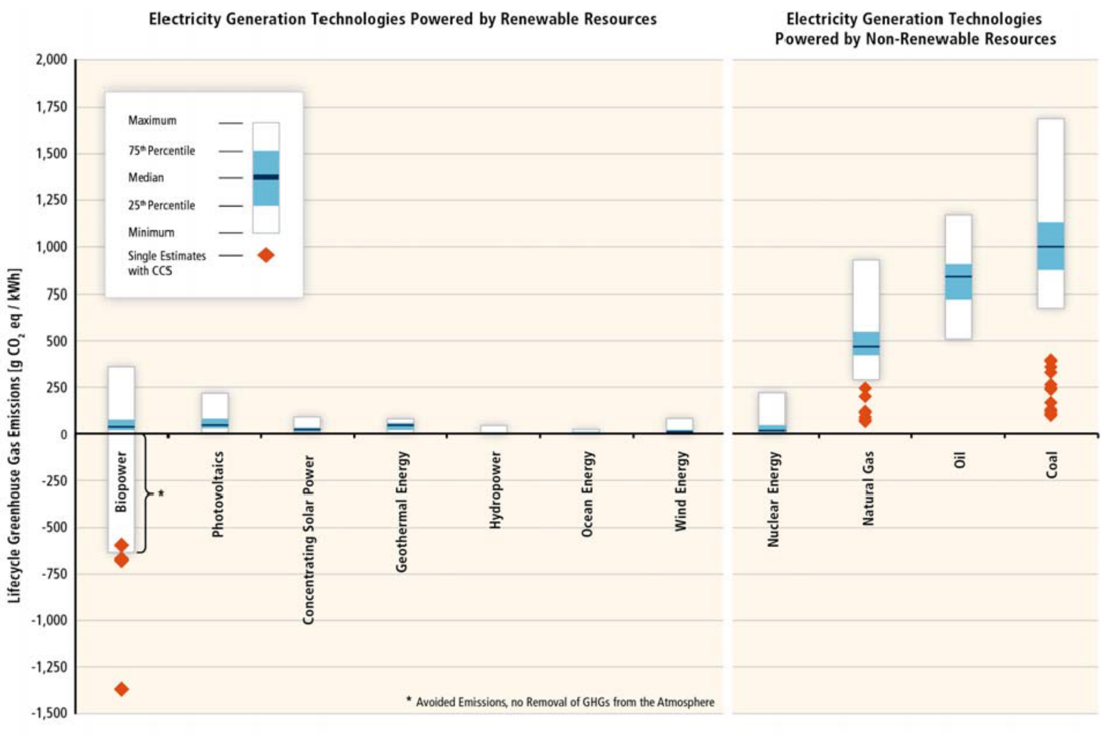

Figure 1 Greenhouse emissions of renewable and non-renewable energy sources

(Table adopted from IPCC Working Group III Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), 2011)

The figure above shows the carbon emissions of natural gas, coal, oil as against renewable sources of energy. Coal emits 1.4 to 3.6 pounds of carbon dioxide equivalent per kilowatt hour and natural gas emits 0.6 to 2 pounds equivalent of carbon dioxide per kilowatt hour as compare to wind turbines which emit 0.02 to 0.04 pounds equivalent of carbon dioxide per kilowatt hour. The difference in emission between renewable and non-renewable energy sources calls for a shift to utilization of renewable energy. Global energy needs would increase by as much an order of magnitude by 2050 and primary energy demand to about 1.5 to 3 times current levels (Dincer, 2000). In the light of this, global and regional efforts are being made to increase the production of renewable energy. The United Nations Environment Programme (UNEP) Solar and Wind Energy Renewable Assessment (SWERA) programme seeks to achieve the objective of helping developing countries to assess their renewable energy resources. The European Union Renewable Directive has set a target to achieve 20% of its energy needs from renewable sources by 2020. In Africa, renewable energy is highly under exploited (Karekezi, Kithyoma, & Initiative, 2003) and its consumption rate contributes to only one quarter of the global average per capital, and with a population projected to increase to about 2 billion by 2050 (International Renewable Energy Agency, 2013) its energy needs with increase. A strong interest particularly in solar and wind energy is surging. This is being driven by improved and new technologies and ample natural availability of solar and wind, and the quick deployment of solar and wind turbines compared to declining fossil fuels. However the spatial variability of renewable energy requires specific location-dependent strategies to efficiently tap the resources (Gross, Leach, & Bauen, 2003). In Ghana, recent SWERA and National Energy Commission (NEC) projects showed that wind energy has the capacity to help meet the energy needs of the country. With a growing population and industrial and household demand exceeding the current energy production, wind energy development is an option which can fill in the energy demand gap. Investment is however lacking because of the unavailability of data on suitable sites for wind farms.

1.1 Problem Statement

The oil crises in the 1970's pushed renewable and in particular wind energy production into a large scale venture (Hoogwijk, de Vries, & Turkenburg, 2004). Besides meteorological wind availability, choosing a site for wind farm the geographic factors of land use and elevation, and the impact of the wind turbines among others on the landscape must be taken into consideration. Generally these factors have been very challenging for both offshore and onshore wind farms with the latter being hugely protested because of conflicts with other land uses and nature and industry stakeholders (Devine-Wright & Howes, 2010). Under the Solar and Wind Energy Resource Assessment program of UNEP and the US Department of Energy's National Renewable Energy Laboratory (NREL), an assessment of wind energy potentials in Ghana concluded that there is a huge potential of 5649MW of wind energy in Ghana between class 3 and 4. The NREL defines Class 3 winds between 6.8 m/s and 7.5 m/s as being fair and class 4 winds is categorized between 7.5m/s to 8.1 m/s as being good for commercial production of wind energy.

Faced with the challenge of inconsistent energy supply, the government of Ghana has been looking at alternative ways of increasing energy production. One of the key priorities is wind energy. Ghana's energy expenditure is expected to grow to about US$5.2 - 5.6 billions, 8-9% of the Gross Domestic Product (GDP) in 2020 (Strategic National Energy Plan 2006- 2020, Ghana Energy Commission EC, 2006). Wind energy was however surprisingly only briefly mentioned as having a huge potential in this report.

The wind energy potential in Ghana is considerable, and this has been corroborated by the Energy Commission in 2001 and 2006 and the UNEP SWERA programme. Ghana in 2011 enacted the Renewable Resources Act, Act 823, which has further fostered the interest in renewable energy. Given that this is a relatively new venture in Ghana, there is a lot of interest by many parties but the amount of work done on the ground is rather scanty. Previous works by the UNEP SWERA programme and the Energy Commission (EC), excluded all land use factors as being critical determinants of wind turbine locations. It is a known fact that citing of wind turbines can have considerable impacts on other land use activities and landscape (Hansen, 2005). Moreover, works done by (Adaramola, Agelin-Chaab, & Paul, 2014) only made an economic analysis of wind energy at selected locations in coastal Ghana, without further considerations on land use conflicts

Greater Accra has a long coastline and much of the region's population are located along the coast. Moreover, it holds the capital city of Ghana and it is the second most populous region. Wind power potential as per measurements taken at the three weather stations in Ada, Tema and Accra on a ten year annual mean wind speed shows wind speeds of 2.6, 2.5 1.8m/s respectively. The Volta and Eastern Regions of Ghana together have the potential of producing 3900MW of electricity (National Renewable Energy Laboratory, 2006).

This study therefore seeks to fill in the gap of location-specific data on wind installations at three regions in south eastern Ghana which have been identified to hold high potentials for wind installation but have no data on specific location for wind farms. This suitability assessment is done incorporating several factors, including landscape, land use, distance to roads and national power gridlines. By incorporating these factors together, the result is that potential conflicting land cover is avoided and suitable distance from roads and national gridlines which reduces the cost of developing the farm and impact on landscape aesthetic are considered.

1.2 Research Question

This study seeks to answer the following questions;

- Which areas are most suitable for siting wind farms in South Eastern Ghana?
- How much energy can these sites produce in a year?

1.3 Research Objective

The main objective of this research is to locate suitable sites for wind farms in the selected regions and, secondary objective is to estimate the amount of energy that can be generated from the selected sites.

1.4 History and Trend of Growth of Renewable Energy Production in Africa

Africa is ranked as having the world’s highest reserves of renewable energy (Mukasa, Mutambatsere, Arvanitis, & Triki, 2013). Renewable energy is energy whose source can be replenished. These include wind, solar, hydro, geo-thermal and biomass. Renewable energy production in Africa, particularly wind and solar, is relatively new and interest is driven by increases in oil prices in the year 2000 and after, and recurrent crises in the conventional power utilities (Karekezi, 2002; Kennedy-Darling, Hoyt, Murao, & Ross, 2008). World governing instruments such as the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil 1992 also boosted the then incipient interest in Renewable Energies. Largely, the bulk of renewable energies in Africa are biomass, geothermal and hydropower (Karekezi et al., 2003). Solar energy in its large, small and micro installations is vastly more utilized than wind energy even though it is also highly under exploited. This leaves wind energy as the least exploited in Africa at 1000MW in 2010 forming just about 0.5% global capacity.

Table 1 World Renewable Energy Potential

Region	Total Renewable Energy	Solar	Wind	Hydro	Geothermal
Africa	18	24	8	11	9
East Asia/Pacific	4	5	3	6	4
Europe/Central Asia	3	0	6	5	14
Latin America/ Caribbean	7	5	8	9	3
Middle East	1	0	1	0	0
South Asia	0	0	1	1	0
All World Bank Regions*	33	34	27	32	30

Source: Buys et al 2007, taken from (Mukasa et al., 2013)

Installed capacity of wind energy is only 1.1 Giga Watts (GW) which is just a little over 0.5% of the global total installation. The International Energy Agency (IEA) projects that wind energy would contribute only 2% of the total energy mix in Africa by 2030. Coastal Africa has the highest wind potential. Egypt, Morocco and Tunisia together contribute about 99% of the installed capacity on the continent. Landlocked parts of Africa with exceptions in high altitude areas such as Ethiopia and Kenya, generally have very low wind potentials with limited capacity for electricity generation (Mukasa et al., 2013).

Between 1995 and 2000, installed wind capacity increased twelvefold with concentration of installed capacity in Northern Africa, mainly completed after year 2000. Southern Africa follows with installed capacity of less than 10MW. West and Central Africa have no completed wind farms, although a few have been planned in West Africa, they have not been completed.

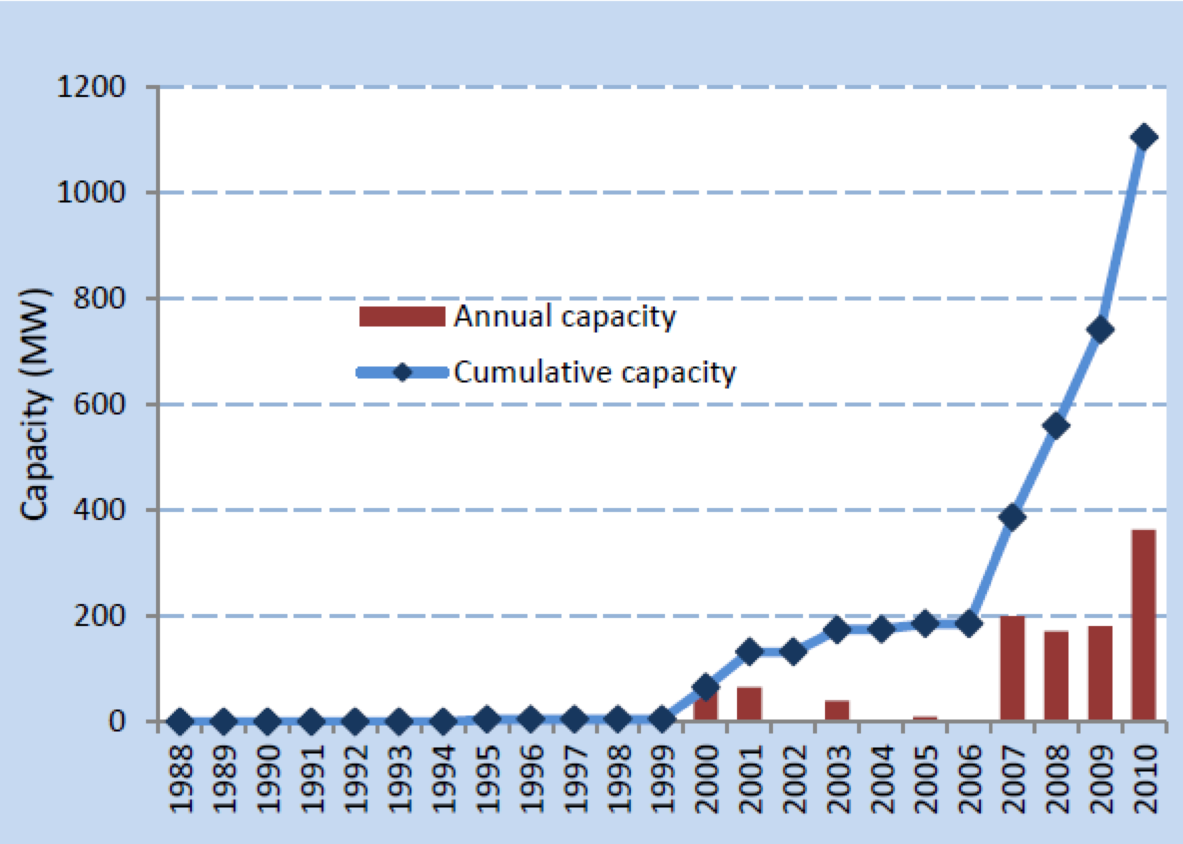

Figure 2 Installed wind capacity in Africa until 2010

Source: Wind Energy Development in Africa, African Development Bank 2013

Across Africa, a huge interest in Wind Energy is on the rise. Several countries including Ghana have planned installations of wind power. Over the last 20 years, considerable research into potential wind energy development has been taking place in Ghana and the general conclusion is that along the coastal regions, wind conditions can support viable wind installations (Kemausuor, Obeng, Brew-Hammond, & Duker, 2011). There is however no wind energy installation project going on at the moment aside those which are still at the planning stages.

1.5 Previous Studies on Siting of Wind Farms

In a paper Baban and Parry (2001) used the results from questionnaires obtained from Local Councils and private wind energy companies to select suitable sites within a 40km by 40km stretch of land in England. The factors or constraints used include physical, planning, economic, environmental, and resource considerations. The criteria used include topography, wind speed and direction, land use/cover, population, hydrology, ecology and resource. Their justification for these criteria is that the wind farm must be elevated enough to avoid summits and to also face prevailing winds. The minimum daily wind speed that should be available at a site is 5 m/s. The farm should be situated 500m away from standing forest because it can affect wind speed and direction. The 2000m distance from urban centres is because of noise pollution, safety and aesthetics. They used IDRIS GIS to put all the different layers together in order to come to a single point of evaluation. The results from this work indicate that urban and road buffers significantly influenced the suitability of the sites in the densely populated cities of England.

In a 2011 work in the Kujawski-Pomorskie Voivodoship, (Sliz-Szkliniarz & Vogt, 2011) using various interpolation methods such as Inverse Distance Weighting (IDW), Polynomial Interpolation Method, ordinary Kriging and ordinary cokriging methods in GIS, they interpolated vertical winds at hub heights at 50, 80 and 100m and horizontally for areas where there is wind record. They overlaid this against ecological, technical and economic criteria. The central focus was on the wind potential in the region and against the backdrop of spatial policy instruments they estimated the load hours of potential energy that can be generated and its cost potential. Their results show that the Kujaskie-Pomorskie region has a very high potential for wind energy production with an average annual wind speed of 5.5m/s.

Spatial Multi-Criteria Analysis was used in a GIS environment by (Van Haaren & Fthenakis, 2011) to determine if existing wind farms met certain environmental and cost criteria. The authors employed three stages in this approach. Firstly, they excluded infeasible sites based on land use and geological constraints. Secondly, they performed an economic evaluation on the feasible sites to see which would return more economic benefits. The costs of feeder road construction to the nearest road, the cost of land clearing, the cost of transmission into national grid were some of the factors evaluated to determine the net values of the wind farms. Lastly, they looked at the ecological impacts on birds and their habitats. 500m is the proposed distance based on their model between important bird areas and the wind turbines. Their results show that none of the existing wind farms fall within the infeasible sites. None of the existing farms also fall within the buffer zones across all the factors used in the study

It is difficult to come by any work on SMCA on wind farm site selection in Africa. Majority of the work done using SMCA is on agricultural farms, water basins, conservation areas. The unavailability of SMCA in siting wind farms in Africa is one of the main reasons this work is important to fill in the missing gap.

CHAPTER TWO

STUDY AREA

2.1 Introduction

Three administrative regions located in Ghana; Greater Accra, Eastern and Volta Region, have been selected for this research based on different criteria. Selecting a study area is often motivated by several factors and motivations. This study area choice is motivated by wind energy potentials and one being administrative capital of Ghana and also varying topography

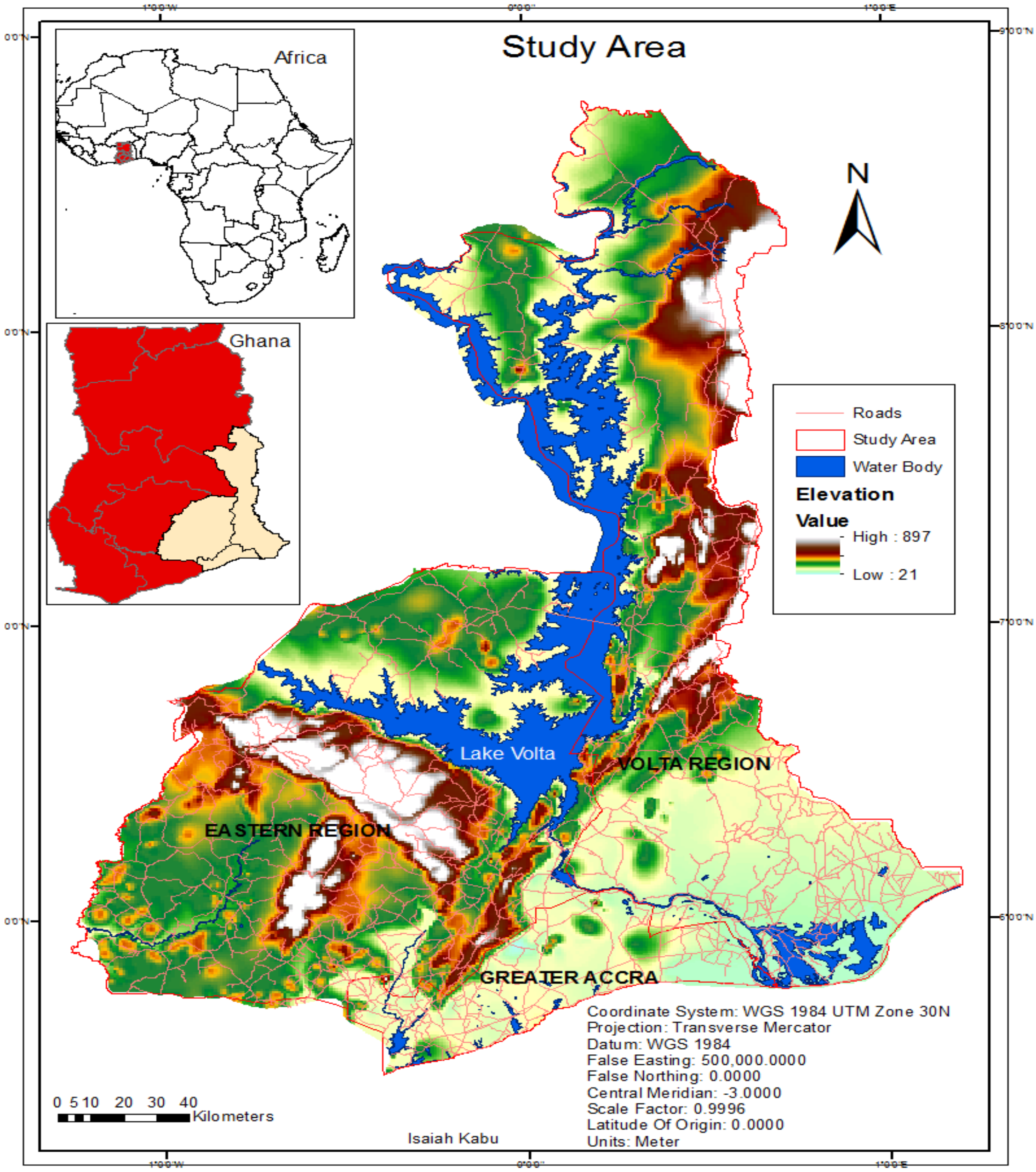

Figure 3 The three regions (Volta, Eastern and Greater Accra) of study in Ghana

2.1 Greater Accra Region

Greater Accra Region is the smallest of 10 administrative regions in Ghana, yet it is the most densely populated. The year 2000 population and housing census puts the figure at 895.5 persons per square km. It is the second most populous region in Ghana after the Ashanti region, with a population of 4,010,054 in 2010 (Ghana Statistical Service, 2010). The region is also home to the capital city of Ghana, Accra.

By anecdotal evidence, Greater Accra is mainly a plain with few isolated hills and inselbergs. It has a coastline of approximately 225 km with dry conditions. Temperature ranges between 20 and 30 degrees Celsius. Rainfall pattern varies from the coast towards the northern boundary where the region is dominated by the Akwapim- Atakora Togo ranges. Annual rainfall is between 635mm and 1140 mm. Two main rivers, the River Volta and the River Densu run through and enter the Atlantic Ocean in the Greater Accra Region. Agriculture is not a mainstay of the region's economy but it boasts of mango plantations, irrigation farms and several hectares of small scale farming

Greater Accra is also the economic hub and administrative capital of Ghana. Economic activity is however not evenly distributed in the region. The Tema Metropolis and the Accra Metropolis together have a dominant share of the region's economic activities. It has the only international airport at Accra and a new international airport has also been proposed in the region to be located at Ningo. All ministerial headquarters are located here. The region also has the country's largest seaport at Tema and a chain of industries.

2.2 Eastern Region

The Eastern Region is the third most populous region in Ghana with a total population of 2,106,696 (Ghana Statistical Service, 2010). The region lies in the wet equatorial semi-deciduous forest region and has a double maxima rainfall from May-June and September-October. Rivers such as Pra, and Birim take their sources from the Southern Voltaian ranges in the Kwahu plateau and Atiwa ranges respectively (Donkor, Bonzongo, Nartey, & Adotey, 2005) and run through the region. Temperature ranges between 26 and 30 degrees Celsius. It has large parts of the Volta lake basins. The region is mainly forest region with elevation rising above 700m above sea level.

There are four main highland regions, the Kwahu Scarp with an elevation of 788m above sea level, The Atiwa-Atwaredu ranges reaching an elevation of 731m above sea level. The Akwapim- Atakora Togo ranges reaching an elevation of 466m feet above sea level and the low and isolated Krobo hills. The region is endowed with minerals such gold, diamond, bauxite, manganese, kaolin, limestone and clay. Diamond and gold are the only minerals being mined in the region.

It has valuable forest and agricultural resources. The main economic activity is agriculture. The forest and savannah soils are suitable for crops such as cocoa, oil palm, citrus, cola-nuts, and staple crops such as cassava, yam, cocoyam, rice, maize and vegetables are also produced in the highland region.

Two hydro-electric dams are located in the region at Akosombo and Kpong. The Akosombo dam has total installed capacity of 1020MW. The Kpong dam has an installed capacity of 160MW. The region also boasts Botanical gardens and several tourist attractions.

2.3 Volta Region

The Volta Region has a land size of 20,570 km2 with a total population of 2, 118, 252 (Ghana Statistical Service, 2010) and it is the 7th most populous region in Ghana. The region stretches from the Gulf of Guinea in the South to the middle belt of the country and so it has varied vegetation types, coastal scrub and coastal savannah in the south, semi- deciduous rain forest and the dry savannah in the north. It has a double maxima rainfall with variations from May-June and September-October. Mean annual precipitation ranges between 300mm in the north to 1500mm in the south.

The region has the highest peak in Ghana. Mountain Afadja is part of the Agumatsa ranges and it is 885m above sea level. The Volta River and the Lake Volta border the region to the west. The topography of the region varies with lowlands and plains located along the coast. The Agumatsa ranges is located on the east and the Akwapim-Atakora Togo ranges lies west north-east across the region. On the east are the Agumatsa ranges which extend into Togo.

Agricultural activities are practiced across the region with fishing activities mainly found along the coast and on the Lake Volta. Cocoa production is centred in the mid-western part of the region.

CHAPTER THREE

DATA

3.1 Introduction

Data collection took place in the summer of 2015 with travel scholarship received from the Nordic Africa Institute in Uppsala, Sweden and the Norwegian Lanekassen. These support packages made it possible for me to travel to Ghana. Aside the wind data from the Ghana Meteorological Agency in Accra, I conducted an interview with the Project Manager of a consulting firm for a proposed Wind Farm in the Greater region of the study area. This interview gave me an overview of what companies take into account when planning a site for wind farm. The datasets on gridlines, road network, slope and land uses were all digitally sourced from the United States Geological Survey (USGS) and the Centre for Remote Sensing and Geographic Information System (CERGIS) in the University of Ghana.

3.2 Data

In this study wind data from 10 meteorological stations in the study areas were obtained from the Ghana Meteorological Agency. The data which cover a period of 10 years from 2003 to 2014 was obtained as daily wind run data. An average for each station over the 10 years was calculated in Microsoft Excel. In order to convert from wind run which is the total amount of wind recorded at the station over a 24 hour period, the daily wind was divided by 24 in order to get the daily wind speeds which were all given in km/h.

$X/24$

X = Wind run in km (Total amount of wind that passes through the station in a day, recorded at 9 am).The 10 year average km/h was then converted to m/s using the formula:

$WS = wr / (3600/1000)$

WS, then = $wr/3.6$

Where WS is wind speed m/s, wr is wind speed in km/h. All the anemometers are situated 10 meters high.

Table 2 Ten year average (2003-2014) Wind Data from ten Meteorological Stations

	Station	Latitude	Longitude	Wind_m/s
1	Ada	5.78	0.6	2.6
2	Accra	5.55	-0.2	2.5
3	Tema	5.63	0	1.8
4	Ho	6.6	0.5	0.6
5	Akatsi	6.1	0.8	0.9
6	Kete-Krachi	7.8	-0.4	0.6
7	Akuse	6.1	0.1	0.8
8	Abetifi	6.6	-0.7	1.8
9	Koforidua	6	-0.3	0.8
10	Akim Oda	5.9	-0.9	0.6

The meteorological stations as shown on the elevation map of the study area below give a visual depiction of the varying topographies that they are located in, and also shows how sparsely distributed the stations are within each region. For this project the presence of wind and its amount and frequency is a very important factor for the site selection. The minimum amount of average wind recorded over the ten year period is 0.6 m/s at Ho, Kete-Krachi and Akim Oda, and the maximum is 2.6 m/s at Ada. It should be however that these are average values over a long 10 year period, and short period wind speeds are often significantly higher. The meteorological stations are located at varying elevations and prevailing environmental conditions. All the three stations in the Greater Accra Region are located in the coastal towns and cities.

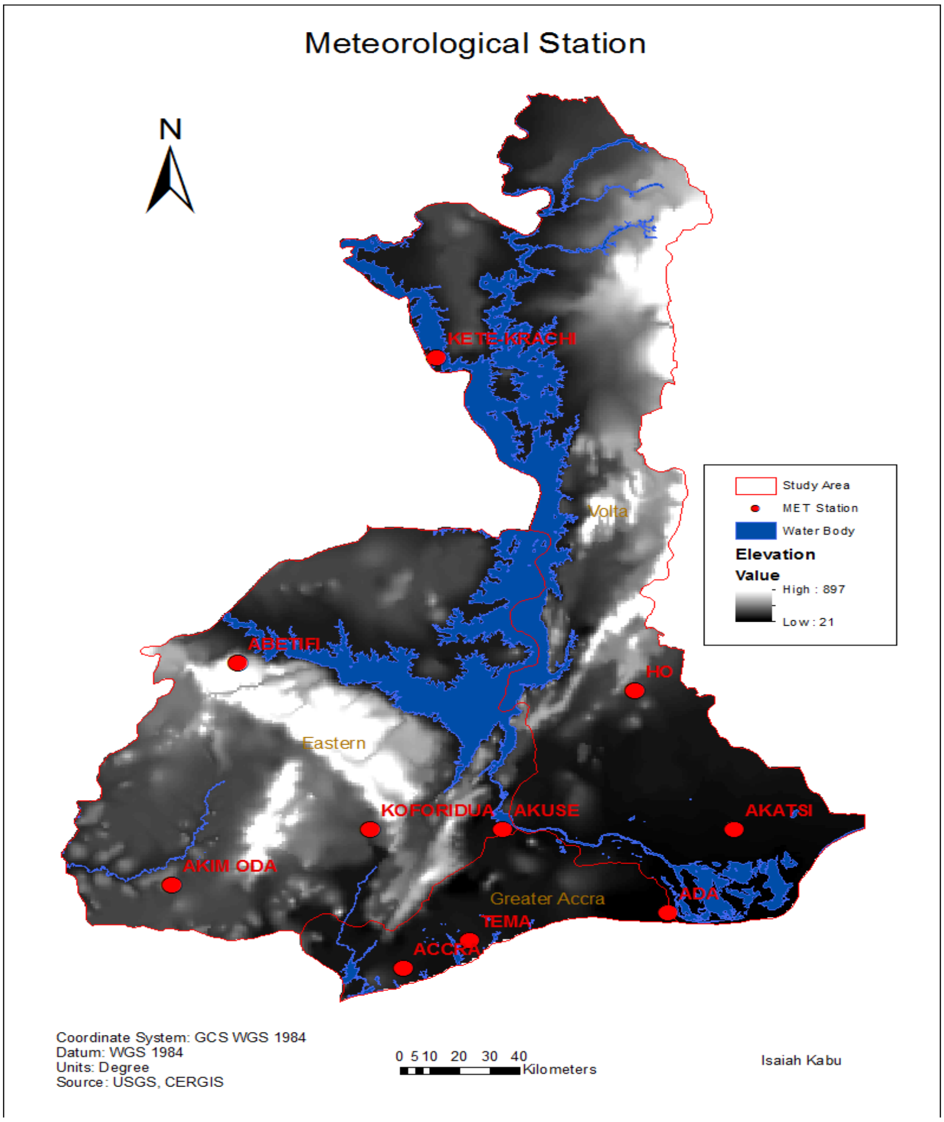

Figure 4 Meteorological Stations and topography

The elevation at the Greater Accra is fairly flat; Tema 79m, Accra 83m and Ada 128m these characteristics give the stations homogeneity in wind conditions. The Volta Region has all three meteorological stations spread across different topographic regions, Akatsi 54m is located in the coastal zone, Ho 154m in the middle belt and Kete-Krachi 92m located in the north of the region and they are located widely apart. The Eastern Region with a long chain of ridges and its semi-deciduous forest also has variations in the topography. Akuse 67m is located in the south east of the region, Koforidua 154m is located in the middle belt of the region, Akim Oda 151m and Abetifi 602m above sea level located on the Kwahu Ridge is the highest altitude of all the ten stations. The areas surrounding Abetifi are the Kwahu

Scarps but there is a sharp decline unto the Afram plains which is likely to affect the wind variations in those areas.

3.2.1 Protected Area

In many of the studies that have been done in wind site selection, protected areas are classified as constraints that need to be eliminated such that wind farm siting is avoided in protected areas. Protected areas have biological, ecological, aesthetic, cultural and spiritual importance (Howard et al., 2000). These are key values that outweigh any other factor suitable for wind farm in the area such as favourable winds or nearby roads or grids. In Ghana protected areas are instituted by law and as such cannot be used for any other purpose than that which they are constituted for (Resources, 2012). In this study all protected areas have therefore been eliminated and classified as not suitable for a wind farm site. They are mostly located in the Eastern and Volta Region in the study area

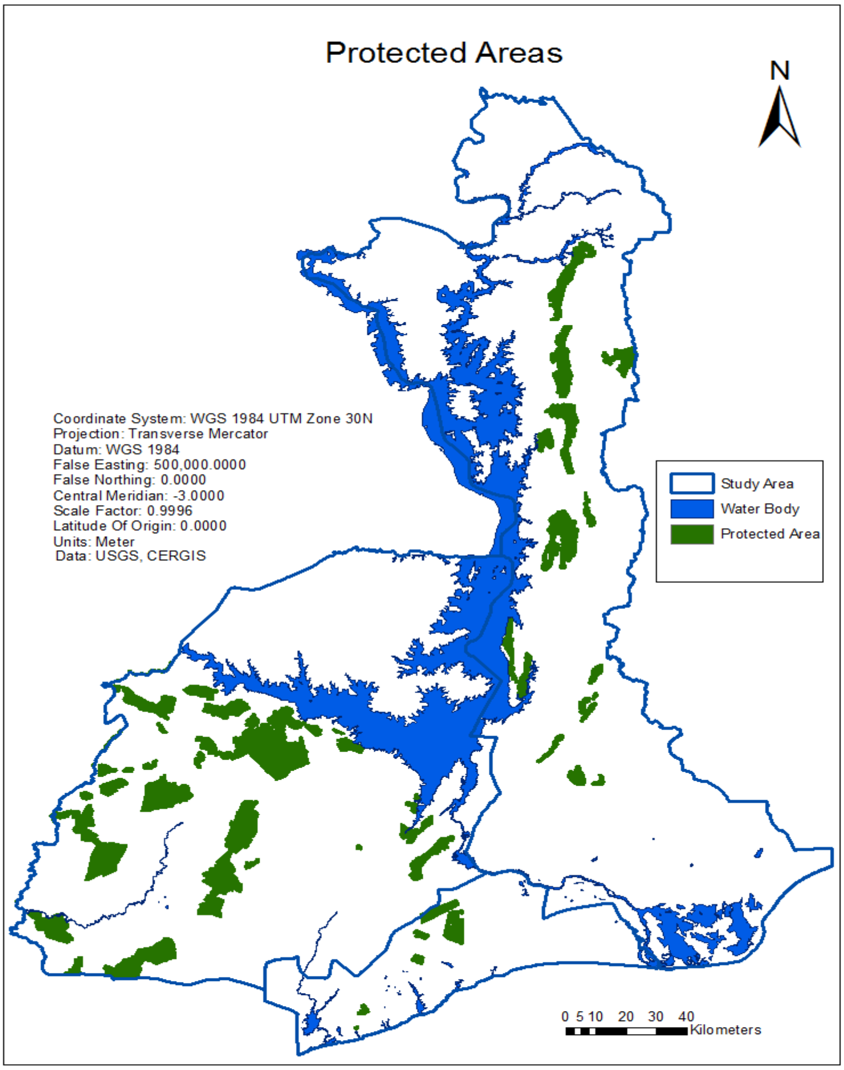

Figure 5 Protected areas in the study area

3.2.2 Major Road Network

Road networks are important for selecting a site for wind farm to enable easy access. Already existing roads reduces cost involved in putting up a wind farm. In a study conducted in the United States, the construction of new roads increased significantly the cost of the production whereas existing roads facilitate easy access to the site (Van Haaren & Fthenakis, 2011). However, the presence of a wind farm along major roads often raises the question of aesthetics as was the case in a study in Spain (Sibille, Cloquell-Ballester, Cloquell-Ballester, & Darton, 2009). It is therefore important that a suitable distance is determined whereby cost reduction is met and aesthetic values of the landscape enjoyed by road users is also kept. A distance of 1-10km betweens major roads is used for the analysis

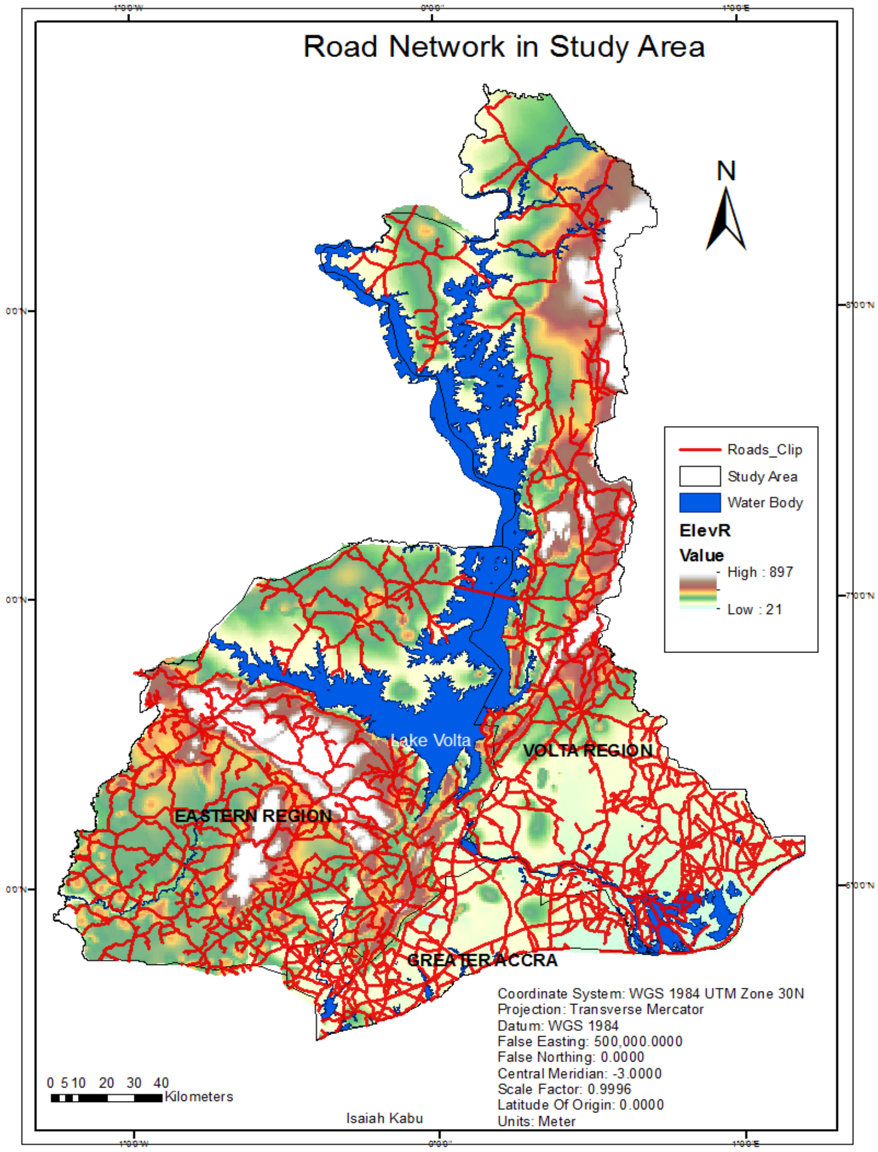

Figure 6 Major road networks in the study area

3.2.3 Water Bodies

Water bodies which in this study include rivers, lakes and wetlands such as lagoons swamps, estuaries, mangroves which are defined as reserved under the Ramsar Convention, an international treaty for sustainable use of wetlands, are vital for human and countless species survival. These sites are named after the city Ramsar in Iran where the convention was signed. These sites (Adaramola et al., 2014) have been classified as not suitable for wind farm sites because of the ecological services they provide. Ramsar sites are intentionally reserved sites for migratory birds and they are backed by law and so any installation of wind turbines would interfere with migratory routes and as a consequence impact bird population

(Baban & Parry, 2001). Water bodies are of very important ecological and economic use. They often form habitats for very rich and diverse species of fauna and flora. In this study a buffer of 4km is created around all water bodies.

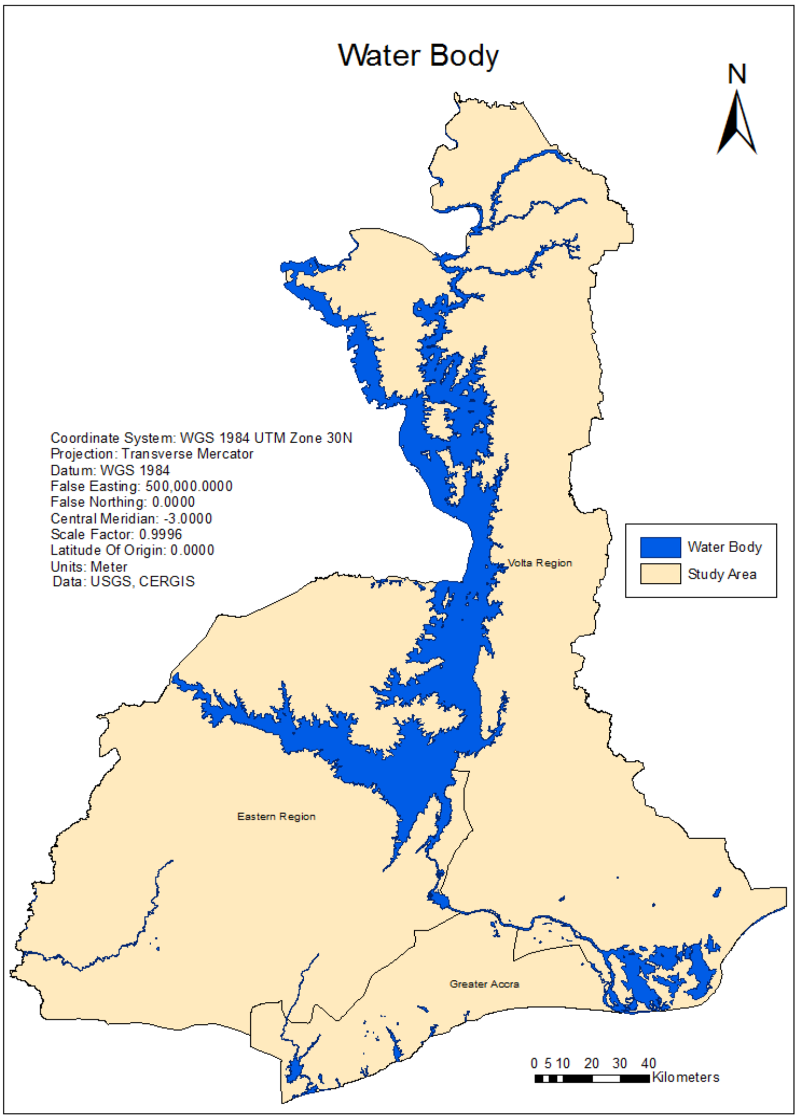

Figure 7 Water bodies in the study area.

3.2.4 Land Use

A Land use data made in the year 2000 for Ghana by the Centre for Remote Sensing and Geographic Information System, (CERSGIS) University of Ghana. Digital Elevation Model data was obtained from United States Geological Survey (USGS) with cell resolution 30m. The data on power gridlines, protected areas, rivers, lakes, and roads were all obtained as shapefiles through contacts at the United States National Renewable Energy Laboratory

(NREL) which was supplied in an NREL Spatial Toolkit App for Ghana. The Spatial Toolkit is an Application developed the NREL for various countries and it contains layers of data and their metadata which can be downloaded.

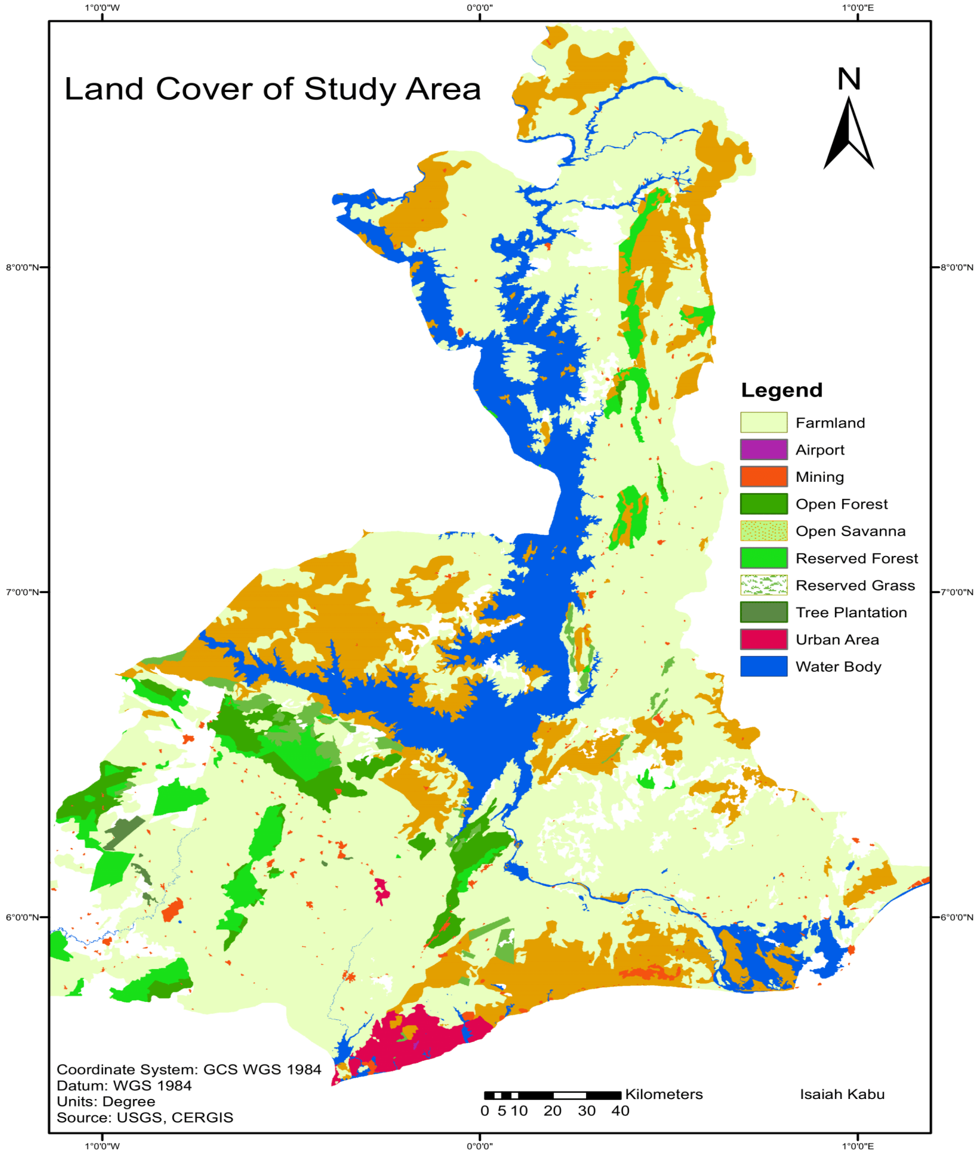

Figure 8 Land use types in the study area

The land use data shows a diverse classification of various themes. Mainly farming and cultivation types and vegetation types are dominant themes in the land use classification. Also water bodies and various wetland areas are also classified in the land use data.

3.2.5 Slope

A slope is the steepness of a terrain. Locating a site for wind installation requires that the topography has gentle slope. This facilitates ease in transporting turbines and installing them. Moreover steep slopes disrupt wind field and cause unpredictable winds. In this study, suitable slope are less than 20 degrees. The slope is calculated from a United Nations Geological Service (USGS) Digital Elevation Model (DEM) for Ghana which was sourced with pixel type as a signed integer.

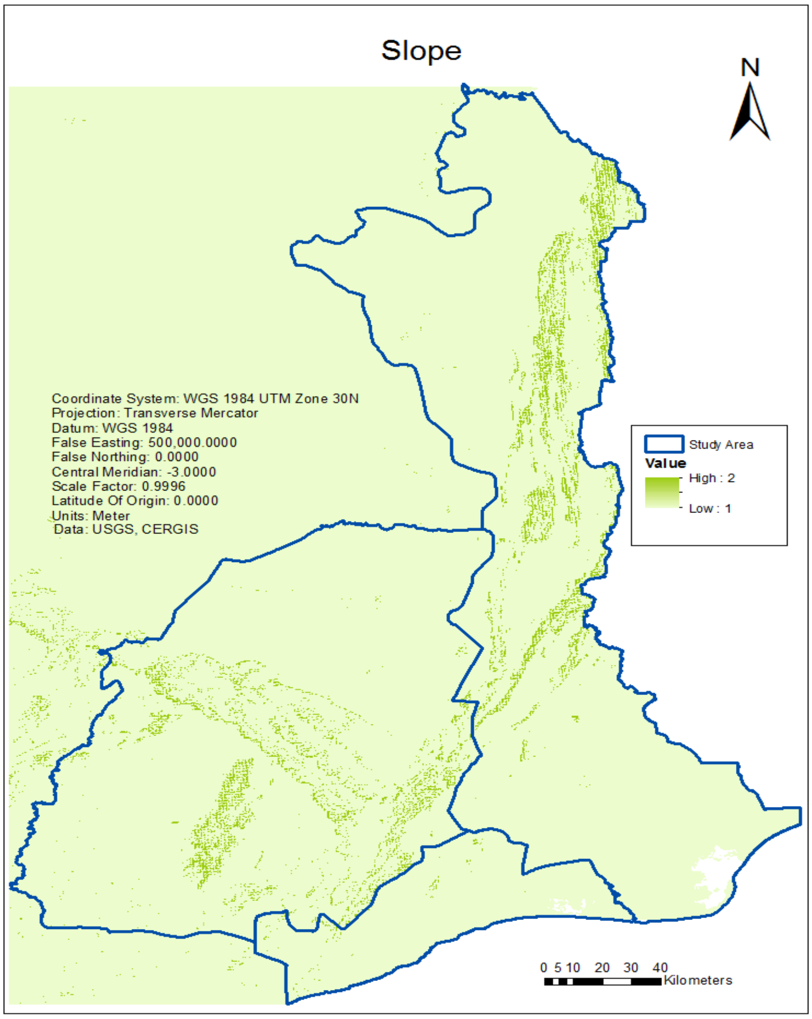

Figure 9 Slope map of the study area

CHAPTER FOUR
METHODOLOGY

4.1 Introduction

The methodology follows sequential steps in order to come to a single point of decision making. Two key methods have been employed and used in ArcGIS10.2 environment in this study. Firstly, Spatial Multi-Criteria Analysis (SMCA) is used to select all the necessary factors that are important for defining the problem under the following constraints; economic, environment, accessibility, aesthetics and topography. The criteria have been generated based on local conditions and what is internationally accepted, and assigned to all the factors. Secondly, Analytical Hierarchy Process (AHP) is used for weighting of the factors in an order of hierarchy. ArcGIS10.2 software is used for all the processes that led to the final suitability map. The tools used include Clip, Conversion tools, Reclassification, Euclidean Distance tool, projection tools, slope calculation tools. The choice of criteria and factors are influenced to some extent by studies that have been done elsewhere, and the NREL in United States recommendations of excluding specific themes such as national parks, water bodies and bird sanctuaries because of their biodiversity, environmental and cultural significance have been taken into consideration, and the significance of observing appropriate distance to existing grid lines and accessibility is also considered for this study because of their economic constraints and aesthetic values of the surrounding landscape which wind turbines can impact, moreover, additional factors such as landscape and topography have been incorporated in this study.

4.2 Spatial Multi-Criteria Analysis (SMCA)

Geographic Information System provides a platform for handling broad and wide range of data at various spatial, temporal and scalar degrees which makes the employment of spatial multi-criteria analysis (SMCA) a very valuable GIS technology to, for example, assess and weigh different spatial factors when siting wind farms (Chen, Yu, & Khan, 2010). SMCA emerged in the 1970s as a result of critiques of the flaws in neoclassical environmental economics way of decision making and site selection. Critique was very particular about the spill over or externalities and associated costs on the environment and considerable economic losses as a result of the traditional decision making style (Carver, 1991). Various alternative planning and problem solving techniques have been put forward to respond to the imminent flaws in the traditional neoclassical environmental economics. One of them is the SMCA which has led to the rise in a new decision making tool which captures multiple criteria involved in reaching a unified point of evaluation. The rise in SMCA in many spheres of decision making has simplified very complex situations in order to satisfy stakeholders with different interests. Geography is spatial by its nature and hence the use of Multi Criteria Analysis (MCA) in geography acquires spatial characteristics so that references can be made to positions and phenomena in space in order to have spatial perspective in all decision making processes. Many times planners are faced with the difficult choice of selecting the most suitable alternatives and at the same minimize conflict such that the decision must satisfy various actors and parties. Spatial Multi-Criteria Analysis is therefore is a decision making process that captures all important factors under the various constraints which then help in reaching a satisfactory point of evaluation. SMCA has four steps in its application; the first is the problem identification, structure and decision making process, and criteria formulation. Step two is criteria trade-off and criteria weight determination. Step three is value judgement of alternatives and evaluation; and the last step is the final aggregation and decision making (Pohekar & Ramachandran, 2004; Taha & Daim, 2013). In any multi-criteria analysis there is a goal that must be reached. There are factors which are categorised under various constraints. The constraints whose factors do not meet the criteria are avoided in the site selection process whereas the factors that meet the criteria are used in the assessment.

Table 3 Criteria and Constraint Factors

Criteria	**Constraint Factor**
A suitable location must:	
1. Have wind speed of > 2m/s	Wind Speed
2. Avoid large and rugged terrain	Topography
3. Have slopes <20%	Topography
4. Be at least 4km away from all water bodies	Hydrology
5. Be 5km away from urban settlements	Population
6. Be 0.5km away from villages and single dwellings	Security Land use
7. Be 10km away from airports	Security
8. Be located 2km away from Protected Forests	Land use Land use
9. Be located 1km from open forests	
10. Be located 1km from mining sites	
11. Be located within 3km -10km from roads	Access
12. Be located not further than 10km from a National gridline	Economy
13. Not be located within 5km from Protected Areas	

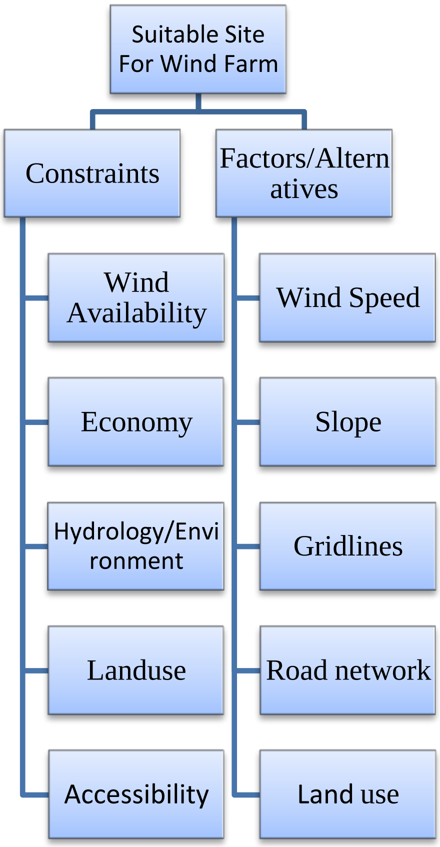

Figure 10 SMCA process showing the factors used in this study

The chat flow above shows a simple process of using SMCA to make decisions. The goal is to locate suitable sites for wind farms and the factors and alternatives are wind, slope, gridlines road network and land use. All these factors have an influence on the decision to be made. The constraints are the limitations that the various factors have, the alternatives that meet the criteria have fewer limitations and they are given higher weights or influence in deciding the suitability of the study area. Applying weights however is not straight forward as the researchers may be biased towards certain factors. To reduce subjectivity to the minimum the Analytical Hierarchy Process is used.

4.3 Analytical Hierarchy Process (AHP)

When the decision is made on what the goal is and the factors have been chosen, AHP is used to rearrange the factors in an order of importance in a hierarchy. Alternatives that are being rated must be independent of each other such that no alternative present or absent would have influence on the other (T. L. Saaty, 2006). When rating alternatives a clear level of intensity or degree of variation needs to be applied to the criterion being used. The reference point can be adduced such that a standard will be established for the alternatives. In this study the scale of reference used to establish relationship and importance of the factors and alternatives against each other is the scale of preference introduced by Saaty in 1987. The values and their intensities are given in the order; 1 = Equal, 3 = moderately dominant, 5 = strongly dominant, 7 = very strongly dominant, 9 = extremely dominant. There are however values in between such as 2, 4 and 8 to show compromise (T. L. Saaty, 2006). These alternatives are then pair wise compared to create priorities which are then normalized (T. L. Saaty, 2006). One way of doing this is using the Analytical Hierarchy Process (AHP). The AHP is a mathematical method that helps when choosing between complex choices and alternative decisions. It is a Multi-Criteria Decision Making tool that enables planners and decision makers to decompose complex problems into hierarchies. (Pohekar & Ramachandran, 2004) This process then systemizes the idea of choosing among multiple objectives. In an AHP, a clear goal has to be made and this sits on the top of the hierarchy, whereas criteria and sub-criteria are placed at middle and then alternatives sit at the bottom (Taha & Daim, 2013). A network structure is developed and it is given a relationship through a pair-wise comparison (R. W. Saaty, 1987). A principle of comparative judgement is used to arrive at the pair-wise comparison matrix in the decision maker's choice of looking at relative importance of elements and shared properties (R. W. Saaty, 1987). The AHP reflects subjectivity in relation to strengths and feelings of the decision maker (R. W. Saaty, 1987) Fundamentally, in an AHP a paired comparison judgement scale of absolute numbers are given to the alternatives in a reciprocal order.

Table 4 Pair-Wise Comparison Matrix applied to this study

	WIND	**LU**	**GRIDLINE**	**ROAD**	**SLOPE**	**Sum**
WIND	1	2	2	2	3	10
LU	0.5	1	2	2	2	7.5
GRIDLINE	0.5	0.5	1	2	5	9
ROAD	0.5	0.5	0.5	1	5	7.5
SLOPE	0.33	0.5	0.2	0.2	1	2.23
SUM	2.83	4.5	5.7	7.2	16	36.23

Unlike rating where a standard is used as reference for comparison, comparative judgment process compares the alternatives against each other. Wind when compared to the other alternatives is prioritized as the dominant factor, thus against land use (LU), gridline and road is strongly dominant and against slope it is moderately dominant. A value of 2 is used as a compromise between Wind and LU, road and gridline as they are seen to be fairly dominant against each other. In the comparative judgment process, when two alternatives show relationship of strength towards one another, then a compromise has to be made to choose between the two, an even number is used to show this relationship. Wind and Land use are both significant factors and they sit on the top of the hierarchy, choosing one over the other is almost impossible as they are both important factors for the wind site selection.

Table 5 Standardized Matrix

	WIND	**LU**	**GRIDLINE**	**ROAD**	**SLOPE**	**AVERAGE**
WIND	0.35	0.44	0.35	0.28	0.19	0.32
LU	0.18	0.22	0.35	0.28	0.13	0.23
GRIDLINE	0.18	0.11	0.18	0.28	0.31	0.21
ROAD	0.18	0.11	0.09	0.14	0.31	0.17
SLOPE	0.12	0.11	0.04	0.03	0.06	0.07
SUM	1.00	1.00	1.00	1.00	1.00	1.00

The factors in the matrix are arranged in an order of magnitude and a scale importance ranging from 1 to 9 used to determine which one is more important against the other factors. Normalization is then obtained by dividing the given value by the sum of the respective column. The purpose of normalization is to appropriate levelness in a multivariate comparison to all the factors because a common scale is used to divide the values so that factors within a certain range do not outweigh factors in another range, this allows for conditional reliance on quality on the elements and so normalization is needed when the criteria depends on alternatives (T. L. Saaty, 2006)

Consistency Index (CI)

The idea of consistency is to check against judgemental inconsistencies in the application of a scale to the values and properties of elements employed in a decision making process. First, the eigen value is calculated as follows:

$\Delta max=S(W)+ S(W)...n$

S is the sum of the COLUMN

W is the average of the normalized ROWS

Δmax = 2.83(0.32)+4.5(0.23)+5.7(0.21)+7.2(0.17)+16(0.07)

0.91+1.04+1.41+1.22+0.96

Δmax = 5.54

CI=Δmax-n/n-1

n=10, the number of factors in the criteria

(5.54-5)/(5-1)

= 0.54/4

=0.14

CI = 0.14

Consistency Ratio (CR)

To calculate the CR, the CI must be compared with a Random Consistency Index (RI) which was randomly generated by Saaty (1988). Since there are five factors used in the Pair-wise comparison, the RI value of 1.12 which is the corresponding value for the size of the matrix in the random consistency index which is 5 in this study is used for this purpose.

Table 6 Random Consistency Index

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: (R. W. Saaty, 1987; T. L. Saaty, 2006)

CR=CI/RI

CR=0.14/1.12

=0.13

The subjective evaluation of the factors in the AHP is thus consistent because the CR is less than 1

4.3 Geographic Information System (GIS) Processes

Geographic Information System (GIS) is a science that captures data, manipulates, analyses, visualizes and interprets data to understand relationships, patterns and trends among various factors and themes, and displaying geographically referenced information (Burrough, McDonnell, & Lloyd, 2015; ESRI, 2016). It provides an environment for performing a multi-criteria analysis on various problems including searching for the right sites to build a wind farm or installing solar panels and performing susceptibility analysis of various themes. Doing a multi-criteria analysis for a suitability map in a GIS environment requires that a process of workflow that uses GIS concepts and toolboxes. This process starts with data collection, preparation and input, processing and analysis and finally an output can be displayed on a map. Data can be accessed from various sources for a GIS project and these sources include aerial photographs, satellite imagery, scanning and digitizing paper maps and use of already existing digital data sets. Geographic Information System therefore provides a platform and interface for an organized flow of geospatial data.

For this study data from already existing digital data sets and meteorological station wind data records have been sourced and processed in ArcGIS10.2. All the dataset with the exception of the Digital Elevation Model (DEM) 30m resolution were in vector format. They also covered the entire extent of Ghana. The Project tool in the Projection and Transformation tool was used to project all the layers to WGS_1984_UTM_Zone_30N. In order to use the Clip tool, first a clip feature whose extent will be taken by the input feature must be available. To do this, the editor tool was activated and the select option in Add Tool was used to select the three regions and a new layer was then created. This new layer called the study area is used to clip all the other layers. Various tools in ArcGIS10.2 Toolset have been used in manipulating and analyzing the data. GIS enables models to be built which streamlines the workflow and gives consistency and ease to carry out the work as is shown in Figure 10. Snap raster, cell size, coordinates system all set in the environment of the Toolbox in Arc map. This is to ensure that all raster datasets adopt the same extent as the snap raster to avoid errors in calculations and overlay analysis, and also to ensure that all layers have the same coordinate system. All layers with different coordinate system were first projected to that of the snap raster. The model builder built in ArcGIS10.2 is for executing tools in a model. The geoprocessing tools used in this model include the clip, reclassification, slope, conversion, and Euclidean distance tools. All the dataset had full extent for Ghana. Running the processes for the entire country will take time, moreover, only three regions out of ten is used in the study. To avoid running processes for the entire country the clip tool is used to extract only the study area out of the feature layer for the feature layer and raster data. For the DEM layer which is already a raster dataset, the Slope tool is used to calculate slope from the clipped DEM raster which is then reclassified into slopes greater than 20 degrees and slopes less than 20 degrees. The tools used for land use include the Dissolve tool which is used for disaggregating a theme and individual themes are selected to form a new feature layer. The Polygon to Raster tool is used to convert the land use data to raster. This is necessary for the reclassification and running the processes in the weighted overlay tools. The road network and the gridline follow the same process in the model. After clipping them to the study area, the Polyline to Raster tool was used to convert them so that the Euclidean distance tool can be used for applying distance criteria to them. The result from the Euclidean distance was then reclassified. All the reclassified layers are then given weights obtained from the Analytic Hierarchy Process. Figure 11 shows the geoprocessing tools employed and the flow of work. The result of the weighted overlay process is a suitability map for the suitable sites for wind farms.

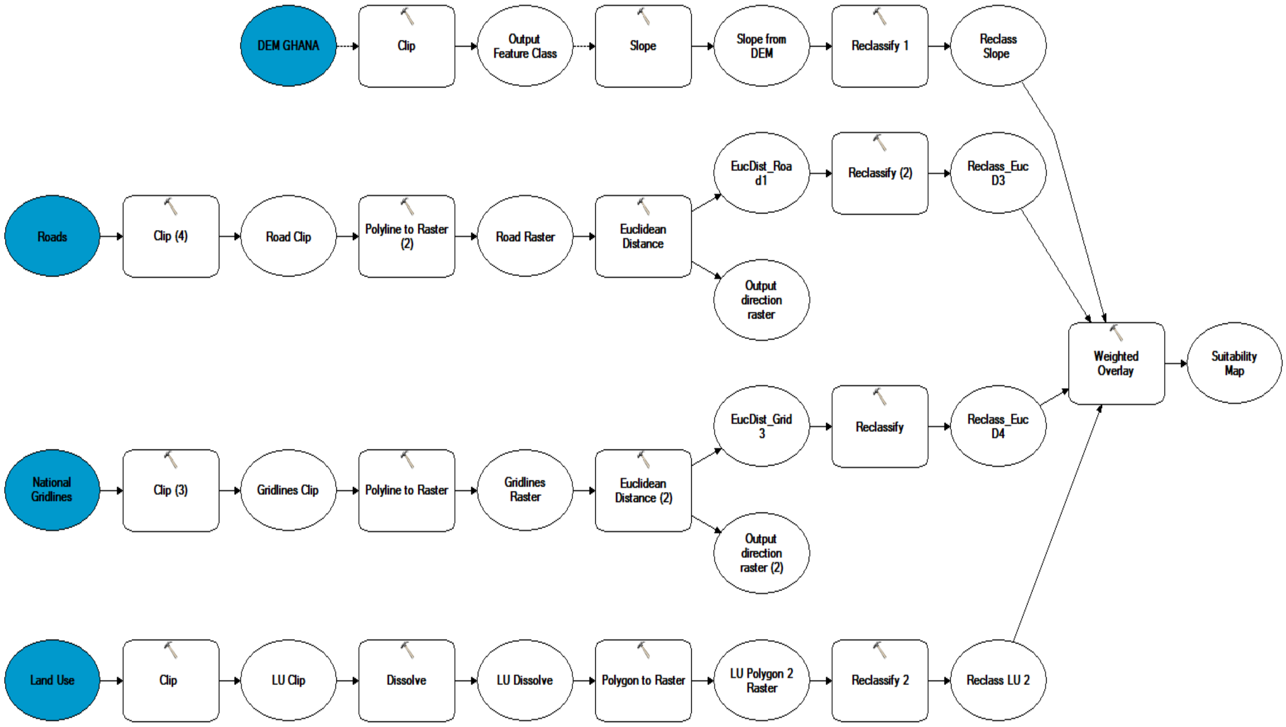

Figure 11 Workflow in ArcGIS10.2 showing Model Builder used for study.

To arrive at the suitability map for this study, the weighted overlay tool can be used. The weighted overlay is chosen for this study because it accepts only integers. All the datasets are in the format signed integer and so to avoid any complexities and errors in the output, the weighted overlay is the best option. All the layers which were vectors needed to be converted to raster. This is because the weighted overlay tool accepts only raster formats. Weights derived from the AHP which are a percentage of influence against other factors were assigned after they have been reclassified using the Reclassify tool and a scale of preference was then given to them.

Various maps have been produced at each stage of the model. The relevant maps are discussed in the next chapter, results.

4.4 Estimating Energy Production

The amount of energy that a site generates depends on several factors such as the turbine height, rotor swept area and wind speeds.

For each wind farm the turbines extract kinetic energy from the wind. This formula (Anderson, 1992) is used to make a rough initial estimate of electricity that a single turbine can produce.

K Vm3 A T

Where

K = 3.2 and is a factor based on a typical turbine performance, Vm is the site annual wind speed in meters per second, At is the rotor swept area and T is the number of turbines.

Another formula which is can be used is the power law which states that

$P=1/2\rho AV^3 Cp$

Where

P is the real power in watts, ρ is the air density in kg/m3, A is the rotor area in m2, V^3 is the wind speed in m/s and Cp is the power coefficient.

Air density is a function of temperature, altitude and humidity. The average monthly temperature of the Greater Accra region is about 30 degrees Celsius. Per the standard atmospheric pressure, air density at 30 degrees Celsius is 1.165 kg/m^3. Power coefficient is a measure of wind turbine efficiency and it is calculated by the manufacturer. It ranges between 0.25 to 0.45Cp

CHAPTER FIVE
RESULTS

5.1 Introduction

The processes leading to the selection of suitable sites for wind farms can be complex. Legal and ethical diligence must be upheld. In a multi – criteria analysis balance should be kept among all the factors. In this study, selecting a suitable site for wind farm in Ghana required an assessment of the land use, presence of an existing national gridline, distance to road network, slope of the terrain and availability of consistent wind. Clearly the constraint factors which have been buffered takes prominence in the map. However the spatial pattern on the map shows a big influence of distance to national gridlines and distance to roads, this is an influence that is also corroborated by Baban and Parry (2001), who saw similar effects in his study in the United Kingdom. The combination of roads and gridlines creates an inverse on the distance where by suitability ranges closest to roads are not suitable whereas ranges closest to gridlines are highly suitable. The farther the distance from a gridline the less suitable it becomes and this can somehow be attributed to the distance decay effect. Protected areas, water bodies, and urban areas have a buffer of 500m around them. Airport has a buffer of 5000m around and urban areas have a buffer of 3000m.

5.2 Wind Variability

A ten year daily wind data collected from 10 stations at 10m (Accra 50m) was collated in Microsoft Excel, annual averages calculated for the stations and a ten year annual average was then derived from the annual averages. It can be seen from table 6 the consistency in the wind speeds. Wind is however spatially and temporally variable. Any site that is selected for a wind farm must have consistent wind power to sustain energy production. The power developed is proportional to the cube of the wind speed, and because wind power production is dependent on wind resources, an understanding of the spatial variability is important for determining the wind power at selected sites (Banuelos-Ruedas, Angeles-Camacho, & Rios-Marcuello, 2011)

Table 7 Annual average wind speeds for the 10 Meteorological stations.

					Annual average wind speed at the 10 Stations in m/s							
Station	Year 2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Ten year average
Tema	1.99	2.04	2.08	1.91	1.87	1.84	1.66	1.49	1.63	1.57	1.49	1.78
Accra	2.73	2.73	2.79	2.68	2.42	2.12	2.34	1.77	2.30	2.61	2.72	2.47
Ada	2.18	2.05	2.05	2.54	2.66	2.54	2.73	2.86	2.76	2.72	3.08	2.56
Akatsi	0.84	0.98	0.94	0.98	0.41	0.68	1.16	1.05	1.01	1.09	1.09	0.93
Ho	0.59	0.69	0.70	0.67	0.61	0.65	0.62	0.51	0.59	0.52	0.49	0.60
Kete-Krachi	0.71	0.72	0.58	0.54	0.64	0.45	0.26	0.79	0.77	0.70	0.59	0.61
Koforidua	0.73	0.76	0.83	0.76	0.76	0.72	0.76	0.76	0.76	0.72	0.79	0.76
Abetifi	1.70	1.67	2.00	1.88	1.84	1.78	1.88	1.81	1.78	1.57	1.68	1.78
Akuse	1.00	0.79	0.93	0.92	0.86	0.81	0.84	0.87	0.58	0.71	0.83	0.83
Akim Oda	0.56	0.57	0.66	0.63	0.66	0.62	0.68	0.65	0.61	0.64	0.65	0.63

There are several methods of gathering wind data for wind site selection analysis. These include Wind Atlas Maps, computer simulation models and data from meteorological stations. In order to use wind data for site selection it has to be interpolated or extrapolated or both must be used in order that areas where wind data have not been recorded can be covered by way of interpolating the wind. The spatial variability such as type of vegetation present, topography of the area must be taken into account because vegetation and topography greatly affect wind. In this study, the wind data shows a spatial variation in wind speeds whereas there is temporal consistency in the wind speeds recorded. Stations in the Greater Accra region, all located near coast, have the highest records of wind. All the inland stations with the exception of Abetifi which has 1.8 m/s, have wind speeds less than 1 m/s. The Greater Accra region with large amount of grassland and sparsely populated areas in the east is most suitable by the wind data standards.

5.3 Reclassified Land Use

The land cover of the study area is very diverse. It includes open and closed access savannah, mixed arable cropping, mixed bush fallow, reservoirs, plantations, towns, mining areas, National Parks and open forests and in 6217 counts. The data was initially classified into ten (10) classes using the Dissolve tool. The classes are Farmland, Mining, Open forest, Open Savannah and Shrub, Reserved Forest, Reserved Grassland, Tree plantation, Water body, Urban and Airport. It was then reclassified into four classes for the purposes of having a uniform weight for all the factors being used in the Weighted Overlay tool

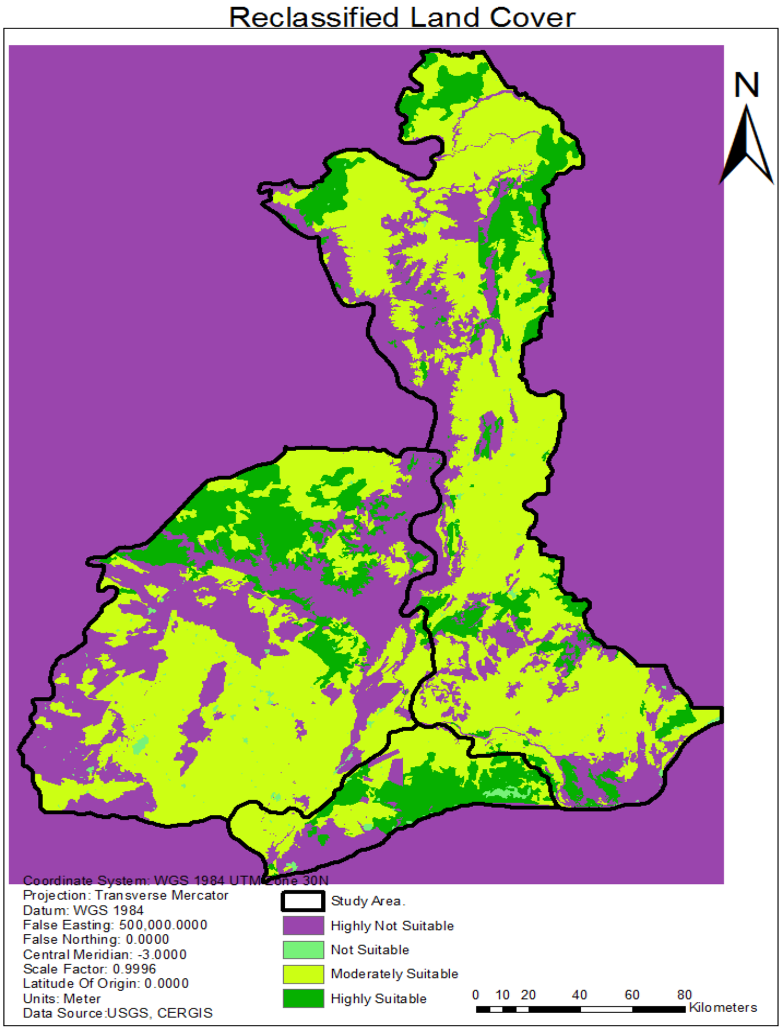

Figure 12 Reclassified Land use map showing land use type suitability for wind farm

The classes are then specified as Highly Not Suitable, Not Suitable, Moderately Suitable, and Highly Suitable.

Highly Not Suitable includes land cover types such as water bodies, national parks, and fire scares. Areas prone for frequent fire put wind installations at risk in case of fire which can increase cost of repairs and putting back wind turbines into operation. Water bodies and areas around water bodies are known to be habitats for highly endangered species (Walsh & Harris, 1996). Wind farms when located too close to bird habitat cause bird collisions. The rotation of the wind blades cause visual blur and so birds perceive it as safe to fly through. The average bird collision to each wind turbine is 0.1 to 0.6 worldwide and 23 annually in Belgium (Aydin, Kentel, & Duzgun, 2010; Drewitt & Langston, 2006). Not Suitable include land cover types such as densely populated areas, mining areas, and plantation farms. Densely populated areas are avoided for reasons such as noise and visual intrusion. Moderately Suitable areas include farmlands, sparsely populated areas. Wind turbines scatter electromagnetic waves of telecommunication, radio and television. Moreover wind turbines produce noise that residents consider a nuisance (Van Haaren & Fthenakis, 2011). It is therefore important that these areas are avoided and an appropriate and suitable distance is allowed between the wind installation and residential areas.

Highly Suitable areas include bare lands and grasslands, scattered settlement, scattered farms in grassland areas. These are ideal locations for wind installation because there is less conflict with other land uses such as plantation farms, protected flora and fauna. They are not located in wetlands, and they are fairly distanced from any dense populations. It is easy to transport equipment to locations that are bare because new trunk roads can be easily build at reduced cost, moreover the cost of cutting down trees and preparing the site is significantly reduced.

5.4 Distance to Roads

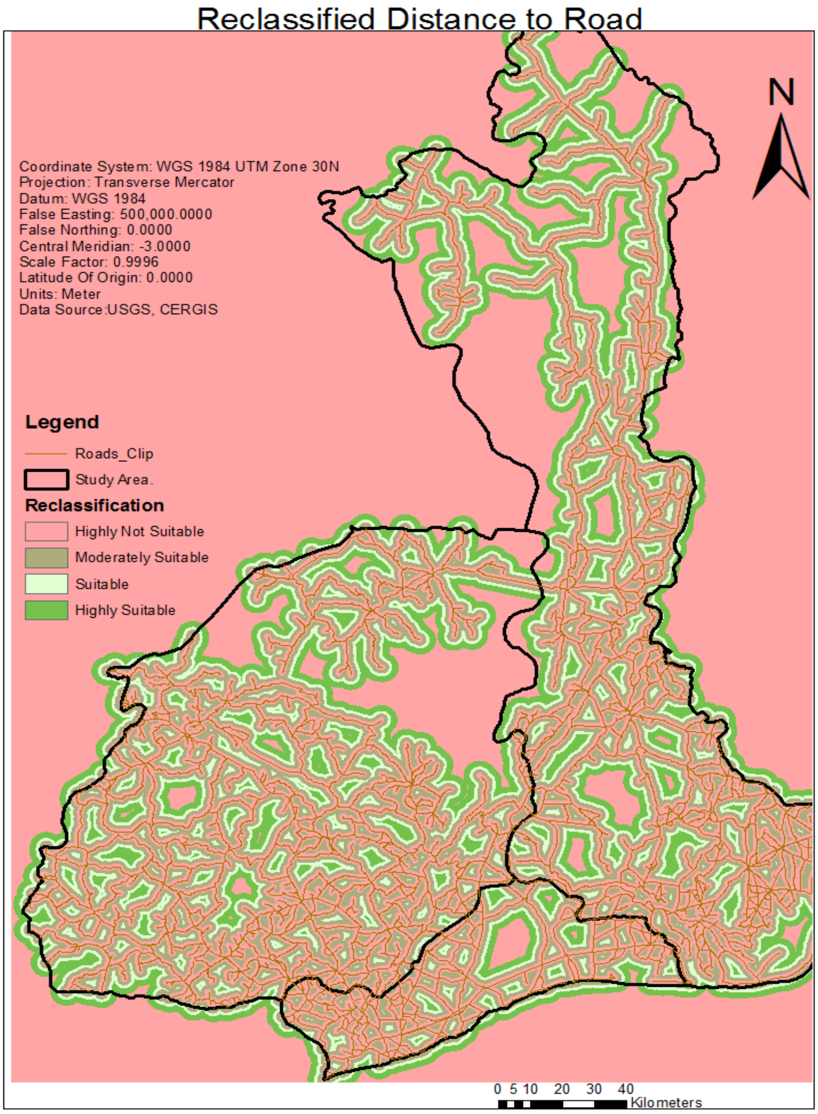

Figure 13 Suitability according to distance from roads

Roads were reclassified based on distance. Using the Euclidean Distance tool in the Spatial Analyst tools, distances of 1km, 2km, 3km, 4km and 5km was used as the determinants of the suitability for possible wind farm sites. Distance of 1km from any road is classified as highly not suitable. This definition is based on the fact that wind turbines cause visual disturbance to the enjoyment of the aesthetic beauty of landscapes. Distances 2km from the road is also classified as not suitable. All distances greater than 5km are classified as highly not suitable. This is because the farther the distance from roads the greater the cost of constructing new roads and the transport of wind turbines and gadgets. 3km from the road is considered moderately suitable because it is not too far from the road and neither is it too close to any road. 4km and 5km are classified as highly suitable. They do not fall within the categorisation of disruption of the aesthetic and landscape beauty for travellers and also the cost of transporting wind turbines and gadgets is small and so it is a perfect combination for wind sites.

5.5 Distance to Gridlines

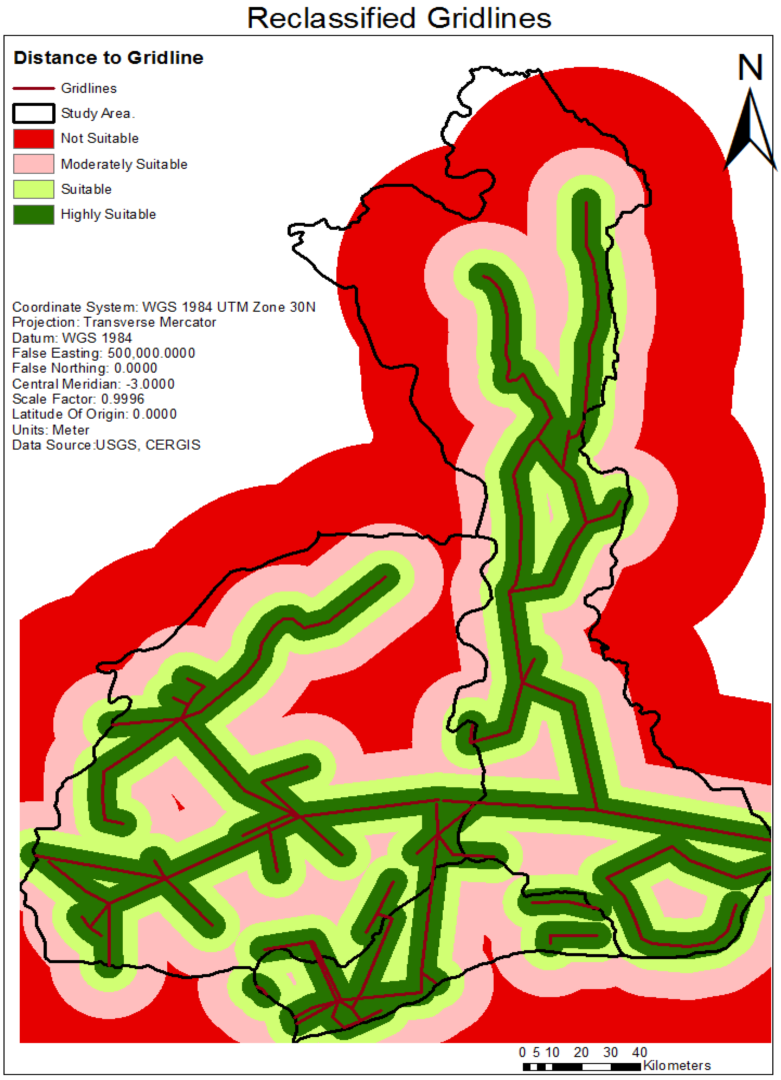

Figure 14 Suitability classification according to distance to power gridlines

Gridlines are key factors when selecting a site for wind installation because it has significant impact on the cost of production. In order to avoid the cost of construction and transmission over long distances, building a wind farm closest to an existing gridline is an important decision to make. In this study gridline is considered the second most important factor after wind potential with an equivalent weight used in the Weighted Overlay.

Under the Distance Toolset, the Euclidean Distance tool was used to calculate distance from the gridlines. The output of the Euclidean Distance was reclassified using the Reclassify Tool under Spatial Analyst toolset. The following categorisation was used; 0-5km is Highly Suitable, 5-15km is Suitable, 15km to 20km is Moderately Suitable and 20km or more is classified as Not Suitable.

5.6 Slope Reclassified

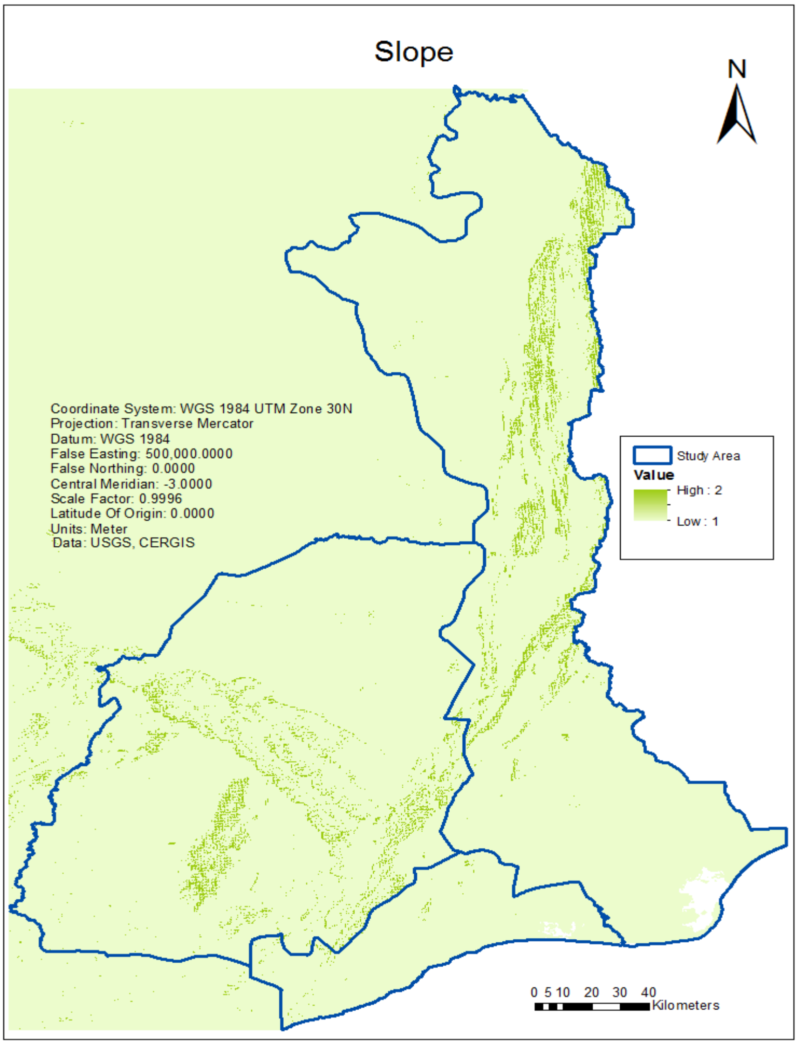

Figure 15 Suitability classification according to topographic slope

The Slope tool under the Spatial Analyst Toolbar was used to calculate the slope. The calculated slope was then reclassified to Suitable and Not Suitable. All slopes below 20 degrees are classified as suitable and slopes above 20 degrees are classified unsuitable for wind installation. Topography has big influence on wind variability and speed (Wiernga, 1993). Generally high altitudes have high wind speeds but they are not consistent and not evenly spread. Moreover rugged terrains make it difficult for transport of wind turbines. Slopes that are less than 20 degrees are fairly flat and the wind speed is consistent and so they have been chosen for the weighted overlay analysis.

5.7 Weighted Overlay Map

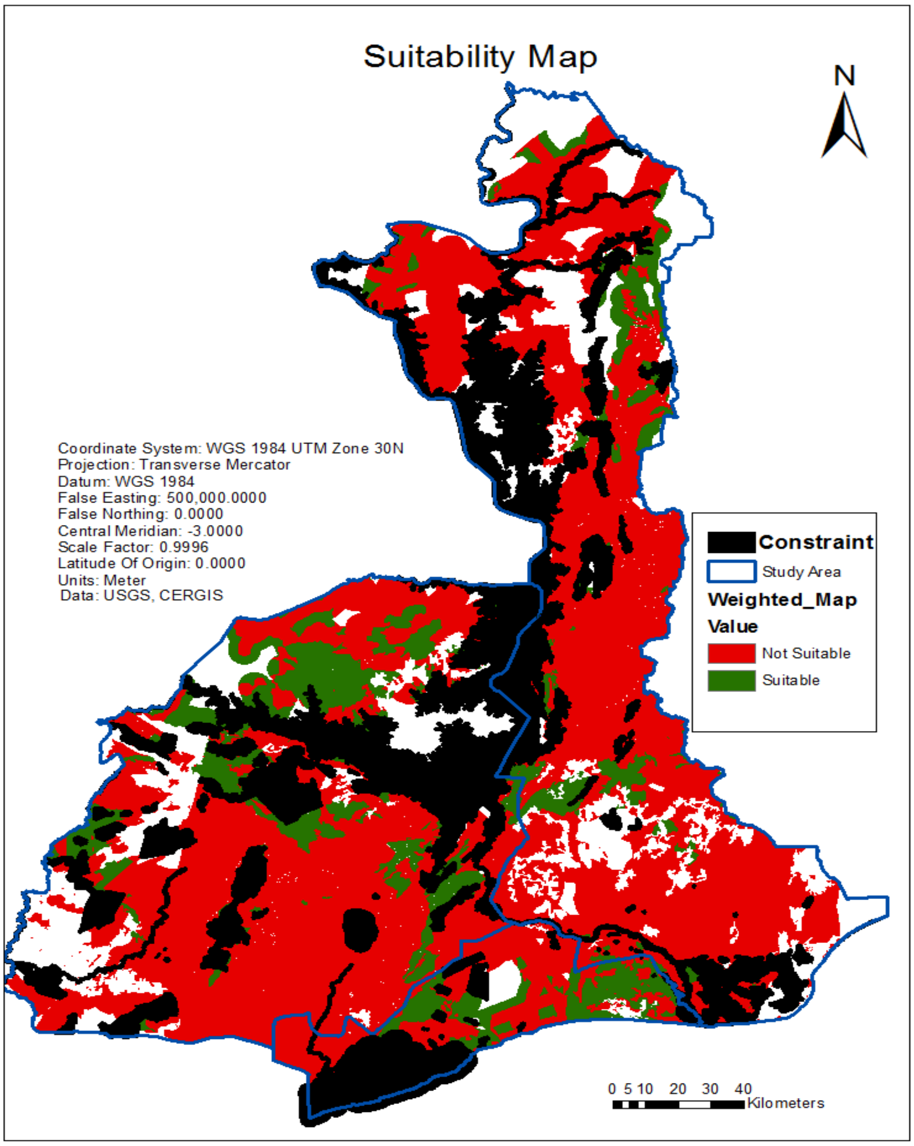

Figure 16 Aggregated suitability map, based on four criteria

The suitability map shows a pattern of higher influence of land use factors and national power gridlines. The isolated white patterns indicate no data which represent features that have not been capture in the land use dataset from source. The outcome of the weighted overlay geoprocessing is representative of only the land use, slope, distance to roads and distance to power gridlines. The wind speed data was not included in the weighted overlay because analysis of the wind speed distribution in the study region showed a clear pattern of wind suitability. The Greater Accra region is the only region that has wind speeds that meet the criteria. Since the other regions are more spatially variable wind measurement from the few meteorological stations may not be representative of the wind characteristics in the region. Care was therefore taken not to generalize wind speeds for these regions. Having performed the weighted overlay for all the regions, ground measurement may have to be taken at various selected locations across the other region in order to determine their potential.

The black colour which represents constraint is representative of water bodies, protected areas and urban settlements. These have been excluded and buffered with 500m buffer zones for water bodies and protected areas and 2000m for urban settlements. The red colour indicates not suitable areas which represent various farming types, vegetation types, high slopes and terrain, areas to far away from power grids, and areas too close to roads and too far away from road network. . The green spots indicate places that meet all the criteria for siting wind farms. These are mainly bare lands and open savannah grassland. They are located in sparsely or uninhabited places and they have close proximity to power gridlines and are not located within distance to roads that are not too far and too close to road networks.

After the wind speed distribution is applied to the suitability, the only places that are most suitable and that have wind speeds above the 3m/s are all located in the Greater Accra. Within the Greater Accra region there is a pattern of distribution whereby locations of big towns and cities in the west make the western part of the region not suitable for siting wind farms. The eastern part of the region has the highest wind records and it is sparsely populated and so the most suitable places from the suitability analysis are found there.

5.8 Energy Production

Estimating how much energy can be produced from the wind farms is one of the objectives of this study. To accomplish this, the suitable areas identified were all reclassified and converted to polygons, the total suitable areas in the regions with best wind conditions were isolated and their total area was calculated. Wind speeds recorded at 10 metres are greatly affected by environmental factors such as topography, altitude and land use type. Also man-made structures such as buildings, chimneys affect wind speeds through friction. To ensure the accuracy and reliability of winds for any wind farm installation, wind measurements are often taken at hub heights which usually range between 60 to 100 m, but a standard meteorological station is not designed to record wind speeds at such heights and so for this reason wind data needs to be extrapolated to turbine heights. In order to do this a simple Hellman exponential law that correlates wind speeds at two different heights is used. It is expressed as:

$$\frac{V}{Vo} = \left(\frac{H}{Ho}\right) \propto$$

Where V is the wind speed measured at the reference hub height H (80m), Vo is the speed at the anemometer height Ho (10m). $\propto$ is the friction coefficient. This is a function of topography and land use factors. The friction coefficient varies from place to place and from time to time. The figure below adopted from gives an overview. The higher the altitude the higher the wind speed (Bansal, Bhatti, & Kothari, 2002)

Table 8 Showing friction coefficient

Landscape type	Friction coefficient $\propto$
Lakes, ocean and smooth hard ground	0.10
Grasslands (ground level)	0.15
Tall crops, heges and shrubs	0.20
Heavily forested land	0.25
Small towns with some trees and shrubs	0.30
City areas with high rise buildings	0.40

Table 9 Showing wind speeds at hub heights of 80m

Wind Extrapolation at Turbine Height 80m

Station	10m	80m
Ada	2.6	3.6
Accra	2.5	3.4
Tema	1.8	2.4
Ho	0.6	0.8
Akatsi	0.9	1.2
Kete-Krachi	0.6	0.8
Akuse	0.8	1.1
Abetifi	1.8	2.4
Koforidua	0.8	1.1
Akim Oda	0.6	0.8

Given that the most suitable areas coincide with the wind readings at Ada and its environs which are the highest in the study area, the raster have been converted to polygons and all polygons with an area less than 100000 square meters were eliminated and the remaining total area was calculated. This was done because a 100000 square meters is less than the 10 hectare size of land required to put up a single turbine, moreover, small patches of suitable sites means also that around them are factors that may be in direct conflict with development of the site. As an example, accessing the site would require constructing roads through farms to get to there. This would also increase the cost of production and maintenance of the turbines. The total most suitable sites in the Greater Accra region which also falls in the region with best wind speed records is 86289 hectares and an extrapolated wind speed of 3.6 m/s. As a rule of thumb, a 10ha/MW size of land is considered acceptable for a wind farm (Bansal et al., 2002). In order to calculate the energy that can be generated from a selected site, the total number of turbines must be known, and the swept area of the turbine which is determined by the diameter of the turbine blade must also be known. According Bansal et al (2002) a single turbine can take up to 10h/MW, this is the average as much bigger turbines can take up to 15 ha/MW of land. Given the size of the most suitable area to be 86289 hectare, it follows then that a maximum of 8628 turbines can be installed over all the entire selected most suitable area.

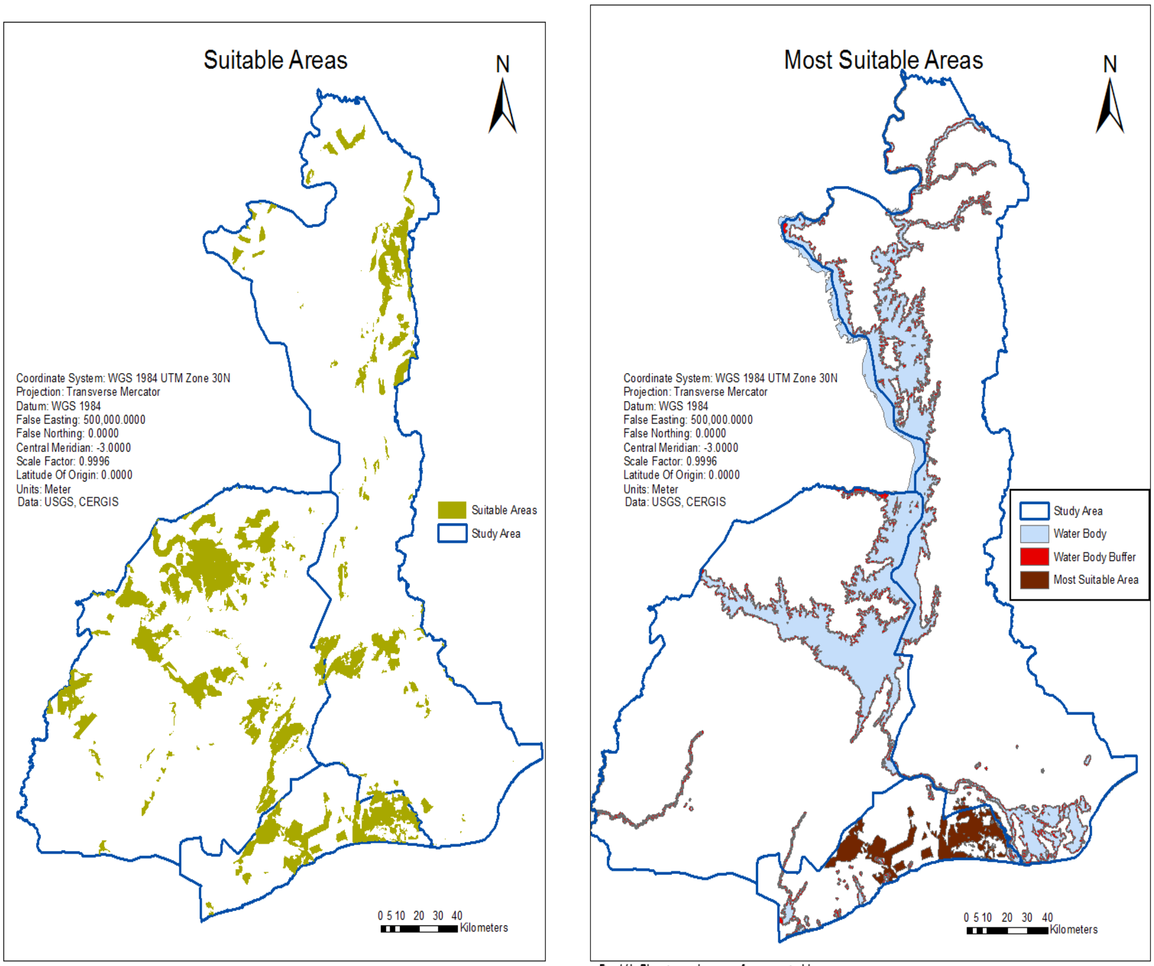

Fig.14a Showing polygons of total suitable areas

Fig. 14b Showing polygons of most suitable areas

Figure 17 a) Polygons presenting sites with total suitability for the study area

b) Polygons representing total most suitable areas

The amount of energy that a site generates depends on several factors such as the turbine height, rotor swept area and wind speeds.

1223kW 1.223MW is the total output for a turbine.

When1223kW is multiplied by the total maximum turbines that can be installed on the site we get the total estimate of initial energy to be 10551788.6kW or 10551MW or 10.5GW

It is however mentioned that the maximum wind power that is eventually converted to mechanical power and further transmitted through mechanical generators and converted to electricity is less than 100 percent of the total wind power (Bansal et al., 2002). This has not been considered in the calculations in this study.

CHAPTER SIX

DISCUSSION

A GIS based Multi Criteria Analysis is used to assess all the factors and then a clear criteria was established for inclusion or exclusion of factors in the decision making process. Establishing criteria is necessary for a multi-criteria analysis because many alternatives have to be considered and determining which alternatives can help achieve the goal may be hectic. Spatial multi-criteria analysis does not just bring clarity in setting out priority and setting up alternatives in a hierarchy, but it also helps to identify constraints that need to be managed properly. When constraints to achieving the goal are properly managed the criteria to be used gets properly defined. Defining a criteria in a multi-criteria analysis can often lead to subjectivity making its way into the decision making process. To reduce subjectivity to a minimum in this study, comparison was made across various geographical spaces and local condition was also taken into account. For example, the distance from an urban area that is appropriate for a wind farm is largely dependent on local legislation. However, in Ghana, there is no such legislation on the details as to what the ground rules are for a wind installation. Internationally, different distance allowances have been used, ranging between 1000m to 2000m. Ghana has an urban population that is growing rapidly and residential acreage is expanding at a very fast pace. This land management problem goes down to the improper and unclear definition of land use. To make room for this expansion in the spatial boundaries of urban areas, a buffering of 3000m is used as a distance from which all wind installations can be made. Not only is the concern about land use and urban growth but also that wind turbines produce noise that is considered by many people as a nuisance, and so to avoid the discomfort a 3000m buffer zone is appropriate. Moreover, the blades of wind turbines interfere with telecommunication and television transmissions and could hence interfere with electronics in urban areas. Turbine blades scatter the electromagnetic signals from these sources (Van Haaren & Fthenakis, 2011). In Ghana telecommunication and television masts are located within the township and so locating wind farms 3000m away will avoid the turbine blades interfering with communication signals.

Another criterion which is important for security is the distance of wind farms from airports. A distance of 5000m is used as a buffer. Not only does the turbine pose a physical threat of colliding with aircraft but it can interfere with communication between ground control and aircraft. A distance of 500m is given between all water bodies and any wind farm. In Ghana, water bodies are habitats to a valuable diversity of birds. Among these are migratory birds that are found at the Ramsar sites such as the Songhor and Sakumo lagoons, a Ramsar site is an internationally reserved wetland for bird species under the Ramsar Convention on Wetlands (Ryan & Ntiamoa-Baidu, 2000). In order to avoid collision with birds, a safe distance of 500m is allowed around all water bodies this is because the areas surrounding a wetland affects the health of the wetland and the services that it provides (Gardner & Davidson, 2011).

The most important criterion is the wind speed. Wind speed decreases towards the equator and generally wind speeds in Ghana are low. The Solar and Wind Energy Renewable Assessment of various countries conducted by the United States National Renewable Energy Laboratory for the United Nations Environment Programme concluded that wind speeds in Ghana are within classes 3 and 4 (National Renewable Energy Laboratory, 2006) which is fair per international standards. Moreover these are not site specific and the best wind locations are on high land areas. The criterion for best wind location is that the location has wind speeds greater than 3m/s. Since the wind speeds for all the stations at 10m anemometer height are less that 3m/s, an extrapolation method has to be employed to measure the wind speeds at 80metres which is considered the hub height for this study. Wind speeds increase with altitude, moreover none of the meteorological stations are designed to measure wind speeds at wind turbine height. In order to meet the criteria for this important factor, all the wind readings had to be extrapolated. After the extrapolation it is only two stations, Ada and Accra that met the criteria.

Data reliability is very important when working in a Geographic Information System environment. This is because any small error with the data whether it comes from the source of the dataset or during data processing will affect the reliability of the output as small errors on the map can mean big discrepancies on the ground. Except the wind data all other data was collected digitally from contact persons at the US NREL through email were originally obtained from USGS AND CERGIS. All the data were projected in different geographic coordinate systems. The land use data is relatively old as it was compiled in the year 2000. A lot of changes have occurred to the land cover mix in Ghana over the years since year 2000. This has occurred mostly in the forest areas with trees being cut, also in other areas which were deforested trees have been planted and urban frontiers have expanded as well, and so the land use data may therefore not represent the true picture on the ground. New national power gridlines have been built to respond to the power crisis and this may not be reflected in the gridline network data. This can affect potential sites that qualify for selection per the distance to gridline criterion because distance to gridlines had a big influence on the suitability map.

The wind data which was obtained from the Ghana Meteorological Agency in Accra, given at a fee during the summer semester break of 2015, is judged as largely reliable except that it was recorded as wind run and not wind speed and it was a daily record that had to be recalculated to average annual wind speeds in m/s. At some of the stations, no wind run was taken for three consecutive days, whilst at another station there was no record for two days in a particular month. This omission can influence the wind speed calculation for these stations. However, the effects on the calculation and its reliability are probably insignificant.

All constraints factors found in the land use dataset were eliminated and so they were not used in the weighted overlay. The constraint factors which include protected areas, water body, urban areas and airport have thus been classified as not suitable with buffer zones created around them. The different datasets were then composed into five layers; slope, land use, gridlines, road network and wind data but only four were used for the weighted overlay. Wind data was exempted because it was clear from the wind readings and the extrapolated results that areas in the Greater Accra region show a higher wind potential. The constraint factors which were identified and excluded include protected areas, water bodies, urban areas and airports. The Analytical Hierarchical Process developed by Saaty (1988) was used to perform a pair wise comparison and using comparative judgement weights were calculated and applied to the factors in a GIS Weighted Overlay tool to produce a suitability map. The use of AHP was to ensure that the influence of subjectivity is reduced to the minimum. An SMCA often produces a result pattern that follows the factor with the greatest weight. The work shows a pattern that is similar to works done in other parts of the world. Distance to power gridlines and land use had a big influence on the spatial pattern. Using a rigorous pair-wise comparison and the described mathematical equations avoids a situation where the researcher's personal view influences the credibility of the study. This weight derivation is necessary in order to use the weighted overlay tool in ArcGIS10.2. The factors thus have been reclassified in order to have a standard scale in the hierarchy. The weighted overlay processes all the factors through reclassification of the values in the input raster's cell to a general assessment scale of preference, it then multiplies the cell values of the individual input raster by their weight of significance and then adds the resulting raster to produce the output suitability map. The result from this rigorous process is shown on the map as suitable or not suitable. A careful examination of the map shows the influence of gridlines which was also reported by Baban and Parry (2000) in the evaluation of wind farms in the United Kingdom where the use of buffer on the road network showed a pattern of strong influence of roads in the results obtained. A bigger influence however is the land use features in the study area, with open savannah grasslands being representing the most suitable areas for a wind farm site. The geographic characteristics of the various regions in the study area also explain the nature of the distribution of the suitable areas. The areas in the Afram Plains in the Eastern region are suitable locations in terms of land and roads and power grids, but the wind speed record of the region is limited. To assess the suitability of this part of the region site specific measurement of wind speed must be taken over a period of time. Taking the wind data into consideration therefore leaves only areas in the Greater Accra Region as the most suitable region. However it is possible that when ground wind measurement is taken at specific sites in the other regions there could be possibilities of high wind speeds. An atlas wind map of Ghana made by NREL in 2006 identified the high land areas of the Volta region and the Eastern region as having high winds (National Renewable Energy Laboratory, 2006) but the rugged terrain and high elevation does not make it an idle place to site a wind farm. Moreover most of these highland places are protected areas and sites for tourism which rules out any possibility of siting a wind farm. A limitation of extrapolating meteorological wind measurement is that local conditions of different terrain characteristics are ignored and this can impact the outcome of a weighted overlay analysis. This is the reason why only the Greater Accra region which is generally a plain with high winds is used for the final analysis and selection of the most suitable sites. Implementing a buffer zone around the urban areas and airport in the Greater Accra region makes sites in the western part of the region not suitable. This is because they have not met the criteria of a distance of 2000meters from urban areas and 5000m from Airports. The use of buffer around urban areas and airports was also adopted by Aydin et al (2000) in a similar study in Turkey who used buffers of 2500m for both large urban areas and airports which confirms the importance attached to security, aesthetics and low noise levels in wind farm siting.

As an objective of this study, the amount of energy from the selected sites was estimated. The selected areas were converted to polygons. The result shows several small polygons which even though qualify as suitable were too small and fragmented. Several small sites which can hold one or less turbines can lead to an increase in cost of developing the sites and complications in site acquisition and management as is the often case in land acquisition in Ghana. These were all eliminated and only polygons with an area greater than 100000 square metres have been maintained and used in the calculations. The total initial estimate of electric power production is 10551MW. This is about 1.223MW per turbine. When this is compared to the wind installations in 1985 in the Altamount Pass region of California which has 6700 turbines and a total output of 305MW, it is significantly huge and surpasses the Altermount Pass installation a thirty-ford. The electricity that could potentially be produced from the sites if developed has the capability to meet the power needs of Ghana and the whole sub-region. Given that Ghana's total installed electricity generation capacity as at the end of December 2014 is 2831MW which also serves neighbouring Togo and Benin, an addition of10551MW to the gridline will be more than enough to meet its energy demand for the foreseeable future despite rapidly increasing power consumption. This will also offset carbon emission by conventional fuels such as natural gas, which emit about one to two pounds of carbon per kilowatt hour of electricity and coal which emits 1.4 to 3.6 pounds of carbon per kilowatt hour (Mitigation, 2011). If these sites are developed, Ghana's reliance on oil and natural gas for its geothermal power will reduce and thus electricity from wind energy with no carbon foot prints will contribute to reducing its carbon emission. Moreover, the availability of energy from the wind farms will go a long way to alleviate the economic difficulties of businesses that rely on reliable power supplies to operate. Since energy is quintessential to development, its availability will boost the development goals of the country. The surplus energy can be sold to countries in the sub-region to generate income for the nation. This is a huge potential for economic transformation. According to the Ghana Energy Commission's report in 2014 and the 2015 energy demand and supply outlook for the country shows that the present energy mix of Ghana is highly dominated by fuel wood and char coal (Commission, 2015). These energy sources cause considerable deforestation and damage to the environment and biodiversity and consequently contribute to carbon dioxide emission (Kindermann et al., 2008), an active element in global warming. They are also the cause of many health problems and several thousands of man hours are used in cutting down trees when this could be expended in other economic and social improvement areas. The availability and supply of a clean energy from wind will have a ripple effect on the health, lifestyle and standard of living.

However it is not all rosy for wind turbines as they are associated with certain environment issues. Selecting a site for a wind farm is a planning process which involves choosing between conflicting choices. These are often a dilemma of choosing between ecology and economic development, biodiversity, conservation and aesthetics. The specific challenges of wind turbines are that modern wind turbines are large and they change the appearance of physical and cultural landscapes and they produce noise that many may consider a nuisance. There have also been records of bird collisions about one to two birds per turbine in a year, a figure which is low when compared to other causes of bird mortality (Drewitt & Langston, 2008; Krijgsveld, Akershoek, Schenk, Dijk, & Dirksen, 2009). Flickering is an impact of turbine blades on homes and passing vehicles which are often considered a nuisance. These problems can all be avoided to the minimum through a thorough assessment during the planning and site selection process. There is a growing concern, however, over whether wind energy is really a clean source of energy. This argument is based on the sources of the raw materials and the processes by which a wind turbine is manufactured. Steel, concrete, aluminium and wood are all components of a wind turbine which can be reused. Dysprosium and neodymium-iron-boron magnets are rare earth elements used for manufacturing permanent magnets in wind turbine generators. The increase in global wind energy production would lead to a strain on these rare earth elements and political and environmental restrictions would need to be used to regulate their extraction (Jacobson & Delucchi, 2011). In other places, poor and unsustainable environmental practices lead to destruction of biodiversity in the mining of these rare earth elements. The demand for dysprosium and neodymium will increase, thus putting the sustenance and future availability at risk (Alonso et al., 2012), however, recycling and reuse can be a strategy against its present critical levels by keeping extraction levels low and thereby sustaining them (Rademaker, Kleijn, & Yang, 2013).

CHAPTER SEVEN

CONCLUSION

This study used land use, power gridlines, road network, slope and wind data in weighted overlay geoprocessing tool in ArcGIS10.2 to locate suitable places in three administrative regions of the Ghana. The Greater Accra enjoys an advantage of bordering the Gulf of Guinea with consistent wind speeds. It has a topography that is mainly flat and the vegetation is largely coastal shrub and grassland. 86288 hectares of land have been identified as suitable locations for installing wind turbines. The result of the assessment shows that 10551 MW of power which is equivalent to 21000 GWh of electricity per year can be generated from wind turbines with hub height 80m, and consistent wind speed of 3.6 m/s. The areas selected are classified as grassland and bare land with suitable distances from power grids and roads. They are also not in conflict with wetlands, water bodies and protected areas and are sparsely populated to uninhabited. The result is an indication that wind energy development is possible in Ghana and if investments are directed into its development, the countries reliance and ultimate vulnerability to the shocks in fossil fuels will be reduced to the minimum.

LIMITATION OF WORK AND RECOMMENDATION

Data reliability is a key determinant in the accuracy of outputs from geoprocessing operations in a Geographic Information environment.

One of the limitations of this study is the age limitation of the land use data. There are no current land use data for Ghana and what has been used for this study is a year 2000 land cover dataset. Key urban centres have not been captured and so anecdotal evidence was used in assessing the location and extent of some urban places. Many new developments and changes in vegetation types may not be present in the data. However none of the suitable locations are found at a known urban centre.

The DEM data for Ghana was obtained in grid format with signed integers as pixel types. The pyramid sampling technique and resampling method had to be changed from nearest linear to bilinear in order to transform the data with the pixel types that generates slopes in a float format. Moreover the cell size was in foot and it had to be converted to meters. It is likely that these geoprocessing operations may have adversely impacted the slope.

Another limitation is that the wind data had some missing records for some stations in a particular year; an average over the previous days was used to fill in the missing records. The impact of this on the results of the wind mapping is however negligible as eight days of missing data in a ten year average wind speed data is insignificant.

It is recommended that ground assessment of wind speeds be taken at hub heights at the selected sites to ascertain the wind speeds over a period of time because any margin of error in the calculations and the dataset can make a big difference on the ground.

A follow up study can be conducted to find community response to any potential wind installation on their land. Future wind farm assessment should use the most current land use dataset and take into account coastal tourism which is growing very fast in Ghana.

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APPENDIX

Appendix A

Nine days of wind data for Ada Meteorological Station in the Greater Accra region

Year	Month	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8
2003	01	115.56	101.16	121.04	126.42	188.38	211.37	207.58	205.68
2003	02	186.44	214.36	239.79	211.63	204.08	177.01	260.3	312.09
2003	03	189.8	178.83	130.97	189.99	251.18	238.31	269.91	271.89
2003	04	225.51	255.07	199.83	172	221.54	169.33	195.81	255.23
2003	05	213.5	203.57	184.24	180.77	229.14	266.72	202.16	207.69
2003	06	246.34	145.88	142.83	171.71	234.54	201.29	63.52	165.97
2003	07	178.24	169.08	75.9	90.44	122.09	157.61	176.82	200.37
2003	08	177.86	163.68	148.24	210.12	156.93	89.23	86.94	142.2
2003	09	199.99	213.24	222.77	238.42	258.12	237.65	172.2	171.83
2003	10	214.56	206.29	205.82	262.29	220.9	138	196.45	261.03
2003	11	86.14	182.05	187.01	108.33	234.87	187.71	99.48	146.58
2003	12	153.62	197.82	169.08	195.43	162.29	149.07	160.28	44.57
2004	01	144.67	158.96	158.8	207.05	163.09	136.02	127.3	83.95
2004	02	0	0	0	0	0	0	0	0
2004	03	163.22	139.65	142.74	133.08	134.27	167.4	143.3	59.47
2004	04	227.68	211.52	174.42	176.95	157.46	151.57	81.82	220.12
2004	05	229.42	206.61	235.97	268.47	268.67	145.27	260.17	299.65
2004	06	42.46	248.64	266.94	89.57	223.84	276.23	163.77	260.92
2004	07	180.69	224.58	223.18	164	213.54	222.12	215.68	219.83
2004	08	182.16	166.79	197.64	229.92	319.14	293.59	285.98	280.6
2004	09	226.51	296.46	248.08	251.38	244.54	237.39	222.67	193.04
2004	10	186.42	313.54	329.96	299.27	134.61	181.97	235.52	200.25
2004	11	251.38	208.5	208.11	194.26	90.12	138.04	95.94	157.16
2004	12	98.87	176.98	225.34	231.71	238.47	214.87	215.17	200.01
2005	01	156.3	115.05	102.84	98.84	111.17	119.95	143.44	171.52
2005	02	271.55	218.54	248.87	285.53	356.41	176.38	175.4	215.29
2005	03	229.71	212.89	197.07	251.08	221.63	214.59	165.89	186.78
2005	04	236.4	233.97	261	251.61	216.93	254.61	259.47	259.89
2005	05	248.44	209.27	221.97	250.79	178.79	118.25	164.76	136.12
2005	06	261.92	292.69	154.18	113.19	189.98	267.36	283.51	274.22
2005	07	194.91	167.12	204.59	242	247.4	170.22	211.21	276.67
2005	08	154.09	159.77	155.86	174.22	196.3	248.58	168.15	158.71
2005	09	273.76	236.79	231.77	272.58	305.39	255.14	246.96	295.51
2005	10	274.17	305.67	281.72	251.76	140.19	169.21	267.77	200.2
2005	11	126.81	143.36	151.57	193.75	92.31	170.62	162.31	212.29
2005	12	238.37	175.52	131.63	214.89	231.26	240.82	202.56	222.58

2006	01	158.31	252.69	244.11	198.57	174.57	183.21	128.72	187.77
2006	02	186.14	212.02	227.89	181.38	175.69	175.65	240.8	290.19
2006	03	256.37	266.86	279.86	312.88	333.2	307.52	198.36	195.06
2006	04	259.36	261.82	240.51	220.11	170.52	264.26	265.11	270.93
2006	05	233.45	227.09	217.57	235.19	222.65	215.15	183.1	169.51
2006	06	197.82	300.78	95.19	252.04	191.36	179.37	187.51	195.76
2006	07	221.28	280.93	275.65	346.42	357.82	269.49	292.63	291.33
2006	08	355.49	266.51	139.75	125.25	166.13	181.98	187.25	251.32
2006	09	148.11	224.73	192.18	169.68	261.81	324.32	323.61	355.88
2006	10	304.32	290.76	242.13	218.71	262.23	260.22	303.26	285.79
2006	11	120.77	206.3	250.94	212.95	221.18	239.04	235.61	142.77
2006	12	190.44	153.84	84.08	132.8	106.17	163.9	165.76	169.95
2007	01	153.36	163.89	121.36	95.21	88.91	136.96	111.92	97.36
2007	02	229.54	246.77	297.03	267.34	307.1	292.89	278.4	221.28
2007	03	171.63	226.61	216.85	245.15	289.45	320.37	284	311.3
2007	04	314.33	200.1	253.78	262.45	88.59	242.03	176.34	204.62
2007	05	187.38	211.54	290.77	320.1	278.8	233.28	212.4	99.24
2007	06	415.89	217.35	101.36	164.79	258.1	278.57	158.47	210.37
2007	07	309.8	320.92	303.28	361.05	133.25	251.4	212.42	220.1
2007	08	261.64	375.81	331.22	279.24	162.29	111.6	166.66	221.42
2007	09	181.4	154.34	262.07	297.59	232.07	147.77	213.35	338.16
2007	10	241.87	185.27	250.6	293.78	229.93	155.68	220.85	264.26
2007	11	131.21	235.99	266.17	181.96	253.99	287.36	241.38	232.34
2007	12	256.63	277.48	247.76	157.6	143.9	212.26	257.71	302.81
2008	01	192.92	128.26	168.71	218.49	263.56	193.06	117.94	102.18
2008	02	94.57	159.65	169.94	219.33	195.97	237.17	202.88	231.85
2008	03	176.22	199.04	210.87	247.56	266.13	282.72	316.41	288.66
2008	04	229.54	212.11	162.65	302.34	157.73	178.06	130.74	142.46
2008	05	172.77	267.1	123.71	213.96	189.35	134.77	196.08	194.97
2008	06	142.77	217.76	136.34	68.17	212.78	92.46	185.02	176.01
2008	07	204.61	297.19	247.92	241.87	189.37	260.11	242.68	162.03
2008	08	301.51	317.81	229.04	205.52	239.15	190.61	169.19	98.23
2008	09	276.22	212.44	264	234.1	160.2	183.79	284.14	286.33
2008	10	255.62	223.95	267.35	232.75	281.17	123.83	330.93	357.31
2008	11	235.1	305.68	281.53	223.33	272.28	273.42	291.39	278.17
2008	12	278.93	258.93	293.34	255.94	174.87	74.86	163.15	241.39
2009	01	224.29	151.82	104.3	184.53	252.7	251.7	265.12	290.17
2009	02	222.2	261.91	225.1	279.91	308.81	328.32	365.14	302.73
2009	03	250.74	130.93	218.61	280.56	283.78	312.94	276.79	165.22
2009	04	329.43	191.88	181.77	212.18	162.97	233.25	224.29	229.38
2009	05	319.61	240.76	88.01	173.79	241.08	156.54	262.98	335.05
2009	06	262.57	268.29	344.28	160.48	120.08	177.82	216.31	309.08
2009	07	238.92	224.6	282.03	252.7	299.66	317.84	328.25	157.54

2009	08	137.85	195.02	200.94	165.89	174.78	129.86	143.54	219.64
2009	09	169.27	170.8	194.41	189.9	238.51	204.11	212.42	232.97
2009	10	270.89	305.24	317.44	287.39	277.18	312.83	404.45	324.63
2009	11	249.8	264.68	324.94	297.2	264.75	290.05	324.58	335.07
2009	12	207.26	255.38	201.17	217.89	199.53	232.35	261.69	285.89
2010	01	196.08	195.44	273.38	260.77	293.98	290.67	249.35	208.7
2010	02	281.31	362.4	328.99	275.73	196.08	209.6	253.9	300.58
2010	03	202.45	239.86	258.3	232.62	251.86	163.19	248.61	336.67
2010	04	291.67	300.88	298.62	315.14	292.89	269.56	202.78	290.76
2010	05	275.39	124.38	164.71	334.54	222.02	176.48	90.25	243.76
2010	06	243.36	185.48	299.46	265.87	199.78	216.22	231.79	269.63
2010	07	299.57	246.31	224.15	201.06	245.77	185.01	161.3	207.54
2010	08	174.54	189.75	226.29	213.85	234.05	264.06	231.26	151.62
2010	09	257.85	285.43	339.32	381.05	339.32	313.76	358.73	368.58
2010	10	246.46	268.56	312.56	255.91	297.07	311.18	204.37	305.15
2010	11	187.19	176.36	239.1	237.19	230.99	175.62	195.56	137.24
2010	12	244.58	258.09	243.34	273.55	357.94	288.12	217.28	129.97
2011	01	158.08	123.94	114.4	194.95	238.05	174.42	137.85	153.87
2011	02	291.92	251.12	156.79	133.71	179.78	194.86	214.8	278.5
2011	03	347.62	267.5	274.96	245.4	267.36	316.65	335.04	380.15
2011	04	260.39	233.17	232.35	109.17	217.77	287.71	321.62	279.97
2011	05	218.87	258.64	248.89	99.89	224.77	219.25	257.08	167.62
2011	06	132.53	288.63	333.98	229.6	219.74	261.93	195.81	195.39
2011	07	256.63	361.71	64.88	250.99	336.32	390.35	355.43	349.55
2011	08	215.26	133.8	256.05	191.82	191.63	219.99	199.6	192.82
2011	09	177.12	309.05	318.04	286.34	213.73	239.84	293.38	346.59
2011	11	228.32	245.06	326.14	305.06	259.37	209.86	217.76	239.38
2011	12	136.93	230.8	295.35	269.11	235.98	223.95	223.57	166.37
2012	01	200.64	159.45	97	92.49	109.16	117.15	113.52	147.2
2012	02	223.3	202.6	161	183.21	232.69	252.7	125.3	198.45
2012	03	273.87	178.36	295.42	291.4	240.14	268.44	346.14	339.79
2012	04	274.35	272.14	313.62	189.34	324.4	318.93	250.9	276.06
2012	05	246.72	313.62	317.01	194.39	245	297.59	265.64	244.37
2012	06	194.63	170.99	154.16	253.55	90.73	197.18	199.32	260.61
2012	07	358.34	285.12	213.12	283.6	251.04	250.33	271.96	274.46
2012	08	197.15	178.14	258.83	268.91	212.47	293.86	238.29	233
2012	09	328.82	350.85	270.59	289.6	231.87	259.86	332.83	379.6
2012	10	201.13	252.8	321.31	322.22	310.08	167.75	296.73	214.5
2012	11	272.3	325.95	276.67	260.31	249.73	243.23	253.66	209.68
2012	12	258.7	322.13	306.3	292.06	258.27	168.55	278.83	126
2013	01	161.41	124.68	127.96	169.02	135.12	133.84	158.14	139.87
2013	02	151.27	160.64	105.75	98.2	203.54	229.1	262.96	289.91
2013	03	307.09	288.67	324.31	280.11	246.11	294.56	319.8	351.21

2013	04	240.01	123.26	243.69	309.35	352.31	352.09	347.87	267.39
2013	05	94.13	133.26	276.34	264.65	217.24	168.18	195.82	87.34
2013	06	219.2	200.15	196.13	358.73	286.66	143.84	237.38	397.69
2013	07	248.04	420.04	370.83	351.04	342.46	283.15	237.19	219.82
2013	08	322.04	286.8	237.33	261.23	244.4	291.84	304.44	196.87
2013	09	314.52	221.02	241.65	321.17	383.04	314.96	318.03	351.62
2013	10	391.91	383.19	412.33	324.29	304.39	273.34	314.53	346.89
2013	11	269.48	182.33	234.91	269.47	249.22	243.32	243.37	298.42
2013	12	311.64	257.81	197.81	274	362.62	361.78	252.87	212.84
2014	05	190.54	120.58	161.77	281.98	372.62	184.72	151.25	107.03

APPENDIX B

Size in area (m2) of suitable sites and identification codes

Table

Most Suitable Area

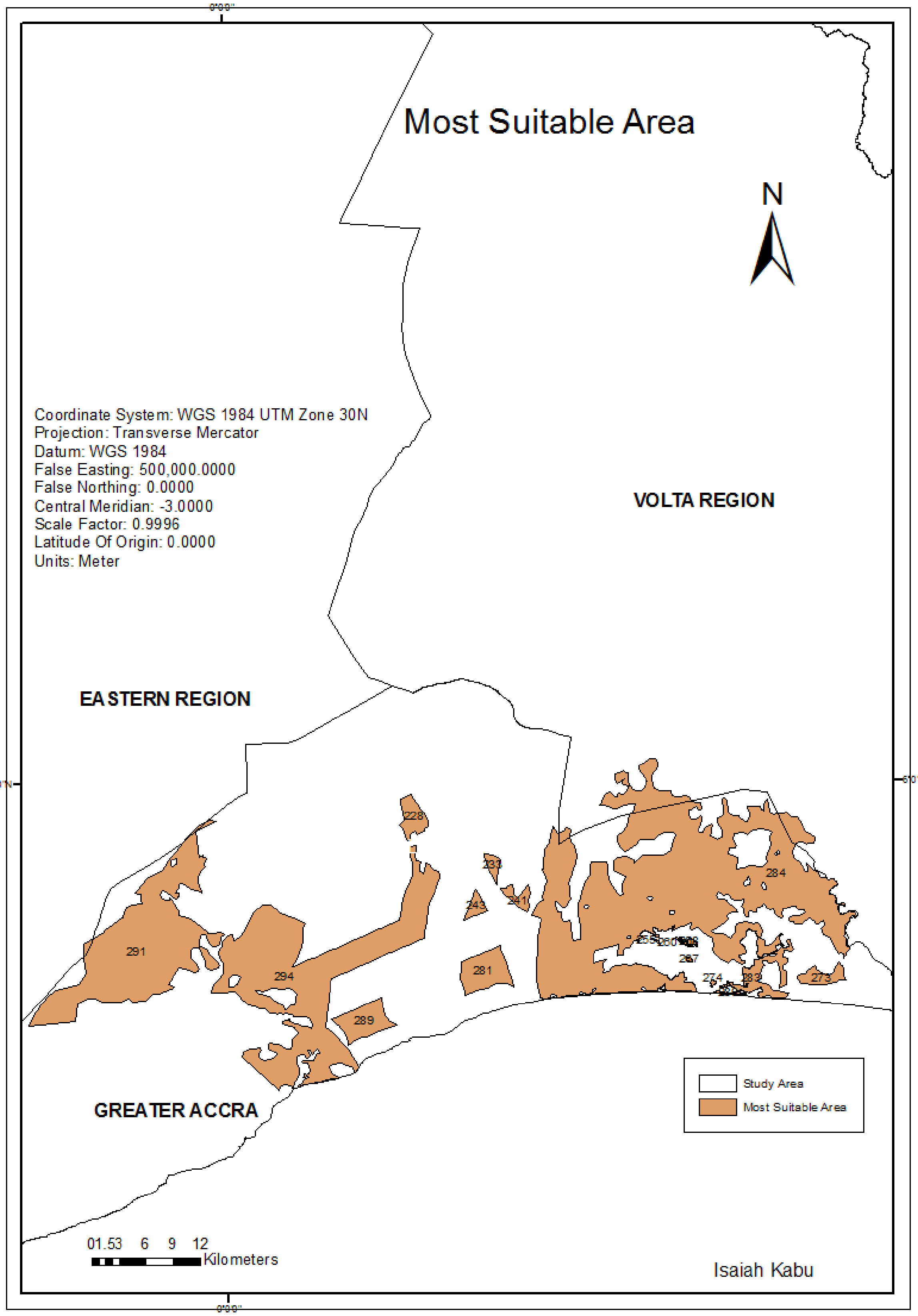
OBJECTID *	Shape *	Id	gridcode	Shape_Length	Shape_Area
228	Polygon	228	1	14168.943143	9621502.521757
233	Polygon	233	1	8774.802171	3042762.258354
241	Polygon	241	1	12002.629549	4644531.021922
243	Polygon	243	1	9150.948232	4046844.531725
255	Polygon	255	1	2464.83474	120106.127427
258	Polygon	258	1	6544.523302	711682.023486
260	Polygon	260	1	6052.282705	324622.875427
267	Polygon	267	1	2415.436932	247230.021579
273	Polygon	273	1	14888.048454	7168893.777133
274	Polygon	274	1	2702.823249	276385.527634
280	Polygon	280	1	7919.783415	457841.336364
281	Polygon	281	1	19034.036895	20091301.874717
283	Polygon	283	1	48303.730849	14799218.539031
284	Polygon	284	1	346126.490868	422549167.905515
286	Polygon	286	1	4684.045145	453833.669564
289	Polygon	289	1	19130.144208	17461638.206177
291	Polygon	291	1	106468.084422	157983917.210322
294	Polygon	294	1	165594.923516	198898333.607397

0 (0 out of 18 Selected)

Most Suitable Area

APPENDIX C

Most Suitable areas object identify



APPENDIX D

List of Land Cover types

Table

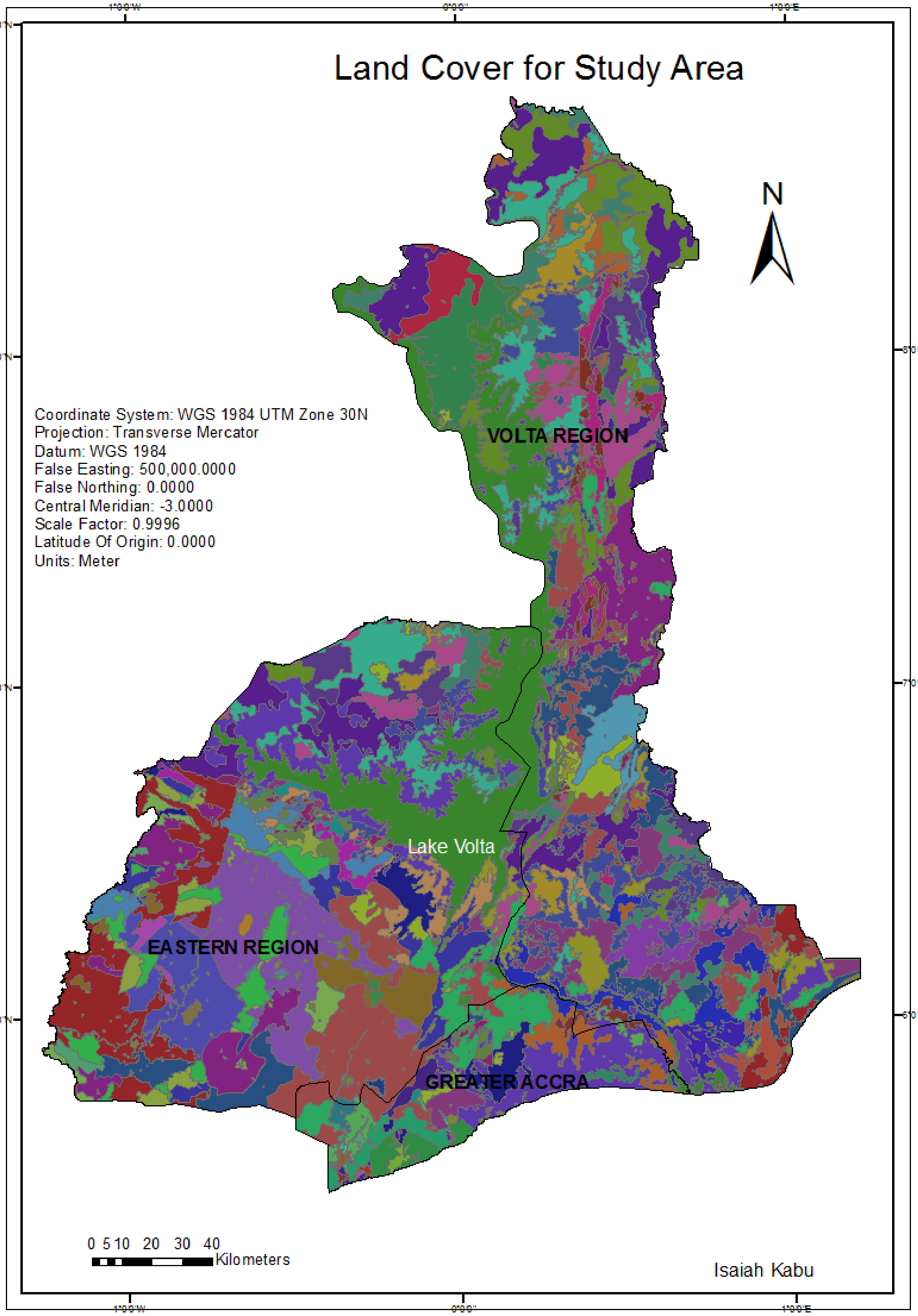
Land_Use_Dissolve

OBJECTID *	Shape *	LEGEND
1	Polygon	
2	Polygon	1112 Tree crop plantation, Oil palm
3	Polygon	1210 Mixed bush fallow cropping (short fallow)
4	Polygon	1211 Mixed arable crops (short fallow) shrubland with/without scattered trees
5	Polygon	1221 Mixed arable crops (long fallow)shrubland with/without scattered trees
6	Polygon	1310 Mixed bush fallow cropping (short fallow)grass/herb with/without savanna/forest trees
7	Polygon	1311 Mixed arable crops(short fallow)grass/herb with/without savanna/forest trees
8	Polygon	1312 Mixed arable and tree crops (short fallow) grass/herb with/without savanna/forest trees
9	Polygon	1314 Mixed arable crops including pineapple
10	Polygon	1320 Mixed bush fallow cropping/grazing (long fallow)
11	Polygon	1321 Mixed arable & tree cropping (long fallow) grass/herb with/without scattered savanna trees
12	Polygon	1410 Mixed bush fallow cropping (short fallow) dense herb/bush/grass cover with scattered trees
13	Polygon	1411 Mixed arable cropping (short fallow) dense/herb/bush
14	Polygon	1412 Mixed arable and tree crops (short fallow) dense/herb/bush/grass
15	Polygon	1413 Mixed arable and tree cropping (short fallow) dense/herb/bush/grass (Cocoa)
16	Polygon	1414 Mixed arable and tree cropping (short fallow) dense/herb/bush/grass (Oil palm)
17	Polygon	1420 Mixed bush fallow cropping (long fallow)
18	Polygon	1421 Mixed arable cropping (long fallow) dense/herb/bush/grass
19	Polygon	1510 Mixed bush fallow cropping (variable fallow)
20	Polygon	1511 Mixed arable & tree cropping (short fallow) herb/bush, high density of forest trees (Cocoa)
21	Polygon	1520 Sub-canopy cropping
22	Polygon	1521 Mixed arable & tree cropping (long fallow) sub-canopy cropping (Cocoa)
23	Polygon	1610 Mixed bush fallow cropping (short fallow)
24	Polygon	1611 Mixed arable cropping (short fallow) mosaic of thickets & grass with/without scattered trees
25	Polygon	1612 Mixed arable & tree cropping (short fallow) mosaic of thickets & grass with/without scattered trees
26	Polygon	1620 Mixed bush fallow cropping (long fallow)
27	Polygon	1621 Mixed arable cropping (long fallow) mosaic of thickets & grass with/without scattered trees
28	Polygon	1631 Mixed arable crops and livestock (long fallow) mosaic of thickets & grass with/without scattered trees
29	Polygon	1710 Mixed bush fallow cropping (short fallow)
30	Polygon	1711 Mixed arable crops (short fallow) closed savanna woodland
31	Polygon	1721 Mixed arable cropping (long fallow) closed savanna woodland
32	Polygon	1810 Mixed bush fallow cropping (short fallow)
33	Polygon	1811 Mixed arable cropping (short fallow) open savanna woodland
34	Polygon	1821 Mixed arable cropping (long fallow) open savanna woodland
35	Polygon	1911 Mixed arable cropping (short fallow) widely open savanna woodland
36	Polygon	1921 Mixed arable croping (long fallow) widely open savanna woodland
37	Polygon	2110 Reserved closed forest
38	Polygon	2120 Open-access closed forest
39	Polygon	2130 Closed forest plantation
40	Polygon	2210 Reserved open forest
41	Polygon	2220 Open-access open forest
42	Polygon	2230 Open forest plantation
43	Polygon	2310 Riverine vegetation with/without scattered farms
44	Polygon	3110 Reserved closed savanna woodland
45	Polygon	3120 Open-access closed savanna woodland (with or without scattered farms / grazing)
46	Polygon	3200 Open savanna woodland (< 150 trees per ha)

1 (0 out of 73 Selected)

APPENDIX E

Land Cover types



APPENDIX E

Land Cover legend

Legend

Study Area

Land Cover

<all other values>

LEGEND

1112 Tree crop plantation, Oil palm
1210 Mixed bush fallow cropping (short fallow)
1211 Mixed arable crops (short fallow) shrubland with/without scattered trees
1221 Mixed arable crops (long fallow)shrubland with/without scattered trees
1310 Mixed bush fallow cropping (short fallow)grass/herb with/without savanna/forest trees
1311 Mixed arable crops(short fallow)grass/herb with/without savanna/forest trees
1312 Mixed arable and tree crops (short fallow) grass/herb with/without savanna/forest trees
1314 Mixed arable crops including pineapple
1320 Mixed bush fallow cropping/grazing (long fallow)
1321 Mixed arable & tree cropping (long fallow) grass/herb with/without scattered savanna trees
1410 Mixed bush fallow cropping (short fallow) dense herb/bush/grass cover with scattered trees
1411 Mixed arable cropping (short fallow) dense/herb/bush
1412 Mixed arable and tree crops (short fallow) dense/herb/bush/grass
1413 Mixed arable and tree cropping (short fallow) dense/herb/bush/grass (Cocoa)
1414 Mixed arable and tree cropping (short fallow) dense/herb/bush/grass (Oil palm)
1420 Mixed bush fallow cropping (long fallow)
1421 Mixed arable cropping (long fallow) dense/herb/bush/grass
1510 Mixed bush fallow cropping (variable fallow)
1511 Mixed arable & tree cropping (short fallow) herb/bush, high density of forest trees (Cocoa)
1520 Sub-canopy cropping
1521 Mixed arable & tree cropping (long fallow) sub-canopy cropping (Cocoa)
1610 Mixed bush fallow cropping (short fallow)
1611 Mixed arable cropping (short fallow) mosaic of thickets & grass with/without scattered trees
1612 Mixed arable & tree cropping (short fallow) mosaic of thickets & grass with/without scattered trees
1620 Mixed bush fallow cropping (long fallow)
1621 Mixed arable cropping (long fallow) mosaic of thickets & grass with/without scattered trees
1631 Mixed arable crops and livestock (long fallow) mosaic of thickets & grass with/without scattered trees
1710 Mixed bush fallow cropping (short fallow)
1711 Mixed arable crops (short fallow) closed savanna woodland
1721 Mixed arable cropping (long fallow) closed savanna woodland
1810 Mixed bush fallow cropping (short fallow)
1811 Mixed arable cropping (short fallow) open savanna woodland
1821 Mixed arable cropping (long fallow) open savanna woodland
1911 Mixed arable cropping (short fallow) widely open savanna woodland
1921 Mixed arable croping (long fallow) widely open savanna woodland
2110 Reserved closed forest
2120 Open-access closed forest
2130 Closed forest plantation
2210 Reserved open forest
2220 Open-access open forest
2230 Open forest plantation
2310 Riverine vegetation with/without scattered farms
3110 Reserved closed savanna woodland
3120 Open-access closed savanna woodland (with or without scattered farms / grazing)
3200 Open savanna woodland (< 150 trees per ha)
3210 Reserved open savanna woodland
3220 Open-access open savanna woodland with/without scattered farms / grazing
3310 Reserved grassland with/without scattered trees
3320 Open-access grassland with/without scattered farms /grazing
3400 Riverine vegetation
3410 Riverine vegetation with /without farms or grazing
4100 Shrub-thicket with/without scattered trees (< 10 trees)
4110 Reserved shrub-thicket
4120 Open-access shrub thicket with/without scattered farms
4210 Reserved mosaic of thickets and grassland
4220 Open-access mosaic of thickets and grassland with scattered farms or grazing
5110 Urban Settlements
5111 City nucleus
5112 Peri-urban
5113 Town
5231 International airport
6122 Diamond
6300 Beach
6400 Salt flats
6410 Salt winning
7100 River
7200 Reservoir (dam)
7300 Lake
7400 Lagoon
8000 Wetland
9100 Cloud or haze cover
9200 Fire scars