# USING GIS AND MULTI CRITERIA DECISION MAKING TO DETERMINE SUITABLE DAM SITES IN THE UPPER WEST REGION OF GHANA



By

REDUWAN KASSIM

(BSc. Geomatic Engineering)

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## DECLARATION

I hereby declare that this submission is my original work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgment is made in the thesis.



KASSIM REDUWAN ……………….................. ……………………………

(STUDENT – PG9267617) (SIGNATURE) (DATE)

Certified By:

Dr. Edward Matthew Osei Jnr. ……………….................. ……………………………

(SUPERVISOR (SIGNATURE) (DATE)

Certified By:

Dr. Jonathan A. Quaye-Ballard ……………….................. ……………………………

(Head of Department) (SIGNATURE) (DATE)

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# DEDICATION

I whole heartedly dedicate this thesis to my wonderful family for all the pain they have had to endure in my absence as I spent a lot of time away studying. To my Dad, Alhaj Kassim Yahaya and my mum Madam Nafisah Koray for their love and support always. Also to my siblings, Atta-ullah, Abdul-Basit and Abida.

## ABSTRACT

The availability of water for use is alarmingly becoming an issue of concern globally and if measures are not implemented to curb this, then the world over faces an impending water scarcity crisis. Studies conducted by the United Nations Environment Program (UNEP) indicate that by 2050, over two billion people will live under high water stress situations. This invariably would limit development and affect quality of lives. Water scarcity and water stress situations will also invariably lead to a decrease in Agricultural output. Dams provide an option for harvesting and storing water for various uses. Irrigation could also be a solution to the decline of agricultural output in the country. However, even though dams are designed to collect and store water for use, for them to function at optimum levels, they have to be sited appropriately. In Ghana, the Ghana Irrigation Development Authority (GIDA) is the government agency primarily tasked with the construction and management of dams. However selecting suitable sites for these dams is done manually and quiet subjectively. This traditional site selection process is tedious fails to accentuate certain terrain characteristics that are not readily visible and may only be highlighted in a GIS environment This study employs the use of GIS and Multi Criteria Decision Making (MCDM) in siting dams using five factors namely Slope, Rainfall, Soil type, protected zones and Settlements. The results shows a suitability map for dam sites. From the map, 4.3% of the study area is suitable for dam construction, 33% of the area averagely suitable, 53.9% poorly suitable and 8.8% unsuitable for dam construction. The study goes further to propose four specific dam sites, determined the profiles and estimates volumetric capacities of these sites and it was found that the sites had capacities of 219,000m3, 1,312,500m3, 557,666m3 and 375,000m3 respectively for dam sites 1, 2, 3 and 4. In conclusion, it is asserted that GIS is a powerful tool that can be effectively used to help in determining suitable sites for dam construction and provides an improvement on the current traditional site selection process employed by decision makers.

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| | |
|---|---|
| AHP | ANALYTICAL HIERARCHICAL PROCEDURE |
| CI | CONSISTENCY INDEX |
| CR | CONSISTENCY RATIO |
| DFID | DEPARTMENT FOR INTERNATIONAL DEVELOPMENT |
| GIDA | GHANA IRRIGATION DEVELOPMENT AUTHORITY |
| GIS | GEOGRAPHIC INFORMATION SYSTEMS |
| MCDM | MULTI CRITERIA DECISION MAKING |
| MOFA | MINISTRY OF FOOD AND AGRICULTURE |
| NSEZ | NORTHERN SAVANNAH ECOLOGICAL ZONE |
| RI | RANDOM INDEX |
| TOPSIS | TECHNIQUE FOR ORDER OF PREFERENCE BY SIMILARITY TO IDEAL SOLUTION |
| UNEP | UNITED NATIONS ENVIRONMENT PROGRAM |

# CHAPTER ONE INTRODUCTION

## 1.1 Background Information

Water is a fundamental resource that supports life. However, a higher percentage of the world's water resources are saline, with only a relatively small percentage of freshwater. Even so, not all of these waters are suitable for use, as some are ice and snow cover mainly distributed in the mountainous regions and some spread across the Antarctica and the Arctic and some still existing as groundwater that is not easily accessible for use. According to (Shiklomanov, 1999) a very insignificant percentage (0.26%) of freshwaters on the Earth are contained in lakes, reservoirs and river systems where they can easily be assessed for use. Great care must therefore be taken to protect what little fresh water is accessible for use. (Macedonia *et al.*, 2012) notes that the availability of water for use is alarmingly becoming an issue of world concern and predicts that if recent patterns continue, then approximately 75% of the world population will live with situations of high water shortage by 2025. Also, (Sekar, 2007) notes that according to a study by the United Nations Environment Program (UNEP) by 2050, over two billion people will live under high water stress situations, and this would serve as a hindrance to future development in many nations around the world. Water scarcity and water stress situations invariably will lead to a decrease in Agricultural output.

In Ghana, there has been a decline in Agricultural production (Ghana Budget Statement, 2017). A study by Regassa *et al.* (2011) postulates that agriculture in Ghana occupies a central socio-economic position with 40% of the country's gross domestic product from this sector, employs about 65% of the labor force and, although the sector has a major influence on the economy the country's economy, its structure is very weak mainly because it is based on rain-fed agriculture during a rainy season of about six months.

To solve the predicted impending water stress situation and also the vulnerability problem of the agricultural sector, dams could be constructed to serve as sources of water for domestic use as well as irrigation.

Dams have been found to be one of the best options for collecting, storing and efficiently managing water resources in order to improve the lives of people in rural areas. They also provide urban centers with water for household use, electricity generation, and water for irrigation and for industrial use. Irrigation dams could therefore be the solution to the decline in agricultural production in the country. Although dams are designed to collect and store water, they must be properly located to function at optimum levels. The geographic information system (GIS) can be an effective tool for determining the optimal sites for these dams. The United States Geological Department defines GIS as a computer system capable of collecting, storing, analyzing, and visualization of spatial information. This system also includes the staff who operate it as well as the data it contains.

GIS as a tool makes it easier to integrate and analyze multiple spatial features and variations. Researchers such as Abramovich (2012) have looked into using GIS as a means for making site selection decisions and concluded that it is rewarding to apply the capabilities of GIS models in determining locations as this leads to a greater potential of success in the delivery of services and economic success of businesses. There is also continuous work on how to apply GIS and GIS methods to hydrological studies.

For example Ahmet (2011) used the Ripple method to calculate the Water Storage Capacity of a Reservoir. Ripple method also referred to as mass curve method is one of the main procedures that can be used to determine storage capacity, approximately. In this method, the crest height is derived from the results from the Ripple method. Employing the Ripple method, dam reservoir storage capacity was calculated, also the height of crest was determined from height-volume plot and the surface area of the water at the same capacity calculated making use of the elevation-area graphic. Dam capacity and dam area of water are then analyzed for each dam site easily to find the site most desirable for the construction of dam. However this research was aimed at comparing different potential dam sites which had already been determined rather than focusing entirely on selecting new optimum locations for siting dams. Others such as Choong-Sung *et al*. (2010) have used location analysis methodology for hydro power works by employing GIS as a tool to determine the most appropriate site for small hydropower plants in the topmost parts of the basin of river Geum, in Korea. To do this, they applied the geospatial information system to the site analysis and were able to establish six potential sites for small hydropower plants.

In southern Africa and in Botswana to be precise, Tshegofatso (2016) used GIS as a tool to determine sites that are suitable for harvesting surface rainwater in an environment that is a semi-arid catchment. Analysis from the study, indicated that of the total catchment area (15,706 km$^2$), only 10% was suitable for harvesting surface runoff and about 37% of the catchment did not show potential for macro runoff water harvesting whereas 16% of the area is moderately suitable and 65% was found to be marginally suitable. Existing dams and reservoirs within the study area were assessed using the developed surface Run-off Water Harvesting suitability criteria. Results from this analysis showed that approximately 39% of existing water harvesting structures belong to the class with suitable potential and 17% belong to the marginally suitable potential class it was thus concluded that the method proved to be an effective one for selecting sites for optimum harvesting of surface runoff water.

In the upper east region of Ghana to be precise, Boateng *et al.* (2016) used Multi-criteria Decision Analysis and GIS as a tool to determine suitable irrigational dam sites in the region. Five factor criteria were used to determine suitable sites and three constraint criteria were subsequently used to determine optimal sites from the suitable sites. The results obtained from their research proposed clear areas where irrigational dams can be located. However, in this research rainfall which is a very important factor for siting an irrigational dam was not used. For this reason if a site is chosen as a good site for an irrigation dam but without supply of an adequate amount of rain water the decision would be flawed. This study would therefore seek to add onto this by making appropriate use of rainfall data.

## 1.2 Research Motivation

According to Scoullos *et al.* (2002), the Integrated Water Resources Management (IWRM) recognizes that water is a precious, limited and scarce resource that is the subject of a competing demand from multiple users. Over the years there has been increasing competing demand for water. As our water resources become more and more depleted, then there is a threat to global food security.

DFID (2005) asserts that food security is a global problem related to many aspects of production, distribution, environment and socio-economic aspects of food. Approximately 2.5 billion people in under-developed countries depend on agriculture as a source of livelihood.

Easterling *et al.* (2007) notes that in Africa, crop yields are likely to fall sharply even for small-scale climate change, as rain fed crops are close to their maximum temperature tolerance and eventually leading to sharp declines of up to 30 percent of agricultural productivity in the 21st century. The main drivers of these projected agricultural declines in the tropics are water stress, increased temperature, the impact of an increasing number of new invasive pests, diseases and weeds.

This study is conducted in the Upper West region of Ghana which falls within the Northern Savannah Ecological Zone (NSEZ). This zone is characterized by extreme climatic conditions such as long periods of dry-spells or droughts, increasing land cover affected by desertification leading to worsening agricultural productivity and poor yields.

The management of the scarce water resources available for use therefore requires more effective and comprehensive management tools such as GIS to mitigate any predicted high water stress situations and prevent food insecurity. There is therefore the need to conduct studies into and identify the potential of gathering and storing water for use in dams. For dams to be able to perform as they are required, they should be located precisely so that they can collect enough water to serve the various purposes.

### 1.3 Problem Statement

The Ghana Irrigation Development Authority (GIDA) is the government agency primarily tasked with the construction of dams. However, finding suitable locations for these dams has been a serious problem. A key informant discussion with the principal engineer of GIDA, Wa indicates that currently the authority does this manually. This traditional site selection process is tedious fails to accentuate certain terrain characteristics that are not readily visible and may only be highlighted in a GIS environment Kolekar *et al.* (2017). Also the manual site selection process is more time consuming and expensive and again more susceptible to errors. This research therefore seeks to solve these problems by making use of GIS and its associated technologies to assist in the site selection process with data available from government agencies and online portals.

## 1.4 AIM AND OBJECTIVES

### 1.4.1 Aim

The Main aim of this study is to use Geographic Information System (GIS) to produce a suitability map for dam construction in the Upper West Region of Ghana.

### 1.4.2 Research Objectives and Questions

**Table 1. 1 Research Objectives And Questions**

| Research Objectives | Research Questions |
|---|---|
| 1. To generate a suitability map for dam construction; | 1. Which locations are suitable for dams? |
| 2. To propose suitable dam sites; | 2. Where along these suitable areas can dams be sited? |
| 3. To assess the volumetric capacity of each site. | 3. How much water can be stored within each site? |

## 1.5 THESIS LAYOUT

The thesis is going to follow this pattern

i. Chapter One Introduction

ii. Chapter Two Literature Review

iii. Chapter Three Methodology

iv. Chapter Four Results and Discussions

v. Chapter Five Conclusions and Recommendations

## CHAPTER TWO LITERATURE REVIEW

### 2.1 IMPACTS OF DAMS

Dams are generally constructed to collect and store water for effective management of water resources. Construction of Small dams have been a key part of the government of Ghana's intervention policies since independence. Acheampong *et al.* (2014) in the study titled "Development of small dams and their impacts on livelihood" noted that small reservoirs and dams give a trusted source of water in the semi-arid regions of Ghana which have unreliable rain patterns. The research further states that even though the construction of small dams is a process which involves different stake holders with competing and diverse interests, small dams open up much more economic opportunities for people and thereby impacts their lives and living conditions in a positive way.

Even though dams generally improve living conditions, the construction of dams in a location also poses a number of negative effects which vary from environmental, to social and economic. For example, Ledec and Quintero (2003) note in the book titled "Good dams and bad dams: Environmental Criteria for site selection of hydroelectric projects" that even though bigger dams offer the most cost effective avenue of generating electric power, they also pose the most significant negative environmental effects. Affirming that permanent biodiversity damage, if important natural habitats do not exist elsewhere, is submerged (or dried) by the dam as the main negative environmental influence of bigger dams.

It has also been postulated by Stot and Smith (2001), that the natural passageways of animals in the territory are hampered by the fact that dams act as obstacles and, consequently, the upstream passage of aquatic animals such as fish particularly for ovulation and feeding is greatly hindered leading to great decrease in fish population. This decrease in fish population will as a consequence have a negative economic impact on the livelihood of fisher folk communities.

Large scale dam construction has been pointed to as a cause of micro and even in some cases regional climatic changes. Tahmiscioglu *et al.* (2007) observed that micro and regional climatic variations may arise related to differences in the atmospheric moisture content, atmospheric temperature rising, and changes in air movements in big scales caused by the stagnant big scale of water mass. This is supported by Pirestani *et al.* (2011) who also go on to give the example of the "Kalghan dam" in the wintry climatic setting of Iran stating that the considerable amounts of water stored in the dam has significant impact on weather and climate, such as increased solar energy absorption in the area, heat exchange between water in dam and the neighboring atmosphere, and variations in amount of vaporization and fog caused by increasing the level of vaporization. Even though these changes don't greatly affect human life directly, they greatly affect plant life and also life of some animals and thus can be said to have a secondary effect on human life.

Health wise, Tahmiscioglu *et al.* (2007) notes that dams have also been notable cause of a spike in water related illness such as cholera, diarrhea, fever, typhoid, and malaria caused by mosquitoes breeding in dams.

Even though dams are noted to pose these negative impacts, they are of great importance to humans and researchers have continuously been proposing ways to mitigate these negative effects. Ledec and Quintero (2003) propose that the most efficient environmental protection measure is a good selection of the site, to ensure that the dam when constructed will cause relatively little or no damage to the environment. Pirestani *et al.* (2011) also propose the use of low-elevation dams and shorter dam walls, which will mitigate the negative effects posed by large dams.

## 2.2 GIS FOR SITE SELECTION

GIS is increasingly being used in the determination of suitable locations for various projects. Selection of optimum sites for projects is very important because no matter how good a project is or how beneficial a project is going to be without optimum siting, it may not serve its intended purpose. GIS as a tool makes it easier to integrate and analyse multiple spatial features and variations. Researchers such as Haaren and Fthenakis (2011), Abramovich (2012), Aydin et al., (2013), Rikalovic *et al*. (2014), Noorollahi *et al*. (2016) have looked into using GIS as a tool to make decisions with regards to location and site selection.

Haaren and Fthenakis (2011) researched into using GIS as a tool to select suitable sites for building wind farms in the city of New York and were able to provide predicted sites suitable for the construction wind farms within the study area based on predefined factors. The results can then assist decision makers in the planning of wind developers. Abramovich (2012) researched into using GIS as a tool to help in making site selection decisions and concluded that it is rewarding to apply the capabilities of GIS models in determining locations as this leads to a greater potential of success in the delivery of services and economic success of businesses. Aydin et al. (2013) also researched into using GIS as a tool for determining suitable sites for renewable energy systems and were able to obtain the best locations suited for wind solar hybrid system. Rikalovic et al. (2014) also researched into using GIS together with Multi-criteria Analysis to select industrial sites. They used GIS as the primary decision making tool for selecting sites for industry by performing spatial analysis of Vojvodina. The successes of GIS as tool for site selection in various fields has aroused the interest of researchers in hydrological studies to apply it in hydrology.

## 2.3 GIS AS A TOOL FOR SELECTING DAM SITES (PRIOR WORK IN FIELD)

There is continuous work on how to apply GIS and GIS methods to hydrological studies.

Qureshi (2015) conducted a research on GIS and remote sensing as tools in determining best sites for constructing dams in Pakistan. In this research, Multi Criteria Evaluation (MCE) techniques were used for overlaying the layers, using the method of weighted linear combination. The problem involved analyzing the initial sites for development considering three criteria namely precipitation, Slope(S) and Settlements (Se) with the attention centered on environmental protection, economic considerations and safety. Settlements and Rainfall were considered as constraint criteria as the dam/reservoir was not to be sited in or near a settlement and must have water accumulated areas. Slope was considered as a factor criteria and the dam was to be sited on a gentle slope to prevent the slope from failing. Criteria were directly responsive to economic parameters and environmental protection. The relative influence of the three criteria had to be assessed. This was done by the pairwise comparison matrix, the calculation of the criterion weight, and the estimate of the consistency ratio. The result of the potential sites met all the constraints conditions of the criteria. The selected impoundments were outside of any settlement, found on gentle slopes leading into water accumulation zones, found in areas of maximum rainfall. The reservoir sites that were selected were indeed good for collecting and storing water. However, this research was limited to only settlement, slope and rainfall whilst neglecting other important criteria such as soil type, protected zones and farms (Agricultural Sites). This may result in a dam sited on an area with soil that is ineffective in water holding and retaining capacity and thereby the collected water will be lost very fast.

Remote sensing and GIS techniques were applied by Abushandi and Alatawi (2015) in flood control systems in Saudi Arabia. The success of flood control as presented by the research depended on locating optimum sites for collecting and storing excess run off water in the area. Aster Global digital elevation model (DEM) with a 30m resolution was used.

In Bortala, Northwest China, Dai (2016) conducted a research on determining a site suitable for dam construction using GIS as a tool together with Analytical Hierarchical Process (AHP) to aid decision making. The factors used included geological layer, slope, soil type, land cover and drainage order. Because of the complex nature of selecting a dam site and also considering the criteria used for the study, the researcher used a multi criteria decision making approach called AHP to assign weights to the factors. The result was a suitability map of dam construction in Bortala. From the suitability map, 8 sites of very high suitability were proposed. Analyzing the map, it was found that areas in the Bortala region with relatively high elevations were found to be of high suitability to dam construction and areas with relatively low elevations were found to be low suitability for the construction of dams. The study went on to analyse the profile of the proposed sites for dam construction and generate characteristics such as dam height and width. From these, the volume of each proposed dam was calculated and then they were classified as small, medium and large dams. The dams had volumetric capacities varying from 122,506 $m^3$ to 5,033,652 $m^3$ and were classified as small, medium and large dams depending on their volumetric capacities. 2 dams were classified as small, 5 dams as medium 1 dam as large.

In the swat valley region of Hindukush in Pakistan, Iftikhar et al. (2016) used geospatial techniques to perform a site suitability analysis for small multipurpose dams. The following data was used for the research. Digital elevation model from ASTER Global DEM with a resolution of 30m. Maps produced from digitized documents describing the geology and rock formation.

Rainfall data collected over a duration of 8 years beginning in 2003 and ending in 2011, discharge collected over 9-year period from 2002 to 2011 and Landsat 5 image from November 2011 covering the swat valley. Landsat 8 images of the area over the time period couldn't be used as they contained significant cloud cover. Four main stages were involved in the research. (i) Data preprocessing, (ii) Conducting an initial hydrological survey of the area (iii) Defining factors and assigning criteria weights (iv) Identifying sites and assessing the volumetric capacity of each site. Flow, Geology, Slope, Terrain Ruggedness Index (TRI), Land Use and Elevation were the main criteria considered with Flow considered as the most important criteria and Elevation as the least important. Four sites were identified making sure that the formation of a valley shape is realized in order to minimize the cost of constructing a dam wall, the previously mentioned geological factors being suitable for the whole area. Secondly, the land use factor was the least important in the first three sites, but considerable for site 4 because it closer to Mingora district. After analysis, it was found that the selected dam sites could be used effectively for efficient water storage, especially in winter, when flow minimizes.

In Iran, Dorfeshan et al. (2014) also researched into applying analytical hierarchical procedure to determine sites suitable for construction of underground dams. In this study, the decision tree was composed as follows: Economic reservoir criteria, four minor criteria were taken into account: the decline, the hydraulic conductivity, the effective porosity and the permeability of the foundation, as well as the economic factors of the location of the dam and the distance of the dam were taken into account. . The study established a priority map for siting of underground dams within the study area and concluded that GIS have a great capacity for analyzing spatial data, in particular by facilitating the integration of different datasets and, finally, selecting the best sites for construction of underground dams.

Still in Iran, in 2018 Jozaghi et al. (2018) performed an extensive study of the AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for selecting Dam sites using GIS in the Sistan and Baluchestan Province. Locations of the existing dams built within the area were used to check the outcome of the two methods. The comparison was made on the basis of water quality and geographical criteria. Geographical criteria include slope, groundwater, geology, erosion, land use, sediment, and discharges. The water quality criteria also include: amount of dissolved solids, potential of hydrogen, percentage of dissolvable sodium and electrical conductivity of water. The individual weights of these criteria were determined using a ratio estimation method.

In Kenya and the Mbeere North sub-county, research by Njiru and Siriba (2018) focused on using GIS for the selection of small earth dam sites with the main problem defined as identifying an effective, efficient and accurate method for dam site selection that will provide accurate field study and adequate information on the selected site for proper planning and design. The purpose of the study was to study hydrology for the selection of small earth dam sites using a combination of GIS and other techniques such as AHP of multi criteria decision analysis to establish the hydrological characteristics of the region good for dam construction. The factors chosen for the study corresponds to different criteria. Topography is one of the main factors considered in the construction of earthen dams, as it has dominant control over the flow pattern in the upstream catchment. Geological foundations in a dam site often have an influence on the type of dam suitable for that site. A site with a geological foundation / impervious and leak-free dam will provide the best water storage capacity while providing ease of construction as well as a guarantee firm structure. The type of soil influences the amount of water that can seep through. The foundations of fine-grained soils, sufficiently resistant to water, are recommended for the construction of a dam. In total, seven factors of, soil type, slope, geological layer, vegetation cover, nearness to water sources (streams and rivers), nearness to roads, and size of the watershed were considered. Approximately 10% of the total area of the study was found to be very suitable, 14% suitable, 45% averagely suitable, 23% with low suitability and 8% unsuitable for dam construction. The very suitable classification included four proposed sites with volumetric capacities ranging between 2 million $m^3$ north-eastern part of the study area and 26.9 million $m^3$ in the northwestern part of the study area. The altitude in the study area varied from 638m to 1798m above sea level. The study therefore concluded that the combination of GIS with AHP's multi-criteria decision analysis is effective in providing hydrological information on the area, which has helped in making decisions with regards to location of dam sites.

Therefore, both are competent and supportive decision-making tools. According to Sen and Al-Suba'I (2002), in any study of determining suitable dam location in any arid region, rainfall data and runoff estimations are very important. However, this research did not consider rainfall/ precipitation in the study area as a determining factor for suitable sites.

In southern Africa and in Botswana to be precise, Tshegofatso (2016) applied GIS to find sites with potential for harvesting surface rain water in a semi-arid catchment. The research was important as in a country like Botswana, there is an unpredictable weather pattern with long periods of rain in some years causing cases of floods and long periods of dry spells in other years causing droughts. The study used a GIS-based multi-criteria decision support method to determine suitable sites by cost-effectively combining a number of factors to explore the potential of surface water harvesting systems. A major consideration of in this study was the effect of strong evapotranspiration on open water surfaces. The analysis shows that out of a total of 15,706 $km^2$ of the catchment area, only 10% has the potential to recover surface rainwater and about 37% of Notwane's watershed is do not possess potential for harvesting surface rain water, while only 16% of the area is marginally suitable. The criteria for the adequacy of the developed rainwater harvesting system was employed to evaluate the existing water management structures in the basin. The analysis shows that 39% of the existing small agricultural dams belong to the class of suitable potential sites, while 17% are in unsuitable potential sites. In addition, using this GIS-based approach, it was realized that the study area could potentially store groundwater, but more studies are required to minimize the effects of evapotranspiration. In conclusion, it has been postulated that the provision of a precise spatial representation of land use and physiology for the analysis of the potential runoff generation site in the study area is an important step in the development of an integrated strategy for the collection and storage of surface rainwater for any basin and the decision support system has proved effective. The study used a 30m*30m DEM and therefore may not give a very accurate elevation model for decision making. For a better DEM for decision making, spatial data of a fine scale should be employed.

In the upper east region of Ghana to be precise, Boateng et al. (2016) used Multi-criteria Decision Analysis within a GIS setting to determine suitable irrigational dam sites in the region. The Upper East region closely resembles the Upper West region – which is the area of study of this research- in terms of vegetation, rainfall pattern and general weather conditions. Five factor criteria were used to determine suitable sites and three constraint criteria were subsequently used to determine optimal sites from the suitable sites. The results obtained from their research proposed clear areas where irrigational dams can be located. 3.69% of the study was classified to be suitable sites for irrigational dam however, a constraint criteria was applied to this result to bring the number to 0.45% as the final optimal areas that were found to be suitable for irrigation dams. The main shortfall of this research however is that Rainfall was not used as a factor in the site selection process. Rainfall is a very important factor for siting an irrigational dams as rain is the fundamental source of water for the dams. Because of this, site maybe chosen as a good site for an irrigation dam but without supply of an adequate amount of rain water the decision would be flawed.

From the review of prior work, it is noticeable that some researchers have not considered rainfall as a factor in their site selection process whilst some researchers even though they considered it relied on rainfall data from gauge stations which are sparsely distributed across the study area together with some form of interpolation.

## 2.4 FACTORS FOR SITING DAM

Factors chosen for determining location of dams vary significantly depending on the location and choice of method to use. Review of literature has shown that some factors such as Slope, Rainfall and Soil type resonates with most researchers.

### 2.4.1 Slope

Slope is considered as one of the most important factors used in siting dams. Researchers such as Qureshi (2015), Dai (2016), Iftikhar et al. (2016), Tshegofatso (2016), (Boateng et al., 2016) and Njiru and Siriba (2018) all considered slope as one the of the factors in the siting of dams with Boateng et al. (2016) and Njiru and Siriba (2018) both considering it as the most important factor and thus assigning it the highest weight. Boateng et al. (2016) argues that slope should be less than 3% as this will allow for water flow into the dam without the flow exerting so much pressure as to cause extra stress to the dam wall.

### 2.4.2 Rainfall

Amount of rainfall a place receives is very important to the ability of the place to be suitable for dam construction. Qureshi (2015), Tshegofatso (2016) and Dai (2016) all considered precipitation as one of the factors in selecting a suitable dam site with Tshegofatso (2016) and Dai (2016) both selecting rainfall as the most important factor in their site selection process. Other researchers such as Boateng et al. (2016) and Njiru and Siriba (2018) however failed to consider rainfall in their site selection process thereby leaving their final decision not very accurate. A site selected as a suitable site for dam construction may have all the requirements for a dam but without adequate rainfall there will be no accumulation of water.

### 2.4.3 Soil Type

Soil type is one of the factors that was considered by almost all researchers in their site selection process Dai (2016), Boateng et al. (2016), Njiru and Siriba (2018), Tshegofatso (2016). The soil types were ranked based on infiltration rates. Soils with low infiltration rates such as clay or fine soils with some form of clay were considered as suitable whilst soils with high infiltration rates were classified as unsuitable. This classification makes sense as the soil within the dam site needs to be able to hold water for long periods of time without allowing seepage.

Some factors including land tenure issues, availability of materials, community needs, environmental concerns, proximity to roads and power supply are not often considered by most researchers. Such factors were only considered as and when they were deemed necessary depending on the purpose, type and cost of construction of the dams.

Stephens (2010) however states that factors such as availability of material, environmental concerns, proximity to roads and power supply should be given consideration at an early stage such that funds are not wasted at initial investigation.

Jozaghi et al. (2018) considered factors such as river flow regime, topographic conditions, dam body and reservoir, economic development, health of dam site, annual yield, water quality, probable dam break, environmental, social, and political to select suitable dam sites.

## 2.5 GIS FOR DAM VOLUME ESTIMATION

GIS and GIS techniques have also proven to be effective in analyzing and determining the surface area and total volume capacity of dams. For example Ahmet (2010) applied GIS techniques to estimate area and volumetric capacities of reservoirs in Turkey. The research used the Ripple method to obtain the water potential of the reservoir that can be stored. The estimated storage capacity at the initial planning criterion was used as a basis to decide the appropriate rise of the dam crest using the GIS-based algorithm. In Ripple's method, the expected total water demand (irrigation, hydropower, domestic use of natural water in rivers and streams) was expressed as a constant rate over time and then drawn in a straight line making the slope being equal to the demand rate. A straight line was then drawn tangent to the mass curve at the initial period of the drought. A second line parallel to the first is also drawn tangent to the mass curve at the minimum point during the period of drought. The vertical distances between these two lines represent the storage required to meet the demand in times of drought. The data that was used to estimate the volumetric capacity of the reservoir was from a topographic map of the area with a scale of 1: 10,000. The map was converted to a format compatible with the GIS environment and projected into the universal transverse mercator co-ordinate system. This was then used to generate a Digital Elevation Model (DEM) of the area. From the DEM map, the basin characteristics, the watercourse network, the estimated volumes of the reservoirs as well as the estimated volume area were all identified.

Ilwis 3.6 GIS software was used to produce the various maps and drainage networks and the elevation-area graphics and elevation-volume were also produced. From the Ripple method, estimated volumetric capacity of the dam reservoir was found as 84 $hm^3$, in this capacity, the estimated maximum dam elevation was 360 meters as derived from the elevation-volume map and the estimation of reservoir surface area was 2.64 $km^2$ from elevation-area graphic.

In the semi-arid conditions of the upper east region of Ghana, Liebe et al. (2005) determined the storage capacities of small reservoirs. The volume estimation was more manual and was done based on bathymetric surveys, accompanied by satellite data and remote sensing techniques. Landsat Images were used to extract the surface area. Four Landsat images were used in total with three images taken around the end of the rainy season in 1999 when the reservoirs were at maximum capacity and the fourth taken in February 2000 when the water levels had receded. Identification of the reservoirs was by maximum likelihood classification. The classification returned a total of five hundred and four reservoirs, but given that the Landsat imagery has a resolution of 30 m, then the probability of identifying very small features wrongly is very high. As a result, 348 reservoirs with an area below 1 ha were removed from the dataset. The Tono and Vea reservoirs which are commercially operated reservoirs within the area of study, were also removed. The irrigation company of the region operates these commercial reservoirs and records variations in their storage volumes. 154 reservoirs remained, covering an area of 999.54 ha, these are then classified as small reservoirs ranging from 1ha to 35 ha. Ground Truthing was conducted between December 2002 and February 2003 and in over 50% of the cases, grounds classified as reservoir sites did indeed have reservoirs and thus presented a good user accuracy.

A sample size of 40% of the reservoirs was surveyed the outline of each was mapped using a GPS. Bathymetric surveys were also conducted to determine the depth of these reservoirs. Depth and surface area values were then used to determine the storage capacities of the reservoirs. It was found that storage volumes and reservoir surface areas are directly related.

Much simpler methods have been proposed for calculating the storage capacities of dams and reservoirs as detailed by Stephens (2010) in the manual for small earth dams. He proposed that Storage Capacity can be determined using the mathematical expression: $Q = \frac{LTH}{6}$ equation 1.

Where:

Q is the storage capacity in meters Cube ($m^3$) and should not be more than Y the catchment yield, L is used to denote the length of the dam wall when the dam is operating at full capacity in meters (m) and T represents the throwback, in meters and is defined in a line which drawn straight from the wall. H is the maximum height of the dam, in meters, at full capacity and 6 is a factor which can be altered to 5 or 4 depending on one's expertise and knowledge of the local terrain. All the above measurements can be determined from an adequate contour map of the area under study.

This method deals with the volume of water as an inverted pyramid of triangular surface and simplifies the reality. With experience, it is possible to judge with sufficient precision how a given valley will approximate such a perfect image and, consequently, to make changes as necessary

The estimated storage capacity determined using this method is correct to about 20 percent, this can however be confirmed or revised by a detailed estimation method once a site has been approved for construction to proceed.

## 2.6 GIS AND MULTI CRITERIA DECISION MAKING (MCDM)

In reality, decision making can be complicated because of the diversity of factors involved. When selecting a site for a dam, overlaying all the maps would have been enough to help in decision making. However, it has recently become apparent that by using GIS as a tool and combining it with multi-criteria factors makes for a more efficient method of decision-making.

Multi-criteria decision making (MCDM) is seen as a complex tool for decision-making which involves both qualitative and quantitative factors. Multi criteria decision making (MCDM) has developed as part of operational research, aimed at designing computer tools to support the subjective assessment of performance criteria by policy makers (Zavadskas et al., 2014).

MCDM methods have been designed to designate a preferred alternative, classifying alternatives in a small number of categories and / or classifying alternatives in an order of subjective preference. MCDM is a generic term for all existing methods to help people make decisions based on their preferences, in cases where there is more than one conflicting criterion (Ho, 2008).

The MCDM investigation can be broken into two main groups dependent on the format used to determine the weights of the criteria: Compensatory and Outranking Decision Making. The example of the former is Analytical hierarchy Process (AHP) and the latter is Elimination and Choice Expressing Reality (ELECTRE). All MCDM methods have the same principle based on which they work: In chronological order, this includes Criteria selection, identifying alternatives, choosing method aggregation or overlay and ultimately selecting alternatives depending on weights.

The Analytic Hierarchy Process (AHP), provides an efficient tool for dealing with complex real world decisions, and helps the decision maker to analyze all the various alternatives and make the best possible decision (Saaty, 1980). AHP breaks complex decisions into a series of pairwise comparisons, then synthesizes the results, and then helps to capture the subjective and objective aspects of a decision. In addition, AHP incorporates a useful technique for verifying the consistency of the decision-maker's assessments, thereby reducing bias in the decision-making process. AHP works by evaluating a set of options, based on a specific criterion, among which the best decision must be made.

In the AHP, the decision maker generates a pairwise comparison matrix using his criteria. A weight is then generated and assigned to each factor in the matrix. The higher the weight, the more important the corresponding factor is as considered in the decision making process. The sum of the weight of the factors should be equal to 1 or equal to 100 when expressed in percentage terms. According to Saaty (1980), the AHP can be implemented in three main stages namely:

1. Computing the vector of criteria weights

2. Computing the matrix of option scores

3. Ranking the Options.

In the calculation of the weight of the vector criterion after developing a pairwise comparison matrix, you then develop a normalized pairwise comparison matrix by summing each column in the previous pairwise comparison matrix equal to 1. Then, a Criteria weighting vector is constructed by averaging the inputs of each row. In the calculation of the option score matrix, it is derived from the pairwise comparison matrix and is a real matrix n x m. Finally, three options are then ranked once the weighting vector and the score matrix are known by multiplying them. For a decision to be acceptable, the consistency index should be determined. A perfectly consistent decision maker must always obtain a CI = 0, but small consistency values may be tolerated. In particular, if $CI/RI < 0.1$. Where CI is calculated as $\frac{x-m}{m-n}$, with m as number of factor criteria and x as scalar of the pairwise comparison matrix and 2. RI is defined as Random Index which is the consistency index when the entries of the matrix are completely random. The values of RI for small problems (m ≤ 10) are shown in Table 2.1

**Table 2. 1 Values for RI**

| *m* | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.51 |

Source: Saaty (1980)

The final outcome of the AHP decision making process is highly dependent on the decision maker's experience, and as such AHP can be seen as a tool that is able to translate the evaluations (both qualitative and quantitative) made by the decision maker into a multi criteria ranking. In addition, the AHP is simple.

# CHAPTER THREE METHODOLOGY

## 3.1 STUDY AREA

The study is conducted in the upper west region of Ghana (Figure 3.1). The study region lies in the north western corner of Ghana with latitude 9° 49’ 19’’N - 10° 59’ 24’’N and Longitude 1° 37’ 14’’W - 2° 54’ 00’’W. The region spans a geographical area of 18,476 $km^2$ which represents 12.7% of the total land area of Ghana. Vegetation is generally short grass and scattered woody trees. Tree species are generally fire resistant and able to cope with long periods of drought and include Acacia, Dawadawa, Baobab and Shea. Vegetation cover in the region is good for livestock farming and this contributes immensely to household income. A prolonged dry season during which the grasses dry out and burn has a major influence on the vegetation leaving the land cover uneven and in most areas devoid of vegetation. As a result, the first torrential rains cause soil erosion. Bush fires reduce vegetation cover and transpiration and this has an effect on average annual rainfall. Typical tropical climatic conditions prevail with an average annual temperature of between 27 °C and 36 °C. According to (Ghana Statistical Service, 2010), the upper west region has a population of 702,110 which represents 2.8% of the entire population of Ghana with majority of the population engaged in Agriculture. The region experiences a unimodal rainfall pattern. Figures from the (Ministry of Food and Agriculture, 2018) indicates that rainfall values within the region increases from the north (Tumu: <900 mm) towards the south (Wa: 1,111 mm) with the total yearly rainfall and the rainfall distribution varying significantly from year to year. Mostly, first rains occur between April and May whilst peak rainfall is experienced in July.

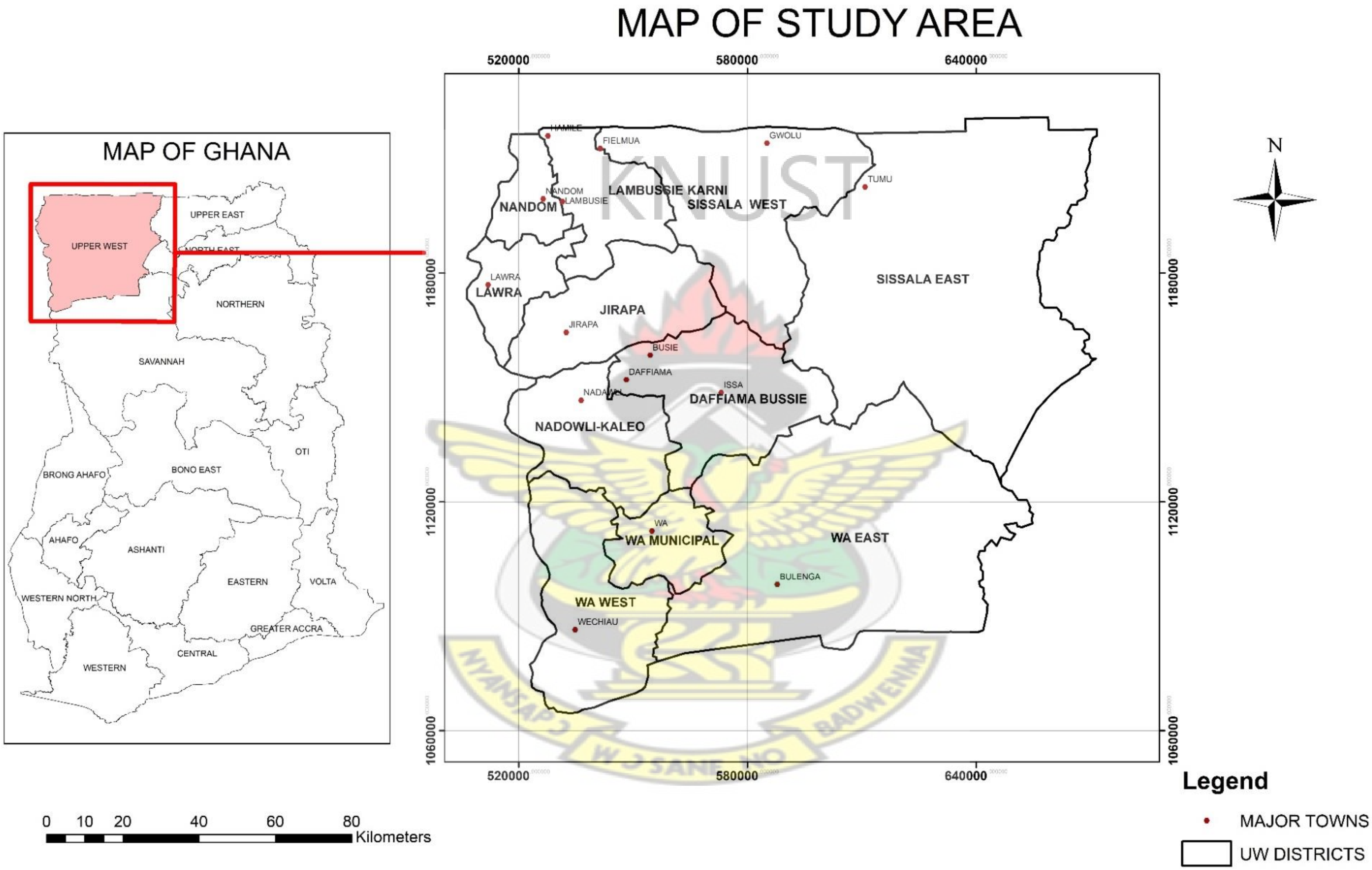


**Figure 3. 1 Map of Study Area**

## 3.2 MATERIALS

The data used for the research and their sources are detailed in Table 3.1.

**Table 3. 1 Sources of Data**

| **Data** | **Type** | **Sources** | **Use** |
|---|---|---|---|
| DEM | Spatial-raster Format | (http://gdex.cr.usgs.gov/gdex/). | To generate the Slope Map and Contour Maps |
| PROTECTED ZONES | Vector Format (Shapefiles) | Environmental Protection Agency and Forestry Commission, Wa, Upper West | To Restrict these Areas and Prevent Selection of protected areas as a Dam Sites |
| SOIL TYPE | Vector Format (Shapefiles) | Soil Research Institute of Ghana, Kumasi | Used to select the suitable soil type in Selecting a Dam site |
| RAINFALL DATA | Spatial-raster format<br>Vector formats | Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) http://chg.geog.ucsb.edu/data/chirps/ | To select areas with suitable rainfall amounts for dams. |
| SETTLEMENTS | Vector Format (Shapefiles) | Town and Country Planning Department, Wa, Upper West | To use in determining how far away Dams should be sited |
| REGIONAL MAP OF GHANA | Vector Format | Geomatic Engineering Department<br>KNUST, Ghana | To define the boundary of the area of study. |

### 3.3 METHODOLOGY

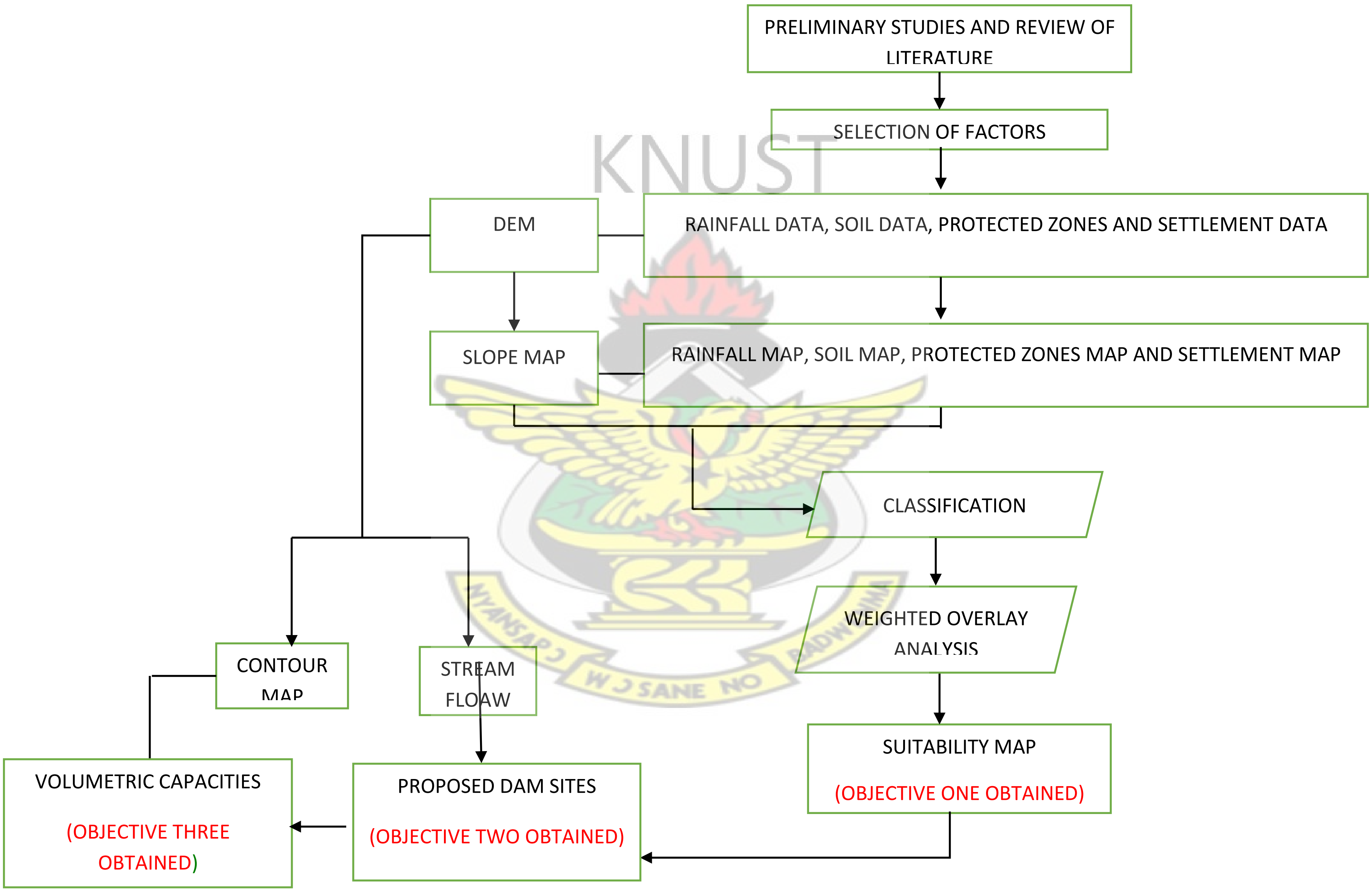


**Figure 3. 2 Methodology in Diagrammatic Representation**

### 3.3.1 SELECTION OF FACTORS AND MCDM

To be able to make a decision on where to site dams, multi criteria decision making (MCDM) was adopted. The factors considered for siting the dams was heavily dependent on the intended purpose of the dam and review of previous literature. And considering the household water supply and irrigational purposes the dams are intended to serve, five factors were chosen. Slope, rainfall, soil type, protected zones and settlements were the factors selected.

Slope was considered as the most important factor in siting the dams. Slopes of 1.5% to 3% were considered as suitable. Larger percentage slopes aren't suitable as they are more susceptible to landslides.

The type of soil should be suitable to hold water for long periods without the water seeping through. Areas with soils that have good water retention capacity are considered suitable.

Amount of Rainfall is another important consideration. Areas with higher rainfall values were considered suitable for dams and vice versa.

Since the dams are to serve the water needs of communities, they should be sited close to settlements but not very close as they may cause floods when they overflow. After reviewing literature, it was decided the dams should be sited at least 5km away from settlements.

Protected Zones mainly forest and game reserves as well as cultural sites of historical importance were considered as unsuitable. These sites were entirely excluded from being considered in the dam selection process. Dams should be sited at least 5km away from all protected zones within the study area

### 3.3.2 PREPROCESSING AND RECLASSIFICATION OF DATA

The acquired data was preprocessed to generate the slope map from DEM, soil map from soil data, rainfall map from rainfall data, map of settlements and a map of protected zones. The derived datasets were then reclassified into 4 different classes of 1 – 4 with 1 as suitable, 2 as averagely suitable, 3 as poorly suitable and 4 as unsuitable. All the vector datasets were rasterized using a cell size of 30m by 30m



### 3.3.3 SLOPE

The slope was derived from the DEM acquired from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global DEM with a resolution of 30m. The study area was fully covered by four tiles:ASTGTM2_N09W002, ASTGTM2_N09W003, ASTGTM2_N10W002 and ASTGTM2_N10W003. The four DEM tiles were mosaicked in ArcGIS using the Mosaic to Rater tool under the spatial analyst tool in ArcGIS 10.4. A shapefile of the Upper West region was used to extract the DEM for the Study Area. And it was projected to the WGS 84_UTM Zone-30N. (Figure 3.3)

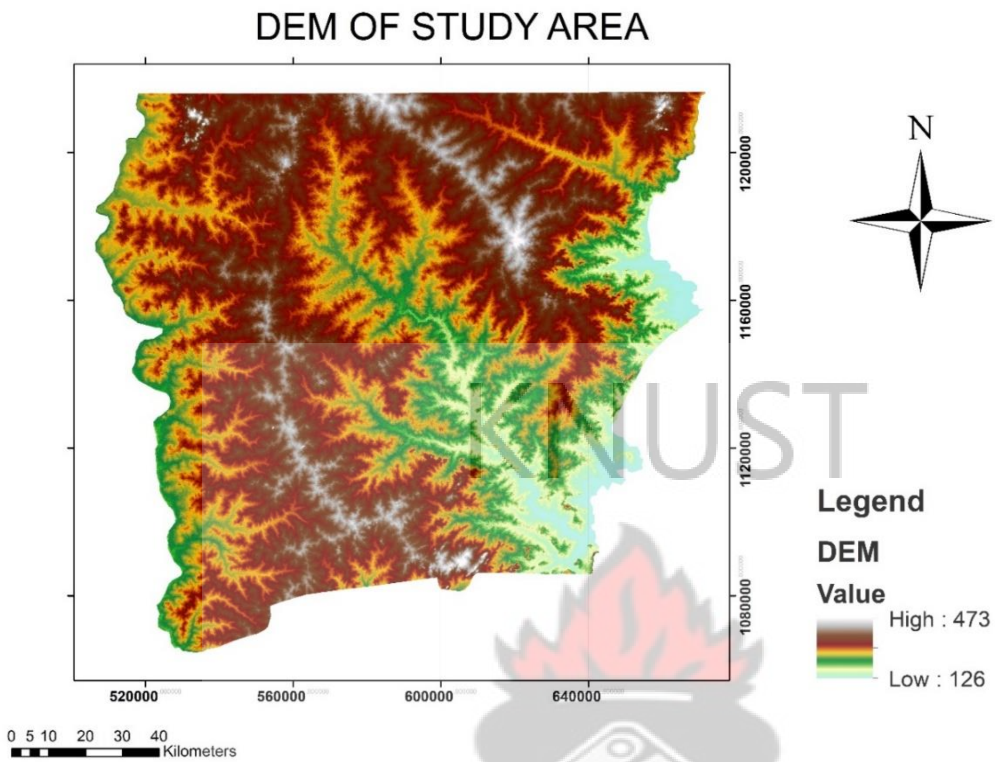


**Figure 3. 3 DEM of Study Area**

The DEM was processed to generate the slope. The slope was then classified into four classes as shown in Table 3.2. Slopes less than or equal to 3% were generally considered as suitable and averagely suitable with slopes greater than 3% generally classified as poorly suitable and unsuitable (Boateng et al., 2016).

**Table 3. 2 Slope Suitability Classification**

| Slope Percentage (%) | Class | Remarks |
|---|---|---|
| 0 - 1.5 | Class 1 | Highly suitable |
| 1.51 and 3 | Class 2 | Averagely Suitable |
| 3.01 and 5.00 | Class 3 | Poorly Suitable |
| Greater than 5 | Class 4 | Unsuitable |

### 3.3.4 RAINFALL DATA

Rainfall data for the study was acquired from the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS). The CHIRPS data was processed in R-Studio. The CHIRPS data used was a yearly data covering a period of 31 years between the years 1988 – 2018. This data was stacked and then the Upper west region shapefile was used to extract the rainfall data covering the upper west. The result was saved as a geotiff file and imported into the ArcGIS environment. The cell statistics tool was then used to calculate the mean yearly rainfall for the duration as visualized in Figure 3.4.

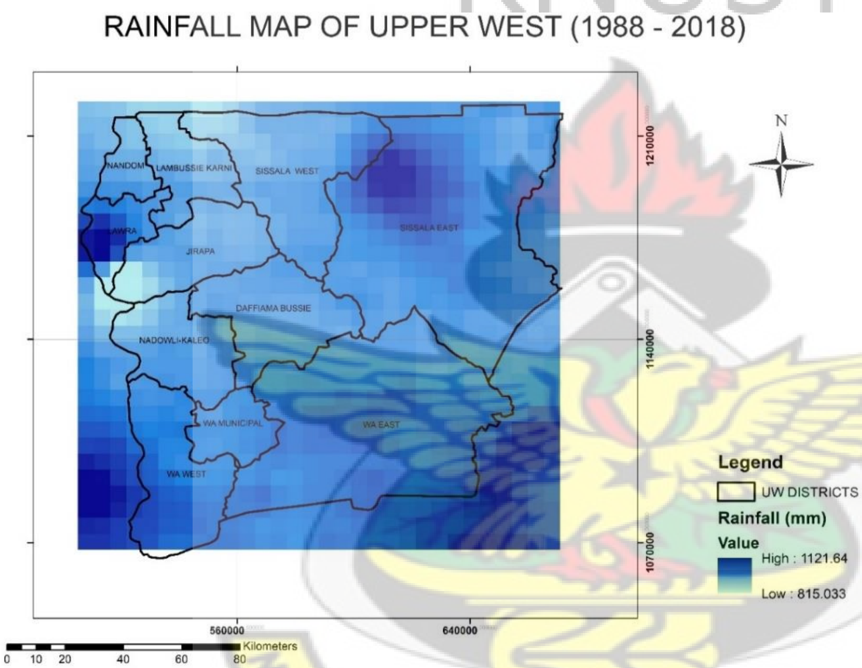


**Figure 3. 4 Rainfall Map of Study Area**

From expert opinion, for areas to be suitable for dam construction, the mean annual rainfall should be greater than or equal to 1000mm. The rainfall data was then reclassified into four classes as shown in Table 3.3

**Table 3. 3 Rainfall Suitability Classification**

| Monthly Rainfall Amount (mm) | Classification | Remarks |
|---|---|---|
| ≥ 1100 | Class 1 | Highly suitable |
| 1000 ≤ and ≥ 1099 | Class 2 | Averagely Suitable |
| 901 ≤ and ≥ 999 | Class 3 | Poorly Suitable |
| ≤ 900 | Class 4 | Unsuitable |

### 3.3.5 SOIL DATA

Soil data for the study was acquired from the Soil research Institute of Ghana. The data was grouped into 8 classes namely Lixisols, Acrisols, Leptosols, Planosols, Arenosols, Plinthosols, Vertisols and Fluvisols. A soil map of the study area is shown in figure 3.5. According to Spaargaren (2007), Fluvisols have very good water retention capacity. Vertisols are soils that develop in shrink well clays and have low porosity and thus good water retention capacity. Lixisols have low dominant clay content and as such have low water retention capacity same as Acrisols, Plinthosols and Planosols. Arenosols and Leptosols have poor water storage capacities.

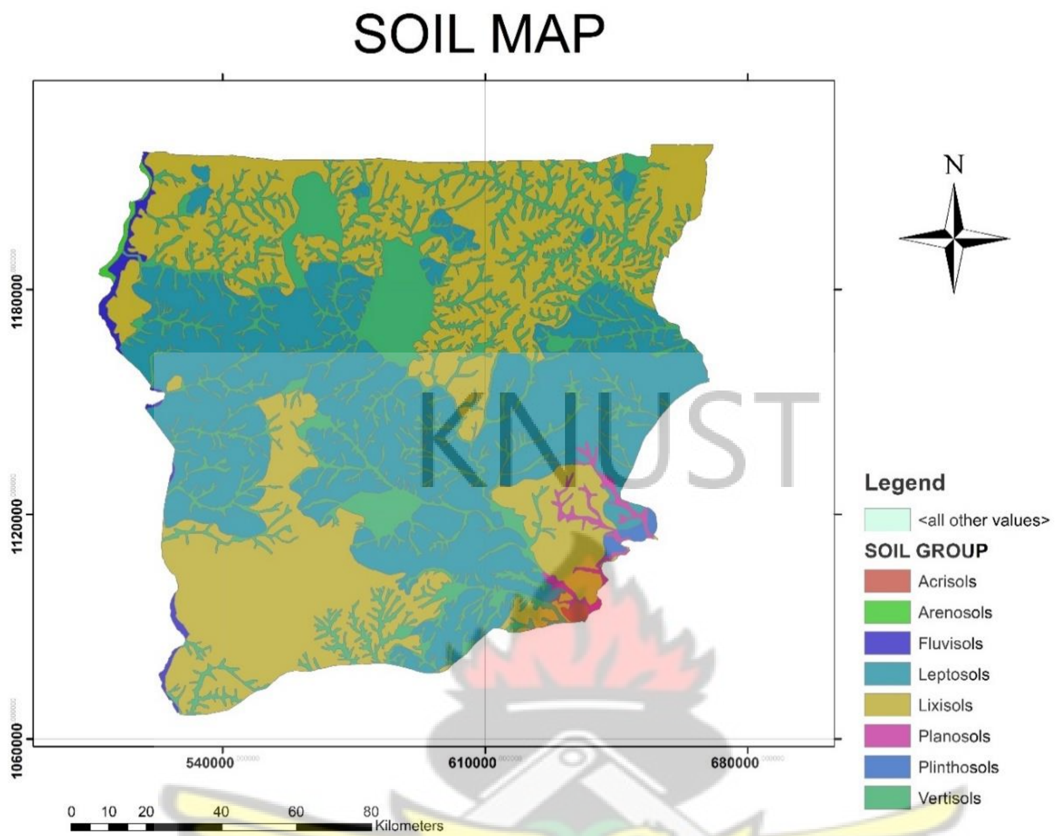


**Figure 3. 5 Soil Map of Study Area**

The soil data was grouped into four classes as shown in Table 3.4

**Table 3. 4 Soil Suitability Classification**

| Soil Type | Classification | Remarks |
|---|---|---|
| Vertisols and Fluvisols | Class 1 | Highly suitable |
| Acrisols | Class 2 | Averagely Suitable |
| Lixisols, Plinthosols and Planosols | Class 3 | Poorly Suitable |
| Arenosols and Leptosols | Class 4 | Unsuitable |

### 3.3.6 PROTECTED ZONES

Data on protected areas in the study area were obtained from the Environmental Protection Agency (EPA) as well as from the Ghana Forestry Commission divisions in the region. For most data, site names and other details were provided but no precise definition of the boundary could be given. The boundaries of these sites were then acquired from the Surveying and Mapping Division of the Lands Commission. The data was in the form of polygon shape files and is shown in Figure 3.6.



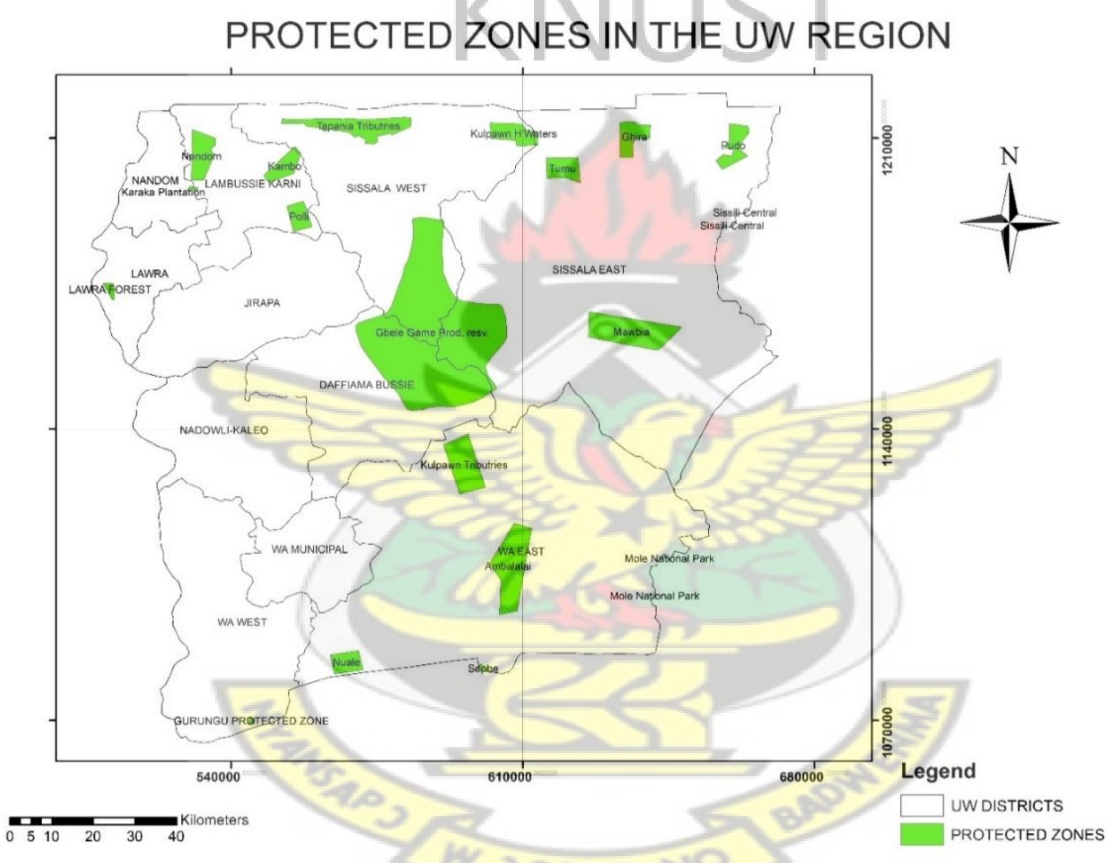


**Figure 3. 6 Protected Zones within the Study Area**

A distance analysis was done on the data and the data was reclassified as shown in Table 3.5

**Table 3. 5 Suitability Classification for Protected Zones**

| Distance from Protected Zones (km) | | Classification | Remarks |
|---|---|---|---|
| > 5 | | Class 1 | Highly suitable |
| 4.01 ≤ and ≥ 5 | | Class 2 | Averagely Suitable |
| 3.01 ≤ and ≥ 4 | | Class 3 | Poorly Suitable |
| ≤ 3 | | Class 4 | Unsuitable |

### 3.3.7 SETTLEMENTS

Settlement data for the upper west region was acquired from the Town and Country Planning Department of the region. This data is in the form of point shapefiles and is visualized in Figure 3.7.

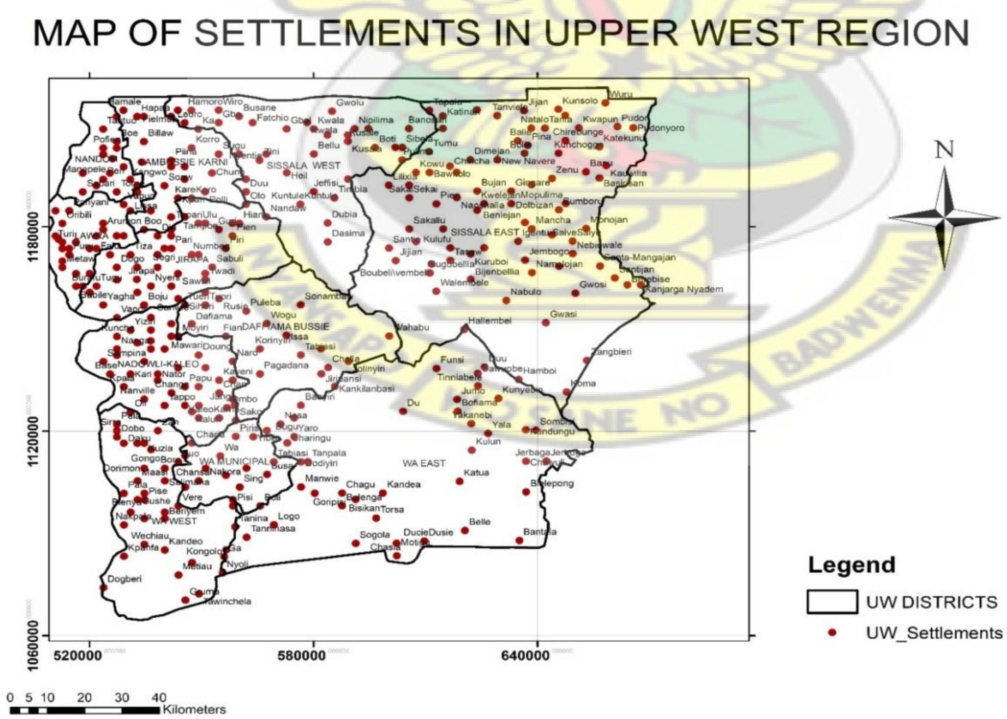


**Figure 3. 7 Settlement Map of Study Area**

A distance tool was used to classify the settlement data as shown in Table 3.6

**Table 3. 6 Suitability Classification for Settlements**

| Distance to Settlements (km) | Classification | Remarks |
|---|---|---|
| 5 ≤ and ≥ 10 | Class 1 | Highly suitable |
| 3 ≤ and ≥ 5.01 | Class 2 | Averagely Suitable |
| 1 ≤ and ≥ 3.01 | Class 3 | Poorly Suitable |
| ≤ 1 | Class 4 | Unsuitable |



### 3.3.8 ASSIGNMENT OF WEIGHTS

Since the factors chosen for siting the dam are not of equal importance, weights were assigned to the factors to ensure that they were evaluated on the basis of their relative importance. This was done by assigning the same numerical range (0-256) to all the factors, then each factor was assigned a weight based on its relative importance and finally multiplying the standardized criteria by the assigned weight to get the suitability index of each factor.

The pairwise comparison matrix was chosen in this study to assign weights to the factors. This method allows for joint decision making with stakeholders. According to Saaty (1980), the pairwise comparison matrix (matrix **A)** is an $m \times m$ real matrix, where $m$ is the number of evaluation criteria considered. Each entry $ajk$ of the matrix **A** represents1 the importance of the $j$th criterion relative to the $k$th criterion. If $ajk > 1$, then the $j$th criterion is more important than the $k$th criterion, while if $ajk < 1$, then the $j$th criterion is less important than the $k$th criterion. If two criteria have the same importance, then the entry $ajk$ is 1.

In consultation with experts and engineers from the Ghana Irrigation Development Authority the pairwise comparison matrix was filled as shown in Table 3.7. The pairwise comparison matrix a 5x5 matrix was generated.

**Table 3. 7 Pairwise Comparison Matrix**

| Criteria | C1 | C2 | C3 | C4 | C5 | Weights | Weights (%) |
|---|---|---|---|---|---|---|---|
| Slope C1 | 1 | 1 | 5 | 7 | 9 | 0.4188 | 41.88 |
| Soil C2 | 1 | 1 | 3 | 5 | 7 | 0.3360 | 33.60 |
| Rain C3 | 0.2 | 0.333 | 1 | 3 | 5 | 0.1389 | 13.89 |
| Settlement C4 | 0.1428 | 0.2 | 0.3333 | 1 | 3 | 0.06982 | 6.982 |
| Protected Zone C5 | 0.1111 | 0.1428 | 0.2 | 0.3333 | 1 | 0.03600 | 3.6 |
| TOTAL | | | | | | 1 | 100 |



The normalized pairwise comparison matrix was then derived by summing each column in the previous pairwise comparison matrix equal to 1 and then the criteria weight vector (that is an m-dimensional column vector) is derived by averaging the individual entries on each row of the normalized pairwise comparison matrix in Table 3.8

**Table 3. 8 Normalized pairwise Comparison Matrix**

| CRITERIA | SLOPE | SOIL | RAINFALL | PROTECTED ZONES | SETTLEMENTS | WEIGHTS | WEIGHT (%) |
|---|---|---|---|---|---|---|---|
| SLOPE | $\frac{1}{2.454}$ | $\frac{1}{2.676}$ | $\frac{5}{9.533}$ | $\frac{7}{16.333}$ | $\frac{9}{25}$ | 0.4188 | 41.88 |
| SOIL | $\frac{1}{2.454}$ | $\frac{1}{2.676}$ | $\frac{3}{9.533}$ | $\frac{5}{16.333}$ | $\frac{7}{25}$ | 0.3360 | 33.60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RAINFALL | $\frac{0.2}{2.454}$ | $\frac{0.333}{2.676}$ | $\frac{1}{9.533}$ | $\frac{3}{16.333}$ | $\frac{5}{25}$ | 0.1389 | 13.89 |
| SETTLEMENTS | $\frac{0.143}{2.454}$ | $\frac{0.2}{2.676}$ | $\frac{0.333}{9.533}$ | $\frac{1}{16.333}$ | $\frac{3}{25}$ | 0.06982 | 6.98 |
| PROTECTED ZONES | $\frac{0.111}{2.454}$ | $\frac{0.143}{2.676}$ | $\frac{0.2}{9.533}$ | $\frac{0.333}{16.333}$ | $\frac{1}{25}$ | 0.03600 | 3.60 |
| TOTAL | 1 | 1 | 1 | 1 | 1 | 1 | 100 |



From the pairwise comparison matrix, the Consistency Ratio (CR) was calculated. According to Saaty (1980) CR = $\frac{CI}{RI}$ , Where 1. CI is defined as consistency index given by $\frac{x-m}{m-1}$ with m as number of factor criteria and x as scalar of the pairwise comparison matrix and RI is defined as Random Index which is the consistency index when the entries of the matrix are completely random. The values of *RI* for small problems ($m \leq 10$) are shown in the Table 3.9

**Table 3. 9 Value for RI**

| *m* | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.51 |

Source: Saaty (1980)

The consistency ratio was thus calculated to be 0.064 and this was acceptable since it is less than 0.1

### 3.3.9 CALCULATING A SUITABILITY INDEX

Several methods exist for calculating the suitability index. The weighted linear combination (WLC) and the Ordered Weighting Average (OWA) were the two methods considered in this study. The WLC was chosen because according to Drobne and Lisec (2009), it allows the evaluation criteria map layers to be combined to determine the generated composite map layer that can be implemented simply in raster and vector GIS environments.

The suitability index was calculated from the equation Suitability Index S.I = $\sum WiXi$ , where $W_i$ is weight of factor i, and $X_i$ is the criterion score of factor i

### 3.3.10 SELECTING PROPOSED DAM SITES

Utilizing the DEM, a drainage network of the study area was produced in ArcGIS, fill analyst tool was used to fill the sinks in the DEM to result in a DEM without depressions. The fill DEM was then used as basis for generating the drainage network of the study area. Based on the drainage network, a contour map and also the suitability map, 4 sites were proposed as dam sites. These sites were manually situated and the coordinates extracted. This was done taking into consideration the following factors:

1. The need for dams to be sited along paths of water flow.

2. The dams were chosen to be located in areas highlighted as suitable for dam construction in the study area.

### 3.3.11 ESTIMATING CAPACITY OF DAMS

To estimate the capacity of the proposed dams, a dam area was delineated and the contour map of the delineated area was investigated to give the highest contour and the lowest contour values. The average difference between the highest contour and the lowest contour was then selected as the proposed dam wall height. The storage capacity of the proposed dams was then calculated from the formula $Q = \frac{LTH}{6}$ (Stephens, 2010) where L = Length of Dam wall, T = throwback of the dam, that is the extent of the dam upstream and H is the maximum Dam wall Height.

Thus a contour map was generated from the DEM and from the contour map, the height of the dam wall (H) for each proposed dam was estimated as well as length of dam wall (L) and throwback (T) and used to compute the storage capacities of the proposed dams.

## CHAPTER FOUR RESULTS AND DISCUSSIONS

### 4.1 RECLASSIFIED MAPS

#### 4.1.1 SLOPE

Figure 4.1 and Table 4.1 shows the slope map and slope suitability classification of the study area, the study area is relatively flat and undulating and composed mainly of gentle slopes. However, some mountainous areas are located east of the study area. Slope percentages were found ranging from 0% to 19.5%. Generally, dams are desired to have gentle slopes (Stephens, 2010).

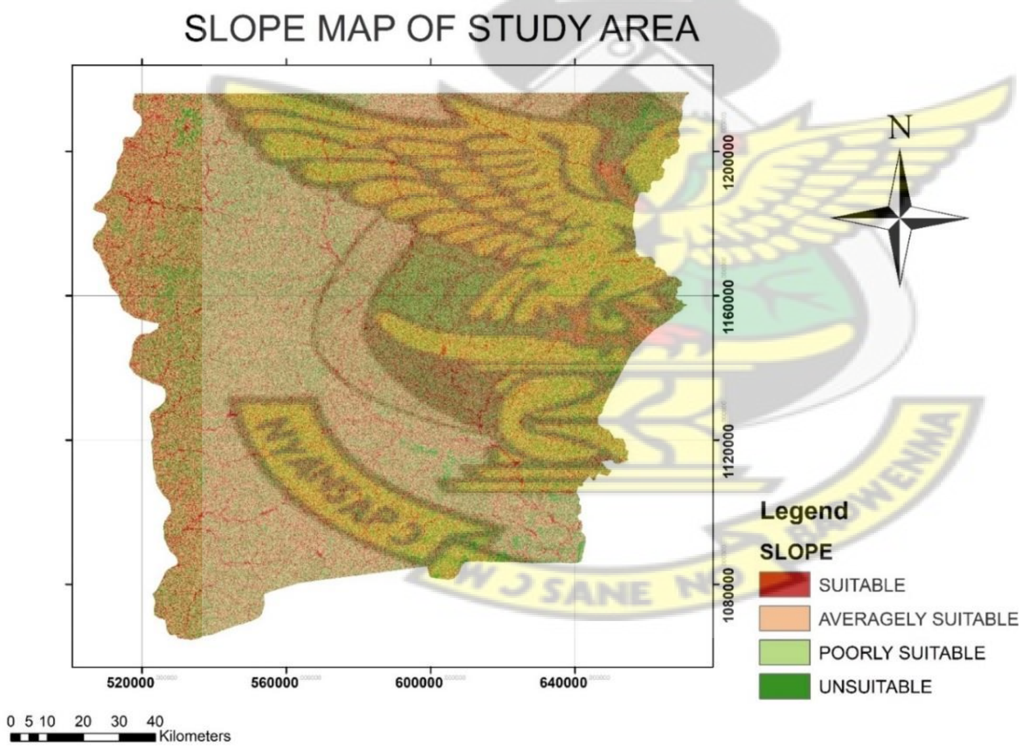


**Figure 4. 1 Slope Suitability Map**

**Table 4. 1 Slope Suitability**

| SUITABILITY | SLOPE % | PERCENTAGE (%) |
|---|---|---|
| SUITABLE | 0 – 1.5 | 4.3 |
| AVERAGELY SUITABLE | 1.51 – 3.00 | 33.0 |
| 0POORLY SUITABLE | 3.01 – 5.00 | 53.9 |
| UNSUITABLE | Greater than 5.00 | 8.8 |
| | | 100 |



Most of the area is covered by gentle slopes, therefore considering the slope as a primary criterion means that a larger part of the study area will be suitable for the construction of dams. Slope is also one of the major factors affecting dam safety as it poses a risk of landslides and increased pressure on building foundations. Dams in areas with steeper slopes may require slope stability analysis and must be designed by a specialist leading to an increase design and construction costs (Stephens, 2010).

### 4.1.2 RAINFALL

Figure 4.2 shows the classified rainfall suitability map of the study area. The study area is a semi-arid area and experiences unpredictable rainfall patterns in both time and quantity. The study area experiences most of its rainfall during the months of April to June and July where it peaks through August to late September with very few rains scattered throughout the rest of the year. Mean annual rainfall values for the study area range between 900mm and 1,111mm (MOFA, 2018). Rainfall values decrease as one moves northwards of the study area towards the desert prone areas.

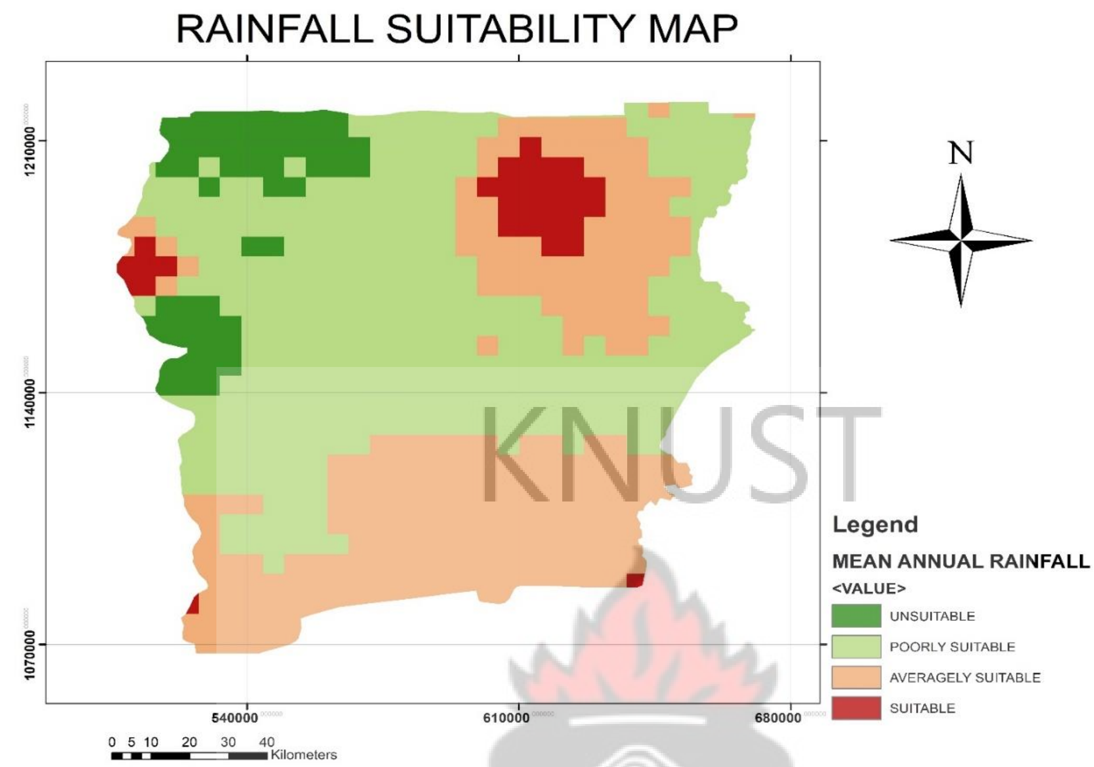


**Figure 4. 2 Rainfall Suitability Map**

**Table 4. 2 Rainfall Suitability**

| SUITABILITY | RAINFALL (mm) | PERCENTAGE (%) |
|---|---|---|
| SUITABLE | ≥ 1100 | 4.3 |
| AVERAGELY SUITABLE | 1000 ≤ and ≥ 1099 | 33.0 |
| POORLY SUITABLE | 901 ≤ and ≥ 999 | 53.9 |
| UNSUITABLE | ≤ 900 | 8.8 |
| | | 100 |

The rainfall suitability classification in Table 4.3 indicates that considering rainfall as a criteria over half of the study area is either unsuitable or poorly suitable for dam construction

### 4.1.3 SOIL

Figure 4.3 and Table 4.3 shows the soil suitability map of the study area. Different types of soils have different water retention and infiltration rates. Soils with low infiltration rates allow more runoff and thus are more suitable for siting dams. The study area has very diverse soil types including fluvisols, vertisols, Lixisols, planosols, plinthosols, arenosols, leptosols and acrisols. These Soils are formed on Birrimian rocks, post-Birrimian granites and associated basal rocks and recent mixed alluvium. The soils formed on recent alluvium are found in the floodplain of the Black Volta and other major rivers and belong to the Bala-Yipiani association. The series of this association found along the river levees are mainly coarse sand, while those occupying the lowest points of the floodplains are poorly drained, greyish brown fine sandy clay or silty clay barns. These soils would approximate to Fluvisols (MOFA, 2018). From the soil classification map of the study area, it is found that Fluvisols and Vertisols which have both been selected as suitable occupy 23.2% of the study area, Acrisols occupy the least area with 0.2% of the study area being covered by these. Plinthosols, Planosols and Lixisols together even though they have been classified as poorly suitable occupy 41.5% of the study area. Arenosols and Leptosols which are also unsuitable occupy 35.1% of the study area. A careful observation of the soil map indicates that Fluvisols and Vertisols which are soils with alluvial deposits lie along the areas of gentle slopes.

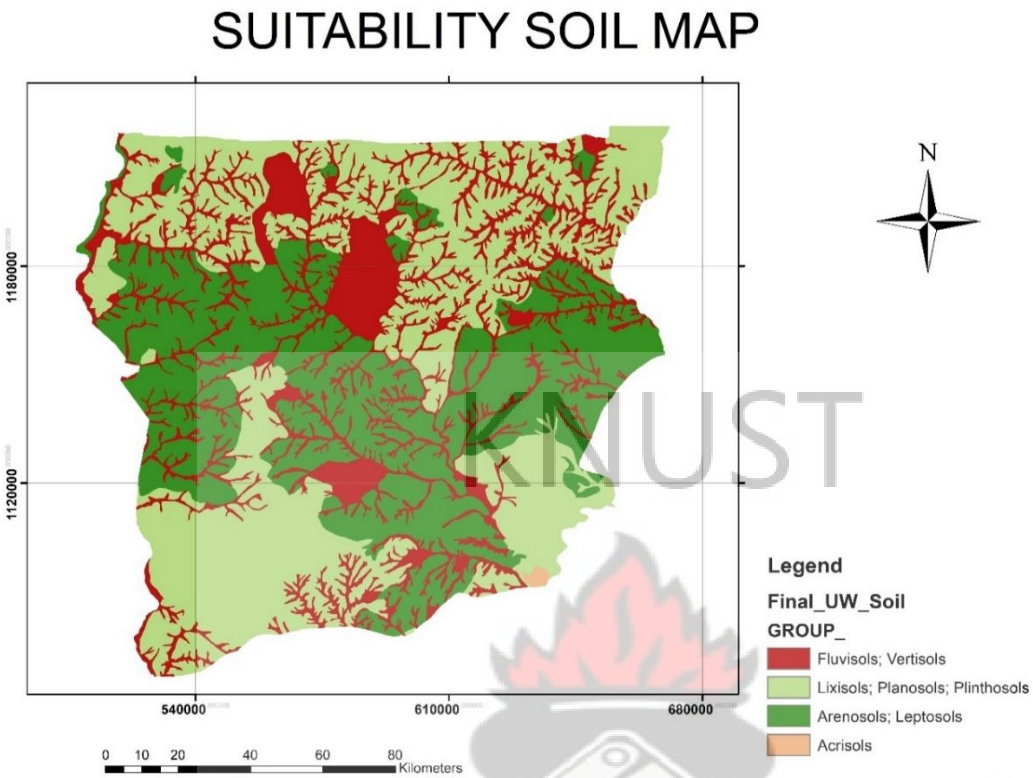


**Figure 4. 3 Soil Suitability Map**

**Table 4. 3 Soil Suitability**

| SOIL TYPE | SUITABILITY | PERCENTAGE (%) |
|---|---|---|
| Vertisols and Fluvisols | Highly suitable | 23.2 |
| Acrisols | Averagely Suitable | 0.2 |
| Lixisols, Plinthosols and Planosols | Poorly Suitable | 41.5 |
| Arenosols and Leptosols | Unsuitable | 35.1 |

### 4.1.4 PROTECTED ZONES

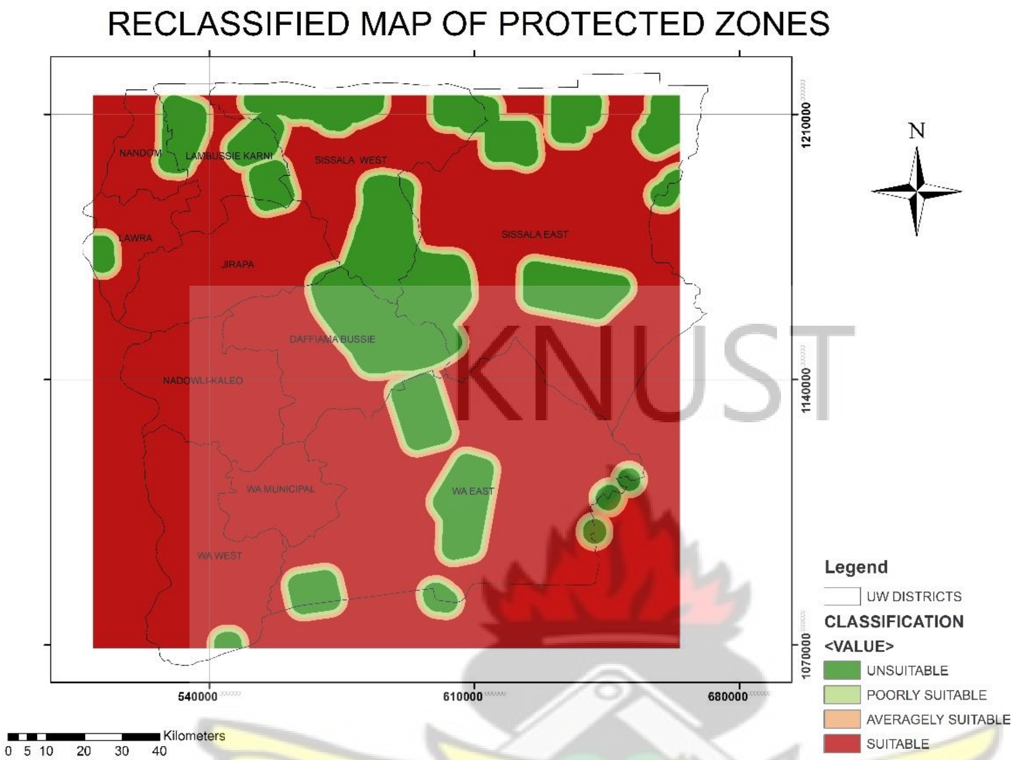


**Figure 4. 4 Protected Zones Suitability Map**

The protected zones shown is Figure 4.4 consists of seventeen forests and game reserves within the study area. These protected zones together covered an area of about 1653km$^2$ which represents about 9% of the entire study area. With a 5km buffer considered as not suitable (averagely, poorly and unsuitable) then the covered area increases to 6177km$^2$ representing 33% of the study area. These protected zones are home to wide variety of plant and animal species with some that are under threat of extinction. Siting of dams in these areas may destroy the natural habitat of some these plants and animals and thus is not advisable. This is supported by Ledec and Quintero (2003) who noted that under the World Bank's Natural Habitats Policy, projects should not be sited at locations where they will cause the significant conversion or degradation of natural habitats that do not occur elsewhere (and, hence, cannot be adequately compensated). Thus considering only protected zones suitability, 33% of the study area was to be excluded from siting dams and 67% of the total area was found to be suitable for siting dams.

### 4.1.5 SETTLEMENT

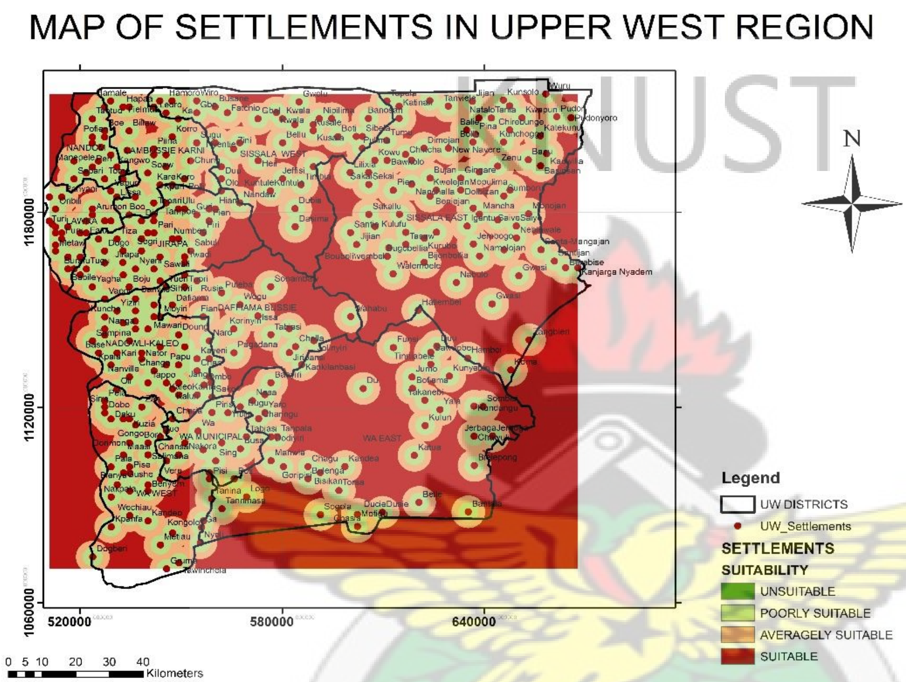


**Figure 4. 5 Settlement Suitability Map**

Figure 4.5 shows the settlement classification map of the study area. From the settlement map of the study area, it is seen that most settlements are clustered. This may be attributed to a sense of security in staying closer together. According to MOFA (2018), the region is essentially agrarian and about 80% of the active population is engaged directly or indirectly in agriculture in production and processing. Northwards of the study area is primarily inhabited by the Dagaati and Sissala tribes who are predominantly farmers thus in these areas, settlements are seen to be closer to rivers which provide an access to water as well as arable lands for subsistence farming. Dams should be sited at least 5km away from settlements to prevent properties being destroyed or people being dislocated in case of flooding (Boateng et al., 2016). But it should be taken into consideration also that since these dams are aimed at providing water for agriculture as well as for use by the inhabitants to mitigate water stress situations, then these dams should not be sited too far away from settlements.

## 4.2 OBJECTIVE 1: GENERATE A SUITABILITY MAP FOR DAM CONSTRUCTION

### 4.2.1 SUITABILITY MAP

After the weighted overlay analysis was done in ArcMap, a suitability map of dam siting in the upper west region was generated and shown in Figure 4.6.



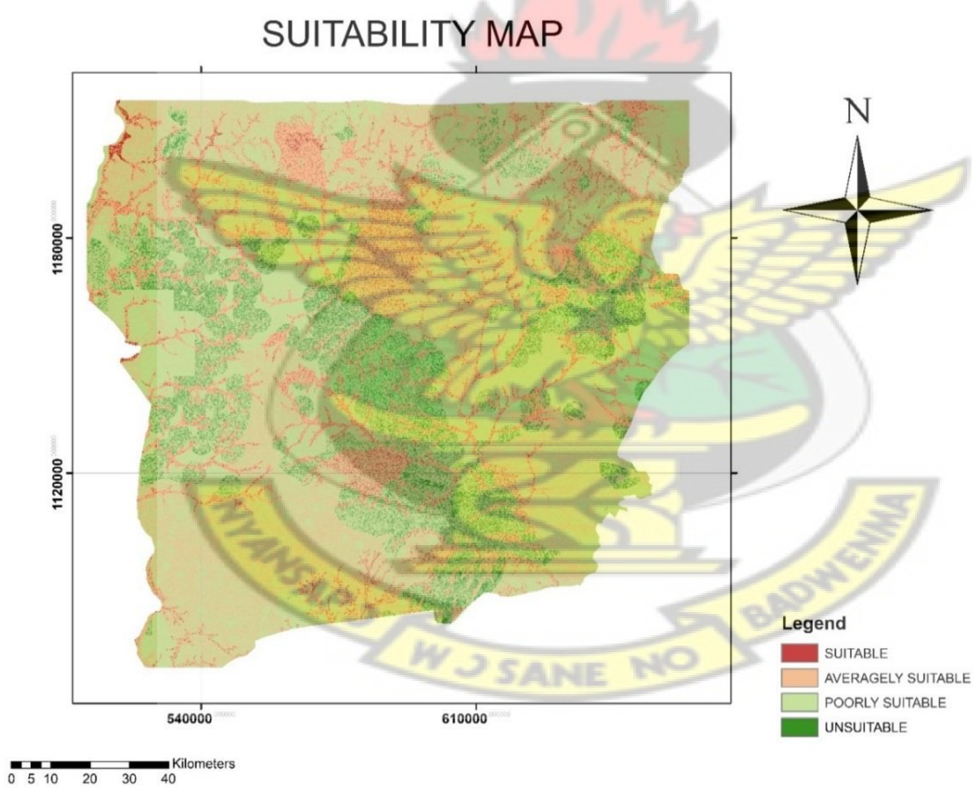


**Figure 4. 6 Suitability Map of Dam Construction**

The suitability map meets the requirements of all the factors selected and used in the study. Areas selected as suitable, are on gentle slopes, have maximum rainfall and also contain soils with good water retention capabilities. From visual inspection of the map, it is evident that suitable areas for dam construction are sparsely distributed across the study area. Most unsuitable areas are found in the central part of the study area. This is probably because the soil type in these areas are mainly arenosols and leptosols which have both been classified as unsuitable for dam construction. The suitability map shows that 4.3% the total area of the study area is suitable for dam construction, 33% of the area averagely suitable, 53.9% poorly suitable and 8.8% unsuitable for the construction of dams and is visualized as a graph in Figure 4.7. This means that a very small percentage of the study area has been found to be suitable for dam construction and thus great care must be taken in siting dams to function as required within the study area. Area-wise in kilometers squared ($km^2$), the Suitable area for dam construction is 792.8$km^2$, averagely suitable is 6097.1$km^2$, poorly suitable is 9956.8$km^2$ and unsuitable is 1629.3$km^2$.

A table showing extent of area covered by each suitability class has been generated and shown in Table 4.5.

**Table 4. 4 Suitability Percentage**

| **SUITABILITY** | **COUNT** | **AREA ($km^2$)** | **PERCENTAGE (%)** |
|---|---|---|---|
| SUITABLE | 880855 | 792.7695 | 4.3 |
| AVERAGELY SUITABLE | 6774633 | 6097.1697 | 33.0 |
| POORLY SUITABLE | 11063102 | 9956.7918 | 53.9 |
| UNSUITABLE | 1810299 | 1629.2691 | 8.8 |
| | | 18476.0001 | 100 |

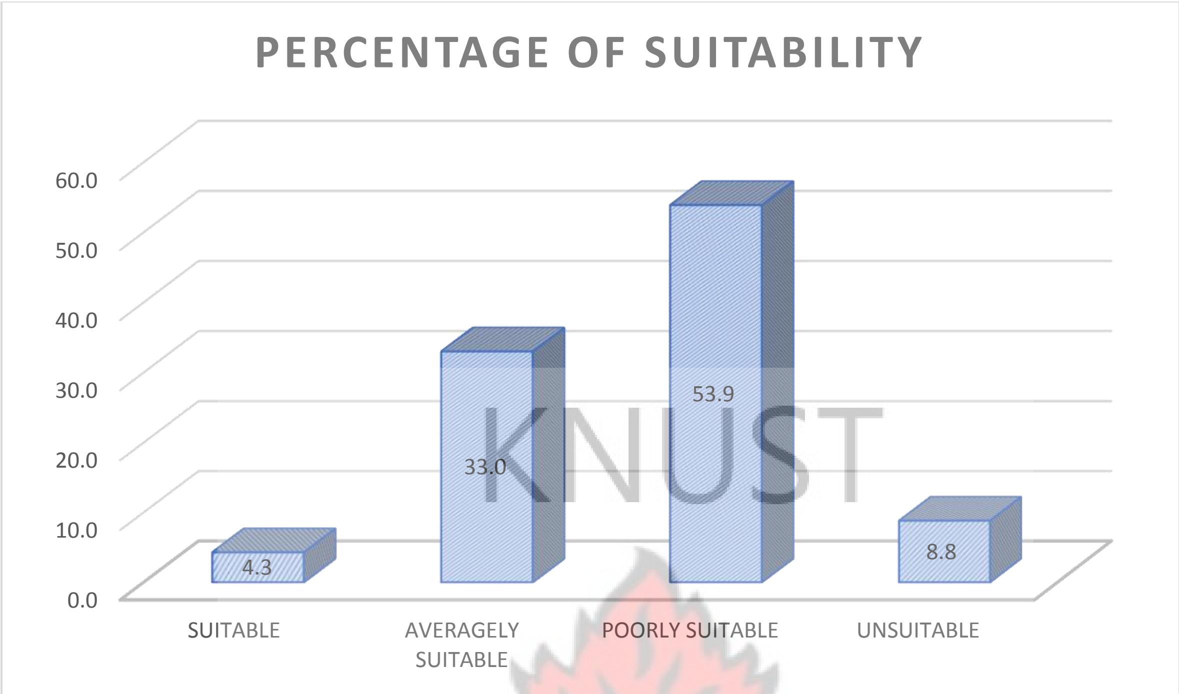


**Figure 4. 7 Percentage of Suitability**

A map showing existing dams and reservoirs within the study area was acquired from the Ghana Irrigation Development Authority (GIDA) and overlaid on the suitability map as shown in figure 4.8 and the percentage overlap calculated. A total of 24 dams and reservoirs were analyzed and it was found that approximately 8.30% of the existing structures were within areas found to be suitable, 66.70% of the existing structures found within averagely suitable areas, 20.80% of the existing structures found within poorly suitable areas and finally 4.2% were found to be within areas classified as unsuitable. A map of the existing dams/dugouts is shown in fig 4.8 and the findings are summarized in Table 4.6.

**Table 4. 5 Comparison of Suitability Map and Existing Structures**

| SUITABILITY | NUMBER OF DAMS | PERCENTAGE (%) |
|---|---|---|
| SUITABLE | 2 | 8.3 |
| AVERAGELY SUITABLE | 16 | 66.7 |
| POORLY SUITABLE | 5 | 20.8 |
| UNSUITABLE | 1 | 4.2 |
| | 24 | 100.0 |



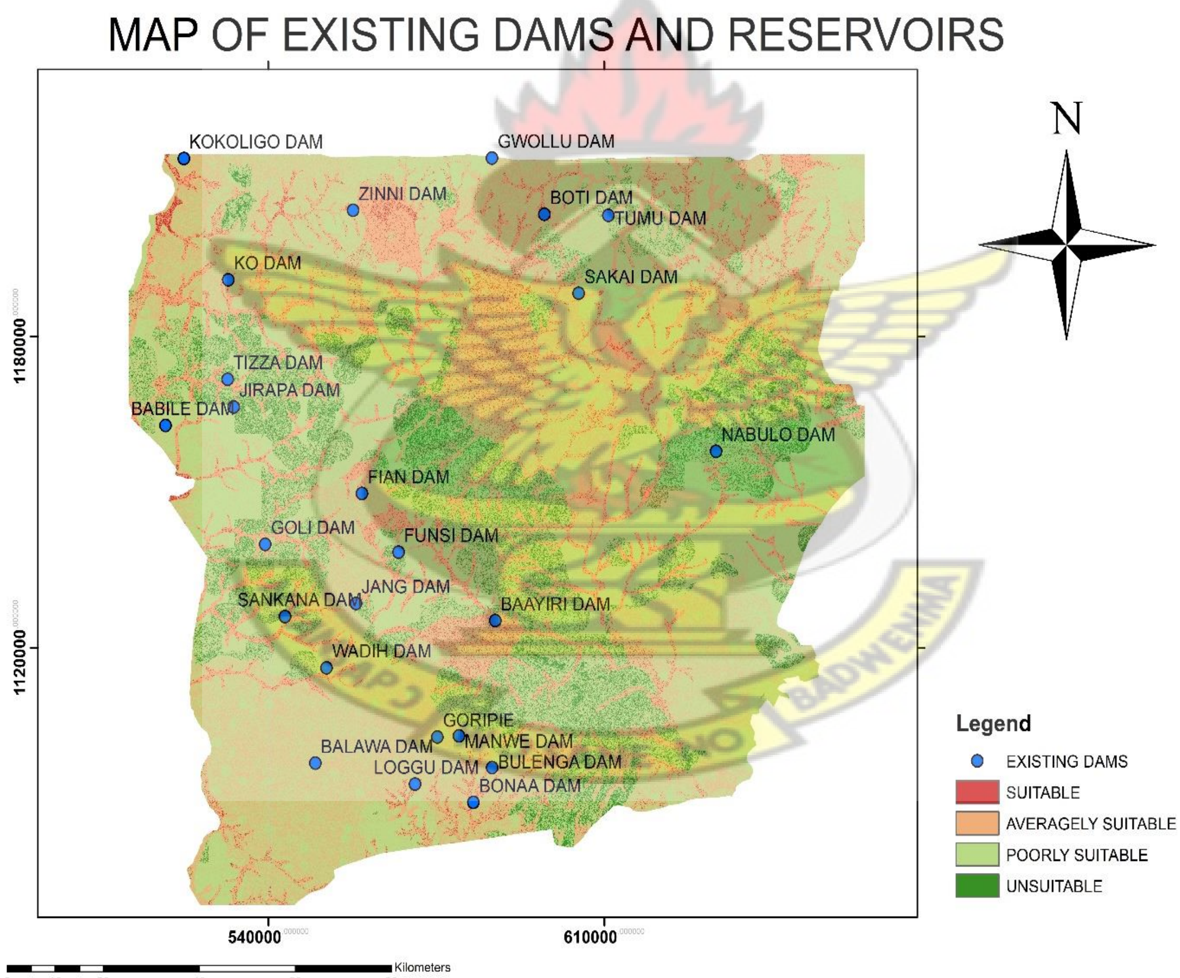


**Figure 4. 8 Existing Dams and Reservoirs**

Investigations revealed that the dam that falls in the area classified as unsuitable wasn't a dam constructed through the conventional site selection process but rather started as a site initially used for excavating gravel in which water started ponding and thus was finally converted into a dam that has been adopted and is now managed by GIDA.

### 4.3 OBJECTIVE 2: PROPOSE SUITABLE DAM SITES

#### 4.3.1 PROPOSED DAMS

Four dams have been proposed for construction in the study area. A map of the proposed dams along with the Suitable areas as well as a map of the proposed dams and stream network of the study area is shown in figures 4.9 and 4.10

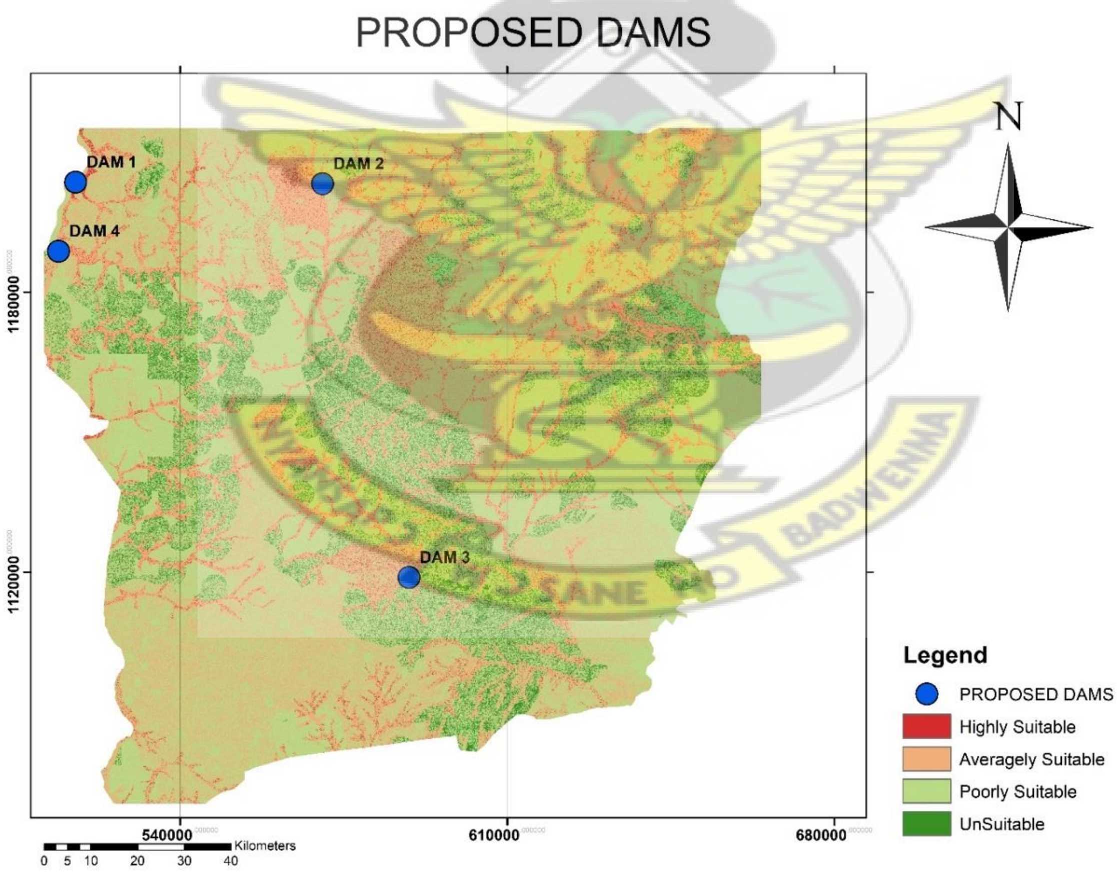


**Figure 4. 9 Proposed Dams**

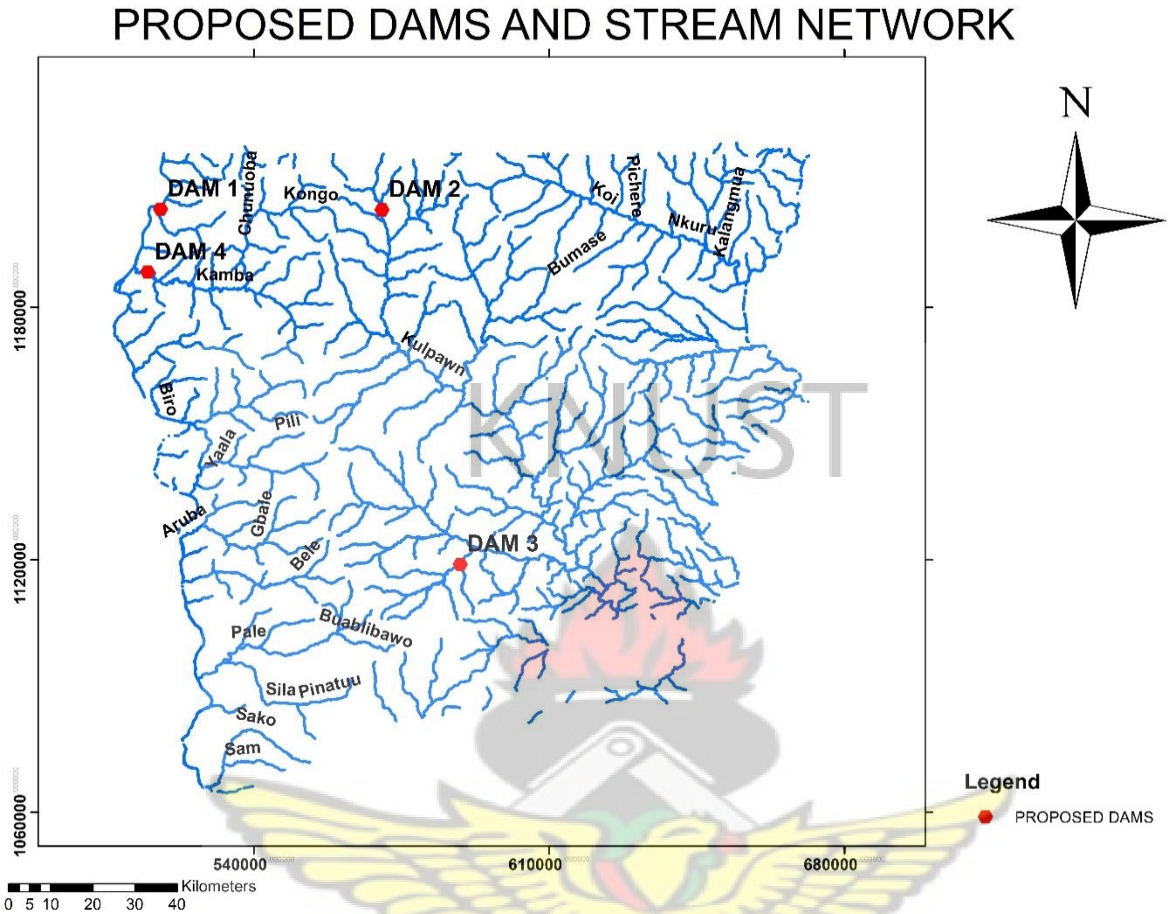


**Figure 4. 10 Proposed Dams and Stream Flow**

table showing the showing the districts and coordinates of the proposed dams is shown in Table 4.7

**Table 4. 6 Proposed Dam Sites**

| No. | EASTINGS m) | NORTHINGS (m) | REMARKS | DISTRICT |
|---|---|---|---|---|
| 1 | 517982.95 | 1203255.89 | DAM SITE1 | NANDOM |
| 2 | 570421.11 | 1203852.85 | DAM SITE 2 | SISSALA WEST |
| 3 | 588969.14 | 1118845.71 | DAM SITE 3 | WA EAST |
| 4 | 514928.78 | 1188309.45 | DAM SITE 4 | LAWRA |

## 4.4 OBJECTIVE 3: ASSESS THE VOLUMETRIC CAPACITY OF EACH SITE

### 4.4.1 PROFILE OF PROPOSED DAMS

The profile of the proposed dam sites were generated from a 5m layer contour map generated from the DEM. Figures 4.11 to 4.14 show a profile of the dams. From the contour map, the spillway heights, lengths of the dam walls and the Throwback of the dams have been estimated and used in estimating the volumetric capacities of the dam. The maximum spillway heights of dams in all cases was selected to be 5m from lowest contour within catchment

**DAM SITE 1**

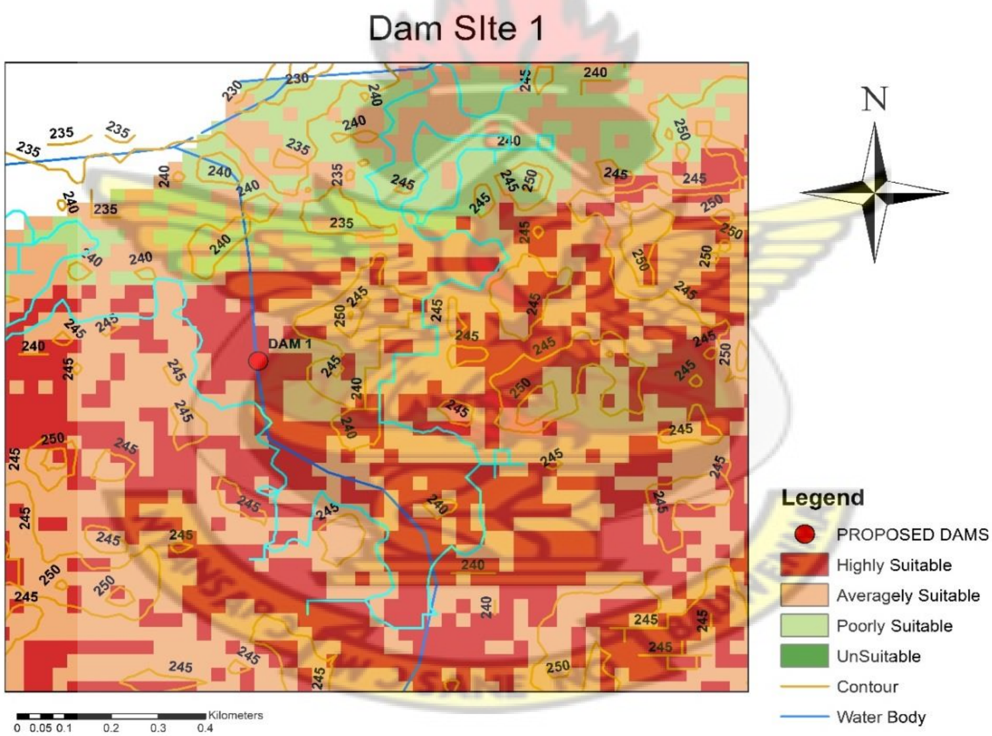


**Figure 4. 11 Dam Site 1**

Dam site 1 (Figure 4.11) which is located in the Nandom district along the flow path of the kopara river has a contour range of 235m - 250m. The selected contour for the dam is at 240m. With this, a dam spillway height of 5m has been proposed. Again Considering the contour map, a dam wall length of 438m was measured with a throwback of 600m and the estimated capacity of the dam was found to be 219,000$m^3$.

**DAM SITE 2**

Dam site 2 shown in figure 4.12 located in the Sissala west district which has Gwollu as its capital town. The contour range is between 265m - 285m. The Selected contour is at 270m. From the contour map, the dam wall length is 700m and the throwback is 2250m and the estimated capacity is 1,312,500$m^3$

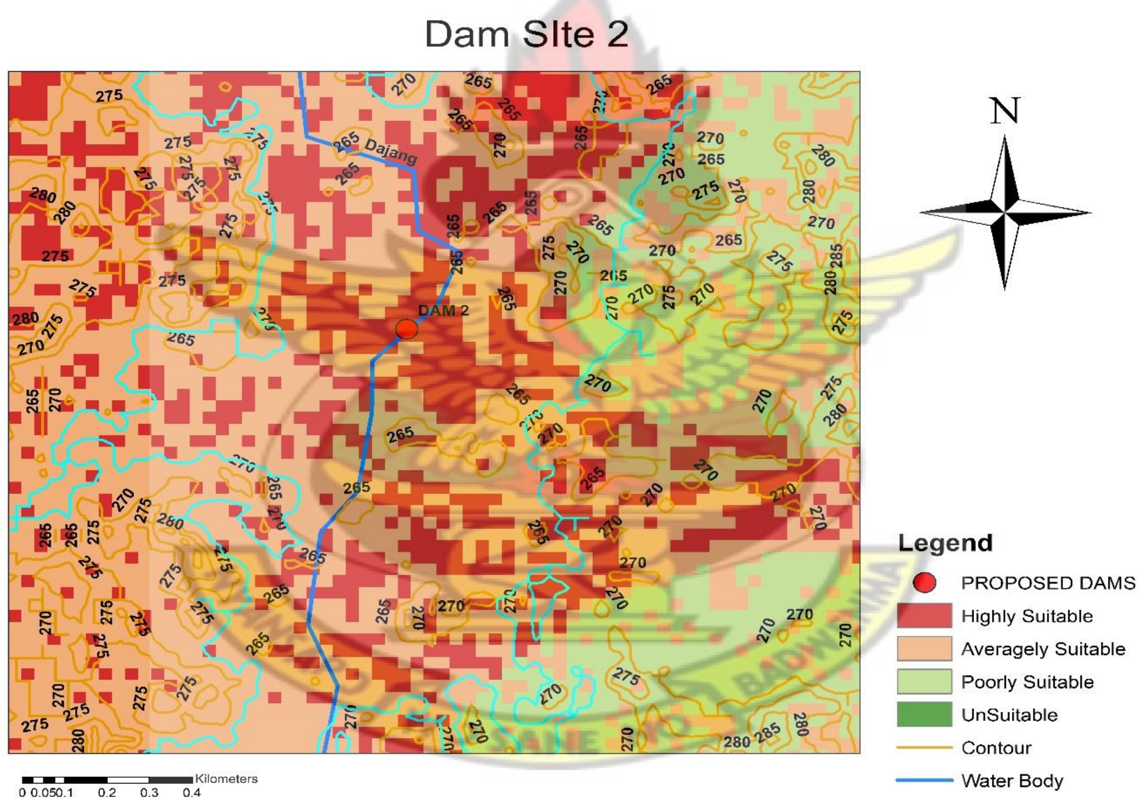


Figure 4. 12 Dam Site 2

**DAM SITE 3**

Dam site 3 visualized in Figure 4.13 is located in Wa East district and has a contour range of 225m – 245m. A dam spillway height of 5m has been proposed and thus a selected contour of 230m is used. A dam wall length of 478m and a throwback of 1400m. The proposed dam has an estimated capacity of 557,666$m^3$.

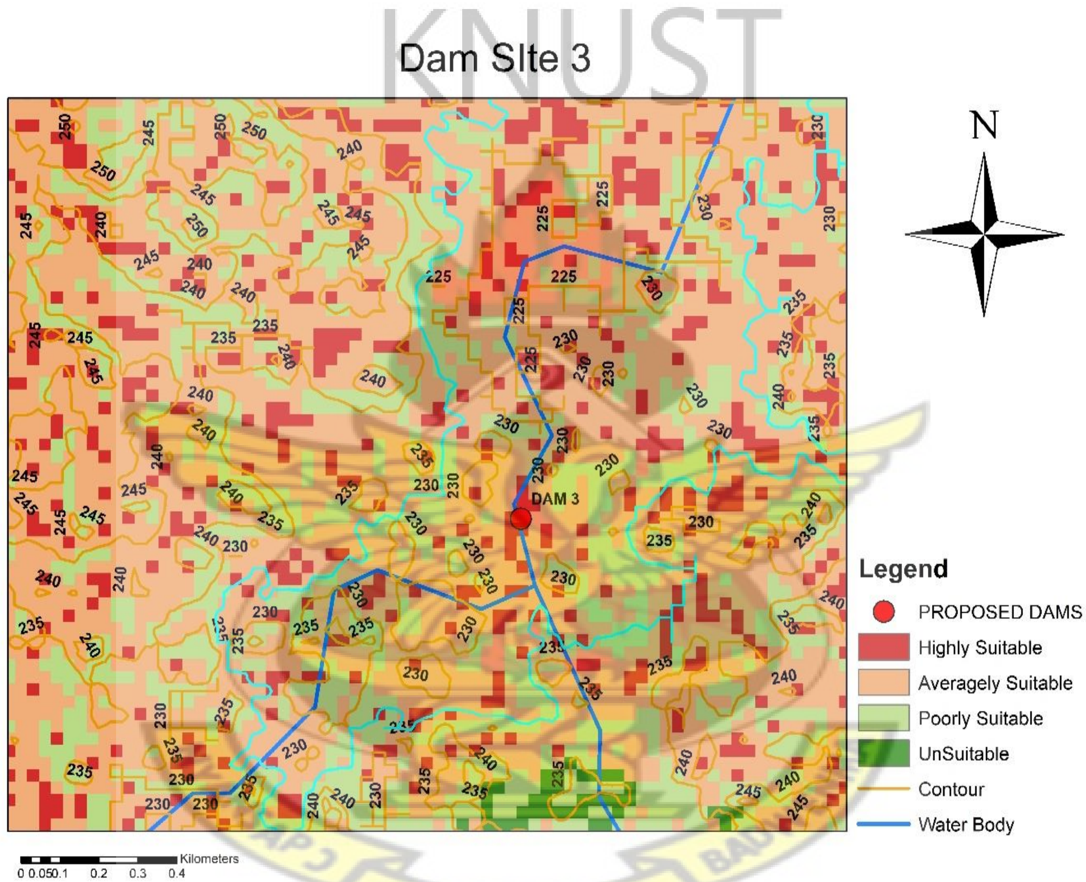


**Figure 4. 13 Dam Site 3**

**DAM SITE 4**

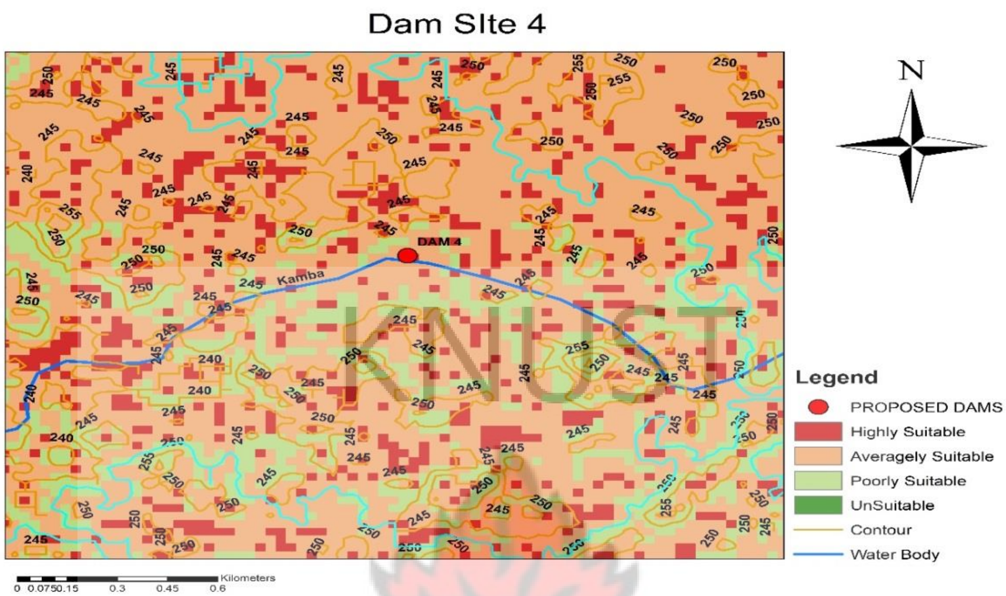


**Figure 4. 14 Dam site 4**

Dam 4 (Figure 4.14) is located in the Lawra district along the Kambaa river. The contour range is 230m – 250m and the selected contour is at 235m hence a dam spillway height of 5m, a wall length of 450m and a throwback of 1000m. The dam has an estimated capacity of 375,000$m^3$ as shown in Table 4.8

**Table 4. 7 Profile of Proposed Dam Sites**

| DAM SITE | LOWEST CONTOUR (m) | HIGHEST CONTOUR (m) | PROPOSED HEIGHT OF DAM WALL (m) | LENGTH OF DAM WALL (m) | THROWBACK (m) | ESTIMATED CAPACITY ($m^3$) |
|---|---|---|---|---|---|---|
| DAM SITE 1 | 235 | 250 | 5 | 435 | 600 | 219,000 |
| DAM SITE2 | 265 | 285 | 5 | 700 | 2250 | 1,312,500 |
| DAM SITE 3 | 225 | 245 | 5 | 475 | 1400 | 557,666 |
| DAM SITE 4 | 230 | 250 | 5 | 450 | 1000 | 375,000 |

### 4.5 DISCUSSION

The study was conducted to apply GIS and its accompanying technologies in finding suitable sites for dam construction within the upper west region of Ghana making use of various geospatial factors such as slope, soil, rainfall, settlements and protected zones.

There has been vast research undertaken in applying GIS techniques to finding suitable dam sites in various places but such research is few and scanty within Ghana and more specifically within the semi-arid regions of northern Ghana.

The first objective of the research was to generate a suitability map of dam construction within the study area. The suitability map was generated and found to meet the requirements of all the factors selected and used in the study. Areas highlighted as suitable on the suitability map are found to be on gentle slopes. This seems to resonate with findings of other researchers such as Njiru and Siriba (2018) whose study on site selection of an earth dam in Mbeere North, Kenya found all highly suitable areas on gentle slopes. They argued that steeper slopes have more safety concerns as they are susceptible to floods and increase pressure on the foundation of the dam wall. Also, most suitable areas were found to be on places of medium elevation (200m – 400m). This was also found to be consistent with the study conducted by Dai (2016) who found all suitable areas to be on places of relatively high elevation and he further postulated that this could be as a result of the positive correlation between elevation and rainfall. Comparing the suitability map with a drainage map of the area also shows that most suitable areas are found around the drainage basin. This is true as the drainage basin primarily contains fairly flat slopes of less than 3% and also contains mostly fluvisols (alluvial soils) which are highly suitable for dam construction. Also it was found that areas chosen as suitable for dam construction occurred away from settlements. However, a few areas shown as suitable for dam construction occurred in sites classified as protected zones. This may be due to the low criterion score (3.6%) assigned to this factor.

From the suitability map, it is realized that most unsuitable areas are found in the central part of the study area. The soil type in these areas are predominantly arenosols and leptosols which are both classified as inappropriate for dam construction and this accounts for most central areas being classified as unsuitable. Also, the unsuitable sites were found to be in areas with mean annual rainfall values of less than 900mm.

Considering the second research objective, which was to propose specific sites for the construction of dams, the study proposed four sites. This result was as expected, as the area of sites highly suitable for the construction of dams according to the map was 792 $km^2$, which is very small compared to the total area of the study (18,476 $km^2$). This also echoes the findings of researchers such as Boateng et al. (2016), Mosate (2016) and Njiru and Siriba (2018) who conducted similar studies in predominantly semi-arid lands, have consistently found in their process of selecting a relatively low percentage of areas highly suitable for the construction of dams. Boateng et al, found only 3.69% of the study to be classified as suitable sites for irrigational dam whilst Mosate (2016) found only 10% of the study area to be suitable.

The third research objective of the study was to estimate the volumetric capacities of the proposed specific dam sites, the findings indicate that Dam site 1 which is located in the Nandom district along the flow path of the Kopara River has an estimated capacity of 219,000$m^3$. Dam site 2, located in the Sissala west district which has Gwollu as its capital town has an estimated capacity of 1,312,500$m^3$. Dam site 3 is located in Wa East district and has an estimated capacity of 557,666$m^3$. Finally Dam site 4 located the Lawra district along the Kambaa River has an estimated capacity of 375,000m$^3$. Analyzing volumetric capacities for the proposed dam sites found that Site 4, located in the Sissala west district has the capacity of storing the most amount of water at 1,312,500m$^3$. Proposed sites have also been classified into small, medium and large dams based on their size, in accordance with documented standardization for the safety of Vermont dams in the United States, which states that 1,233,482m$^3$ and 61,674,092m$^3$ in storage capacities are the borderlines between small, medium and large dams (Government of Vermont, 1990). Sites 1, 3 and 4 have all been classified as small dams since they have estimated storage capacities less than 1,233,482m$^3$ while Site 2 which has an estimated storage capacity exceeding 1,233,482m$^3$ but less than 61,674,092m$^3$ has been classified as a medium dam. This result was considered desirable and is in line with the conclusions of Acheampong et al. (2014) that small and medium-sized dams are the most preferred dam type for construction in Ghana, mainly because of high cost of constructing large-scale dams coupled with underperformance. Small dams with shorter dam walls are also preferred as they allow for the preservation of natural aquatic life upstream.

From the findings of the study, it has also been observed that even though the use of GIS makes the decision-making process more effective by accentuating all-terrain characteristics that may not be readily seen without employing GIS and also more objective by involving both experts and stakeholders, it still involves some form of bias attributed mainly to the allocation of criterion weights. It therefore means that the final results derived still contains some form of bias depending on the decision-makers involved. This finding is corroborated by Qureshi (2010), who concluded in his research that there remains an element of subjectivity associated with the assignment of criteria weights. In this study, the distances assigned and used in the classification of settlement data and protected areas were based on subjective opinion, although this opinion was formed on the basis of expert opinion and a thorough review of literature.

# CHAPTER FIVE CONCLUSIONS AND RECCOMENDATIONS

## 5.1 CONCLUSIONS

This study was aimed at using an Integration of GIS and AHP to determine suitable sites for constructing dams based factors such as slope, soil type, rainfall, settlement and protected zones and the results is suitability map that shows sites suitable for dam construction. This leads to the conclusion that GIS in combination with AHP is an effective tool in determining suitable dam sites.

Based on the second objective, using the suitability map four dam sites were proposed for construction within the study area. These sites are located in the Sissala West, Wa East, Lawra and Nandom districts of the region. We can thus conclude that GIS can be used to determine specific dam sites.

From the results of the volumetric capacities of the proposed sites, Dam Site 2 had a volumetric capacity of 1,312,500$m^3$ and was concluded to be a medium dam whilst the dam sites 1, 3 and 4 less were classified as small dams.

It was also found that employing GIS for suitability analysis highlights various terrain characteristics and properties that may otherwise not be immediately evident in manual surveys therefore improving upon the accuracy of the decision making. Again it was realized that GIS as a tool for determining the suitable sites employs minimal man power and as such is less laborious and cost effective as compared to the manual site selection process. From the findings of the research, it is possible to conclude that GIS is a powerful tool that can be effectively used to help in determining suitable sites for dam construction and provides an improvement on the current traditional site selection process employed by decision makers.

## 5.2 RECCOMMENDATIONS

Based on the conclusions of the research, the following recommendations have been made:

1. GIS is recommended as a tool for determining suitable dam sites and in general for making decisions with regards to water resources management.
2. GIS is also recommended for use in selecting specific sites for dam construction and this would aid the GIDA to be able to select dam sites more accurately.
3. From the outcome of the study, GIS is recommended for use in estimating the volumetric capacities of dam sites in order to know how the dams will best serve the water needs of the communities they are constructed to serve.
4. Further research is recommended to be conducted to determine water loss due evapotranspiration to be able to more accurately know the amount of available water for use to better guide decision makers.

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