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Geographical Information System (GIS) as a Tool for Determining Suitable Dam Sites in the Upper West Region of Ghana

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ABSTRACT

Access to water continues to dwindle worldwide. There are global concerns over impending situations of this high-water stress, which invariably would limit domestic and industrial water usage. This development would affect the quality of livelihoods and lead to a decrease in agricultural output. Dams are one of the best options to store, use water efficiently and improve living conditions for rural and urban populations by providing water for industry, irrigation and drinking. Even though dams are designed to collect and store water for use, their best function lies in siting it appropriately. The Ghana Irrigation Development Authority (GIDA) is the government agency primarily tasked with constructing and managing dams in Ghana. The new attention of the Government in constructing dams under their flagship programme, 'one Village one Dam,' necessitates research in areas where these programme objectives can be achieved. The traditional site selection process is manual, tedious and fails to accentuate certain terrain characteristics. However, using the Geographical Information system (GIS) can automate and scientifically solve this challenge with additional spatial capability. This study used Multi-Criteria Decision Making (MCDM) in a GIS environment in siting dams using five factors namely, slope, rainfall, soil type, protected zones, and settlements. This resulted in a suitability map of sitting dam showing 4.3% suitable for dam construction, 33% of the area averagely suitable, 53.9% poorly suitable and 8.8% unsuitable for dam construction. The study recommends GIS and MCDM for effective sitting of dams primarily in semi-arid regions to solve the problem of dams not working efficiently because of the poor location of sites.

INTRODUCTION

There continue to be a huge challenge in the ability to access this resource, especially for potable water to meet important needs such as domestic water consumption, irrigation, food production, health, sanitation and sustainable development (Owusu *et al.* 2016). The availability of water for use is alarmingly becoming an issue of world concern, and pundits in the area predict that should this trend persist, about 75% of the sector populace will stay with conditions of excessive-water scarcity through 2025 (Macedonia *et al.*, 2012). According to 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 (Sekar and Randhir, 2007). Water scarcity and water stress situations invariably will lead to a decrease in Agricultural output. Due to changes in weather, fertility, and prolonged drought, Agricultural Water Management Interventions (AWMI) has brought about great portability to smallholder farmers and thus reduced poverty, increased food security and efficient climate change management, variability and adaptability (UNEC, 2011).

There has been a decline in agricultural output in Ghana over the years (Baada *et al*., 2021). The structure of the Ghanaian economy is largely agrarian and highly reliant on rainfed agriculture. However, the increasingly unpredictable nature of the rainfall patterns in the Northern part of Ghana, especially, leads to much more dry grounds that do not support agriculture production all year round. Therefore, rain-fed agriculture is the main source of employment for most farmers in Ghana, especially Northern Ghana (Diao 2010; Limantol *et al.*, 2016). The long dry season in the northern part of Ghana necessitates complementary water sources for all-year farming like dams. These dams bridge the gap between the North and South as there are more rains at the southern belt than the former.

To solve the predicted impending water stress situation and the agricultural sector's vulnerability problem, especially in northern Ghana, dams could be constructed to serve as water sources for domestic use and irrigation. Dams have become alternatives for collecting, storing and successfully handling water resources to enhance the lives and livelihood of people in the rural and some peri-urban areas (Obour *et al.*, 2016; Shrestha *et al.*, 2018). This has aided water irrigation, household water use, industrial and commercial use (Jobin, 2014; Muller, 2015). 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 as efficiently as they can be. The Ghana Irrigation Development Authority (GIDA) is the government agency primarily tasked with the construction of dams. However, the Authority primarily uses a manual system of site selection. This makes the site selection process laborious and time-consuming. Also, certain characteristics which cannot be readily integrated into the manual site selection process are overlooked. These lead to dams not being able to function at maximum capacities

In this research, GIS and Analytical Hierarchical Procedure (AHP), a multi-criteria decision-making method, have been employed to determine the suitable location of dams (Mahmoud, 2000; Rezaei, 2013; Chezgi, 2016) in the Upper West Region of Ghana. This is because the data used for the project is mostly geospatial data, and GIS environment offers the ability of spatial data to be integrated and analyzed over large areas. Multi-criteria decision making enables researchers to break complex decisions into smaller components and aid the decision-maker to set priorities to make the best decision (San Cristóbal, 2011; Jozaghi *et al.*, 2018). In general, there are many factors considered in siting dams. These factors range from terrain topography or modelling and materials available, environment and cost of construction. Stephens (2010) and Rahmati *et al.*, (2019) states that factors such as availability of material, environmental concerns, proximity to roads and power supply should all be considered early so that costly investigation work is not wasted. Factors chosen for determining the location of dams vary significantly depending on the location and choice of method to use. However, research has shown that some factors such as slope, rainfall, and soil type resonate with most researchers. For example, in selecting dam sites using GIS in Bortala-Northwest China, Dai (2016) considered precipitation, slope, soil type, land cover, geological layer and drainage order. In this research, precipitation was considered the most important factor and assigned the highest weight. The researcher argues that precipitation is the main source of runoff water recharge and has a positive influence on runoff amount and ultimately a positive influence on dam function.

In the Upper East Region of Ghana, Boateng *et al.* (2016) considered five-factor criteria to determine suitable dam sites, and three constraint criteria were subsequently used to determine optimal sites from the suitable sites. The criteria considered included slope, soil group, proximity to agricultural activities, towns and settlements, and roads. Boateng *et al.* (2016) selected slope as the most important criteria and thus assigned it the highest weight. Slopes between 0 – 3% were considered suitable, while slopes above 3% were generally regarded as unsuitable. They argue that gentle slopes of less than 3% are preferred over steeper slopes as they will allow for water flow into the dam without the flow exerting so much pressure as to cause extra stress to the dam wall. In this research, however, it is noticed that rainfall has not been considered a factor even though the Food and Agricultural Organization's manual for siting small dams considers it as a crucial factor in siting dams.

Tshegofatso (2016), in "Application of GIS to Determine Suitable Sites for Surface Rainwater Harvesting in a Semi-Arid Catchment," considered factors such as slope (topography), land use/cover, rainfall (climate) and hydrology (rainfall-runoff relationships), soil (structure, texture and depth) and socio-economic issues (accessibility, related project implementation cost, population density, workforce, water laws, people's priority and land use). In this research, rainfall was considered the most important factor, while land use was considered the least important factor.

In the selection of sites for an Earth Dam in Mbeere, Kenya, Njiru and Siriba (2018) used a seven-criterion method, which included topographic factors slope, geological factors, soil type, catchment size, land cover, proximity to river and proximity to roads. The researchers posited that dam site selection should be on topography that is well-drained and gently sloping. They further argued that gentle slopes were the best as they minimize construction costs, and thus, they were assigned a high scale of preference; steep slopes were given the lowest scale of preference.

Generally, decisions and processes leading to dam siting often involve a diverse array of actors operating at different levels, with multiple interests. This normally overrides technical consideration due to political interest or other selfish considerations of the actors that needs this to happen instead of the factors that necessitate the success of it (Darko *et al.,* 2019). There have been dams constructed in Ghana that have either failed or not produced the standard amount of water needed for all year farming or other purposes (Dinye and Ayitio, 2013). Notwithstanding, the factors chosen for determining the location of dams vary significantly depending on the location and choice of method to use as well. A review of the literature has shown that some factors such as slope, rainfall and soil type resonate with most researchers. How all these factors are integrated spatially in a GIS environment is the added advantage using Multi-Criteria Decision Making (MCDM that enables efficient sitting of dams.

Five factors were used to achieve this objective. :slope was considered because steeper slopes exert more pressure on dam walls, and as such, in the site selection process, gentle slopes are more preferred. Most of the water source in Northern Ghana is rainfall; thus, areas of higher rainfalls were also preferred. Soil type was one of the key factors considered as it is key to the dam's ability to hold and store water. Other factors considered were settlement and protected zones in determining suitable sites for dam construction within the Upper West Region of Ghana. This paper therefore used) MCDM in a GIS environment as a tool for determining Suitable dam Sites in the Upper West Region of Ghana.

MATERIALS AND METHODS

Study Area

The study was conducted in the Upper West Region of Ghana (Fig. 1), which lies in the northwestern corner of Ghana with latitude 9.822109° to 10.990000° North and longitude 1.620818° to 2.900000° West. The region covers a geographical area of 18,476 km^2 which represents 12.7% of the total land area of Ghana. The vegetation is typically characterized by short grasses and few woody plants and trees. Tree species are usually drought and fire-resistant and include baobab (*Adansonia digitate*), dawadawa (*Parkia Biglobosa*), shea (*Vitellaria Paradoxa*) trees and acacia. The vegetation cover is very suited to livestock production, which contributes significantly to household incomes. The greatest influence on the vegetation in the region is the prolonged dry season, during which time grasses dry up and subsequently burn. This leaves the land cover patchy and mostly bare. Consequently, the torrential early rains cause soil erosion. Bush burning reduces the vegetative cover and transpiration, and this affects average annual rainfall totals. The climate is the tropical continental type with the mean annual temperature ranging between 27 °C and 36 °C (Ministry of Food and Agriculture, 2018). According to the Ghana Statistical Service (2021), the Upper West Region has a population of 904,695, accounting for 2.9% of Ghana's population, with a majority engaged in Agriculture. The region experiences a unimodal rainfall pattern. Figures from the Ministry of Food and Agriculture (2018) indicate that the average annual rainfall increases from the North (Tumu: <900 mm) to the south (Wa: 1,111 mm). Other sources of drinking water in the

Municipality include borehole pump/tube well, pipe-borne and public tap/standpipe (GSS, 2021).

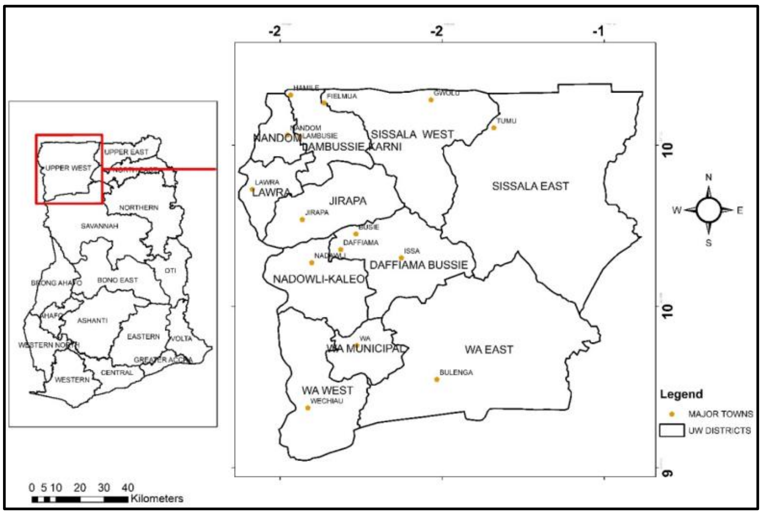

Figure 1. Map of Upper West Region

Methods

Analytical Hierarchical Procedure (AHP), a method of multi-criteria decision making (MCDM), was used in this research to determine the suitable sites for dam construction. The method comprises four (4) stages. The first stage included planning and selection of factors to be used for research. The second stage was data acquisition from the various sources, after which data verification was done. Next, the data was preprocessed and classified as to whether suitable, averagely suitable, poorly suitable or unsuitable based on the attributes of the various factors. Lastly, weights were assigned, and weighted overlay analysis was done to generate suitable sites.

Selection of Factors

The factors considered for siting the dams depended heavily on our intended purpose and previous literature review. Five (5) factors were chosen considering the irrigational purposes of the dams: slope, rainfall, soil type, protected zones and settlements. Characteristics of these factors considered are briefly explained as follows:

-Slopes of 1.5 to 3% were considered as suitable. Larger percentage slopes are considered not suitable as they are more susceptible to landslides.

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

-The amount of rainfall is another important consideration. Areas with higher rainfall values were considered suitable for dams and vice versa.

-The dams are intended to mitigate impending high water stress situations. So their locations are selected to be close to settlements but not very close as they may cause floods when they overflow. After reviewing the literature, the dams should be sited at least 5 km away from settlements. Protected zones, mostly forest and game reserves, and cultural sites of historical importance were considered unsuitable. These sites were entirely excluded from being considered in the dam selection process. Dams should be sited at least 5 km away from all protected zones within the study area.

Data Preprocessing

Slope

The slope was derived from the DEM acquired from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global DEM with a resolution of 30 m. Four tiles fully covered the study area: ASTGTM2_N09W002, ASTGTM2_N09W003, ASTGTM2_N10W002 and ASTGTM2_N10W003. The four DEM tiles were mosaicked in ArcGIS using the Mosaic to Raster 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 was projected to the WGS 84_UTM Zone-30N. The slope was classified into suitable, averagely suitable, poorly suitable and unsuitable, as shown in Table 1.

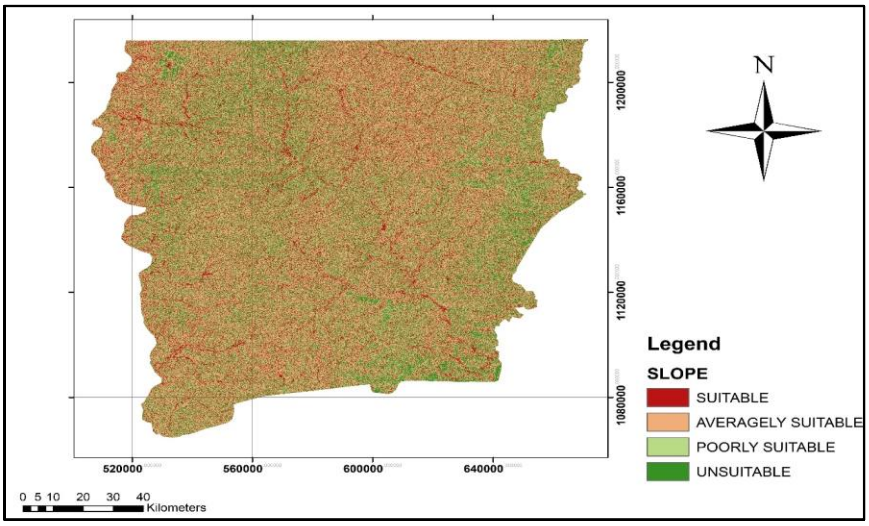

Figure 2. Slope Map of Upper West Region

Table 1. Slope Classification

Slope Percentage	Class	Remarks
Less than or equal to 1.5%	Class 1	Highly suitable
Between 1.5% and 3%	Class 2	Averagely suitable
Between 3% and 5%	Class 3	Poorly suitable
Greater than 5%	Class 4	Unsuitable

Rainfall Data

Rainfall data for the study was acquired from the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) and the Ghana Meteorological Agency (GMA). The CHIRPS data was processed in RStudio 1.1.383. The CHIRPS data used was yearly data covering 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 ArcGIS. The cell statistics of each cell were calculated for the duration. The rainfall data was then reclassified into four classes, as shown in Table 2.

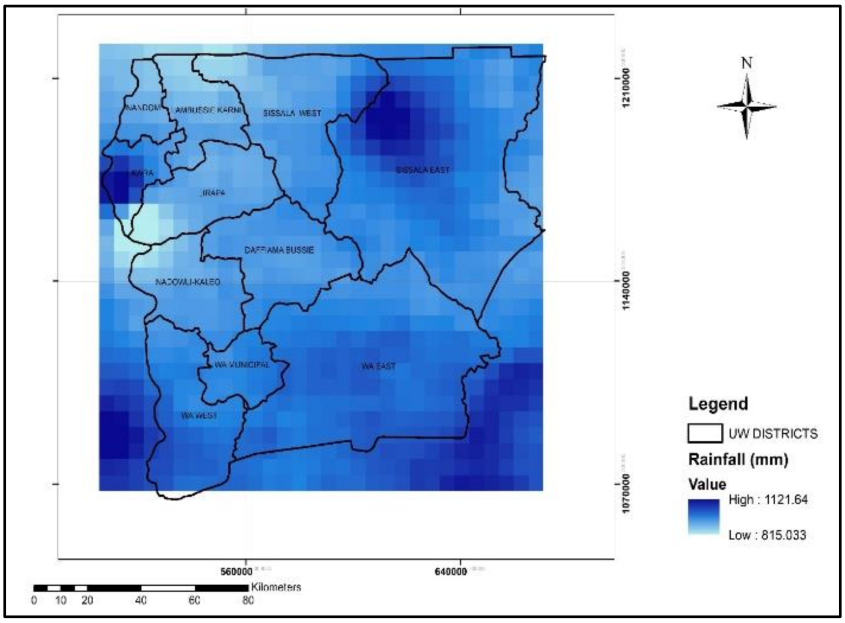

Figure 3. Rainfall map of study area based on data from 1988 to 2018

Table 2. Rainfall Classification

Yearly Rainfall (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

Soil Data

The soil data were acquired from the Soil Research Institute of Ghana. The data were grouped into eight classes: Lixisols, Acrisols, Leptosols, Planosols, Arenosols, Plinthosols, Vertisols, and Fluvisols. A soil map of the study area is shown in Fig 3. According to Spaargaren (2007), Fluvisols have a very good water retention capacity. Vertisols are soils that develop in shrink well clays and have low porosity and average water retention capacity. Similar to Acrisols, Plinthosols and Planosols, Lixisols have low dominant clay content and, as such, have low water retention capacity. Arenosols and Leptosols have poor water storage capacities. The soil data were then grouped into four classes, as shown in Table 3.

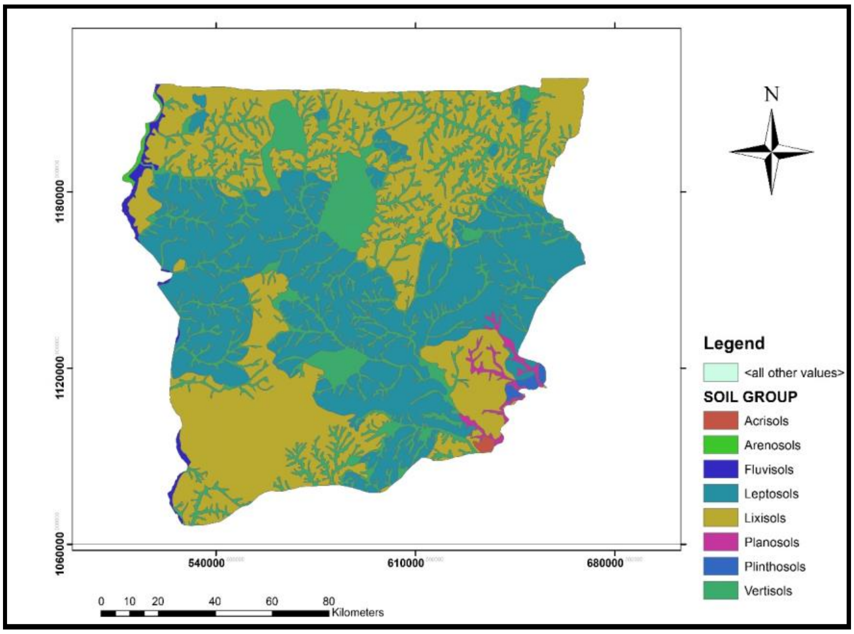

Figure 4. Soil Map of the Study Area

Table 3. Soil 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

Protected Zones

Data for protected zones within the study area was acquired from the environmental protection agency (EPA) and the Ghana forestry commission divisions in the region. The data was in the form of polygon shapefiles and is shown in Fig.5. The Euclidean distance tool was used in a GIS environment to set proximity to protected zones. This Euclidean distance identifies the straight line distance to the closest source cell, set of source cells, or source location for each cell (Boateng *et al.*, 2016). The data was reclassified as shown in Table 4.

Table 4. Protected Zones Classification

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

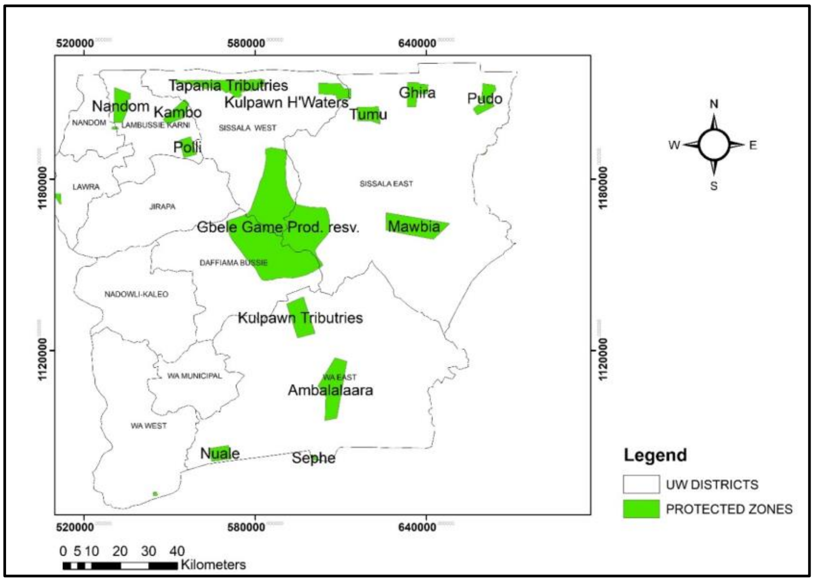

Figure 5. Map Showing the Protected Zones in Upper West Region

Settlements

Settlement data for the upper west region was acquired from the region's town and country planning department. Again, in processing the settlement data, the Euclidean distance tool was implemented, and the distances were classified, as presented in Table 5.

Table 5. Settlement Classification

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

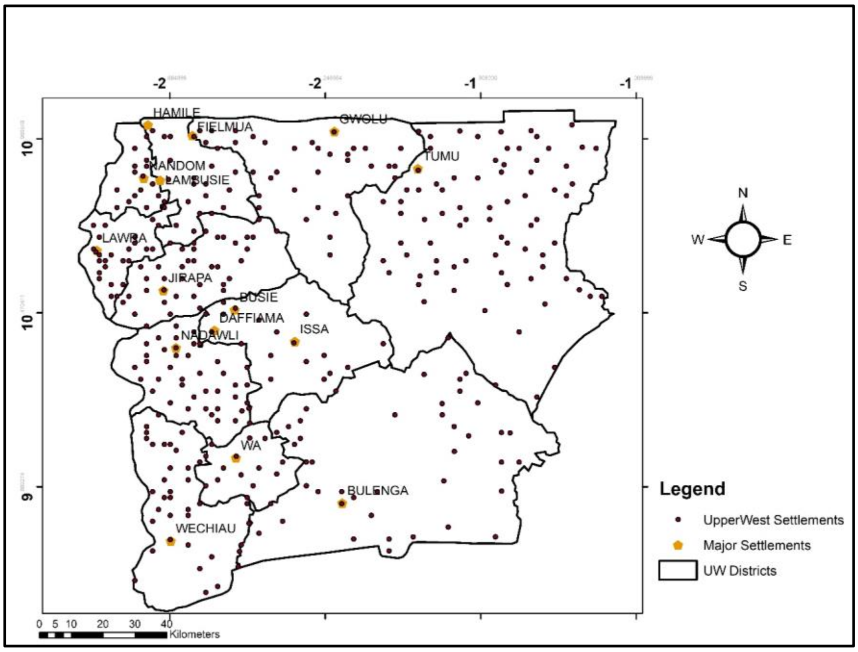

Figure 6. Settlement Map of the Upper West Region

Assignment of Weights

In consultation with experts, i.e. the regional engineer and surveyor of the Ghana Irrigation Development Authority (GIDA) and an extensive literature review, pairwise comparison matrix was developed based on priority of the factors, as shown in Table 6.

Table 6. 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

Source: Field Survey (2021)

From the pairwise comparison matrix, the normalized pairwise comparison matrix was derived by taking the sum of each column equal to 1. The criteria weight vector (that is, an m-dimensional column vector) is built by averaging the entries on each row of the normalized pairwise comparison matrix (Saaty, 1980). From the pairwise comparison matrix, the Consistency Ratio (CR) was calculated using the Eq. 1 (Saaty, 1980).

Table 7. 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

Source: Field Survey (2021)

C.R. = $\frac{CI}{RI}$ …………………………Equation 1

Where: CI = Consistency index given by $\frac{x-m}{m-1}$, with m as a number of factor criteria and x as a scalar of the pairwise comparison matrix, and RI = Random Index, the consistency index when the matrix entries are completely random.

The values of RI for small problems ($m \leq 10$) have been developed by (Saaty, 1980). The consistency ratio was thus calculated to be 0.064, and this was acceptable since it is less than 0.1 (Saaty, 1980).

Calculating a Suitability Index

There have been several methods in calculating the suitability index such as the parametric evaluation method, Storie method, root method, Boolean overlay and Fuzzy overlay. However, the weighted linear combination (WLC) and the Ordered Weighting Average (OWA) were the two methods considered in this study. The WLC was chosen because it allows the evaluation criterion map layers to be combined to determine the composite map layer, which is output and can be implemented simply in both raster and vector GIS environments (Drobne and Lisec, 2009). The suitability index was calculated from the equation 2:

Suitability Index (SI) $=\sum WiXi$ ……..Equation 2

where W_i = Weight of factor I, and X_i = Criterion score of factors i

Model Validation

In validating the resultant suitability map, 24 existing dams and reservoirs within the study area was overlaid on the suitability map.

RESULTS AND DISCUSSION

After the weighted overlay analysis was done in ArcMap, a suitability map of the dam sitting in the Upper West region was generated as shown in Figure 7.

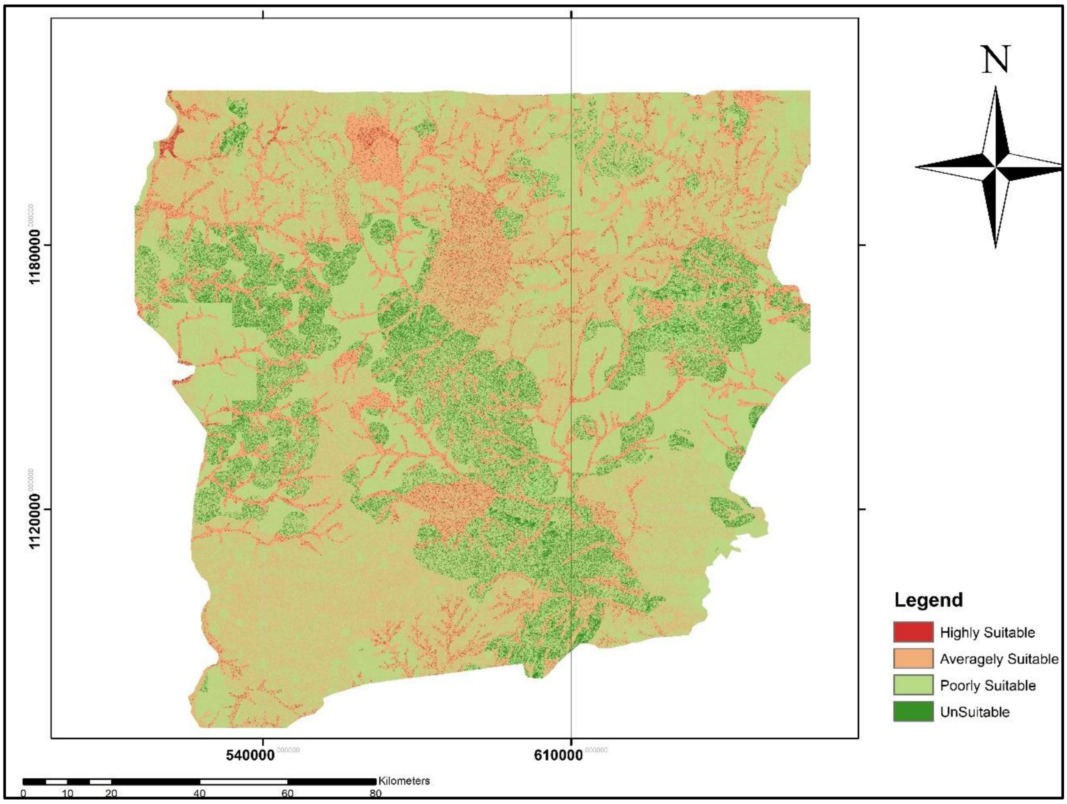

Figure 7. Dam Sitting Suitability Map

The suitability map meets the requirements of all the factors selected and used in the study. The selected areas are on gentle slopes, have maximum rainfall, and contain soils with good water retention capabilities. From a visual inspection of the map, it is evident that suitable areas for dam construction are sparsely distributed across the study area. Most unsuitable areas were found central to the study area. This is probably because the soil type in these areas is arenosols and leptosols which are classified as unsuitable for dam construction (Table 3). The suitability map shows that 4.3% of the total land area of the study area is suitable for dam construction, 33% of the area is averagely suitable, 53.9% poorly suitable and 8.8% unsuitable for dam construction (Table 8). This means that a very small percentage of the study area is suitable for dams. Great care must therefore be taken in siting dams to function as required within the study area. Area-wise (in 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 (Table 8).

Table 8. Area of Dam Sitting Suitability in Upper West Region

Suitability	Count	Area (km^2)	Percentage (%)
Suitable	880855	792.8	4.3
Averagely suitable	6774633	6097.2	33.0
Poorly suitable	11063102	9956.7	53.9
Unsuitable	1810299	1629.3	8.8
Total		18476.0	100

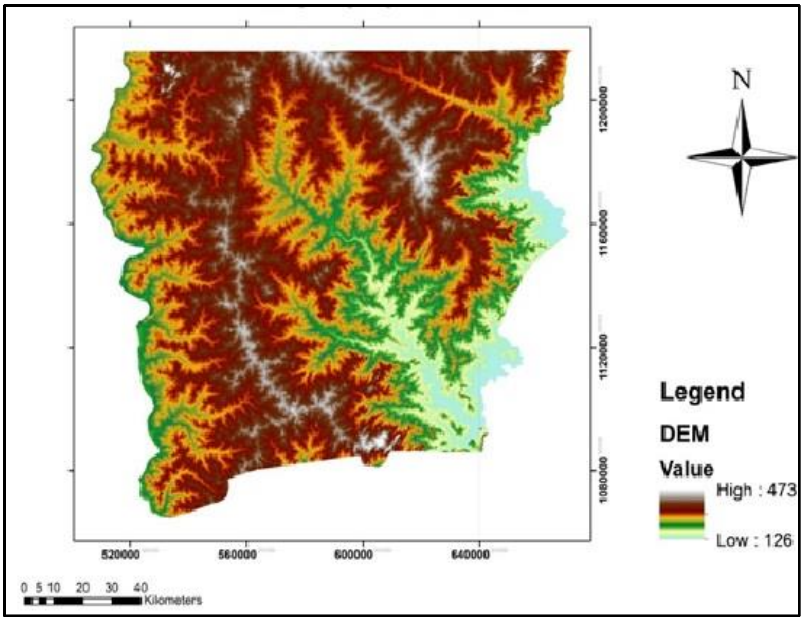

Figure 8. Digital Elevation Model of the Upper West Region

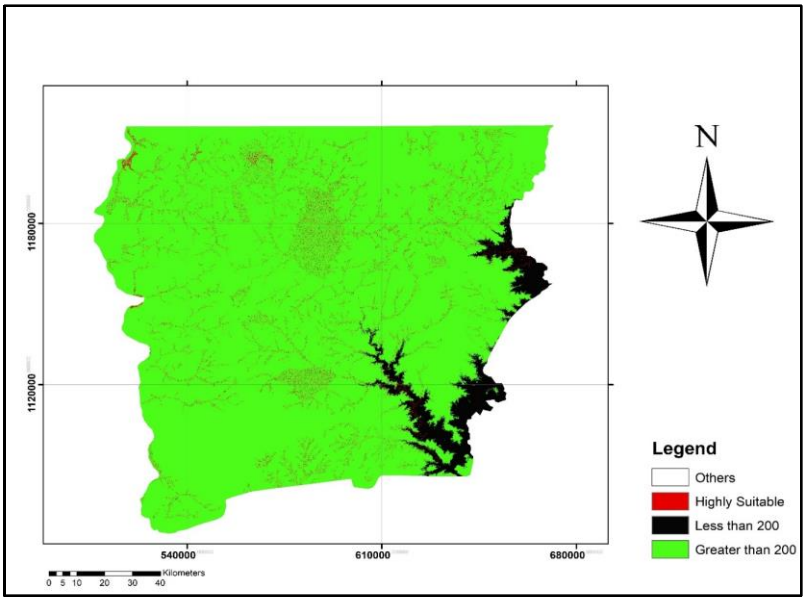

Figure 9. Overlay of Suitability Map and Digital Elevation Model (High and Low Elevations)

A comparison of the suitability map and the DEM was made, and it was found that most of the suitable areas were found in areas of medium to high elevations between 200 m to 400 m. Similarly, Dai (2016) found all high and very high suitability areas in places with high elevations and attributed it to the positive correlation between elevation and rainfall, which was considered as an essential factor for selecting suitable sites. Again, most areas classified as suitable were found in areas of gentle slopes when the suitability and slope maps were compared. Steep slope areas were found to have been classified as unsuitable. This agreed with the findings of Njiru and Siriba (2018), whose study on on-site selection of an earth dam in 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. Comparing the suitability map with a drainage map of the area also shows that the 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 mostly fluvisols (alluvial soils), which are highly suitable for dam construction. Also, it was found that areas chosen as suitable for dam construction occurred at least

5 km away from settlements. This was found acceptable as that was the classification criteria used (Table 5). 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.
The study's findings have also observed that GIS makes the decision-making process more effective by accentuating all-terrain characteristics that may not be readily seen using manual techniques and more objective by involving both experts and stakeholders. In this study, the distances assigned and used to classify the settlement data and protected zones were based on expert advice and an extensive literature review.

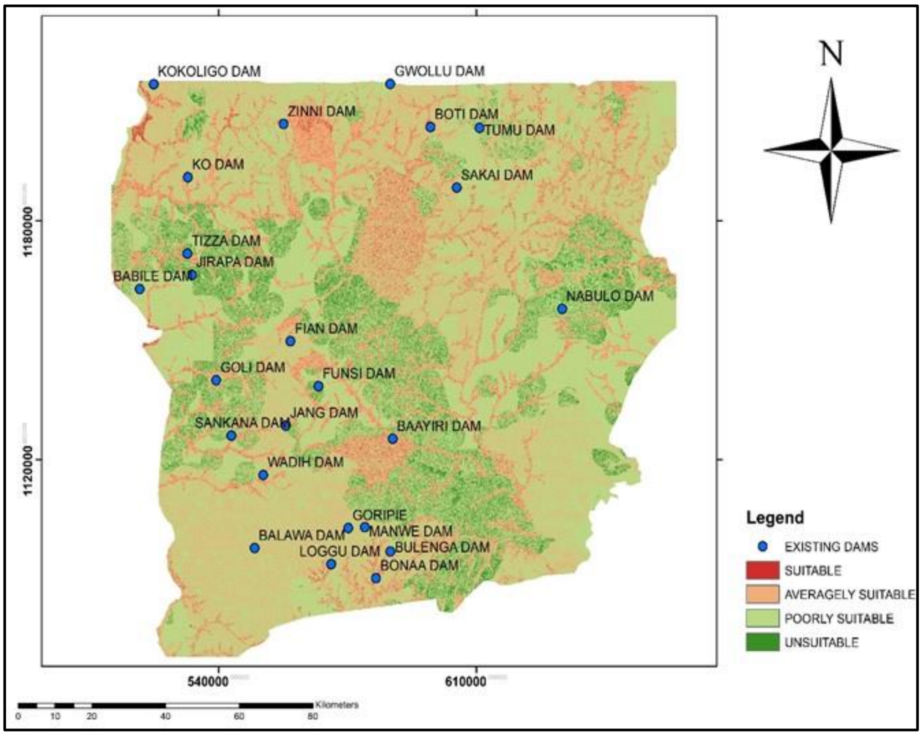

Figure 10. Existing Dams on Suitability Map

Existing dams and reservoirs within the study area were overlaid on the suitability map to validate the model, as shown in Figure 10, and the percentage overlap was calculated. A total of 24 dams, reservoirs and dugouts were analyzed. About 75% of the existing structures were within areas found to be suitable or averagely suitable, validating the model appreciably.

CONCLUSION

This study employed GIS and multi-criteria decision making (MCDM) to determine suitable sites for constructing dams based on factors such as slope, soil type, rainfall, settlement and protected zones. Criteria selection and weights were based on a review of relevant literature and local experts' elicitations. A suitability map delineating sites suitable for dam construction in the Upper West Region of Ghana was successfully generated and had 75% accuracy in predicting the locations of existing dams, reservoirs and dugouts. The study concluded that GIS is a powerful tool that can be effectively used to help in determining suitable sites for dam construction and improves the current manual site selection process employed by decision-makers. Moreover, it makes the process faster and highlights certain terrain characteristics and properties that may otherwise not be immediately evident in manual surveys. Thus, the present study recommended that the relevant stakeholders should integrate GIS and MCDM in determining suitable dam sites during the rolling out of the Government's "one district, one dam" project.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

REFERENCES

Baada, J. N., Baruah, B., and Luginaah, I. (2021). Looming crisis–changing climatic conditions in Ghana's breadbasket: the experiences of agrarian migrants. Development in Practice, 31(4), 432-445.

Boateng, K. B., Stemn, E., and Sibil, S. (2016). Multi-criteria-GIS based site selection for the irrigational reservoir – a case study. European Agrophysical Journal, 3(1), 1 - 17. http://dx.doi.org/10.17830/j.eaj.2016.03.001

Chezgi, J., Pourghasemi, H. R., Naghibi, S. A., Moradi, H. R., & Kheirkhah Zarkesh, M. (2016). Assessment of a spatial multi-criteria evaluation to site selection underground dams in the Alborz Province, Iran. Geocarto International, 31(6), 628-646.

Dai, X. (2016). Dam Site Selection using an integrated method of AHP and GIS for decision making support in Bortala, Northwest China.

Darko, D., Kpessa-Whyte, M., Obuobie, E., Siakwah, P., Torto, O., and Tsikata, D. (2019). The Context and Politics of Decision Making on Large Dams in Ghana: An Overview (May 01, 2019). Future DAMS Working Paper 002, May 2019, Available at SSRN: https://ssrn.com/abstract=3793481

Diao, X. (2010). Economic importance of agriculture for sustainable development and poverty reduction: findings from a case study of Ghana. In: Global forum on agriculture, policies for agricultural development, poverty reduction and food security. OECD, Paris contaminants in the zone of the contribution of a public supply well in Modesto, eastern San Joaquin Valley, California. USGS Scientific Investigations Report 2008–5156

Dinye, R. D., and Ayitio, J. (2013). Irrigated agricultural production and poverty reduction in Northen Ghana: A case study of the Tono Irrigation Scheme in the Kassena Nankana District. International Journal of Water Resources and Environmental Engineering, 5(2), 119-133.

Drobne, S. and Lisec, A. (2009). Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging

Fito, J., and Van Hulle, S. W. (2021). Wastewater reclamation and reuse potentials in agriculture: towards environmental sustainability. Environment, Development and Sustainability, 23(3), 2949-2972.

Ghana Statistical Service (2021). Population and Housing Census: Release of Provisional Results. Retrieved from http://www.census2021.statsghana.gov.gh

Jobin, W. (2014). Dams and disease: ecological design and health impacts of large dams, canals and irrigation systems. CRC Press.

Jozaghi A, Alizadeh B, Hatami M, Flood I, Khorrami M, Khodaei N, Ghasemi Tousi E. (2018). Comparative Study of the AHP and TOPSIS Techniques for Dam Site Selection Using GIS: A Case Study of Sistan and Baluchestan Province, Iran. Geosciences. 2018; 8(12):494.https://doi.org/10.3390/geosciences8120494

Limantol, A. M., Keith, B. E., Azabre, B. A., and Lennartz, B. (2016). Farmers' perception and adaptation practice to climate variability and change: a case study of the Vea catchment in Ghana. SpringerPlus, 5(1), 1-38.

Macedonia , F. , Drioli , E. , Gusev , A. A. , Bardow , A. , Semiat , R. and Kurihara , M. (2012). Efficient technologies for worldwide clean water supply. Chemical Engineering & processing:Process Intensification , 51 : 2 – 17.

Mahmoud, M. R., and Garcia, L. A. (2000). Comparison of different multi-criteria evaluation methods for the Red Bluff diversion dam. Environmental Modelling & Software, 15(5), 471-478.

Ministry of Food and Agriculture (2018). Upper West Region: General Information. Http://www.mofa.gov.gh/site/?page_id=656 Html. Accessed 10th September 2018.

Muller, M. (2015). The nexus as a step back towards a more coherent water resource management paradigm. Water Alternatives, 8(1).

Njiru, F. M., Siriba, D. N. (2018). Site Selection for an Earth Dam in Mbeere North, Embu County—Kenya. Journal of Geoscience and Environment Protection, 2018, 6, 113-133.

Obour, P. B., Owusu, K., Agyeman, E. A., Ahenkan, A., and Madrid, À. N. (2016). The impacts of dams on local livelihoods: a study of the Bui Hydroelectric Project in Ghana. International Journal of Water Resources Development, 32(2), 286-300.

Owusu, A. P, Asumadu-Sarkodie S, Ameyo P. (2016). A review of Ghana's water resource management and the prospect. Cogent Engineering 3:1164275

Rahmati, O., Kalantari, Z., Samadi, M., Uuemaa, E., Moghaddam, D. D., Nalivan, O. A. and Tien Bui, D. (2019). GIS-based site selection for check dams in watersheds: Considering geomorphometric and topo-hydrological factors. Sustainability, 11(20), 5639.

Rezaei, P., Rezaie, K., Nazari-Shirkouhi, S., and Tajabadi, M. R. J. (2013). Application of fuzzy multi criteria decision-making analysis for evaluating and selecting the best location for constructing an underground dam. Acta Polytechnica Hungarica, 10(7), 187-205.

Saaty, T. (1980). "The Analytic Hierarchy Process." McGraw-Hill, New York.

San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in Spain: The Vikor method. Renewable energy, 36(2), 498-502.

Sandhu, G., Wood, M. O., Rus, H. A., and Weber, O. (2020). Bulk Water Pricing Policies and Strategies for Sustainable Water Management: The Case of Ontario, Canada. Environmental Policy: An Economic Perspective, 71-88.

Sekar, I., and Randhir, T. O. (2007). Spatial Assessment of Conjunctive Water Harvesting Potential in Watershed Systems. Journal of Hydrology, 334(1), 39-52.

Shrestha, A., Roth, D., and Joshi, D. (2018). Flows of change: dynamic water rights and water access in peri-urban Kathmandu. Ecology and Society, 23(2).

Spaargaren, O. (2007). Soils of the world and their Physical properties. SRIC, Wageningen, Netherlands.

Stephens, T. (2010). Manual on Small Earth Dams. A Guide to Siting, Design and Construction. Food and Agriculture Organization of the United Nations, Rome.

Tshegofatso, M. (2016). Application of GIS to Determine Suitable Sites for Surface Rainwater Harvesting in a Semi-Arid Catchment. Master thesis, University of Dar Es Salaam

United Nations Economic Commission for Africa (UNEC) (2011). Agricultural Water Management in the Context of Climate Change in Africa, working paper.