Application of Particle Swarm Optimization based Fuzzy AHP for Evaluating and Selecting Suitable Flood Management Reservoir Locations in Adamawa Catchment, Nigeria

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Abstract
Seasonal flooding arising from current climate changes is a major problem in Adamawa catchment. Flood management reservoirs is a useful tool to catch flood, prevent jump, reduce congestion of runoff in the plains, and implement a long-time solution to the existing flood threats. This study applies Particle Swarm Optimization (PSO) based Fuzzy AHP to model flood reservoir site selection in Adamawa catchment located in the Upper Benue River Basin of Nigeria. Nine essential criteria and constraint were identified based on literature, and evaluation by experts. Weighted Linear Combination algorithm was modified and used to aggregate information from the factors and constraint. Pairwise Comparison Matrix (PCM) was obtained and weights for each of the PCM were determined using a Fuzzy Analytical Hierarchical Process (AHP) based PSO algorithm. MATLAB software was used to implement the PSO algorithim to derive the weights in the PCM. Consistency of generated weights obtained is not above 0.00213. The method resulted to a reservoir sites suitability map. Analysis of the proposed best reservoirs shows that, the maximum height of reservoirs corresponding to cross section of reservoir locations varies from 3m to 11m; width of reservoir varies from 140m to 680m; the maximum storage capacity varies from 66,768 m^3 to 4,242,975m^3; maximum surface area of the reservoir varies from 11,602m^2 to 955,871m^2. *Field verification was conducted and* most of the identified sites correspond with field based studies*. Potential impacts of the candidate sites were identified and baseline survey data obtained in the field were engaged to establish the present state of the environment, taking into account changes resulting from natural events and from other human activities before arriving at top ranking sites. This present study has provided solution to the flood problem in Adamawa catchment through selection of suitable location for siting flood mitigation reservoirs.*

Keywords: Adamawa catchment, Flood management, reservoirs site suitability, Particle Swarm Optimization, Weighted Linear Combination

1.0 INTRODUCTION

The problem of flooding is a major concern globally. The United Nations International Strategy for Disaster Reduction describe flooding as a threat to sustainable development and poverty-reduction initiative (UN-ISDR, 2009). Flood has negative impact on population and environment. Flooding is among the most devastating natural hazards in the world, claiming more lives and causing damage to property and infrastructure than any other natural phenomena (Nwilo *et al.,* 2012; Dilley *et al.,* 2005). There have been catastrophic flood events around the world, for example, in USA (1993), Bangladesh (1997), Ecuador (1997), Mozambique (1997), China (1998), Poland (2000), Czech Republic (2001) and Nigeria (2012), to name a few countries. Across Africa, thousands of people were displaced from flooding. For instance, Huq *et al.* (2007) reported cases of heavy rains in East Africa in 2002 that brought floods and mudslides, and forced tens of thousands to leave their homes in Rwanda, Kenya, Burundi, Tanzania, and Uganda.

In Nigeria like other parts of the world, floods are seasonal in many areas. Flood sometimes occur with several negative consequences (loss of properties, disruption of human activities, loss of lives, destruction of farm lands, spread of several diseases such as cholera and typhoid). Flood problems along the Benue River particularly the Upper Benue basin have affected more communities in recent times. There is increasing vulnerability of populations and infrastructure to flooding and flood related hazards. The problem faced is that of developing strategies that would catch flood and prevent jump, and reduce flood effects while converting the flood to benefit for agriculture in which majority of the people depends. Flood reservoirs appears to be a useful tool to reduce congestion of runoff in the plains and implement a long-time solution to the existing flood threats (Xinyi, 2016; Abushandi and Alatawi, 2015; Mobarakabadi, 2012). Flood control reservoirs in the Benue River basin are an important solution to curbing the seasonal flood disaster. The biggest issue in reservoirs projects implementation is finding a suitable location for construction. Baban and Wan-Yusof (2003) observed that choosing a suitable site is a crucial phase in reservoir construction. Optimal benefits are derived with little or no negative downstream effects when reservoir locations are selected using scientific approach with field verification. Tsiko and Haile (2011) observed that identification of an optimum reservoir site is a decision-making process that involves the consideration of diverse criteria. Multi-criteria decision-making (MCDM) (Rietveld, 1990; Voogd, 1983; Janssen), is an established technique that can be used for addressing the problem of choosing materials involving multiple criteria. In MCDM problems, evaluation is a necessary task to obtain a final solution. The evaluation stage combines the information from various factors and constraints.

This flood control and vulnerability management reservoirs location suitability study can be a useful tool to implement a long-time solution to the existing threats in Benue river basin. Selecting optimal location for reservoir is challenging and complex due to involvement of a wide range of influential factors. Different published work in the field of reservoir site selection utilize different factors as criteria (Raza *et al*., 2018; Yue *et al*., 2017; Iftikhar *et al*., 2016; Forzieri *et al*., 2008), as well as engage different method to measure the influences from each criterion (Abushandi and Alatawi, 2015; Alaibakhsh *et al*., 2013; Mobarakabadi, 2012; Tsiko and Haile, 2011; Baban and Wan-Yusof, 2003). Once a system or phenomena are identified to be complex in nature, any of the Artificial Intelligence (AI) techniques (for example, Artificial Neural Network, Genetic algorithm, Fuzzy, etc.) can be used to solve the complexity (Hamid-Mosaku 2014; Negnetivisky, 2005). Hence the need for the use of PSO, Fuzzy, and AHP in this study. The theory of fuzzy can be considered as a modelling language, well suited for situations in which fuzzy relations, criteria, and phenomena exist (Zimmermann, 2010). Furthermore, studies have shown that aggregation of criteria is necessary in a study of this nature, however, there are different views of theories on Multi-Criteria Evaluation (MCE) for aggregation of criteria for sites suitability decision making process. It appears most scholars focused on either Boolean overlay approaches (Baban and Wan-Yusof, 2003), Ordered Weighted Average or Multi Criteria Analysis (MCA) using both Analytical Hierarchical Process (AHP) presented in 1980 (Saaty, 1980), the Rank Order System (ROS) (Forzieri *et al*., 2008; Naseri *et al*. 2006; Atila *et al*., 2006) and Weighted Linear Combination (WLC) (Tsiko and Haile, 2011; Hopkins, 1977). The main concern is the use of an effective, efficient and accurate method for reservoir site selection. This study will adopt and modify the Weighted Linear Combination for aggregation of criteria to model flood reservoir site selection in Adamawa catchment located in the Upper Benue River Basin of Nigeria. The WLC is specifically chosen as the method of aggregation because it is widely used and popular.

1.1 Study Area

Adamawa catchment in Nigeria is located along river Benue in the Upper Benue drainage basin. It cut across the boundaries of six local governments' areas in Adamawa State. They are Demsa, Funfore, Ngurore, Numan, Yola North, and Yola South. The location occupies large floodplain zone in Nigeria. About 30% of the lowlands in Nigeria are situated in the central part (Kogi, FCT, Nasarawa and Benue States) and about 55% in the eastern area (Plateau, Taraba and Adamawa States) (NFDP-II, 2003). Adamawa catchment usually experience seasonal flood problems. Large volumes of sediment are seasonally discharged into the floodplains and help to renew the fertility of the soils. The area is characterized by two seasons: wet or rainy season (from May to October) and dryness (from November to April). Yearly rainfall averages 900 to 1,500mm (NFDP-II, 2003). Adamawa begins to experience cold-dry and dusty trade wind from January to April (Harmattan period) with temperature rise. Jamala and Oke (2013) noted that the Harmattan season is very dry and as result, humidity may be as low as 10-20%. Temperature in the region can be as high as 40^0C and as low as 18^0C. The relief is nearly level to gentle undulating plain with few outcrops. The Sub-catchment border is approximately defined by longitudes 11^o 46'E and 14^o 14'E and latitudes 8^o 37' N and 9^o 41'N (Figure 1). The area is characterized by two seasons: wet or rainy season (from May to October) and dryness (from November to April). Yearly rainfall averages 900 to 1,500mm. Temperature in the region can be as high as 40^0C and as low as 18^0C.

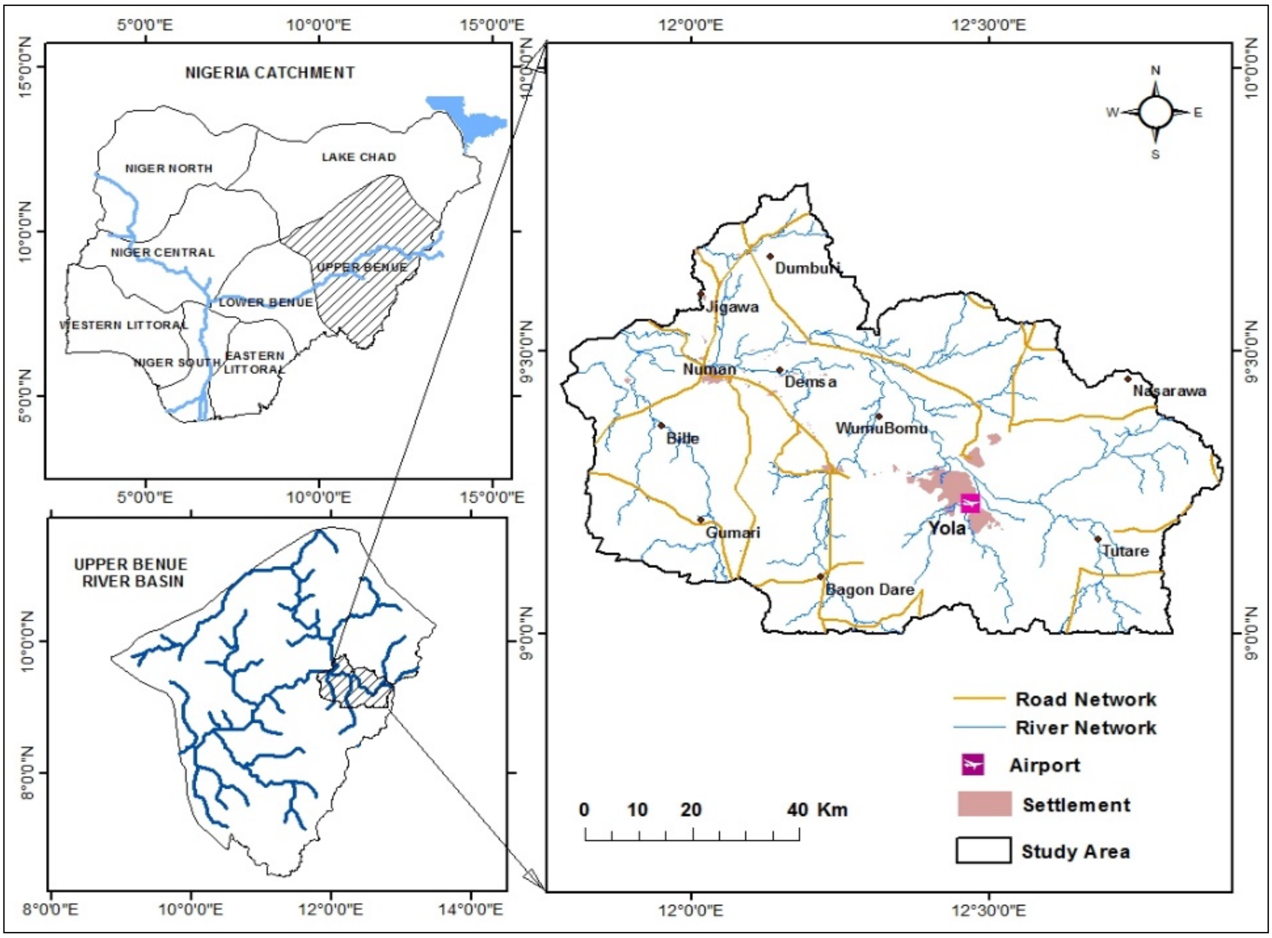

Figure 1: Study area location

2.0 MATERIALS AND METHOD

2.1 Data collection

Data sets used in this study were extracted from ALOS PALSAR Global DEM with a resolution of 12.5m, Landsat image of 2018 with a resolution of 30m, 2004 edition of geological map of Nigeria produced by Nigeria Geological Survey Agency, soil map obtained from a 1996 compilation of soil map for Nigeria: a nationwide soil resource and land form inventory by Centre for World Food Studies (SOW-VU) with a resolution of 1: 1:300,000, as well as predicted precipitation data

- the downscaled IPPC5 (CMIP5) data using Global Climate Model (GCM) CCSM4 under scenario representative concentration pathway (RCP) 6 with available predicted precipitation in CMIP5 dataset of 2014 to 2060. These include elevation, slope river network, fault lines, settlement areas, soil types, bedrock, rainfall and water discharge.

2.2 Methodology

The study used Multi-Criteria Decision Analysis (MCDA) in a GIS environment to model suitable sites for flood control reservoir. Specific software environment utilized include IDRISI, ArcMap and MATLAB. Based on relevant studies (Xinyi, 2016; Lai *et al*., 2015; Tsiko and Hailey, 2011L Baban and Wan -Yusof 2003; Chang, 1996), the procedure for modelling suitable sites for flood control reservoir is highlighted.

Step 1: Evaluation of criteria *and establishing decision hierarchy model*

This step involves evaluation of criteria that affect reservoir site selection in order to govern the required data. The evaluation of reservoir sites factors requires two stages: (i) generation of constraint map (s); and (ii) criteria (factors) description and pre-processing. Factors influencing reservoir site selection includes topography (slope/aspect), hydrology (rainfall, drainage network), geology (mineral), soil, land use/cover (agriculture, forestry), road network, and development plan (Shahabi *et al*., 2016; Xinyi, 2016; Tsiko and Hailey, 2011; Baban and Wan-Yusof, 2003; Adinarayana *et al*., 1995; Gismala *et al.,* 1996). Considerations from these works, experts' opinion, and availability of data guide the choice of input factors and constraint. Nine essential criteria considered for this study as major factors affecting the siting of flood control reservoirs are shown in Table 1.

Table 1: Selected criteria

S/N	Element	Way of influence	Explanation (Experts opinion)
1	Bedrock	Factor	Selected site should have hard rock. Stronger foundations are preferred for reservoir construction.
2	Elevation	Factor	For more water collection the selected site must be located in anti-dip valley
3	Slope	Factor	The gentle the slope the better.
4	Fault lines	Factor	Low density of tectonic lines so that internal water movement is less
5	Soil	Factor	The lower the soil infiltration rate the better
6	Water discharge	Factor	Selected site should have high water discharge from across the study area
7	Precipitation	Factor	The higher the precipitation the better.
8	Stream (river) order	Factor	Higher drainage value indicates that more tributaries are flowing into the stream.
9	Distance from settlement	Factor	The farther away the reservoir from settlement the better.

The decision hierarchy model of flood control reservoir siting was structured as shown in Figure 2. The hierarchy consists of the main objective at the top (Flood Control and Vulnerability Management Reservoir Siting), followed by three levels of hierarchy. The 9 criteria (also known as factors) used in this research were divided into three main groups; environmental, hydrological and economic factors, to form the second hierarchy. These were further split into 9 factors of which, five were environmental (slope, elevation, bedrock types, distance from faults lines and Soil), three were hydrological (rainfall, stream order and water discharge) and one was economic (Distance from settlements) to form the final hierarchy.

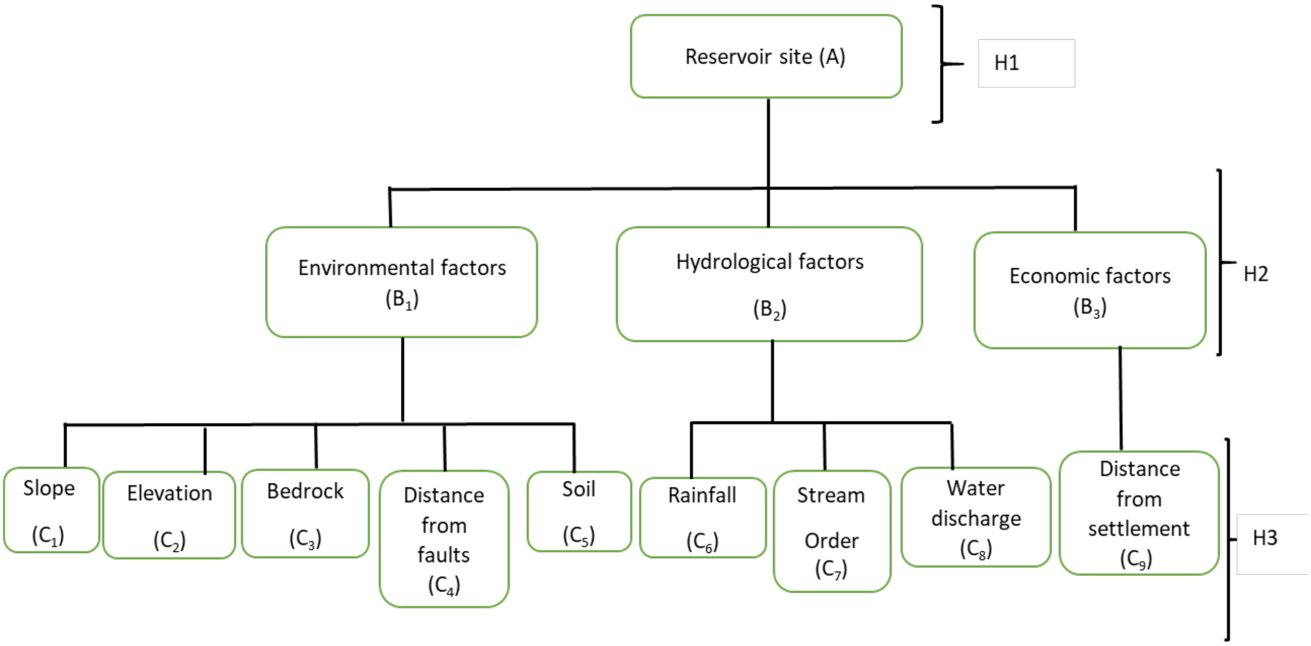

Figure 2: Hierarchical model for 9 inputs

Step 2: Factors/criteria's normalization. As different criteria have different range and dimension, they should be converted to a uniform standard in the same evaluation system (Lai *et al.*, 2015). The purpose of normalization is to eliminate the effects of value range and dimension. It involves assigning the same dimensionless scale to all the input/factor layers. In this work, each input layer was divided into 5 classes, a process which helped to standardize the layers since they all now use the same 1-5 dimensionless scale, indicating a variation from least suitable site to most suitable site (i.e. class 1 represents least suitable while class 5 represents most suitable). The RECLASS function in TerrSet IDRISI was used to accomplish this. Maps of all the reclassed factors were generated and used in the reservoir location suitability analysis.

Step 3: Weight determination

The procedure for obtaining weights in this study are as follows:

a. *Get pairwise comparison matrix using Fuzzy AHP extent analysis method* (Tsiko and Haile, 2011; Chang, 1996): The fuzzy TFNs proposed in the work of Putra *et al.* (2018), presented in Table 2 were utilized in this study to get the pairwise comparison matrix. The first step is to break down the complex decision-making problem into a hierarchical structure (as in Figure 2) before developing pairwise fuzzy comparison matrices. This is considered a prioritization problem at a level with n elements, where pairwise comparison judgments are represented by fuzzy triangular numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. As in the conventional AHP, each set of comparisons for a level requires $n(n-1)/2$ judgments. The fuzzy judgment matrices, $\bar{A}\,(\widetilde{a_{ij}})$, used to construct pairwise comparisons for criteria at each level of the hierarchy, were of the form shown in Equation 1 (Step 3 *b*).

Table 2: FAHP linguistic scales for relative importance (Putra *et al* 2018)

Linguistic scale for importance	Saaty's scale of relative importance	FAHP (Triangular fuzzy scale)	Triangular fuzzy reciprocal scale
Equally important	1	(1,1,1)	(1,1,1)
Intermediate 1	2	(1,2,3)	(1/3,1/2,1)
Moderately important	3	(2,3,4)	(1/4,1/3,1/2)
Intermediate 2	4	(3,4,5)	(1/5,1/4,1/3)
Important	5	(4,5,6)	(1/6,1/5,1/4)
Intermediate 3	6	(5,6,7)	(1/7,1/6,1/5)
Very important	7	(6,7,8)	(1/8,1/7,1/6)
Intermediate 4	8	(7,8,9)	(1/9,1/8,1/7)
Absolutely important	9	(9,9,9)	(1/9,1/9,1/9)

b. *Compute weights for each of the pairwise comparison matrix in (a) using a Fuzzy AHP based particle swarm optimization algorithm*: Although, the conventional fuzzy AHP method includes two additional steps to obtain weights for the pairwise comparison matrix as detailed in the work of Javanberg *et al.* (2012) and Chang (1996), our own approach skipped those steps. Instead, a fuzzy optimization model was used to calculate weights for the fuzzy AHP pairwise comparison matrix. Unlike the conventional fuzzy AHP method, the fuzzy optimization model method drives exact weights from consistent and inconsistent fuzzy comparison matrices, which eliminate the need for additional aggregation and ranking procedures. The method transforms a fuzzy prioritization problem into a constrained nonlinear optimization model. Thereafter, an improved particle swarm optimization (PSO) algorithm is then applied to solve the optimization model as a nonlinear system of equations (Javanbarg *et al*., 2012).

Consider a prioritization problem at a level with n elements, where pairwise comparison judgments are represented by fuzzy triangular numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. As in the conventional AHP, each set of comparisons for a level requires $n(n-1)/2$ judgments, which are further used to construct a positive fuzzy reciprocal comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ such that:

$$\tilde{A} = \{\tilde{a}_{ij}\} = \begin{bmatrix} \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{mn} \end{bmatrix} \quad (1)$$

Where $i \; and \; j = 1,2 \ldots \ldots n$. Moreover, it is assumed that$(l_{ij} < m_{ij} < u_{ij})$, when $i \neq j$. (*N/B: all equations are cull from Javanbarg et al., 2012*). The works of Chang (1996), and Tsiko and Haile (2011) describe in details the mathematical basis for developing pairwise fuzzy comparison matrices of the form in Eq. 1.

If $i = j$, then, $\tilde{a}_{ij} = \tilde{a}_{ji} = (1,1,1)$. Hence, an exact priority vector $(w_1, w_2, \ldots \ldots w_n)^T$ derived from $\tilde{A}$ must satisfy the fuzzy inequalities;

$$l_{ij} \tilde{\leqq} \frac{w_i}{w_j} \tilde{\leqq} u_{ij} \quad (2)$$

where, $w_i > 0, w_j > 0, \quad i \neq j$ and the symbol $\lesssim$ means "fuzzy less than or equal to". To measure the degree of satisfaction for different crisp ratios $\frac{w_i}{w_j}$ with respect to the double side inequality of equation (2), a new membership function can be defined as;

$$\mu_{ij}(w_i/w_j) = \begin{cases} \frac{m_{ij}-(w_i/w_j)}{m_{ij}-l_{ij}}, & 0 < \frac{w_i}{w_j} \leq m_{ij} \\ \frac{(w_i/w_j)-m_{ij}}{u_{ij}-m_{ij}}, & \frac{w_i}{w_j} \geq m_{ij} \end{cases} \tag{3}$$

Where $i \neq j$. Unlike the triangular membership function in Eq. 3, the value of $\mu_{ij}(w_i/w_j)$ may be larger than one and it is linearly decreasing over the interval $(0, m_{ij}]$ and linearly increasing over the interval $(m_{ij}, \infty]$. A smaller value of $\mu_{ij}(w_i/w_j)$ indicates that the exact ratio w_i/w_j is more acceptable.

To find the values of the elements of the priority vector$(w_1, w_2, \ldots \ldots w_n)^T$, all exact ratios w_i/w_j should satisfy $n(n-1)/2$ fuzzy comparison judgements, i.e. $l_{ij} \lesssim \frac{w_i}{w_j} \lesssim u_{ij}$ as possible as they can, where $i \; and \; j = 1,2 \ldots\ldots n, \; i \neq j, and \; \sum_{i=1}^{n} w_i = 1$. This last requirement is the main constraint of the conventional AHP method. Hence, the problem of crisp priorities assessment in Eq. 3 is transformed into an optimization problem. Assuming that the system of nonlinear equations in Eq. 3 is soluble and its solution is $(w_1, w_2, \ldots \ldots w_n)^T$, the solution is equivalent to minimizing a master function described as follows:

$$minJ(w_1, w_2, \ldots\ldots w_n) = min \sum_{i=1}^{n} \sum_{j=1}^{n} \left[\mu_{ij}^2\left(\frac{w_i}{w_j}\right)\right]$$

$$= \min \sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{n}} \left[\delta\left(m_{ij} - \frac{\mathrm{w_i}}{\mathrm{w_j}}\right)\left(\frac{m_{ij} - (w_i/w_j)}{m_{ij} - l_{ij}}\right)^2 + \delta\left(\frac{w_i}{w_j} - m_{ij}\right)\left(\frac{(w_i/w_j) - m_{ij}}{u_{ij} - m_{ij}}\right)^2\right] \tag{4}$$

Subject to:

$$\sum_{i=1}^{n} w_k = 1. \quad w_k > 0, \quad k = 1,2, \ldots \ldots, n \tag{5}$$

Where $i \neq j \; and \; \delta$ is Heaviside function defined as:

$$\delta(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases} \tag{6}$$

This prioritization model is a constrained nonlinear optimization model. General optimization algorithms limited to convex regular functions cannot be applied to this optimization problem. Particle Swam Optimization algorithim is applied to solve the system of nonlinear equations (Eq. 4 to Eq. 6). Researchers have documented more on fuzzy optimization models (e.g., Javanberg *et al*., 2012; Mikhailov, 2003).

The Particle Swam Optimization (Kennedy and Eberhart, 1995), is a simple model of social learning whose emergent behaviour has found popularity in solving difficult optimization problems (Wang *et al*., 2010). The initial analogy had two cognitive aspects, individual learning and learning from a social group. The original idea was to simulate the social behaviour of a flock of birds trying to reach an unknown destination (fitness function), e.g., the location of food resources with flying through the field (search space). In standard PSO, the swarm is manipulated according to the following updated equations (Shi, 2004):

$$v_{id}(t+1) = v_{id}(t) + c_1 r_1\big(p_{id}(t) - x_{id}(t)\big) + c_2 r_2\left(p_{gd}(t) - x_{id}(t)\right) \tag{7}$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \tag{8}$$

where $i = 1,2,\ldots\ldots,N$ is the particle's index, $d = 1,2,\ldots\ldots,n$ indicates the particle's *dth* components, c_1 and c_2 are the positive constants referred to as cognitive and social parameters, respectively and r_1 and r_2 are random numbers uniformly distributed in [0,1], denoted as $r_1, r_2 \in [0,1]$. Consider the *dth* dimension of the search space, $d = 1,2,\ldots\ldots,n$. The right-hand side of Eq. 7 consist of three parts (Shi, 2004). The first part $v_{id}(t)$ is the momentum part. The second part is the ''cognitive'' part which represents personal thinking of itself-learning from its own flying experience. The third part is the ''social'' part which represents the collaboration among particles learning from group flying experience.

In fact, the sum of the last two parts, i.e., $c_1r_1\left(p_{id}(t) - x_{id}(t)\right) + c_2r_2\left(p_{gd}(t) - x_{id}(t)\right)$, can be considered as the newly gained velocity term towards a potential position in the promising region around $p_{gd}(t)$ and $p_{id}(t)$. Consequently, summing the momentum part and gained velocity part results in the current velocity$v_{id}(t+1)$. However, these two terms do not consider the influence of the feasible region. For example, each or both of these two components might be so large that the corresponding particle would leave far away from the feasible region. One problematic characteristic of PSO is its propensity to converge, prematurely, on early best solutions. Many strategies have been developed in attempts to overcome this but by far the most popular are inertia and constriction presented respectively in Eq. 9 and Eq. 10 (Shi and Eberhart, 1998);

$$v_{id}(t+1) = \omega v_{id}(t) + c_1r_1\left(p_{id}(t) - x_{id}(t)\right) + c_2r_2\left(p_{gd}(t) - x_{id}(t)\right) \qquad (9)$$

where, ω is a parameter known as inertia weight. Eberhart and Shi (2000) indicate that the optimal strategy is to initially set ω to 0.9 and reduce it linearly to 0.4, allowing initial exploration followed by acceleration toward an improved global optimum. Constriction (Clerc and Kennedy, 2002), χ, alleviates the requirement to clamp the velocity and is applied as follows:

$$\mathrm{v_{id}(t+1)} = \chi\{\mathrm{v_{id}(t)} + \mathrm{c_1r_1}\left(\mathrm{p_{id}(t)} - \mathrm{x_{id}(t)}\right) + \mathrm{c_2r_2}\left(\mathrm{p_{gd}(t)} - \mathrm{x_{id}(t)}\right)\} \qquad (10)$$

where

$$\chi = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}, \quad \varphi = c_1 + c_2 > 4$$

Javanbarg *et al*. (2012) explained that a constant φ = 4.1 was used in the work of Eberhart and Shi (2000) to ensure convergence. The values obtained are χ = 0.72984, and $c_1 = c_2$ = 2.05. Furthermore, if the system of nonlinear equations (Eq. 3) is represented in the form shown in Eq. 8, then PSO can be applied to solve equations. The system of nonlinear equations (Eq. 11) is equal to the optimization problem in Eq.7:

$$\begin{cases} f_1(x_1, x_2 \ldots\ldots, x_n) = 0 \\ f_2(x_1, x_2 \ldots\ldots, x_n) = 0 \\ \quad - - - - - \\ \quad - - - - - \\ f_n(x_1, x_2 \ldots\ldots, x_n) = 0 \end{cases} \qquad (11)$$

$$minf(x) = \textstyle\sum_{i=0}^{n} f_1^2(x) \qquad (12)$$

Thus, the master function presented in Eq. 4 is similar to Eq. 12, and PSO can be applied to solve the optimization problem (Eq. 4). The PSO algorithm is presented as follows (Javanbarg *et al.*, 2012):

(1) Setup up the control parameters, and iteration $t = 1$;

(2) Initialize position $x_i = (x_{i1}, x_{i2},\ldots x_{in}) \in S$ and velocity $v_i = (v_{i1}, v_{i2},\ldots v_{in}) \in S$ of each particle *I;*

(3) Update position of each particle $p_i = (p_{i1}, p_{i2},...p_{in}) \in S$;
(4) Evaluate objective (fitness) function of each particle $f(x_i)$;
(5) Update personal best position P_{id} (t) for each particle and swarm best position P_{gd} (t);
(6) If $f(x_i) < P_{gd}$ (t), output the best position (global solution); and
(7) Otherwise, update iteration, $t = (t-1)$ and repeat the steps 3–6.

MATLAB software was used to implement the PSO algorithim used for solving the nonlinear optimization to derive the weights in the pairwise comparison matrix. Weights for the pairwise comparison matrix in Tables 3 to 6 were derived using steps (a) and (b). Fuzzy Consistency Ratio (FCR) was used in determining consistency of generated weights. The method used is that proposed by Modarres *et al.* (2010), which is based on the preference ratio concept. More details on the mathematical concepts can be found in Modarres *et al*, (2010); Tsiko and Haile (2011). The preference ratio (or FCR) of all comparison made for the criteria at each hierarchical level in this study are less than 10% (0.1), which indicated that the weights were acceptable (Tables 3 to 6).

Table 3: The pairwise comparison matrix A-B_{1-3}

A	B_1	B_2	B_3	Weights
B_1	111	2,3,4	4,5,6	0.6119
B_2	1/4, 1/3, 1/2	111	2,3,4	0.3108
B_3	1/6, 1/5, 1/4	1/4,1/3, 1/2	111	0.0773

A = Water reservoir site suitability; B_1 = Environmental factors; B_2 = Hydrological factors; B_3 = Economic factors. FCR =0.00213

Table 4: The pairwise comparison matrix B_1-C_{1-5}

B_1	C_1	C_2	C_3	C_4	C_5	Weights
C_1	111	2,3,4	4,5,6	6,7,8	7,8,9	0.4522
C_2	1/4, 1/3, 1/2	111	2,3,4	4,5,6	6,7,8	0.3086
C_3	1/6, 1/5, 1/4	1/4, 1/3, 1/2	111	2,3,4	3,4,5	0.1256
C_4	1/8, 1/7, 1/6	1/6, 1/5, 1/4	1/4,1/3, 1/2	111	2,3,4	0.0667
C_5	1/9, 1/8, 1/7	1/8, 1/7, 1/6	1/5,1/4, 1/3	1/4,1/3,1/2	111	0.0469

B_1 = Environmental factors; C_1 = Slope; C_2 = Elevation; C_3 = Bedrock; C_4 = Distance from stream; C_5=Soil. FCR =0.00213

Table 5: The pairwise comparison matrix B_2-C_{6-8}

B_2	C_6	C_7	C_8	Weights
C_6	111	2,3,4	4,5,6	0.6119
C_7	1/4, 1/3, 1/2	111	2,3,4	0.3108
C_8	1/6, 1/5, 1/4	1/4, 1/3, 1/2	111	0.0773

B_2= Hydrological factors; C_6 =rainfall; C_7 = water discharge; C_8 = stream order. FCR =0.00213

Table 6: The pairwise comparison matrix B_3-C_9

B_3	C_9	W (weight)
C_9	111	1

B_3= Economic factors; C_9 = distance from settlements. FCR =0.00213

c. *Compute the final weights using a hierarchical process as described by Chang (1996).* The weights of every latest factor in Table 7 to the main objective of the hierarchy (A) was calculated by normalizing the weights of each factor in Tables 3 to 6. This was done by multiplying the weight of a factor in the lower level by that of the elements in the upper level as long as they are directly related in the hierarchical structure.

Table 7: Hierarchical structure

Goal A	Hierarchy B	Hierarchy C
A	B_1	C_1
		C_2
		C_3
		C_4
		C_5
	B_2	C_6
		C_7
		C_8
	B_3	C_9

This was done for all the input layers and the results are shown in Table 8. The sum of the final weight is 1, a requirement which must be fulfilled during the process of assigning weights.

Table 8: Final weight

Goal A	Hierarchy B	Hierarchy C	Final weight (new)	Name
A	B_1	C_1	0.27670118	Slope
		C_2	0.18883234	Elevation
		C_3	0.07685464	Bedrock
		C_4	0.04081373	Distance from Faultline
		C_5	0.02869811	Soil
	B_2	C_6	0.19017852	Rainfall
		C_7	0.09659664	Water discharge
		C_8	0.02402484	Stream order
	B_3	C_9	0.0773	Distance from settlement

Step 4: *Aggregation*. The Weighted Linear Combination (WLC) algorithm from IDRISI software MCE module was utilized to combines the information from the various factors and constraint. This method multiplies each standardized factor map (obtained in step 2) by its factor weight then sums the results. This process was done on a pixel by pixel basis and it yielded a suitability map with the same range of values as the standardized factor maps that were used. The factor maps were first converted to byte binary format before being used. Furthermore, the result was then modified. This was done by multiplying the results by the constraint map to mask out the areas unsuitable for siting a water reservoir (Eq. 13). The constraint map is a binary coded image showing all areas in the study area were siting of a water reservoir was simply not possible. These areas were assigned a value of zero (0) whilst the other areas (were siting of a water reservoir was possible) were assigned a value of (1).

$$\boldsymbol{S} = \sum W_i x_i * r_j \tag{13}$$

where $\mathrm{S} = \text{suitability}$, $\mathrm{W_i} = \text{weight of factor i}$, and $\mathrm{x_i} = \text{factor i}$, and $\mathrm{r_j} = \text{river network constraint j}$

The final outcome of Eq. 13 is a map showing suitable sites for locating water reservoirs.

Step 5: *Reservoir storage*: Reservoir siting is also affected by the volume of water that can be stored at a particular location (Tsiko and Haile 2011). To calculate the volume of water that can be stored at each of the reservoir sites, the methodology proposed by Liebe *et al*., (2005) (Equation 14) was adopted. Liebe *et al*. (2005) work was conducted in West Africa with similar environmental condition with this present study. This was also used in the work of Tsiko and Haile (2011). To determine the precision of the model, Tsiko and Haile (2011) noted that evaluation of the goodness of fit between measured and modelled volumes using Eq. 14 explains 97.5% of the measured variance despite the variety of reservoir shapes used.

$$Volume = 0.00857 * Area^{1.4367} [m^3] \tag{14}$$

A volume map was created in IDRISI software and published in ArcGIS software environment. The volume map was then, reclassified to identify the best three classes in terms of potential water volume; best volume site, very good volume site and good volume site. Furthermore, the volume map was overlaid on the suitability map. The output of the overlay will enable us to obtain two categories of potential suitable sites based on volume of water and suitability values. The two categories obtained are labelled as best site and very good sites. In order to understand the spatial distribution with respect to Local Government Areas (LGAs), LGAs shapefile was obtained and overlay analysis were carried out with the potential suitable sites, the volume map and river network. Maps showing the best two possible reservoir sites based on suitability values and volume per local government area and the best two possible reservoir sites along with the river network based on suitability values and volume per local government area is produced.

Furthermore, ALOS PALSAR DEM of 12.5m resolution was engaged in ArcGIS software environment for profile processing and generation of other characteristics of the proposed flood control reservoir sites. A Triangulated Irregular Network (TIN) layer, and contour line layer were derived from the DEM and used. Cross profile of each of the sites were drawn and reservoir characteristics such as reservoir height, reservoir width, and reservoir elevation were identified. ArcGIS 3D Analyst tool was used to calculate the maximum storage capacity and maximum reservoir surface area.

Step 6: Verification of proposed reservoirs location*.* Field verification for the purpose of comparison, identification of potential impact, and baseline survey data gathering was carried out at this stage. Baseline information is intended to establish the present state of the environment, taking into account changes resulting from natural events and other human activities (Glasson, 1994; Canning *et al*., 2003). Global Positioning System (GPS) and Electronic Distance Meter (EDM) were some of the equipment used. Other relevant information were sourced from focused discussion and literature. Baseline information sourced form field survey include vegetation pattern, biodiversity (flora - vegetation types; and fauna - animal life), distance from closest settlement, land ownership, local land uses, waste disposal (cemetery where the communities bury their dead ones), and occupational pattern. Moreover, others are soils, water resources, cultural or historically important site(s), and drainage identified within the study influence areas for each Local Government Areas. The potential impacts and mitigation investigated in this study focused physical, and socio-economic.

3.0 APPLICATION-RESULTS AND DISCUSSION

3.1 Suitable site for flood control reservoirs

Criteria for flood control reservoir were applied in this study based on considerations from relevant literature, and experts' opinion. Nine essential criteria considered as input factors and a constraint affecting the siting of flood control reservoirs are slope, elevation, bedrock types, distance from faults lines, soil, rainfall, stream order, water discharge, and distance from settlements. The only constraint considered in this study is river network. Standardized factor maps were generated for the analysis using TerrSet IDRISI and ArcGIS environment. The aggregation of information from the factors and constraint on a pixel by pixel basis using the Weighted Linear Combination method yielded a suitability map with the same range of values as the standardized factor maps that were used. The final outcome is presented in Figure 3 showing suitable sites for locating water reservoirs in different classes, (ranging from 0-1, 1.000000001- 2, 2.000000001 – 3, and 3.000000001 – 3.472264767). Figure 4 shows the two most suitable potential best sites (class 1 and class 2) based on suitability values obtained from equation 13. Class 1 is the most suitable followed by class 2. (Reclassification was done to obtain the two most suitable sites per local government based on suitability values obtained from equation 13).

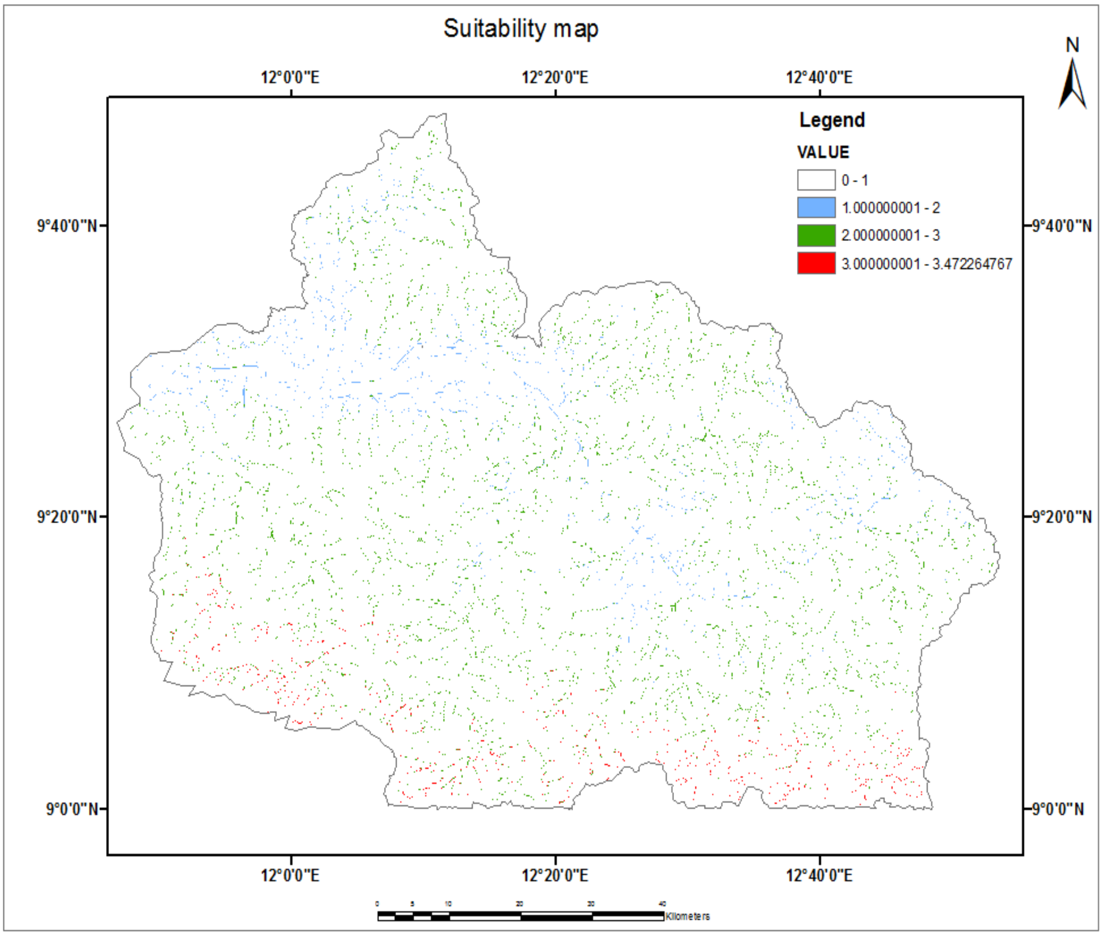

Figure 3: Suitable sites in different classes

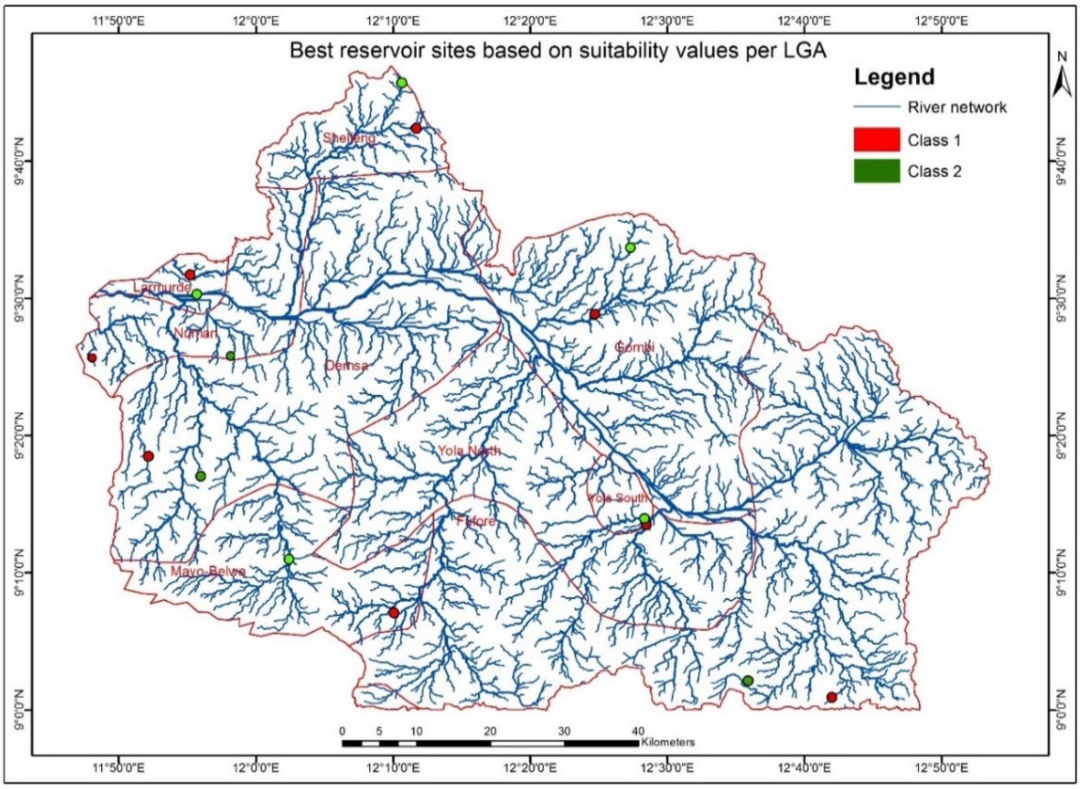

Figure 4: Most suitable potential best sites based on suitability values

3.2 Final Suitability Maps based on volume calculation

Since the volume of water that can be stored in a location influences reservoir siting, the final suitability map in this study was produced based on volume calculation. Water volume for each location was calculated following the methodology described earlier in section 2.2. A volume map was created in TerrSet IDRISSI software and published in ArcGIS as shown in Figure 5. The volume map was reclassified in Figure 6 to remap the raster values (or change the values) into a range that is not overlapping. This helps to identify the best three classes in terms of potential water volume; best volume site, very good volume site and good volume site. Overlay analysis was carried out with the volume map, the suitability map, and river network of the study area. The output of the overlay analysis resulted in two categories of potential suitable sites based on volume of water and suitability values. The two categories obtained are best site and very good sites. Figure 7 is the map of the best two possible reservoir sites along with the river network based on suitability values and volume per local government area. Table 9 shows the overall reservoir sites in two categories (best site: reservoir 1 to reservoir 18 or R1-R18; and very good sites: S1 to S18), and their coordinates. The total numbers of candidate sites identified are 36. The best sites are 18 and the very good sites are also 18 (Table 9). The volumes in different classes in each local government are also summarized in Table 9.

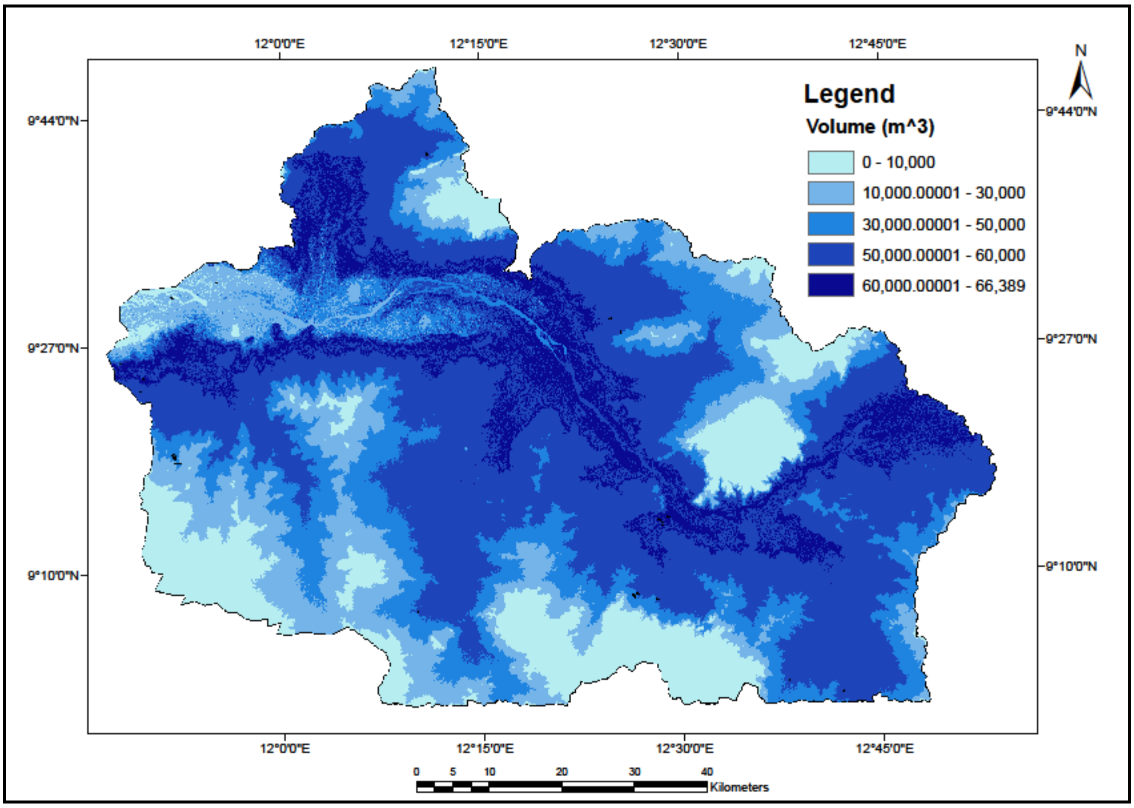

Figure 5: Volume map

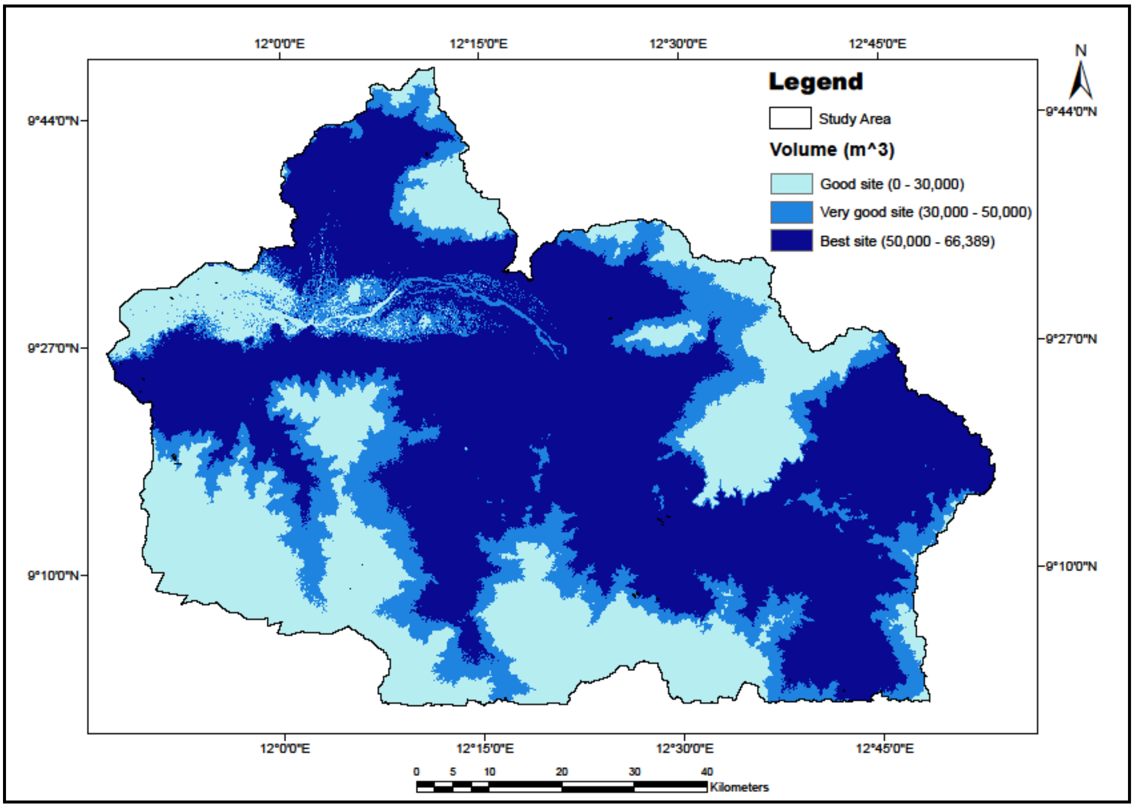

Figure 6: Reclassified Volume map

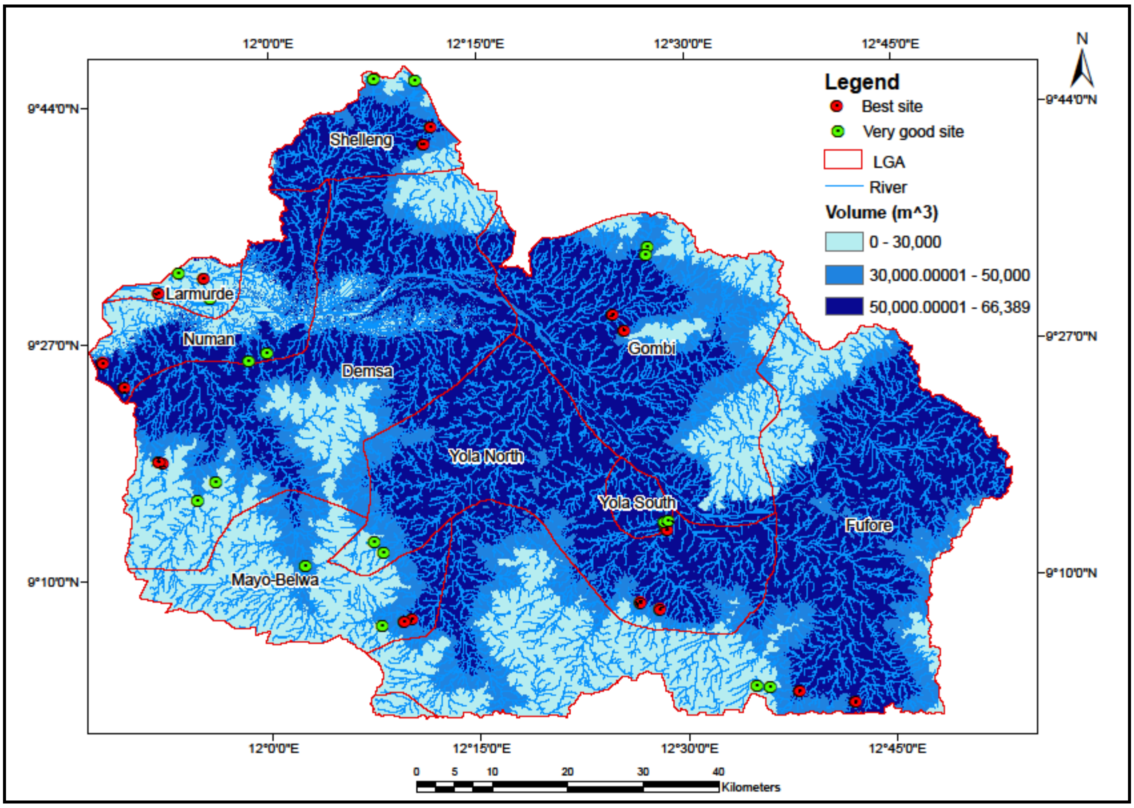

Figure 7: Map of reservoir sites on the river network

Table 9: Overall best sites in each category, estimated volume capacity and coordinates

LGA	ID	Class	Coordinates		Volume (m^3)	Distance from closest Settlement
			Longitude	Latitude		
	R1	Best sites	11.8	9.429	5e4 ≥ volume ≤	2.37km from Ngbalapin
Numan	R2		11.824	9.399	66.4e3	7km from Ngbalapin
	S1	Very good	11.974	9.43		800m from Dowaya
	S2	sites	11.996	9.439		3km from Ngbolung
	R3	Best sites	12.4426	9.136	5e4 ≥ volume ≤	4km from Gujibabu
Yola North	R4		12.466	9.128	66.4e3	1.9km from Bantaje
	S3	Very good	12.134	9.199	3e4 ≥ volume <	2.5km from Bakurehi
	S4	sites	12.123	9.211	5e4	1.6km form Dalehi
	R5	Best sites	12.474	9.226		600m from Yola
Yola South	R6		12.477	9.224	5e4 ≥ volume ≤	7km from Jimeta
	S5	Very good	12.472	9.232	66.4e3	450m from Jimeta
	S6	sites	12.477	9.233		850m from Yola
	R7	Best sites	11.92	9.529	5e4 ≥ volume ≤	1.52km from Chumun
Larmurde	R8		11.865	9.511	66.4e3	7km from Kabawa
	S7	Very good	11.928	9.505	3e4 ≥ volume <	300m from Opalo
	S8	sites	11.89	9.535	5e4	3km from Giwano
	R9	Best sites	12.195	9.707	5e4 ≥ volume ≤	1.5km from Lakati
Shelleng	R10		12.186	9.687	66.4e3	1.3km from Lakati
	S9	Very good	12.177	9.763	3e4 ≥ volume <	3.2km from Junkulum
	S10	sites	12.127	9.765	5e4	1.3km from Lainde-Dama
	R11	Best sites	12.168	9.118	5e4 ≥ volume ≤	2.5km from Nyibango
Mayo-Belwa	R12		12.158	9.116	66.4e3	3.2km from Nyibango
	S11	Very good	12.04	9.183	3e4 ≥ volume <	3km from Gumari
	S12	sites	12.132	9.111	5e4	3.2km from Wuro-Jombe
	R13	Best sites	12.412	9.481	5e4 ≥ volume ≤	3km from Karal
Gombi	R14		12.426	9.462	66.4e3	4k from Karal
	S13	Very good	12.455	9.562	3e4 ≥ volume <	2.4km from Baijam
	S14	sites	12.453	9.553	5e4	2.5km from Baijam
Fufore	R15	Best sites	12.7	9.015	5e4 ≥ volume ≤ 66.4e3	2.5km from Wuro-Babawo
	R16		12.633	9.028		2.92km from Luggarewo
	S15	Very good	12.592	9.035	3e4 ≥ volume <	1.02km from Dorodi
	S16	sites	12.598	9.034	5e4	1.64km from Dorodi
	R17	Best sites	11.869	9.308	5e4 ≥ volume ≤	3.5km from Bali
	R18		11.867	9.309	66.4e3	3.5km from Bali
Demsa	S17	Very good	11.911	9.263	3e4 ≥ volume <	3.5km from Gada
	S18	sites	11.933	9.284	5e4	3km from Gada

Site ID: R1 – R18 (Reservoir 1 to Reservoir 18) = Best sites; S1 – S18 = Very good sites

3.3 Proposed reservoir sites profile

Information regarding profile and other characteristics of the proposed flood control reservoir sites were obtained for the best sites (Reservoir 1 to Reservoir 18) according to the location of the sites. Profile of the reservoirs consisting of cross sections and other reservoir characteristics such as height of reservoir, elevation of reservoir, width of reservoir, surface area of reservoir, and storage capacity of reservoir were derived with digital elevation model, 1m contour and triangulated irregular network in ArcGIS environment. The cross sections of the best sites are displayed in Figure 8. No specific interval was used for the height identification. Consideration for possible heights of reservoirs were at the base, midway and top of the reservoir due to the topography distribution. Width of reservoir were generated according to cross profiles and height of reservoirs. The profiles of the proposed reservoirs are shown in Table 10.

This study revealed that in all the 18 proposed best reservoirs, maximum height of reservoirs corresponding to cross section of reservoir locations varies from 3m to 11m; width of reservoir varies from 140m to 680m; following topographic distribution, the maximum storage capacity varies from 66,768 m^3 to 4,242,975m^3; maximum surface area of the reservoir varies from 11,602m^2 to 955,871m^2. It was also observed that, the storage capacity of reservoir 4 reached a limitation while there was still space for larger reservoirs like reservoir 11, reservoir 14, and reservoir 17. This is believed to be due to the lower elevation surrounding most parts of the catchment boundary than the maximum reservoir height.

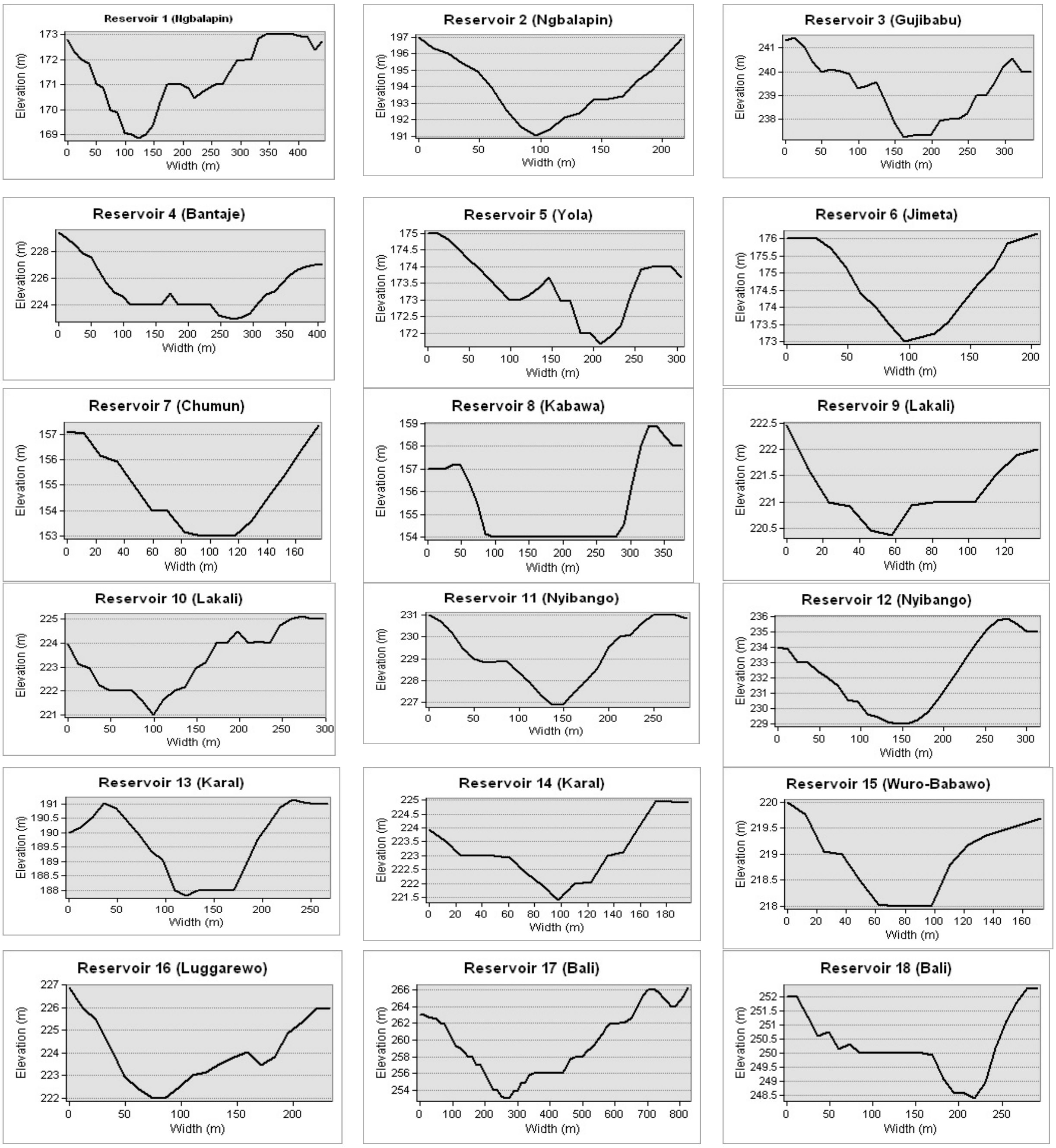

Figure 8: Cross section of proposed reservoir sites

Table 10: Parameters of proposed reservoirs

Site ID	Elevation (m)	Height (m)	Width (m)	Storage Capacity (m^3)	Surface Area (m^2)
Reservoir 1	169	0	0	0	0
	171	2	200	382,069	153,696
	173	4	340	786,583	257,455
Reservoir 2	191	0	0	0	0
	194	3	140	2,519,854	506,064
	197	6	220	4,242,975	641,278
Reservoir 3	237	0	0	0	0
	239	3	160	139,582	71,334
	241	4	310	326,286	116,498
Reservoir 4	223	0	0	0	0
	225	2	200	1,055,391	527,695
	227	4	420	1,055,391	527,695
Reservoir 5	171	0	10	0	0
	173	2	150	7,451	13,975
	175	4	260	72,806	54,759
Reservoir 6	173	0	0	0	0
	175	2	100	27,489	32,652
	176	3	205	66,765	44,876
Reservoir 7	153	0	0	0	0
	155	2	90	77,704	11,602
	157	4	180	100,900	11,602
Reservoir 8	154	0	300	0	0
	155.5	1.5	400	16,478	329,562
	157	3	500	494,343	329,562
Reservoir 9	220	0	0	0	0
	221	1	80	51,187	236,789
	222	2	140	287,976	51,187
Reservoir 10	221	0	0	0	0
	222.5	1.5	100	1,545,905	386,476
	224	3	200	2,318,858	386,476
Reservoir 11	227	0	0	0	0
	229	2	150	1,742,230	348,446
	231	4	250	2,439,122	348,446
Reservoir 12	229	0	0	0	0
	232	3	150	196,679	138,421
	234	5	240	214,767	141,250
Reservoir 13	188	0	50	0	0
	190	2	150	872,769	436,384
	191	3	230	1,309,154	436,384
Reservoir 14	221	0	0	0	0
	223	2	100	1,911,742	955,871
	224	3	180	2,867,613	955,871
Reservoir 15	218	0	0	0	0
	219	1	80	826,273	206,568
	220	2	160	1,445,979	206,566
Reservoir 16	222	0	0	0	0
	224	2	120	8,290	25,943
	226	4	300	175,907	134,617
Reservoir 17	252	0	0	0	0
	260	8	380	1,888,329	944,164
	263	11	680	2,832,493	944,164
Reservoir 18	248	0	0	0	0
	251	3	150	896,453	224,113
	252	4	230	1,344,680	224,113

3.4 Verification/validation results

(A) Baseline environmental conditions: Field verification was conducted in this study to establish the baseline environmental conditions of the reservoir candidate sites. Findings from the field verification shows that the general vegetation pattern of the study area is basically savannah, characterized by mixtures of scattered trees, shrubs, grasses, and herbs. The scattered trees noticed in most of the sites include Prosopis Africana, Daniella oliveria, Acacia polyacantha, Citrus aurantium, Lannea acida, Tarmarindus indica, Adansonia digitata, Balanite aegyptica, Xymenia Americana, and Terminalia glaucescens. The dominant trees include Lannea acida (Faru), Terminalia glaucescens (Baoshe), Prosopis Africana (Kirya), Acacia polyacantha (Kantakara), and Daniella oliveria (Maje) with little riparian vegetation along river /stream courses. Regarding distance from closest settlement, the study observed that majority of the proposed reservoir locations are not within or in close proximity to settlements. Out of the 36 suitable sites selected, only 3 of the sites are in close proximity (less than 800m threshold) to settlement (Table 9). They are: Opalo site (in Lamurde LGA) which is 300m from Opalo settlement; and two sites in Yola South LGA which are respectively 450m and 600m from Yola town. These are settlements that may have direct/indirect effect on the quality of water to be stored in the proposed reservoirs particularly those located or have access to the upstream locations of the reservoirs. Apart from Yola and Numan towns all other settlements are remotely located. Communities within the investigated area (Lamurde, Funfore, Demsa, Opalo, Numan, etc), are inhabited by the native landowners. These communities satisfy their water needs from rivers, perennial streams, water ponds and hand-dug wells. The investigation also shows that the proposed sites are inhabited by different tribes. Bachama/Bata (Bwatiye) languages are the major medium of communication. Other languages spoken around the locations are Vere, Fulani, Nyandang, Kanakuru, Yandang, Mumuye, and Mbula.

On waste disposal locations, no sign of cemetery where the communities bury their dead ones was identified within or in close proximity with any of the proposed reservoir sites. Areas with cemetery are not recommend for reservoir because it historic and has to do with heritage. Since the communities are more of rural, the people use pit latrines and/or bush to discharge their excreta. Contaminations of reservoir are envisaged from excreta discharged in the bushes. Finding from the investigation of occupational pattern of people revealed that, majority of the people are farmers. Cattle rearing was also identified as a major occupation, while village communities living on the river banks engage in fishing and farming. Irrigation farming was noticed in some of the project areas.

Different types of soils were identified within the project influence areas but loamy soils were predominant in all the reservoirs location except the sites at Shelleng and Lamurde LGAs wherein brown clay soils and black clay soils were respectively predominant. Other soils noticed include clay soils which are good for rice cultivation, and sandy soils. From Fauna verification, identified animal life in the project influence areas were insects, signs of grazers (antelopes), rodents, and birds. The presence of cows, sheep, donkey, horse, and goats were also noticed in some of the areas. Investigation on the state of water resources show that, currently apart from the Kiri dam at Shelleng, there is no other water dam in the areas. Also, there is no evidence of underground water tank for water storage or laid pipe network noticed in the areas. Field investigation regarding drainage revealed that, apart from the sites in Numan LGA which is largely flat topography with dry drainage valleys, all other locations are well drained with wet river valleys evident. Storm water drains were also visible in some areas.

The study identified cultural or historically important site (s) in most of the areas. For example, *Bolon shrine at Numan (they are* traditional places the Bachama people visit to settle dispute among themselves through swearing or seek the help of the gods of the land before going to war); Fare-Fare (a cultural festival for the whole Bwatiye federation that comes up once a year. Showcasing dancing, traditional wrestling and initiation of male child was identified at the sites in Demsa); Ngurore international cattle market which have existed for a very long time is within the project influence area (people come from all West African and Central African countries to buy cattle in the market at Yola North); the international horse racing event in Yola town that comes up once in a year (Horse racers come from mostly West and North African countries for the event); and Kiri dam at Shelleng (a famous dam where yearly fishing competition take place). The dam was initially constructed for electricity generation but later on, it was changed to water supply dam, irrigation farming and fishing activities. The only areas with no cultural or historically important site are the reservoir locations in Fufore, Gombi, and Mayo Belwa LGAs.

(B) Potential impact and mitigation: Generally, communities downstream or upstream would experience reservoir impact in one way or the other. The downstream communities would suffer the downstream impacts of the reservoirs such as reduced availability of river water (especially during dry season) to downstream users. These could be mitigated by ensuring penstock releases to mimic minimum ecological flows. Communities upstream would have effects of the quality of water stored in the reservoirs. Ensuring that the reservoirs are not in close proximity from settlements could be a mitigation measure. Other areas of impact would be people affected by land-take and/or loss of crops, river bed erosion, landslides that would happen as a result of the water fluctuations of the reservoir and increased moisture in the lands around the reservoir. Compensation for farm crops and/or economic plants and liaising with chiefs to allocate alternative land to farmers could address the issue of loss of control and income of land to be inundated by the reservoir. Another potential impact is reduction from nutrient sediment transportation. Reduction in sediment transport downstream would affect floodplain agriculture as nutrient that settles on the plains when flood water recede will drastically reduce and farmers would be forced to depend on agricultural fertilizers. The point is that indiscriminate and unconscious usage of these fertilizers reduce the quality of river water and groundwater in the long term periods as observed by Mahmouei *et al*., (2017). All in all, the advantages that would be derived from the flood control reservoirs are far great and should compensate for the negative effects. Following the consideration that five of the areas were in close proximity to settlements the identified sites were reduced to 33 flood control reservoirs.

4.0 CONCLUSION

The main aim of this present study is to identify suitable location for siting flood management reservoirs with which to catch flood, prevent jump and reduce congestion of runoff in the plains of Adamawa catchment. Spatial information regarding suitable locations for designing and constructing reservoirs obtained through scientific analysis is important to decision makers for implementing long term solution to flood threat in the Benue River basin. PSO based Fuzzy AHP and Fuzzy Extent Analysis Method has thus been applied. The method spatially analyses nine essential criteria. The criteria are elevation, slope, bedrock, soil, precipitation, water discharge, distance to settlements, distance to fault lines and stream order. River network was used as constraint in this study. The Weighted Linear Combination was adopted as method of aggregation. Weights is assigned to each criteria to reflect their relative importance using a series of pairwise comparison judgment matrices. The consistencies of the weights were checked and results indicate that the matrices are reasonably consistent. The Benue River basin particularly

Adamawa catchment has witnessed seasonal flood disaster arising from current climate changes in recent time. The study provided a methodology for solving the flood problem experienced in the investigated area through reservoirs site selection. Field work was conducted and most of the sites identified correspond with field based study.

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