

**SITE SELECTION ANALYSIS FOR FISH POND FARMING IN KAFUE  
DISTRICT, ZAMBIA: A MULTI-CRITERIA EVALUATION APPROACH**

**By**

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**A dissertation submitted to the University of Zambia in partial fulfilment of the  
requirements of the degree of Masters in Geo-information and Earth  
Observation Science**

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## **DECLARATION**

I, Muzamba Martha Siachinga, do hereby declare that this dissertation is my own work and that it has never been produced or submitted for any degree, diploma or other qualification at the University of Zambia or indeed any other university for academic purposes. I further declare that all published work and material from other sources used in this dissertation have been duly acknowledged.

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Muzamba Martha Siachinga

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## CERTIFICATE OF APPROVAL

This dissertation on Site Selection Analysis for Fish Pond Farming in Kafue District, Zambia: A Multi-Criteria Evaluation Approach has been approved as fulfilling the requirements for the award of the degree of Master of Science in Geo-information and Earth Observation Science by the University of Zambia.

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## ABSTRACT

Aquaculture site selection involves the identification of areas that are economically, socially, and environmentally suitable and available for fish farming. Site selection using conventional method is rather inefficient because it is slow, financially costly and it covers a very small area. Due to inaccurate site selection, fish farmers face challenges such as water seepage, fish mortalities, poor aeration, and poor water quality. To overcome these challenges, a multi-criteria evaluation method is used to allocate aquaculture fish ponds to suitable locations. The advantage is not only in time and cost effectiveness but also in achieving an integrated treatment of aquaculture development criteria, which is difficult through conventional techniques alone. This study determined suitable sites for on-land aquaculture in Kafue district using multi-criteria evaluation approach. It specifically determined the criteria for selecting suitable fish pond sites and develops a suitability map showing fishpond sites. Data were collected through remote sensing, key informant interviews, and focus group discussion. The data sets used were Kafue DEM, soils, roads, slope, rivers and 2019 Landsat images. Key factors identified were land use/cover type, soil type, distance to roads and rivers, slope and elevation. Data were analysed using content analysis, Microsoft excel and ArcGIS 10.1. Analytical Hierarchy Process (AHP) was used for ranking and developing relative weights called priorities to differentiate the importance of the criteria using pairwise comparison. Consistency ratio of 0.027 was obtained which is less than 0.10 hence the results were reliable. After this procedure was done, findings show that the most important factor was land use/cover type (43%) and the least was slope (3%). Results show that of the total area (459,890 Ha) of the study area, highly suitable sites cover (10.99%), suitable sites (33%), moderately suitable sites (49%), constraint (7%) and not suitable sites (0.01%). The most suitable land use/cover type was cropland and grassland near the Kafue River. Sites close to roads and wetland were suitable because it is easy to access water and sell fish in good time since fish is a perishable good. The findings imply that aquaculture would greatly improve if sites are selected using MCE. Four points of each class from the final suitability model were compared with field data and found to be consistent.

The study concludes that Site selection for aquaculture using Geographic Information System is accurate, quicker, cheaper and easier compared to conventional methods. The model can be used by fish farmers and stakeholders to make progressing decisions for their suitable site plan.

**Keywords:** Multi-criteria evaluation (MCE), analytical hierarchy process (AHP), weighted overlay.

## **DEDICATION**

I dedicate this work to my parents Artfellow Aaron Siachinga and Bessie Beenzu Siachinga, and to my daughters Charisa and Christeta.

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## ACRONYMS

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
CRI	Consistency Random Index
CW	Criteria Weights
DEM	Digital Elevation Model
FAO	Food and Agricultural Organisation
GCPs	Ground Control Points
GIS	Geographical Information System
GPS	Global Positioning System
Ha	Hectares
KML	Keyhole Mark-up Language
LULC	Land Use/Cover Type
MCE	Multi- Criteria Evaluation
MCDM	Multi-Criteria Decision Making
RCI	Random Consistency Index
RGB	Red, Green and Blue
RI	Random Index
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WLC	Weighted Linear Combination
WSV	Weighted Sum Value

## CHAPTER ONE: INTRODUCTION

### 1.1 Background of the study

Site selection using conventional method is inefficient because it is slow, uses a lot of money and it covers a very small area, which is, only the sampled area. This method uses humans to demarcate the areas suitable for aquaculture. For example, the method used to identify the soil suitability is cumbersome since someone has to keep rolling out balls of soil in the area and checking if the ball can easily roll. Various soils will be different when rolled out into a ball shape. This form of identification is rather tedious and uses a lot of time. Instead of the aforesaid labour-intensive and time-consuming method, Geographical Information System (GIS) and remote sensing techniques can be used to site aquaculture areas economically using less time at a larger scale (Mukami, 2010). Site selection for fish ponding farming using Multi Criteria Evaluation (MCE) overcome the disadvantages of conventional methods.

Aquaculture contributes directly and indirectly to income generating opportunities in Zambia, the country has an estimated 12,000 registered small-scale farmers (Genschick et al., 2017). Aquaculture refers to the cultivation, propagation or farming of fish, aquatic vegetation, or other living aquatic resources whether from eggs, spawn, spat, or seed, or by rearing fish lawfully taken from the wild or lawfully imported into the country, or by other similar process (Fisheries Act No. 22, 2011).

Multi Criteria Evaluation (MCE) is a method for combining data according to their importance in making a decision. MCE is perhaps the most fundamental of decision support operations in GIS (Jiang et al., 2000). The Boolean overlay operations and the weighted linear combination (WLC) methods have been the most frequently used approaches for land use suitability analysis (Malczewski 2006). The multi-criteria decision-making (MCDM) methods deal with the process of making decisions in the presence of multiple criteria. It is often used to solve various decision-making and/or selection problems and requires the decision makers to provide qualitative and/or quantitative assessments for determining the performance of each alternative with respect to each criterion, and the relative importance of evaluation criteria with respect to the overall objective in fish ponds site selection (Kuo et al., 2006).

The Analytic Hierarchy Process (AHP) in fish ponds site selection is an MCDM method based on priority theory. It deals with complex problems which involve the consideration of multiple criteria/alternatives simultaneously. Its ability to incorporate data and judgement of experts into the model in a logical way, to provide a scale for measuring intangibles and method of establishing priorities to deal with interdependence of elements in a system to allow revision of judgements in a short time to monitor the consistency in the decision-maker's judgements to accommodate group judgements if the groups cannot reach a natural consensus, makes this method a valuable contribution to the field of MCDM.

Geographic information system is a digital database management system designed to manage large volumes of spatially distributed data collected from a variety of sources. GIS is ideal for site selection studies because it efficiently stores, retrieves, analyse and display information according to user-defined specifications (Guiqin et al., 2009). Geographic information systems and remote sensing technologies, which facilitate the integration and analysis of spatial and attribute data from multiple sources, have been widely used for selecting suitable sites for different land uses. GIS-based MCDM involves the utilisation of geographical data, the decision maker's preferences, and the combination of data and preferences according to specified decision rules (Malczewski, 2006). Spatial MCDM is complex, large numbers of factors need to be identified and considered, with high correlated relationships among the factors (Malczewski 2004).

Suitability in fish ponds site selection is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (Humberto et al., 2019). Fish ponds site selection can be viewed as a spatial MCDM problem. It aims to achieve solutions for spatial decision problems, derived from multiple criteria. Site selection for aquaculture development is a complex task involving identification of areas that are economically, socially, and environmentally suitable and also be available for aquaculture (Mukami, 2010).

Selecting sites which may have the least environmental stress, maximum potentials for species growth, minimum production costs, and avoiding or at least minimizing potential conflict with other users is vital in fish pond site selection (Perez et al,

2005). Therefore, methods of selecting sites for fishponds are crucial for environmentally sustainable, and economically profitable, which optimises the available social conditions such as road infrastructure and cultural acceptability.

This study therefore applied multi-criteria evaluation approach in site selection analysis for fish pond farming in Kafue district in order to reduce the challenges experienced through conventional methods. Human population growth and high demand for fish has led to large quantities of fish being harvested from natural water systems at a large scale by fishers. This has resulted into decimation of some fish species and loss of certain fish species. Hence, such practices have shown to be unsustainable. Aquaculture in Kafue district is mainly practiced at a commercial scale; however, some small-scale fish pond famers have ventured into this activity.

## **1.2 Problem Statement**

Aquaculture has become one of the fastest growing agricultural activities in Zambia. It holds promising potential to meet the current fish deficit of about 85, 000 tonnes per year in the country (Shamilenge, 2019). Conventional methods such as physically collecting soil and water samples then testing them in the laboratory have commonly been used to select suitable sites for fish ponds. The Department of Fisheries uses conventional methods in site selection. However, selecting suitable sites using conventional methods has been rather ineffective and inefficient. These methods are slow because they require collection of soil and water samples of all required points *in-situ*; require a lot of money and are ineffective if large areas have to be covered and consequently, the methods mostly cover small areas (Mukami, 2010).

Currently, because of incorrect site selection using conventional methods, fish farmers in Kafue district are facing several challenges. The challenges being encountered include water seepage due to pond construction on unsuitable soils; fish mortalities resulting from predation by wild animals from protected areas/national parks; poor aeration in ponds due to siting on areas with inadequate water supply thereby leading to fish mortality; poor water quality if ponds are constructed where water quality is bad and as a result fish does not grow as expected and algae/planktons constantly grow in the pond competing for oxygen with the fish. As a consequence, there is poor harvest due to low production and lack of sufficient feed. The feed tends to be insufficient because of the long distances between the fish ponds and markets where

feed can be accessed. Other challenges experienced by fish farmers include access to natural capital (land and water) that is a critical entry point for aquaculture, high cost of inputs and equipment, availability of seed and feed, lack of finances, knowledge and skills (Kaminski et al, 2019).

In order to overcome these challenges, there is a great need to allocate fish ponds to suitable locations, by using Multi-Criteria Evaluation Method (Richard and Ogba, 2016). Site selection using GIS and remote sensing can be potentially a valuable tool in solving problems at a regional level. The advantage is not only in time and cost effectiveness but also in achieving a more comprehensive and integrated treatment of aquaculture development criteria, which is difficult through conventional techniques alone (Mukami, 2010). There is need of offering GIS training programmes in the Department of Fisheries so that officers attain knowledge in site selection for fish farming using Multi-Criteria evaluation method instead of the conventional method that is currently used. This will result into fish farmers facing less challenges and reduce labor for fisheries officers. Hence this study attempted to show how multi-criteria evaluation method can be utilized to speed up and make site selection for fish pond farming in Kafue district of Zambia more efficient.

### **1.3 Aim of the Study**

The aim of the study was to determine suitable sites for on-land fish pond farming in Kafue district, using multi-criteria evaluation approach.

### **1.4 Objectives**

- I. To determine the factors for selecting suitable fish pond sites in Kafue district, Zambia
- II. To determine the constraints for selecting suitable fish pond sites in Kafue district.
- III. To develop a suitability map showing fish pond sites in Kafue district.

### **1.5 Research Questions**

- I. What are the factors to be considered in selecting suitable fish ponds sites in Kafue district?

- II. What constraints need to be considered in selecting suitable fish ponds sites in Kafue district?
- III. Which sites are most suitable, moderately suitable, suitable, and not suitable for fish pond farming based on the factors and constraints?

### **1.6 Significance of the study**

The findings will contribute to literature on multi-criteria evaluation approach to site selection for suitable on-land fish farming, they will also benefit the Department of Fisheries in their decision making on selecting suitable on-land aquaculture sites. Furthermore, the findings will be relevant in the selection of suitable sites for fish pond farming hence attain sustainability and economic efficiency when developing aquaculture sites, this therefore meets the goal of environmental sustainability in Zambia's Vision 2030.

These findings will be vital in selection of fish pond sites that are correct, less time consuming, cover large areas and cheaper. The suitability map developed will be used to locate suitable fishpond sites hence making it easier for the fish farmer when a pond is dug knowing what kind of site they are dealing with. The value of using geo information techniques to determine suitable fish pond sites will be shown in that technicians are able to understand and interpret the model therefore vital to the fisheries sector.

When sites for on-land fish farming are selected correctly, Sustainable Development Goal number 14 whose mission is to "Conserve and sustainably use the ocean, seas and marine resources for sustainable development" will be achieved. This is so because when fish farming practice increases, they will be less pressure on capture fisheries on the Kafue River hence different fish species would be conserved for the future generation.

### **1.7 Organisation of dissertation**

The dissertation consists of six chapters. The first chapter is the introduction and comprises background of the study, problem statement, aim, research objectives, research questions and significance of the study. The second chapter reviews literature relevant to the study. Chapter three is made up of the description of the study area. Chapter four is research methodology which has data collection method, criteria for selecting suitable fish pond sites, data preparation and how the suitability map for fish

pond farming was produces. Chapter five is consists of results and discussion. Chapter six, which is the final one, has conclusions and recommendations drawn from the study.

## **CHAPTER TWO: LITERATURE REVIEW**

### **2.1 Introduction**

This chapter presents a review of relevant literature on site selection for on-land aquaculture using multi-criteria evaluation approach. It focuses on multi-criteria evaluation, analytical hierarchy process (AHP), criteria (factors and constraints) for selecting suitable fish pond sites and GIS in site selection. The review draws on site selection for fish farming from Iran, Bangladesh and Nigeria. This so because in the three countries factors and constraints similar to this study were considered.

### **2.2 Multi-Criteria Evaluation**

Multi-criterion evaluation (MCE) method is mostly applied for land suitability analysis. Multi-criterion evaluation of land suitability involves different criteria like geological and biophysical elements (i.e., geology, soil characteristics, relief, atmospheric conditions, and vegetation). It also involves economic and socio-cultural conditions in decision making process (Joerin et al., 2001) to solving different land problems with multiple alternatives (Yu et al., 2011). The multi-criteria decision-making (MCDM) methods deal with the process of making decisions in the presence of multiple criteria. This approach is often used to solve various decision-making and/or selection problems. It requires the decision makers to provide qualitative and/or quantitative assessments for determining the performance of each alternative with respect to each criterion, and the relative importance of evaluation criteria with respect to the overall objective (Kuo et al., 2006).

Multi-criteria decision-making were designed to define the relationship between data input and data output. MCDM methods can be broadly divided into either multi-objective or multi-attribute methods (Malczewski, 2004), and are primarily concerned with ways of combining several criteria to form a single evaluation index. In MCDM, each and every criterion is given a weight to represent its genuine importance in the phenomenon (Chow and Sadler 2010). Chen et al. (2010) stressed the importance of recognising the conditional state of the MCDM derived ranking weights. These are dependent on the nature of the alternatives under consideration, the criteria used to compare alternatives, and the weights derived for criteria (Al-Mashreki et al., 2011). The integration of GIS and MCDM methods provides powerful spatial analysis functions (Yu et al., 2009).

### **2.2.1 Analytical Hierarchy Process**

The Analytical Hierarchy Process is a flexible and yet structured methodology for analysing and solving complex decision-making problems by structuring them into a simple and comprehensible hierarchical framework (Boroushaki and Malczewski, 2008). The analytical hierarchy process, first proposed by Saaty (1980) is a popular method for solving multi-criteria analysis problems involving qualitative data (Coyle, 2004). Since its introduction, the AHP has become one of the most widely used MCDM methods (Lee et al., 2008). Pairwise comparison is the basic measurement procedure employed in the AHP method. This comparison is used in the decision-making process to form a reciprocal decision matrix, thus transforming qualitative data to crisp ratios, and making the process simple and easy to handle (Coyle, 2004).

The AHP is an effective means of dealing with complex decision making and can assist with identifying and weighting selection criteria, analysing the data collected for the criteria, and expediting the decision-making process. By making pairwise comparisons at each level of the hierarchy, participants can also develop relative weights to differentiate the importance of the criteria. The scale recommended by Saaty (1994) is from 1 to 9 was used in this study with 1 meaning no difference in importance of one criterion in relation to another and 9 meaning one criterion is maximally more important than another, with different degrees of importance in between. Reciprocals of these numbers are used to express the inverse relationship. (Boroushaki and Malczewski 2008).

Coyle (2004) suggested that the main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives. The further strength of the AHP is its ability to detect inconsistent judgements. The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other on the basis of preference factors. The weights can then be aggregated. GIS based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision-making problems (Hossain and Das, 2010).

The application of AHP process involves the following steps (Elaalem et al. 2011): Criteria or factors contributing to the set of suitable are identified; the relative importance of each factor to each other factor, i.e. between pairs of criteria. This is usually done by domain and experts' opinions; and the consistency of the overall set of pairwise comparisons is assessed using its Consistency Ratio.

Some of the weaknesses AHP has are that AHP utilisations accurate qualities for judgments, for instance in useful cases, the human emotions are obscure and the chiefs may be not able fix the careful numerical qualities to the examination judgments. For this situation AHP is not material. It can settle just direct models. AHP is difficult to use when the number of criteria is high for example more than 7. It is also difficult to add or remove a new criteria and, lastly, repeating evaluations to attain consistency is cumbersome (Feizizadeh and Blaschke, 2012).

According to Hossain and Das (2010) AHP may aid the decision maker to set priorities and make the best decision by: reducing complex decisions to a series of pairwise comparisons and then synthesizing the results. AHP helps to capture both subjective and objective aspects of a decision. It incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process. Subjectivity of AHP is later dealt with by the structured approach. This is so because they are different steps followed in AHP calculations. These combine all the rankings from different experts and different formulas in each step are used. AHP calculations later become objective by sticking to the existing formulas. This thereby incorporates the subjective judgements into the objective structured approach (Liberatore et al. 1992)

### **2.3 Criteria (factors and constraints) for selecting suitable fish pond sites**

For aquaculture site selection, ecological, biological, and social factors need to be considered. Ecological factors include; soil quality, water quality, water quantity, and topography. Biological factors include the following: the species to be cultured, availability of fingerlings, and seed source. Social factors such as proximity to all

weather road connection, availability of supplementary feeds, availability and cost of equipment (Pillay and Kutty, 2005).

### **2.3.1 Requirements for selecting aquaculture sites**

The four most critical criteria are adequate water, water quality, suitable soil type, and the appropriate topography.

Hora (1962) conducted a study on fish culture and his findings were that aquaculture requires large volumes of good quality water. Normally, a well or surface water source (river, stream or spring) is required. The source of water may be an irrigation canal, river, creek, reservoir, lake, spring, rainfall run-off and dug or deep wells. Water can be supplied through feeder channel, storage tank or pipeline by gravity or by pumping to the ponds. The most economical method is by gravity.

William (2013) further established that quality of water is one of the most significant factors to be considered in site selection, water must be of high quality and free of pollutants, sewage and toxic contaminants. Generally, water that is safe for livestock and domestic use or that supports wild fish populations is safe for aquaculture. A well-drained, gently sloping site (1-5%) is best for pond construction. Extensive earth moving may be required on land with slopes greater than these; increasing construction costs. The land should be free from deep flooding.

According to Pillay and Kutty (2005), an adequate amount of water is required to build the fish farm because water depth needs to be adjusted at regular intervals. Natural water bodies such as reservoir, river, and lakes have stable water quality parameters such as water temperature, dissolved oxygen, pH, alkalinity, and water hardness when compared to bore well and well water. The site should be away from the flood area. The ideal water temperature is 20-30°C for a fish farm.

Pillay and Kutty (2005) suggested that sandy clay to clayey loam is the best type of soil both for pond construction and growing natural foods at the pond bottom. Areas with a layer of organic soil over 0.60 m in thickness are unsuitable for any kind of fish pond, because it would be difficult to maintain water levels in the ponds due to high seepage. Big surface stones or rock outcrops may make an area unsuitable for anything except lined ponds or concrete raceways. Soils must be impervious more than 35% clay to ensure minimum water is not lost through seepage. Clay or clay-loam soils are ideal, the site must have soils that hold water and can be compacted. If pond levees

are constructed with soil that has high water permeability, the cost of pumping water could become prohibitive and uneconomic. Soils with high sand and silt compositions may erode easily and present a piping hazard. Soils classified between sandy loam and sand do not contain enough clay for pond construction. Silt loams and loams may or may not have adequate clay. Particle size is the determinant of how soil is classified.

It is also important to know the social and economic background of the area and understand the culture and traditions, particularly ideas and beliefs locally associated with aquaculture practices. The social fabric, market, and its structure, services directly or indirectly linked with aquaculture sector such as transportation, storage, wholesale market aspects are to be considered. The land identified for farm should be without legal issues and fish farming should be accepted by the local people. Other factors include availability of labour, electricity, medical facilities, and transportation (Pillay and Kutty, 2005). Sites or areas to be avoided include the following: sandy soil, rocky soil, sites with large trees, areas with intense acid sulphate soils and containing too high organic matter, areas near industrial or highly populated areas and National parks.

Feizizadeh and Blaschke (2012) identified four main criteria namely: topography, climate, soil properties, and water resources for irrigation selected based on local expert knowledge. Eight causal factors, including elevation, slope, aspect, soil fertility, soil PH, temperature, precipitation, and groundwater were then selected. The causal factors were chosen based on the four main criteria but also under consideration of literature inputs and data availability.

#### **2.4 GIS in Site Selection**

GIS is an important tool for aquaculture industry. It can be used to monitor, qualify, and evaluate best aquaculture sites, management concerns such as water quality, resources sustainability as well as the economic viability of a selected species resources can be assessed within a GIS environment. Collecting appropriate data for aquaculture site assessment is required if a resource is to be managed effectively. GIS applications provides insight into the quality of the physical and socio-economic environment as well as the sustainability of resources. GIS-based MCDM involves the utilisation of geographical data, the decision maker's preferences, and the combination of data and preferences according to specified decision rules (Malczewski 2006).

Image classification process involves grouping the image pixel values into meaningful categories and classes. There are several satellite image classification methods and techniques (Karlsson, 2003). Image classification can also be referred to as extracting information from satellite images. Satellite image classification is not complex, but the analyst has to take many decisions and choices in satellite image classification process. Satellite image classification involves interpretation of remote sensing images, spatial data mining, studying various vegetation types (Briney, 2014).

There are two types of image classification, supervised and unsupervised. Supervised classification methods require input from an analyst. The input from analyst is known as training set. Training sample is the most important factor in the supervised satellite image classification methods. Accuracy of the methods highly depends on the samples taken for training. Training samples are two types, one used for classification and another for supervising classification accuracy. Unsupervised classification technique uses clustering mechanisms to group satellite image pixels into unlabelled classes/clusters. Later analyst assigns meaningful labels to the clusters and produces well classified satellite image. (Al-Ahmadi and Hames, 2009). In terms of classification, this study used maximum likelihood to come up with training sites and the signature file. Supervised classification was used to produce the land use/cover map in the study (Mukami, 2010).

Accuracy assessment or validation is a key component of any project employing spatial data. There are a number of reasons why this assessment is so important including: (1) The need to know how well you are doing and to learn from your mistakes; (2) The ability to quantitatively compare methods; and (3) The ability to use the information resulting from your spatial data analysis in some decision-making process (Congalton, 2001).

For the land use/cover map used in this study, error matrices were computed from which measures of accuracy (indices) i.e. Error of Omission (E.O), Error of Commission (EC), Overall Accuracy (O.A), User Accuracy (U.A), Producer Accuracy (P.A), and Kappa Coefficient (KC) were computed by comparing reference points and actual points on the LULC map. An error matrix is a square table with mapped data in rows and reference data in columns. Mapped data refers to data that was obtained

through classification of remotely sensed data. Reference data refers to data representing actual LULC class.

Error of Omission (EO) also called Type I Error allowed to determine what reference sites (actual land cover type) were omitted from the correct class of the classified LULC map. Therefore, a separate EO was determined for each class for the purpose of evaluating the classification accuracy and error of each class. EO was calculated by adding all the incorrect classifications along each column and dividing them by the sum of reference sites for each class (Congalton and Green, 2009).

Error of Commission (EC) also referred to as Type II Error, provided information to the researcher as to which classes were incorrectly classified and it was determined by adding all the incorrect classifications across the rows for each class and dividing the sum with the total number of classified sites for each class (Congalton and Green, 2009).

Overall Accuracy (O.A) is a measure of accuracy expressed as a percentage used to indicate the proportion of LULC map correctly classified out of all the reference sites (Lillesand et al., 2008). O.A has a weakness of only providing the map user with basic information because it is just a summary value which does not reveal if error was evenly distributed between classes or if some classes were really bad and some really good (Congalton and Green, 2009).

User Accuracy (U.A) and Producer Accuracy (P.A) were computed so as to understand the accuracy of individual classes. U.A was used to determine how often LULC classes on the map were truly represented on the actual ground as this shows the reliability of the LULC maps. U.A complimented the EC ( $U.A = 100\% - EC$ ) and it was computed by taking the sum of correct classifications of each class and dividing it by the total number of reference sites used for each class (Lillesand et al., 2008). P.A provided information on how often real features on the ground were correctly indicated on the classified LULC map. P.A compliments the EO ( $P.A = 100\% - EO$ ) and it was computed by adding the number of reference sites for a particular class that were accurately classified divided by the sum total of the number of reference sites for that class (Lung and Schaab, 2009).

Kappa Coefficient (KC) used to determine how well the LULC classification agreed with reference data (Naemi et al., 2011). The coefficient ranges from negative one (-1) to positive one (1). A value of zero (0) indicates that the classification is no better than a random classification. A negative number indicates that the classification is significantly worse than random. A value close to positive one (1) indicates that the classification is significantly better than random. Furthermore, Landis and Koch (1997) indicated that a value below 0.40 represents poor agreement; a value ranging between 0.40 – 0.80 correspond to moderate agreement and a value greater than 0.80 correspond to strong agreement. The coefficient was calculated using the formula shown below.

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} \times x_{+i})}$$

Where

**N** -- Total number of samples in the matrix; **r** -- number of rows in the matrix; **x<sub>ii</sub>** -- number in row **i** and column **i**; **x<sub>+i</sub>** -- total for row **i**; and **x<sub>i+</sub>** -- total for column **i** (Naemi et al, 2011).

According to Valavanis (2002), the identification of sustainable aquaculture sites is a complex spatial problem requiring in-depth knowledge of the environment as well as an understanding of numerous social and civil factors. Naylor et al. (2000) suggested that poor site selection can result in stressed ecosystems, stressed culture species, decreased production, inferior economic performance, displeased neighbours and a disgruntled public. The application of GIS-based models to the site selection task provides an efficient and effective tool under which a protocol for the structured analysis of spatial data for the purposes of resource assessment and management can be developed (Peter et al., 2008).

Shree et al (2000) pointed out that GIS is a potential powerful tool that assists decision-makers for selecting suitable sites for aquaculture development. The GIS and Remote Sensing technology has helped decision makers in the formulation of policies regarding site selection. Location, areal extent, topography, land use type, soil types, and market proximities of selected aquaculture can be integrated with GIS. Inherent

spatial components of biophysical and socio-economic characteristics which vary from location to location aided aquaculture planning.

Geographical Information System is best suited for handling a wide range of criteria data at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating GIS capability with MCDM processes (Chen et al., 2010).

Wanganeo et al. (2009) conducted a study that demonstrated the potential use of remote sensing and GIS techniques for aquaculture site selection and planning for responsible aquaculture. In order to plan aquaculture at national level, multi objective land allocation method needs to be followed to avoid land conflicts. Important parameters such as accessibility to the site, topography, water source, soil types and distance to the market were considered. Soil texture is a significant factor in pond productivity because of its ability to absorb and release nutrients that are ultimately used by plankton which is natural food of fish. Infrastructure is considered as an important criterion for the development of aquaculture.

## **2.5 Site selection for fish farming in different countries**

Feizizadeh and Blaschke (2012) conducted a study in Iran. A GIS-based Multi Criteria Decision Making land suitability analysis was performed. Several suitability factors including soils, climatic conditions, and water availability were evaluated based on expert knowledge from stakeholders at various levels. An AHP was used to rank the various suitability factors and the resulting weights were used to construct the suitability map layers. In doing so, the derived weights were used, and subsequently land suitability maps for irrigated and dry-farm agriculture were created. Finally, a synthesized land suitability map was generated by combining these maps and by comparing the product with current land use SPOT 5 satellite images. The resulting suitability maps indicate the areas, in which the intensity of land use for agriculture should increase, decrease or remain unchanged. Their investigations revealed that 65676 hectares may be suitable for irrigation and 120872 hectares may be suitable for dry-farm agriculture. This indicated a substantial potential to satisfy the significantly increasing regional demand for agricultural products.

Hossain et al. (2007) conducted a study on Multi Criteria Evaluation Approach to GIS-based land-suitability classification for tilapia farming in Bangladesh. The criteria included water quality, soil quality, topography and socio-economic factors. AHP was then used for ranking and weighting the criteria. Factors included water temperature, water pH, soil texture, slope, elevation. Constraints included distance to roads, markets and hatcheries.

Ssegane et al. (2014) conducted a study on Geo-spatial modelling of site suitability for pond based tilapia farming in Uganda. Seven criteria were considered which include water requirement, water temperature, terrain slope, potential farm gate sales and access to local and regional markets. These were analysed to determine site suitability for tilapia and Claris. A multi criteria evaluation approach was used.

Richard et al. (2016) conducted a study on site selection analysis for suitable aquaculture fish pond in Andoni L.G.A rivers state, Nigeria. Their study utilised GIS software and remote sensing technology for aquaculture site selection analysis in Andoni LGA, Rivers State, Nigeria that would create direct and indirect employment opportunities to the men, women, and the youths thereby eradicating youth's restiveness in the area. Data used for the study were 2002 Landsat image, DEM data, and settlements point data. The software used was ArcGIS 10.1 for weighted overlay analysis and IDRISI TAIGA 16.0 for image classification. The three criteria (land use/cover, DEM, settlement) were weighted in the weighted overlay tool with percentage of influence for LULC 40%, DEM 20%, and settlement 40%. The suitability model for aquaculture ponds was produced with seven (7) classes from not suitable class value "0" to very highly suitable class with value "6". The very highly suitable class was made-up of 51 polygons with a total area of 278.1 Ha and this represented 1.0% of the total area (32928.4 Ha.), occurring more in the south and few in the northern map position along the rivers.

It was observed that area covered by 51 polygons can support aquaculture ponds and also the location of it can support fresh and salt water ponds. The class 0 (not suitable) represents the water body in the study area covering an area of 8099.0 Ha. This represented 29.15% of the land area. It was not suitable because aquaculture cannot be sited in the water body since its serves as the food basket of the people. The study therefore justified that GIS and remote sensing integration can be used for aquaculture

site selection because of the spatial components inherent in the criteria. The Local Government Authority should consider aquaculture programmes as key to the eradication of unemployment and youths restiveness through direct investment in the sector (Richard et al., 2016).

Hossain et al. (2012) suggested factors to be considered when choosing a suitable site for inland aquaculture. These factors were traditionally grouped as water quality, soil quality, topography, infrastructure and socio-economic conditions and should be specific to the desired culture system and species selected. The model had three levels, the top or upper level is the goal of the project, sub model which is the intermittent level includes the factors to be considered and the bottom level consists of a breakdown or components of the factors considered.

Hossain et al. (2007) had different criteria grouped in four sub models (water quality, soil quality, topography, and infrastructure and socio-economic factors), which were combined to generate a final output showing the most suitable areas for tilapia culture development. Similarly, this study combined the criteria and analytical hierarchy process was used for ranking and weighting the criteria. The most suitable areas for tilapia farming are recognised as those with water of good quality which is well-oxygenated and of favourable temperature, salinity, and pH. Such areas cover existing agriculture, aquaculture, and grassland. They further suggested that the soil affects the initial cost of pond construction, because soil permeability affects the capacity of the pond to hold water. Permeable soils are least suitable for ponds, in as much as water loss from seepage increases the demand for water, and pumping costs. The most suitable areas with regard to topography were those with low slope (0–5%).

Hossain et al. (2007) further suggested that moderately suitable areas with regard to water quality are located in areas of paddy and seasonal vegetable cultivation. The most suitable areas with regard to topography are found to be along the coastal embankment with low slope (0–5%) and elevation of less than 5 metres with appropriate land-use types and with access to water, a source of fish fry, and markets. The unsuitable zone is located mainly in areas with higher slope and elevation.

Availability of sources of fish fry and easily accessible well-established marketing facilities favour tilapia farming development in the study area. Their study took into consideration of the existing land-use pattern, topographic conditions and financial

involvement in converting the existing land, the ranking was performed on the basis of the professional judgment of the researchers and the knowledge of indigenous people.

From all these studies conducted in several countries, factors and constraints vary based on a study's objectives. Factors and constraints considered are greatly affected by literature reviewed as well as key informants interviewed, these can be in between five to ten for easy calculation of weights using AHP. In this study AHP was adopted as a form of Multi Criteria Evaluation, this was so because it considers both objective and subjective judgements.

In this study, the top level which is the goal was site selection analysis for fish pond farming in Kafue district, a multi-criteria evaluation approach. The sub model consists of factors considered in fish pond farming which are; soil quality, engineering factors, and water availability and socio economic factors. The bottom level which is the criteria considered and constraints, these are soil texture which falls under soil quality, land use/cover type, elevation and slope fall under engineering factors, distance to water is the bottom level of the sub model water availability, under socio-economic factors we have distance to roads, this distance determines how fast and easily transportation of fish to the market can be. Kafue River is a constraint in on-land aquaculture for a fish pond cannot be dug on water.

In Kafue district, aquaculture site selection is usually done using conventional methods which are expensive and time consuming. These methods are slow because they require collection of soil and water samples of all required points: require a lot of money and are ineffective if large areas have to be covered as such mostly cover small areas (Mukami, 2010). It is for this reason that this study will determine suitable aquaculture fish ponds using multi criteria evaluation approach for it is cheaper, less time consuming and covers a large area.

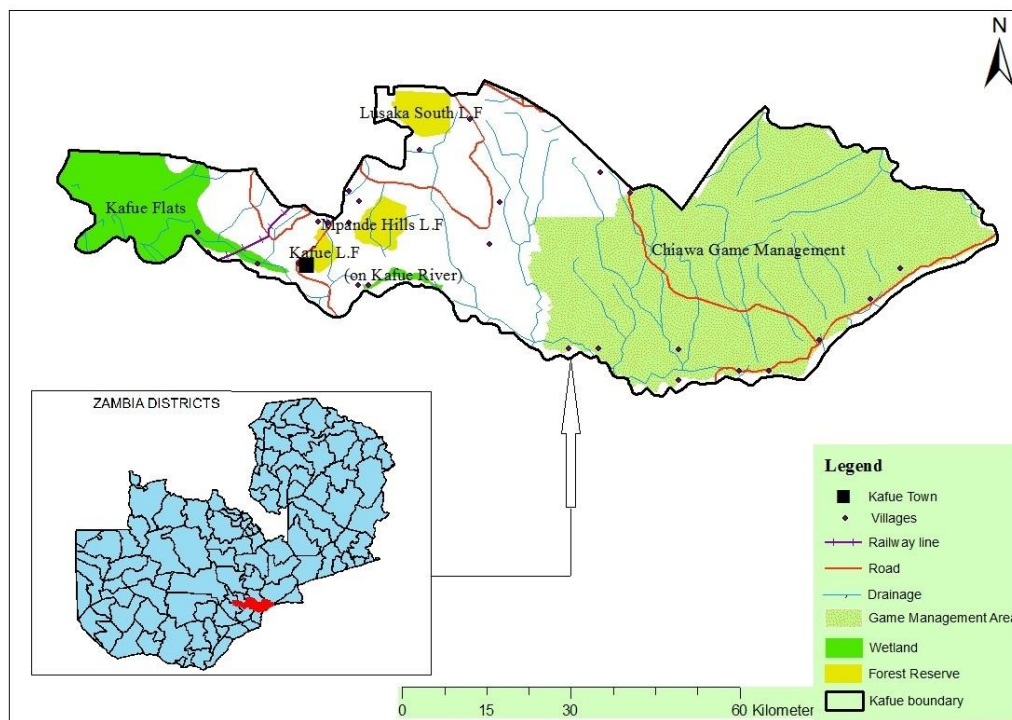
## CHAPTER THREE: DESCRIPTION OF STUDY AREA

### 3.1 Introduction

This chapter presents the characteristics of Kafue district in terms of location and size, rainfall and temperature, population, infrastructure and socio-economic activities. Kafue district was chosen because the Kafue river is reducing in size due to weeds (Zurbrugg et al., 2010) hence there is need to reduce pressure on capture fisheries by venturing more into on-land fish farming away from the Kafue river which is already been put into practice.

### 3.2 Location and size

Kafue is a town in Lusaka Province of Zambia. It lies on the north bank of the Kafue River where it gets its name from. It is the southern gateway to the central Zambian plateau on which Lusaka and the mining towns of Kabwe and the Copperbelt are located. Kafue district is at the south-eastern foot of a range of granite hills rising 200 m and extending over an area of about 250 km<sup>2</sup>, and occupies a shelf of land between the hills and the river, just high enough to avoid its annual flood. The district extends along some shallow valleys between the hills (Hobson et al., 2019). The study area map is shown in Figure 3.1.



**Figure 3. 1: Kafue district map.**

Source: Field data, 2019.

### **3.3 Rainfall and Temperature**

Kafue is mostly affected by the movement of the inter-tropical convergence zone. The amount of rainfall varies considerably between November and March. It receives rainfall of about 800mm (Hobson et al., 2019). Rainfall is received between December to April, the greatest amount of precipitation occurs in December with an average of 199 mm. The average amount of rainfall is 769 mm in a year. The driest months are between May and August which are in the cool and dry season with 0 mm of rain. The hot and dry season lies between September to October. October is the warmest month of the year with an average temperature of 25.7 °C. The lowest average temperatures in the year occur in July, when it is around 16.7 °C. The average annual temperature is 21.5 °C (Chikowo, 2018).

### **3.4 Population**

According to the 2010 Zambia Census of Population and Housing, Kafue has a total population of 219,000 of which 108,939 are males and 110,061 are females (CSO, 2010)

### **3.5 Socio characteristics**

Agriculture (both crop production and livestock rearing) is the traditional occupation of the area, commercial farming area extends along the edge of the Kafue Flats for 35 km north-west of the town. Fish farming is mainly practiced on a commercial scale. Kafue has a large proportion of manufacturing industries such as Kafue quarry, Nitrogen Chemicals of Zambia, and Cotton Ginning Company. Kafue Gorge Upper Power Station operated by the Zambia Electricity Supply Company (ZESCO) generates hydroelectricity 30 kilometres downstream from the town. Kafue also has a number of health facilities both governmental and privately owned which reduces challenges of accessibility of health facilities ([www.lsa.co.zm](http://www.lsa.co.zm)).

In terms of the hospitality industry, Kafue has a number of lodges and hotels such as the Kafue River Cliff, Chita Lodge, Sandy's Creation Resort and Twangale Park Hotel. These promote tourism within the district and country. Munda Wanga Park attracts people within and outside Kafue thereby contributing positively in the tourism sector as well. Zambia's oldest and largest national park which is the Kafue national park is found in Kafue district (Zambia Tourism, 2019)

## **CHAPTER FOUR: METHODOLOGY**

### **4.1 Introduction**

This chapter outlines the methodological procedure that was followed in this study. It highlights the data collection method, data analysis and criteria identification. Assigning weights using Analytical Hierarchy Process (AHP) and how the suitability map showing fish pond sites in Kafue district was produced are elaborated in this chapter.

### **4.2 Data collection method and Sampling**

Data collection was done using both primary and secondary methods. Primary data was collected from in-depth interviews and field surveys. Secondary data was gathered from Landsat imagery, newspaper articles, journals from various websites, rainfall and temperature data was collected from the Zambia meteorological department, soils data from the national remote sensing centre, Landsat images and Digital Elevation Model (DEM) were downloaded from USGS.

Purposive sampling technique, also called judgment sampling, is the deliberate choice of an informant due to the qualities the informant possesses. It is a non-random technique that does not need underlying theories or a set number of informants. Simply put, the researcher decides what needs to be known and sets out to find people who can and are willing to provide the information by virtue of knowledge or experience (Bernard 2002; Lewis & Sheppard 2006).

Purposive sampling was used to select key informants, people who had knowledge and practice on fish farming were drawn from both government and non-governmental organisations. An interview guide was used to conduct in-depth interviews with six (6) key informants. Two of the key informants came from each of the following governmental and non-governmental organisations: Department of Fisheries (DOF), Wildfish, and Zambia Aquaculture Enterprise Development Programme (ZAEDP). Appendices A, B, and C shows the interview guides used to interview the key informants. According to Bernard (2002) key informants are observant, reflective members of the community of interest who know much about the culture and are both able and willing to share their knowledge, these were selected using purposive sampling. Purposive sampling was used because it stays robust even when tested

against random probability sampling, choosing a purposive sample is fundamental to the quality of data gathered (Tongco, 2007).

One focus group discussion consisting of 15 fish farmers was conducted. Discussants were of different sex and education background. It comprised of men and women who were interviewed separately so as to allow each group to freely express themselves. After this was done, a combined discussion was conducted. Appendix D shows the interview guide used to conduct the discussion, it was done in Bemba, Nyanja, and Tonga. All 15 participants were made comfortable to discuss and give their different opinions with the topic under discussion. Each person's opinion was regarded important and respected. The fish farmers had first-hand information on the criteria used for fish pond farming and challenges experienced in fish farming. A voice recorder was used to record the discussion with permission from the respondents.

#### **4.2.1 Criteria for selecting suitable fish pond sites in Kafue district**

Criteria identification and suitability rating for each level of a factor was done through literature review and professional judgment of experts. Potential to construct a pond is an important consideration in site selection, land use/cover type, elevation, and slope were the factors considered under this sub model. In terms of soil quality, soil texture was considered. Under the sub model water availability and socio-economic factor, distance to water bodies and motorable roads were considered respectively.

#### **4.2.2 Data preparation**

Data preparation has two parts, the first part being input data that was used and the second part was obtaining the extent of the project from various maps using the Kafue district shapefile.

##### **4.2.2.1 Input Data**

Shapefiles of Zambian districts, rivers, soils and Roads in Kafue district were obtained from National Remote Sensing centre. Two Landsat 8 scenes of path and row 171071 and 171072 for March 2019 covering Kafue District (Raster) were used to extract land use/cover of the area. Three Digital elevation models for Kafue (Raster) S16E027, S16E028 and S16E029 were used for elevation and extracting slope. Landsat and Digital Elevation Model (DEM) were downloaded from USGS. Arc geo-processing tools were used so that the new output files had the same projection as the input files.

#### **4.2.2.2 Obtaining the extent of the project**

The Kafue district boundary was obtained from the Zambian districts shape file. The Landsat images used were enhanced and georeferenced to the Lusaka local coordinate system: UTM zone 35S; Datum WGS 84. The area covered by the Kafue district boundary obtained was extracted from the Landsat images.

The DEMs were then mosaicked using the mosaic tool, where the DEMS were the input datasets. The resultant mosaic was overlaid with the Kafue district boundary and then the Extract by Mask tool was run with the mosaic as the input data set and the Kafue District boundary shapefile as the mask. The resultant raster was named Final DEM. In order to obtain soil data within the bounds of the Kafue district boundary, the Zambia soils shapefile was overlaid with the Kafue District Boundary Shape file and the Clip tool was used. The Zambia soils shape file was the input feature and the Kafue District Boundary shapefile was the clip feature, the resultant shape file was named Kafue Soils Map.

A slope map was created from the final DEM Map using the slope (spatial analyst) tool. Slope percentages were used, the input raster was the final DEM raster, the output was named Kafue slope map. Rivers data within the Kafue district boundary was obtained by overlaying the Zambia rivers shapefile with the Kafue District Boundary Shape file and clipped.

### **4.3 Data analysis**

Texts, recordings and field observations were analysed using content analysis. According to Hsieh and Shannon; (2005), content analysis is the study of contexts, meanings, subtexts, intentions contained in the messages. In simple terms, content analysis is the analysis of what is being said, written or recorded, such as dairy entries, books, newspaper, videos, text messages, tweets, Facebook updates. Nayeem and Parveen, (2017) suggested that content analysis is basically a set of procedures used to transfer discrete information into an organised format allowing analysts to make inferences. It is a research technique of coding and interpreting text to make a valid and replicable inference. Through this method of data analysis, inferences about the characteristics and meaning of written and other forms of recorded communication can be gauged effectively.

As the discussants were talking during the focus group discussion, a voice recorder was used with their permission to record their views. After listening to their discussion, each respondent was given an anonymous name. A summary of what each discussant said was written down and analysed. The same procedure was used for key informants. Calculation of criteria weights using AHP was done using Microsoft Excel (2013), which is addition, multiplication and division. In order to produce a suitability map, GIS and remote sensing software (ArcGIS 10.1 by Esri, 2012) was used for data extraction and analysis.

#### **4.3.1 Criteria identification and assigning weights using Analytical Hierarchy Process (AHP)**

In this study, six (6) criteria were identified; 1. Land use/cover type (LULC), 2. Elevation, 3. Slope, 4. Soil type, 5. Distance to river (D. river) and 6. Distance to roads (D.roads). The analytical hierarchy process (AHP) is a proven, effective means of dealing with complex decision making and can assist with identifying and weighting selection criteria, analysing the data collected for the criteria, and expediting the decision-making process (Borouhaki and Malczewski 2008).

The first step was to identify the criteria (factors and constraints) as shown in Table 4.2. This was followed by decomposing the decision problem into a hierarchy. The third step was doing a pairwise comparison of each criteria. Fourthly the column entries were normalised and the fifth step was to average each row in the normalised matrix and finally the consistency ratio was checked. These calculations were done using Microsoft Excel 2013.

**Table 4. 1: Criteria used in site selection for fish pond farming in Kafue District.**

<b>Criteria</b>	<b>Factors</b>	<b>Constraints</b>
Topography	Slope Elevation	Water bodies Industrial areas
Land use	Land use/ cover type	
Soil quality	Soil texture	
Socio economic factors	Distance to motorable roads	
Water quantity	Distance to water body/source	

Source: Field data, 2019.

#### **4.3.2 Image classification and Accuracy Assessment**

Image classification was considered so as to know the land parcels in an area. Supervised classification was used to classify the 543 band combination. This was chosen because forest and agricultural areas can clearly be distinguished near infra-red. Land use/ cover types identified and classified in the study area were forestland, other land, wetland, grassland, settlement and cropland. For each class, 60 Sample data sets were trained using the “training sample manager” in the classification toolbar, from these samples, a signature file was created then maximum likelihood classification tool was run. The classification scheme was adopted from the Intergovernmental Panel on Climate Change (IPCC). The classified image classes were then compared with the land use/cover type on the google earth image. Maximum likelihood classification was chosen because it achieves good separation of classes.

Accuracy assessment or validation is a key component of any project employing spatial data. There are a number of reasons why this assessment is so important including: (1) The need to know how well you are doing and to learn from your mistakes; (2) The ability to quantitatively compare methods; and (3) The ability to use the information resulting from your spatial data analysis in some decision-making process (Congalton, 2001).

Accuracy assessment was conducted in ArcGIS software version 10.4 to validate and quantify the reliability and thematic accuracy of LULC maps. Stratified random

sampling was adopted to generate reference random points for each LULC map (see Table 4.3). The number of the sampling points in each LULC class depended upon the size of the class. The larger the area of the LULC class, the greater the number of sampling points allocated. It was made sure that all random points identified represented ground truth data by checking those visually using topographic maps, high resolution Google Earth imagery. Results from the assessment are shown in the findings and discussion chapter.

### **4.3.3 Suitability map for fish pond farming in Kafue district.**

The suitability map was produced from the overall evaluation of all the criteria suitability maps.

#### **4.3.3.1 The Evaluation Process**

In land suitability analysis, each evaluation criterion is represented by a separate map in which a ‘degree of suitability’ with respect to that particular criterion is ascribed to each unit of area (Sehgal, 1996; Prakash, 2003).

After the data had been prepared, the following datasets were used; Kafue District Boundary (Shapefile), final DEM Raster, Kafue Soils Map (Shapefile), land use/cover type map, slope map, Kafue roads map and Kafue Rivers map. Reclassification was done so as to assign ranks.

Euclidean distance was calculated. Using the Buffer tool, the road shapefile was buffered with a buffer distance of hundred meters (50 m from the centreline on each side of the road). The Euclidean distance was computed from the roads buffer, this was done using the Euclidean distance tool where the roads buffer was the input feature and the roads Euclidean distance raster was the final output.

The roads Euclidean distance raster was then reclassified with five classes, one to five (1 to 5) of equal interval using the Reclassify tool. The reclassification was as follows; the range zero to six point five (0km-6.5km) was assigned the highest value of 5 because it is nearest to the road, 6.5km-12.84km was ranked 4, 12.84km-19.25km was ranked 3, 19.25km-25.67km was ranked 2, 25.67km-32km was ranked 1 and is the least suitable due to its further distance from roads.

The final DEM raster was also reclassified into five classes using the reclassify tool with the lowest elevation values being ranked the highest score of 5 and the highest values being ranked the lowest value of 1. The resultant raster had five categories, 5 for the most suitable to 1 the least suitable. This raster was called Reclassified Elevation Map.

The soils map was in vector format, it could not be reclassified because the reclassify tool only takes raster data sets as inputs and therefore it had to be converted to a raster. For this, the polygon to raster tool was used, the input polygon was the soils map shapefile. The resultant was a raster image, the raster image produced was reclassified into five categories 1 (least suitable soils) to 5 (most suitable soils). The resultant raster was called reclassified soils map.

The land use/cover type map raster was also reclassified from 1 (least suitable) to 6 (most suitable). The classes were ranked as follows; cropland - six (6), grassland - five (5), forestland – four (4), settlement – three (3), other land - two (2) and Wetland – one (1), the resultant was named reclassified land use map.

The slope map raster was reclassified into five categories, zero - three (0-3%) as five (5) and the most suitable three – six (3-6%) as four (4), six – nine (6-9%) as three (3), nine – twelve (9-12%) as two (2) and finally twelve – fifteen (12-15%) as one (1) and was the least suitable. The resultant map was reclassified slope map.

Euclidean distance was calculated with equal intervals of 1000 meters. The river buffer of 100 meters was used. Distance to river map was reclassified into five categories, 0 – 1km as five (5) and most suitable, 1km – 2km ranked four (4), 2km – 3km ranked three (3), 3km – 4km ranked two (2), 4km – 5km ranked one (1) and is the least suitable, the resultant was named reclassified distance to river.

**Table 4. 2: Parameters used for ranking in ArcGIS 10.1**

Criteria	HS				LS
Soil Type	Clayey	Cracking fine clay	Loamy	Coarse loamy	Coarse
D. river(km)	0-1	1-2	2-3	3-4	Coarse
Slope (%)	0-3	3-6	6-9	9-12	4-5
Elevation(m)	346-570	570-794	794-1018	1018-1242	2-15
D.roads(km)	0-6.5	6.5-12.84	12.84-19.28	19.28- 25.67	1242-1466
LULC	cropland grassland	forestland	settlement	other land	wetland

Source: Field data, 2019.

HS-highly suitable, LS-least suitable, D.river-distance to river, D.roads-distance to roads.

Cropland was the most preferred land use/cover type, the ideal site should be flat or almost flat with a slope of 0.5 – 1% recommended, up to a maximum of 2.5%. Slope of zero to three percent (0-3%) was the most suitable and elevation of 346m-570m were preferred. Heavy clay soil is best for digging ponds and preventing seepage therefore stony or sandy soil was avoided, sandy soils have a high infiltration rate and low field capacity hence clay soils were the most suitable soil type for fish pond farming. Water quality and quantity are vital in fish farming, distance to river was considered in this study because water from the river is well oxygenated and pumping cost is cheaper compared to pumping underground water into a tank. Proximity of fish ponds to roads is an important factor, money spent on transporting the fish to the market or by customers buying the harvested fish from the ponds is less when the pond is near motorable roads.

#### **4.3.3.2 Weighted overlay analysis**

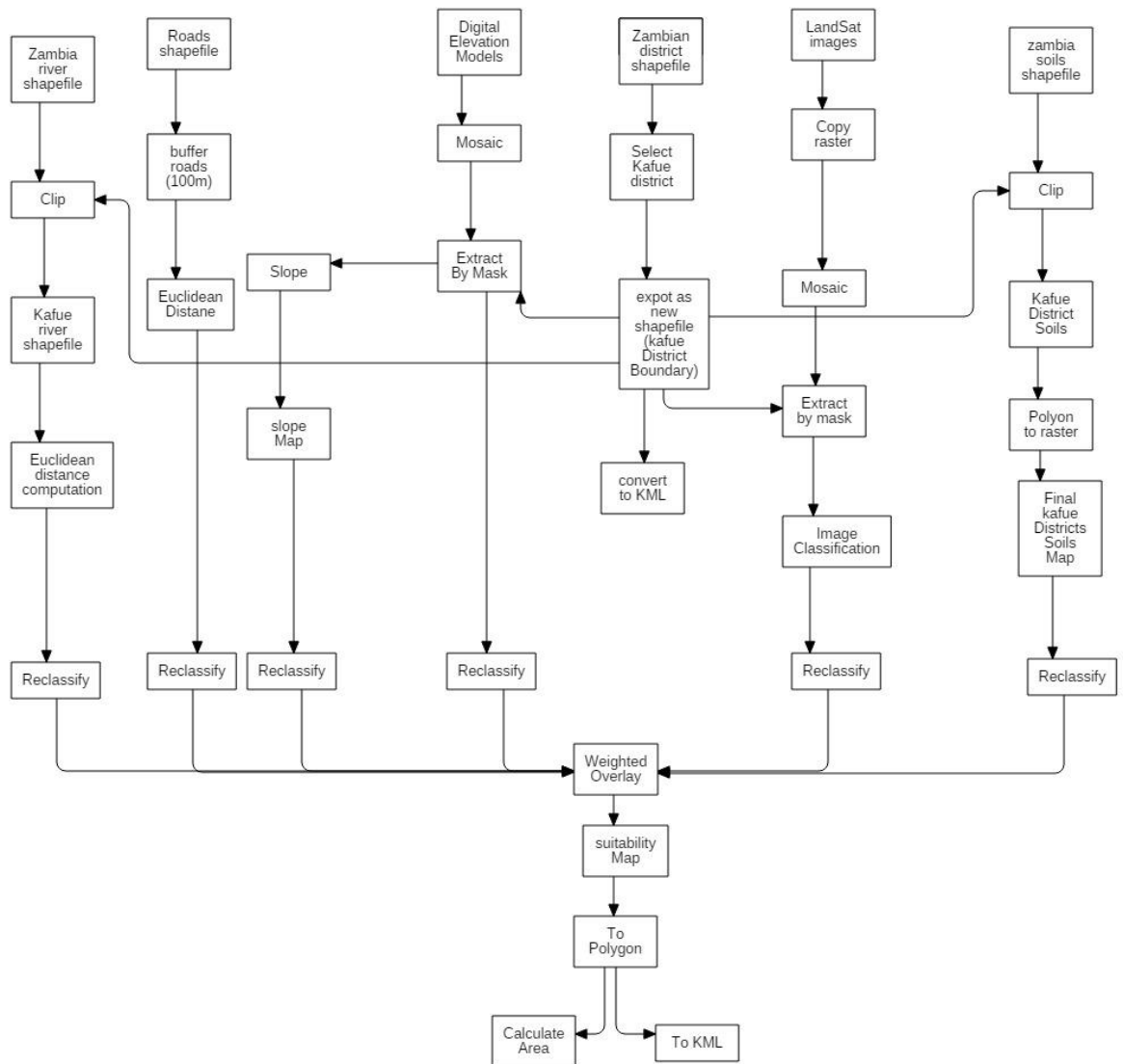
The Weighted Least Criteria approach involves standardization of the suitability maps, assigning the weights of relative importance to the suitability's maps, and then combining the weights and standardized suitability maps to obtain an overall suitability score (Malczewski 2004). The result is a continuous suitability mapping. The higher the score, the more suitable the location is for the intended land use. This approach was used in the study. Different maps generated were then overlaid to come up with one suitability map.

The following steps were followed in assigning weights using AHP. First, the identification of the Criteria (factors and constraints) which are; land use/cover type (LULC), distance to roads and river (D.roads and D.river), slope, soil type and elevation. These were identified from key informants and literature review. Second, there was need to structure the decision problem into a hierarchy. The decision problem was then decomposed into a hierarchy in order to analyse each problem independently. This way each element of the hierarchy can relate to any aspect of the decision problem. In addition to this, pairwise comparison is easily done, the point where one same criterion meets on the row and column entry is assigned the number one that makes it easier to do pairwise comparison on the other gaps once one is filled in a hierarchy.

All the reclassified maps that is; slope map, soils map, land use/cover map, elevation map, distance to rivers and roads maps were inputted into the Weighted Overlay tool. The weighted overlay map was classified according to suitability ratings that were established by FAO classification on the appropriateness of land for defined uses. These ratings are as follows: highly suitable, suitable, moderately suitable, and unsuitable (FAO, 1976; Kapetsky, 1994).

Using the raster to polygon tool, the suitability map raster was converted to a polygon shapefile. In the attribute table of this shape file a field for area in hectares was created and the areas of the individual polygons was calculated. Using the summarise tool the sum of areas under the four suitability categories were calculated. Finally, the shape file was converted to a KML file using the KML tool. This was done so that the suitability categories shapefiles could be opened in Google Earth. This procedure was also done for the land cover/use map. The KML file was later opened in Google Earth in order to view these sites and get geographic coordinates for ground truthing.

Verification of the model was done by using recent images (2019) on Google Earth and ground truthing. Four (4) different geographic coordinates of each class on the map were collected and a GPS was used to load these coordinates to navigate them on the ground. The methodology used in Arc map is shown in Figure 4.1



**Figure 4. 1: Methodology in Arc Map**

Source: Field data, 2019.

## CHAPTER FIVE: FINDINGS AND DISCUSSION

### 5.1 Introduction

This chapter presents the findings based on the objectives and discussion of results. The first part presents accuracy assessment, the criteria that were identified for fish pond farming as well as weights assigned to each criterion. The second part presents the suitability map for fish pond farming in Kafue district and explains what the suitability rates mean. The criteria identified in this study were land use/cover type (LULC), distance to roads and river, slope, soil type and elevation, these were assigned ranks and weights using pairwise comparison. Results in this study were compared with existing literature. Interpretation of the different criteria from the maps is done here. This chapter further compares findings from this study with those from other studies.

### 5.2 Accuracy assessment

Accuracy assessment was done and the results are shown in Table 5.1 and 5.2

**Table 5.1: Components of Accuracy Assessment**

		Reference Data							M.A	
		Cropl and	For est	Grassl and	Settle ment	Wetl and	Other land	tot al	U.A	EC
LULC_2019	Cropla nd	54	3	0	0	1	2	60	90	10
	Forest	3	54	6	4	1	2	70	77.1 429	22.8 571
	Grassl and	2	5	97	1	3	0	10 8	89.8 148	10.1 852
	Settle ment	3	2	1	87	1	0	94	92.5 532	7.44 681
	Wetla nd	0	2	0	2	90	1	95	94.7 368	5.26 316
	Other land	0	0	0	1	0	58	59	98.3 051	1.69 492
	total	62	66	104	95	96	63	48 6		

M.A	E.O	12.90 32	13. 64	6.730 77	8.4210 5	6.25 508	7.936				
	P.A	87.09 68	81. 82	93.26 92	91.578 9	93.75 349	92.06				
	O.A	90.54%									
	Kappa	0.89									

Source: Field data, 2019.

M.A = Measures of Accuracy

E.O = Error of Omission

P.A Producer Accuracy

O.A = Overall Accuracy

U.A User Accuracy

Error of Commission

In this study, Kappa Coefficient is 0.89, this value is greater than 0.80 and it corresponds to strong agreement. This therefore indicates that the classification is significantly better than random.

**Table 5.2: Overall Accuracy**

<b>Overall Accuracy</b>	90.535		A	213840
<b>Kappa</b>	0.88527		B	41339
			C	236196
			E	41339
Total True Samples		440		
Total Samples Taken		486		
Accuracy		90.53		

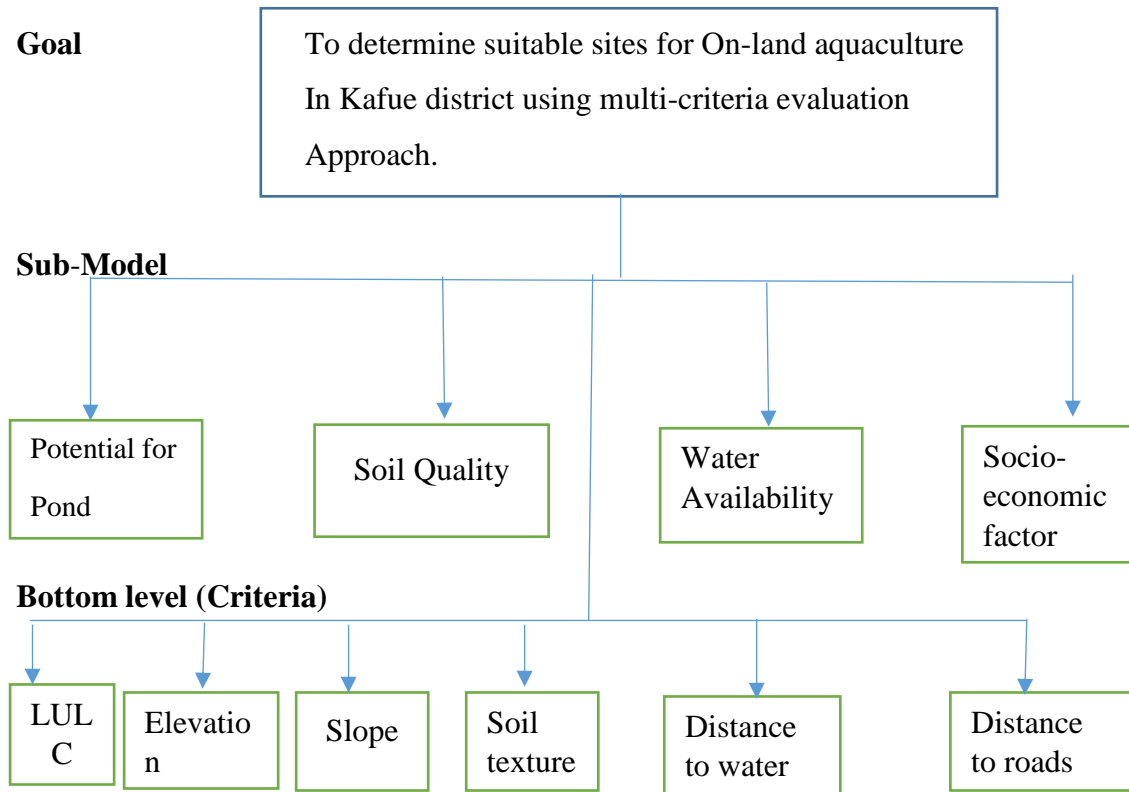
Source: Field data, 2019.

The overall accuracy is 90.53 %. This indicates the proportion of LULC map correctly classified out of all the reference sites.

### 5.3 Criteria identification and assigning weights using AHP

In this study, six (6) criteria were identified from key informant, focus group discussion and literature review; land use/cover type, distance to roads and river, slope, soil type and elevation. They were identified from key informants, focus group discussion and literature review. These were grouped into four sub models which are potential for pond construction (land use/cover type, elevation and slope). Soil quality (soil texture), water availability (distance to river) and finally socio-economic factor

(distance to motorable roads). The six criteria were first decomposed into a hierarchy and ranking was done so as to do pairwise comparison. The 6 criteria were structured into a hierarchy as shown in Figure 5.1.



**Figure 5. 1: Factors structured in a hierarchy.** Adapted from Hossain et al (2007)

Source: Field data, 2019.

Pairwise comparison was applied in order to evaluate the hierarchy by comparing the relative importance between two criteria and to establish priorities among the elements of the hierarchy. The criteria were decomposed into a hierarchy so as to do pairwise comparison of each criteria in order to evaluate the different criteria by comparing them to each other two at a time with respect to their impact on the criteria above them in a hierarchy. This is done in order to know how important each criterion was from the other. A pairwise comparison was done using the ranking system in Table 5.3. This ranking system was discovered by Saaty (1991).

**Table 5.3: Pairwise comparison ranking system**

1	Equal importance	A and B are equally important
3	Moderate importance	A is thought to be moderately more important than B
5	Strong importance	A is thought to be strongly more important than B
7	Very strong importance	A is thought to be very strongly more important than B
9	Extreme importance	A is thought to be extremely more important than B
2,4,6,8	Intermediate values	

Source: Saaty & Vargas, 1991.

The ranks in Table 5.4 were then used in the pairwise comparison of the criteria. For example, if soil type was ranked 6 over land use/cover type then under soil type column, land use/cover type will have the reciprocal value of 6 which is 1/6. Assigning decimals to pairwise ranks is required in order to allow the criteria to be compared to one another in a consistent way. The assigned pairwise ranks fractions were then converted into decimals so as to make calculations of the sum and averages easier as shown in Table 5.4. This in turn lessens work when normalising.

**Table 5.4: Pairwise comparison ranks of the main criteria with respect to the goal**

Criteria	LULC		Soil type		D.river		D. roads		Elevation		Slope
LULC	1		2		4		9		9		9
Soil type	1/2	0.5	1		2		9		9		8
D.river	1/4	0.25	1/2	0.5	1		4		6		5
D. roads	1/9	0.11	1/9	0.11	1/4	0.25	1		1		1
Elevation	1/9	0.11	1/9	0.11	1/6	1.67	1/1	1	1		2
Slope	1/9	0.11	1/8	0.125	1/5	0.2	1/1	1	1/2	0.5	1
Sum	<b>2.08</b>		<b>3.85</b>		<b>9.12</b>		<b>25</b>		<b>26.5</b>		<b>26</b>

Source: Field data, 2019.

Normalisation was done to synthesise the judgements so as to yield a set of overall priorities for the hierarchy. Therefore, the column entries were then normalised by dividing each entry by the sum of the column, these normalised column entries are shown in Table 5.5.

**Table 5.5: Normalised column entries and Criteria weights**

Criteria	LULC	soil type	D. river	D. roads	Elevation	slope	RS	CW
LULC	0.48	0.52	0.53	0.36	0.34	0.35	2.57	0.43
soil type	0.24	0.26	0.26	0.36	0.34	0.31	1.77	0.29
D. river	0.12	0.13	0.13	0.16	0.23	0.19	0.96	0.16
D. roads	0.05	0.03	0.03	0.04	0.04	0.04	0.23	0.04
elevation	0.05	0.03	0.02	0.04	0.04	0.08	0.26	0.04
slope	0.05	0.03	0.03	0.04	0.02	0.04	0.21	0.03
SUM	1	1	1	1	1	1	6	1

Source: Field data, 2019.

The normalised matrix must be averaged in order to calculate the criteria weights (CW). In this case, criteria weights for land use/cover type (LULC), soil type (Soil t), distance to river (D.river), slope, elevation (El) and distance to roads (D.roads) were calculated by taking the row averages (RA). This was done by dividing each column element over the column sum, then dividing the row sum (RS) over (n) which is the number of criteria, in this study n was six (6). The criteria weights (CW) are shown in Table 5.6.

Checking for consistency is a key requirement in suitability analysis because consistency is required to derive meaningful priorities and it helps understand how consistent the subjective judgements were. According to Saaty (1980), consistency ratio is calculated in order to measure how consistent the judgements have been relative to large samples of purely random judgements. A consistency ratio (CR) which is less than or equal to 0.1 indicates sufficient consistency for decision, which means that human judgements from key informants were not random but critically analysed in relation to literature review and their experiences. If CR is greater than 0.1, the judgements are untrustworthy reason being that they are too close to randomness.

The criteria ranks were randomly compared with each other and the results are valueless hence the exercise must be repeated.  $CR = \text{consistency index (CI)} / \text{random index (RI)}$ . Consistency index is calculated for comparison with the consistency random index (CRI) that are used in order to calculate the consistency Ratio. Table 5.6 shows the weighted sum value (WSV), criteria weights (CW) and  $WSV/CW$ , it is important to derive these in order to calculate the consistency index. The consistency error is high or low based on how high or low the consistency index (CI) is.

**Table 5.6: weighted sum value/criteria weights**

Criteria	LULC	soil.	D. river	D. roads	Elev	slope	WSV	CW	WSV/CW
LULC	0.43	0.59	0.64	0.35	0.39	0.31	2.71	0.43	6.32
soil type	0.21	0.29	0.32	0.35	0.39	0.28	1.84	0.29	6.25
D. river	0.11	0.15	0.16	0.15	0.26	0.17	1.00	0.16	6.26
D. roads	0.05	0.03	0.04	0.04	0.04	0.03	0.24	0.04	6.15
Elev	0.05	0.03	0.03	0.04	0.04	0.07	0.26	0.04	6.00
slope	0.05	0.04	0.03	0.04	0.02	0.03	0.21	0.03	6.06

Source: Field data, 2019.

In order to derive the consistency index, the un-normalised elements (ranks) were multiplied with the criteria weights, the row sum was then calculated and this was called weighted sum value (WSV) in Table 5.6. Weighted sum values per row were divided by criteria weights of that row, the sum of these values was calculated. Lambda matrix was calculated by dividing the sum (weighted value/criteria weights) by n which is 6 the number of criteria, n was then subtracted from lambda matrix, n – 1 was the number of criteria (6) – 1 and consistency index is then calculated from lambda matrix – n divided by n – 1. The Random index (RI) derived by Saaty (1980) was 1.25 for six as n. In this study the number of criteria was six (6), that is why we had a 6 by 6 matrix, therefore n = 6.

$$CR = CI/RI$$

$$CR = 0.034/1.25$$

$$CR = 0.027$$

#### 5.4 Six identified criteria and their weights

Hossain et al. (2007) in their study had different criteria grouped in four sub models (water quality, soil quality, topography, and infrastructure and socio-economic factors), which were combined to generate a final output showing the most suitable areas for tilapia culture development. On the contrary, this study had six criteria combined to generate a final output showing suitable sites and AHP was used for ranking and weighting the criteria.

In this study, all the reclassified maps that is; slope map, soils map, land use/cover map, elevation map, distance to rivers and roads maps were inputted into the Weighted Overlay tool and assigned percentage of influence of 43% land use/cover type, 30% soil type, 16% distance to rivers, 4% elevation, 4% distance to roads and slope with a lowest slope of 3%. Richard et al. (2016) considered three criteria (land use/ cover, DEM, settlement) weighted in the weighted overlay tool with percentage of influence for LULC 40%, DEM 20%, and settlement 40%. Similarly, in this study land use/ cover was weighted the most important criterion for the type of land use/cover greatly affect fish pond farming.

From AHP calculations, which was proven meaningful and consistent by having a consistency ratio of 0.027 (2.7%), the most important factor was land use/cover with 43%, this was followed by soil type (30%) and distance to river (16%), elevation (4%), distance to roads (4%) and the least being slope with 3%. These weights were each multiplied by 100 so as to be used in the weighted overlay for the overall suitability map as shown in Table 5.7.

**Table 5.7 Criteria and assigned weights using AHP**

Criteria	Criteria weights	Weights (%)
LULC	0.428466047	43
Soil type	0.294970808	30
Distance to river	0.159996289	16
Elevation	0.043125822	4
Distance to roads	0.038539045	4
Slope	0.034901989	3

Source: Field data, 2019.

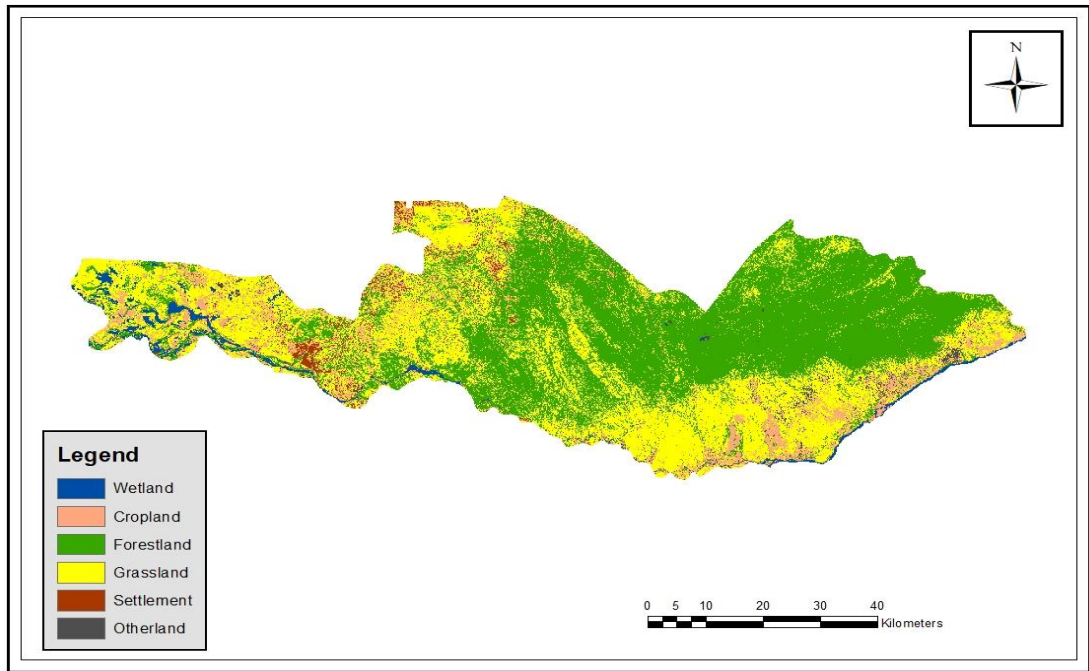
#### **5.4.1 Land use/cover type (LULC)**

Richard et al. (2016) considered three criteria (land use/cover, DEM, settlement) weighted in the weighted overlay tool with percentage of influence for LULC 40%, DEM 20%, and settlement 40%. Similarly, in this study, of the six identified criteria, LULC type was weighted the most important with 43% from pairwise comparison using AHP. This is because the type of land use/cover greatly affects fish pond farming due to variety of features per class.

In terms of LULC type; Kafue district has cropland, forestland, grassland, other land (bare and rocky land), settlement and wetland. It is mainly forestland 221,199 Ha (47.8%) followed by grassland 172,713 Ha(37%) and cropland 43,285 Ha (9.3%), wetland occupy 10,561 Ha (2.3%), settlement 10,343 Ha (2.2%) and other land occupy the least area of 4,971 Ha (1.1%) as shown in Figure 5.2. The land use/cover type map was reclassified so as to assign ranks, it had six (6) ranks as shown in Figure 5.3. The higher the rank, the more suitable an area is for fish pond farming and vice versa. Of the different LULC types, cropland was ranked six (6) and is the most suitable land use/cover type for fish pond farming. This was so because most of it generally had soil types such as clayey with high field capacity and low infiltration rate. When a pond is dug on such land, water is stored for a longer period of time and is well oxygenated.

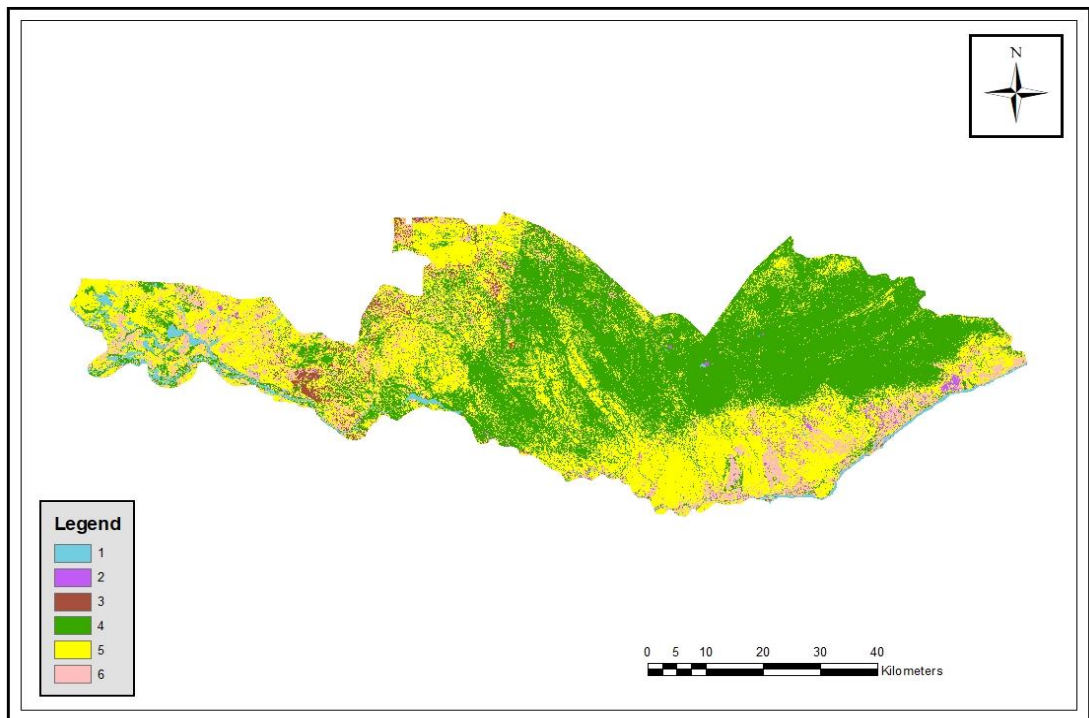
Hossain et al. (2007) identified cropland as the most suitable area for fish farming because existing agriculture areas are recognised as those with water of good quality which is well-oxygenated and of favourable temperature, salinity, and pH are.

Grassland were ranked five (5) because they support life hence the soil type found there can support fish when a fish pond is dug. In such areas there is no uprooting of trees. Forests were ranked four (4). These had better soil types as compared to settlements, water is held by the soil for a period of time that is the reason as to why trees survive in forest area. Settlements were ranked three (3) because some of the settlements had good soil types and water availability. The type of LULC classified as Other land such as bare land and rocky land were ranked two (2), digging a fish pond in such areas is expensive for there is need to break the rocks first and bringing clayey soils or cracking fine clayey soils to such areas for low infiltration of water or building a concrete pond.



**Figure 5.2: Kafue District land use/cover type map**

Source: Field data, 2019.



**Figure 5.3: Reclassified Kafue district land use/cover type map**

Source: Field data, 2019.

In their study, Richard et al. (2016) found that highly suitable sites were located close to the river on the suitability map. The location of these very suitable areas closer to water source is an added advantage for the development of aquaculture ponds because

of the steady and consistence supply of water directly from its source. The class 0 (not suitable) represents the water body in the study area. It is not suitable because aquaculture cannot be sited in the water body since its serves as the food basket of the people.

In this study, wetland was ranked One (1) and these were not suitable for fish pond farming. Therefore, wetlands are classified as a constraint in on-land fish farming since a fish pond cannot be dug on water. Integration of other farming activities is practical on cropland. Farming and livestock keeping can take place in one farm at the same time hence fish pond farming becomes cheaper for products from farming can be used to fertilise the pond and feed the fish.

One of the key informants (A) stated that:

Agricultural areas are the most suitable land use/cover type because they generally have fertile soils, a pond can be dug where the soil is most fertile after practicing crop rotation on a piece of land for a long time, this reduces seepage of water from the pond (Person.Com.20191).

One of the discussants from the focus group discussion stated the following:

Vegetables and crops from farming can be used to feed the fish whilst manure from the livestock would be used to fertilise the ponds, water from the fish ponds can be used for watering the crops and vegetables through irrigation (Pers.Com.2019g).

Another discussant from the focus group discussion similarly observed that:

Members of the cooperative also plant crops such as maize and vegetables near the fish ponds. In cold season when they do not stock fish, people have other farming activities that they practice for the cooperative and it is for this reason that they always have something to do as a source of income. (Person.Com.2019e).

Highly suitable sites such as the one shown in Figure 5.4 constitutes sites whose LULC is cropland and grassland that are near the river, Suitable sites like the one shown in Figure 5.5 and Figure 5.6 have grassland and cropland distant from the river. Moderately suitable sites were mainly forestland and grassland as shown in Figure 5.7.



**Figure 5.4: Highly suitable site (grassland and cropland near river).**

Source: Field data, 2019.

In this study water was vital in fish pond farming, the two earthen ponds for the cooperative were about 200 metres and 100 metres away from the river respectively, these do not experience water shortages for it is permanently available all year around and water is pumped from the river during dry season. These ponds were dug on clay soils which hold water for a long time and so there were no issues of seepage. The study established that site selection using the conventional method is laborious and expensive in that for any site to be suitable, all the factors and constraints have to be tested. If for instance someone had a big piece of land, in order to determine where to put up a pond, different points would be sampled and for every point soil and water samples have to be collected and tested.



**Figure 5.5: Suitable site (grassland far from river)**

Source: Field data, 2019.



**Figure 5.6: Suitable site (cropland far from river)**

Source: Field data, 2019.



**Figure 5.7: Moderately suitable site (forestland).**

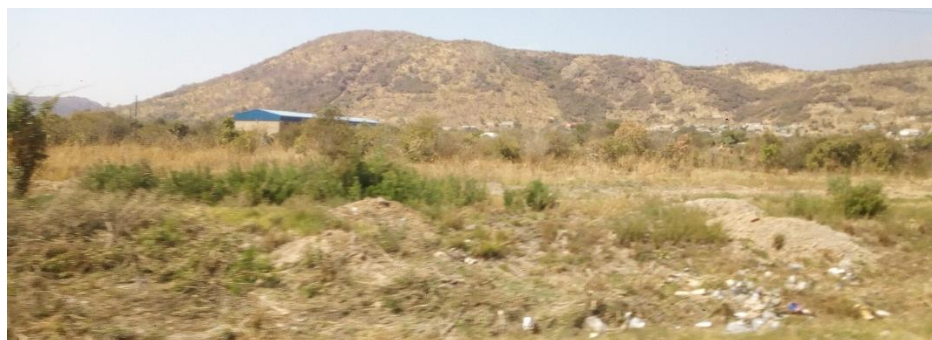
Source: Field data, 2019.

Moderately suitable sites were mainly settlements such as the one shown in Figure 5.8. Not Suitable sites shown in Figure 5.9 and Figure 5.10 are mainly other land such as bare land, hilly and rocky land .



**Figure 5.8: Moderately suitable site (settlement).**

Source: Field data, 2019.



**Figure 5.9: Not suitable site (other land i.e. bare land and hilly land).**

Source: Field data, 2019.



**Figure 5.10: Not suitable site (other land i.e. rocky land).**

Source: Field data, 2019.

Wetland as shown in Figure 5.11 are a constraint in on land aquaculture for a pond cannot be dug on water. This therefore makes wetland permanently not suitable for fish pond farming.



**Figure 5.11: constraint (wetland).**

Source: Field data, 2019.

#### **5.4.2 Soil type**

Soil type weighted 30% and was the second most important of the six identified criteria from AHP because the type of soil greatly affects fish pond farming due to their different infiltration rates and field capacity. The study recognised that Kafue district is mainly covered by coarse loamy soils, with coarse soils occupying the least area as shown in Figure 5.12. The south eastern part of the district was covered by clayey soils and the north eastern part had coarse loamy soils, part of the southern and south west were covered by loamy soils and part of the north western were covered by coarse soils. The western part was occupied by cracking fine clayey soils.

Pillay and Kutty (2005) suggested that soils must be impervious more than 35% clay to ensure minimum water is not lost through seepage. Clay or clay-loam soils are ideal, the site must have soils that hold water and can be compacted. If pond levees are constructed with soil that has high water permeability, the cost of pumping water could

become prohibitive. Soils with high sand and silt compositions may erode easily and present a piping hazard. Soils classified between sandy loam and sand do not contain enough clay for pond construction. Silt loams and loams may or may not have adequate clay. It is particle size that determines how soil is classified.

Of the five different soil types; clayey soils were ranked five (5) and are the most suitable for fish pond farming because they have a low infiltration rate and high field capacity, good soil quality such as clayey or any soil type with a higher percentage of clay holds water and provides various nutrients that the fish feeds on. They were followed by cracking fine clayey soils that were ranked four (4), loamy soils were ranked three (3), coarse loamy soils were ranked two (2) and coarse soils were ranked one (1). Hence coarse soils were the least suitable soil type in fish farming reason being that they have big soil particles that have large air spaces in between them. It is for this reason that they have a high infiltration rate and low field capacity. Infiltration rate is the rate at which water passes through the soil and field capacity is the maximum amount of water that can be held by the soil. It is expensive to dig a pond in such areas because water is not easily retained and it drains so quickly therefore increasing the pumping cost of water. Highly permeable soils are least suitable for fish pond farming because water loss from seepage increases the demand for water resulting into high pumping costs. (Pillay and Kutty, 2005). Reclassification of the soil texture map was done so as to assign ranks.

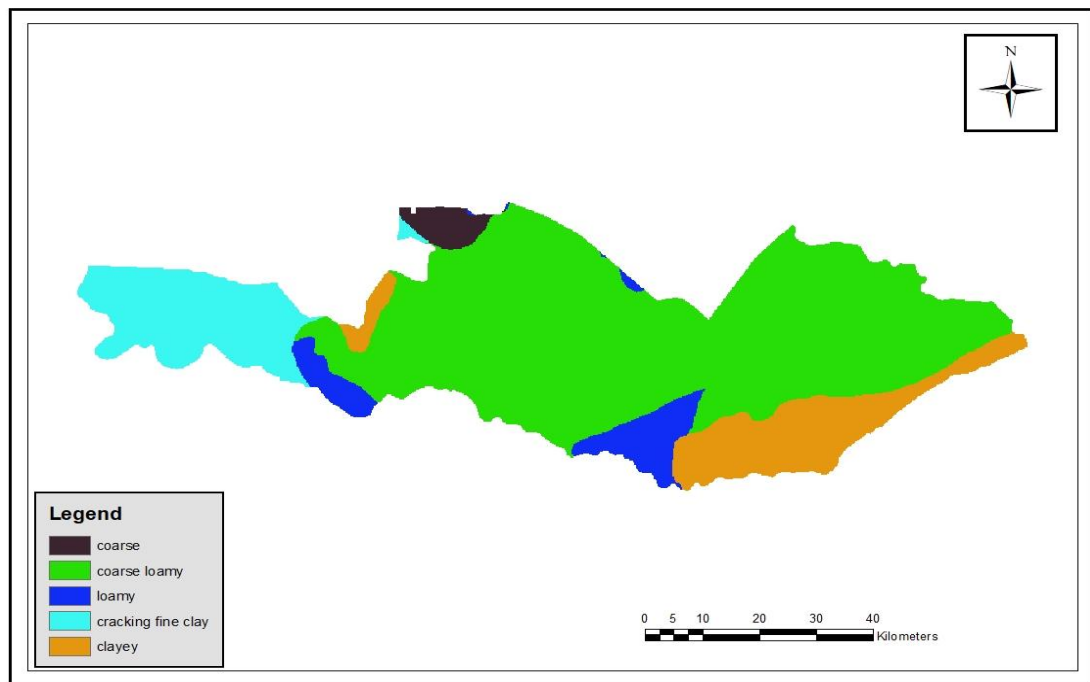
One of the discussants from the focus group discussion stated that;

Soil type is the most important factor to consider in site selection, when digging a pond, Clay is the most suitable type of soil because it holds water for a long time. The fish pond for the king fisher multi-purpose cooperative is dug on clay soil, it is for this reason as to why issues of seepage due to high infiltration rate, fish mortalities, high pumping cost of water, poor aeration and having a dry pond are not experienced by this cooperative (Pers.Com.2019a).

In agreement, one of the key informants stated that, “*Clay soil is the best soil type, nutrients contained in the soil helps the fish grow well too*” (Pers.Com.20192).

Hossain et al. (2007) were of the view that soil type affects the initial cost of pond construction, because soil permeability affects the capacity of the pond to hold water.

Permeable soils are least suitable for ponds, in as much as water loss from seepage increases the demand for water, and pumping costs.



**Figure 5.12: Kafue District soils map.**

Source: Field data, 2019.

The most conducive soil type for fish pond farming is clayey due to its high field capacity and low infiltration rate, such soil types are found on highly suitable sites such as the one shown in Figure 5.13.

Wanganeo et al (2009) conducted a study that demonstrated the potential use of remote sensing and GIS techniques for aquaculture site selection and planning for responsible aquaculture. In order to plan aquaculture at National level, multi objective land allocation method needs to be followed to avoid land conflicts. Soil texture is a significant factor in pond productivity because of its ability to absorb and release nutrients which is ultimate used by plankton, the natural food of fish.

Suitable sites generally have clayey and cracking fine clayey soil. Moderately suitable sites had coarse loamy and loamy soil type and not suitable sites were mainly covered by coarse as shown in Figure 5.14 and coarse loamy soil type which is highly permeable and has a low field capacity, ponds dug on such sites experience high water seepage.

Challenges experienced by some existing fish farmers included seepage from the ponds dug on sandy loam due to high infiltration rate, sandy and sandy loam soil does not hold water for a long time. As a result of seepage, pumping cost of underground water for the pond becomes expensive because water has to be pumped in and out frequently. Lack of training for fish farmers is a challenge in that new skills and knowledge on fish farming is not attained, they keep practising what they were taught in the past.



**Figure 5.13: Highly suitable site (Clayey soil type)**

Source: Field data, 2019.



**Figure 5.14: Not suitable site (Coarse soil type)**

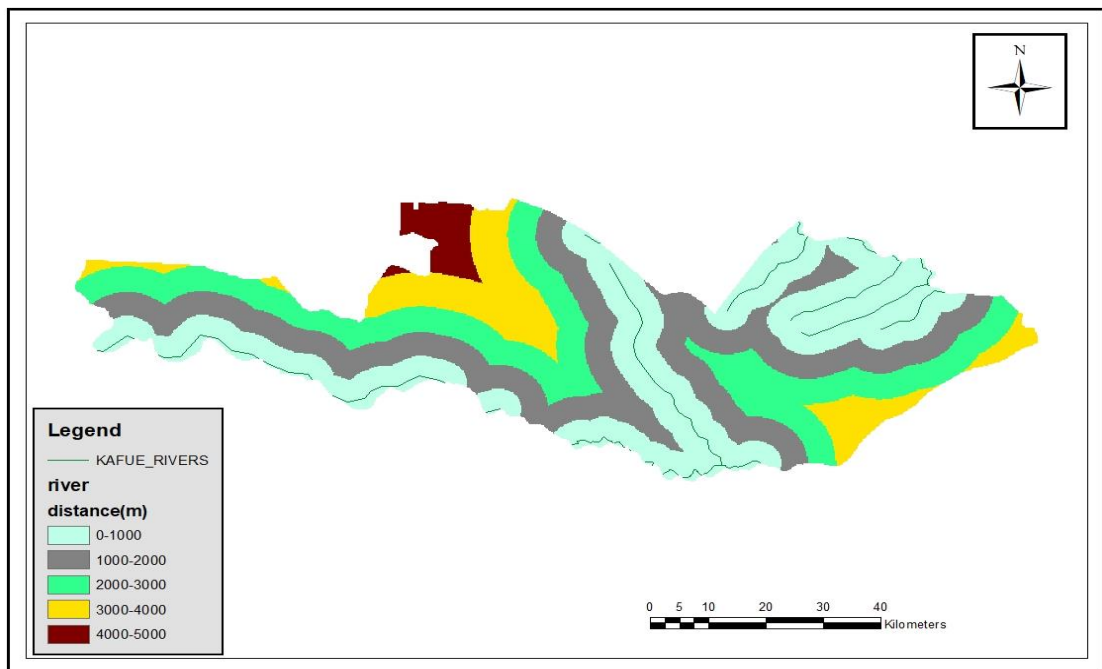
Source: Field data, 2019.

### **5.4.3 Distance to river**

Distance to river weighted 24% and is the third most important criteria, this is because water is vital for fish pond farming. The north eastern part of Kafue district has more sources of water compared to the other parts of the district. Kafue River flows along the lowest part of the boundary as shown in Figure 5.15.

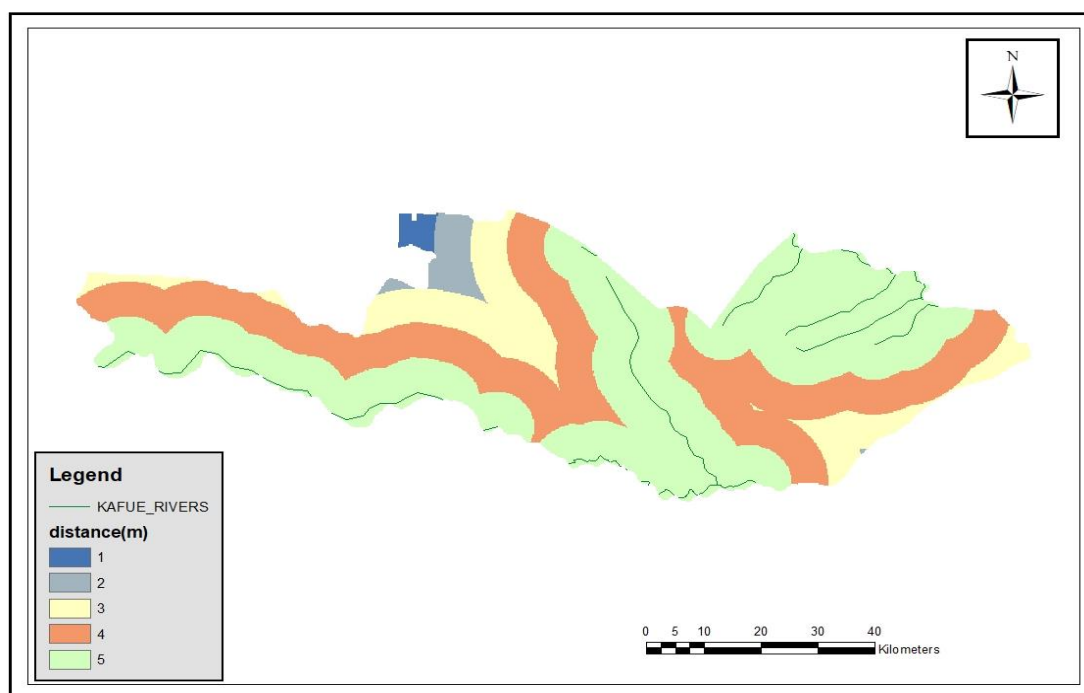
Within distance to river, sites covered by distances of 0km to 1km from the river were ranked five (5) and these were the most suitable for fish pond farming because water is permanently available and pumping water is cheaper. This is followed by sites covered by distances of 1km to 2kms from water bodies and these are ranked four (4),

water is easily accessed. Distances of 2kms to 3kms from water bodies were ranked three (3), rank two (2) had sites covered by distances of 3kms to 4kms from water source, these are moderately suitable and rank one (1) had sites covered by distances of 4kms to 5kms from water bodies, these were the least suitable sites for fish pond farming for they are the furthest from water bodies hence the cost of pumping water is expensive and water is not permanently available for the fish pond. The further a site is from the source of water the less suitable it is for fish pond farming. Reclassified distance to river map is shown in Figure 5.16.



**Figure 5.15: Kafue district distance to river map**

Source: Field data, 2019.



**Figure 5.16: Reclassified Kafue district distance to river map.**

Source: Field data, 2019.

Kapembwa and Samboko (2017) established that water shortages are a major challenge faced by fish farmers in other regions of Zambia who cannot rely on groundwater resources during the warm season and in drought years. This study therefore considered highly suitable sites as those closer to the river so as to reduce challenges of water shortages.

Key informant B was of the view that distance to the water source preferably a natural reservoir should be short. The source of water is vital for fish pond farming and fish mortalities are reduced when water is readily available and well oxygenated (Pers.Com.20192).

In tandem with the above statement, a discussant from the focus group discussion elaborated that the two fish ponds owned by the King Fisher Cooperative are 200m and 100m away from Kafue River respectively. It is for this reason that they have water permanently available for the pond throughout the year. During the dry season when ground water slowly fills the pond, they pump water from the river. This is reasonably cheap because the ponds are very close to the river. The only fish mortalities experienced are less than five fish per cycle (Pers.Com.2019d).

Highly suitable sites shown in Figure 5.17 are areas whose distance to the river is between zero to two km (0-2km). This short distance therefore reduces the pumping cost of water and the source of water is permanently available all year round. Suitable sites have a distance of less than 3kms from the river. Moderately suitable sites have a distance less than 4kms from the river and not suitable sites are covered by a distance of 3km-5km from the river hence it is very expensive to pump water into a pond dug on such a sites.



**Figure 5.17: Highly suitable site (distance to water is between 0-1km)**

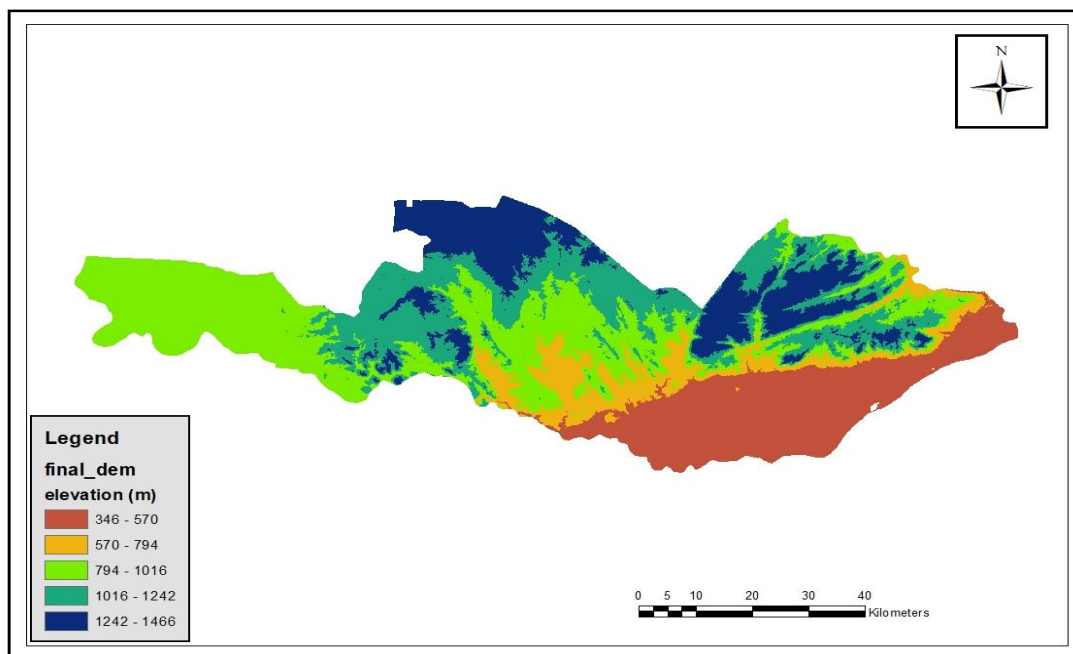
Source: Field data, 2019.

#### **5.4.4 Elevation**

Of the six criteria, elevation weighted 4% and was the fourth most important criteria. Elevation of the contours in Kafue district range from 346 meters to 1,466 meters above sea level are shown in Figure 5.18. The higher the elevation the least suitable a site is for fish pond farming, from the different elevation ranges, the most suitable sites had elevation of 346m-570m and were ranked five (5), the cost of digging a pond and pumping water in such areas is less. These were followed by sites with elevation of 570m-794m and were given a rank of four (4), rank three (3) had elevation range of 794m-1018m, elevation between 1018m-1242m was ranked two (2) and finally rank one (1) had the highest elevation range of 1242m-1466m, sites with such elevation were the least suitable for fish farming because the cost of digging a pond is rather high on areas with higher elevation. This is shown in Figure 5.18.

Key informant C stated that:

The cost of digging a pond and pumping is high on sites with higher elevation than those of lower elevation. It is better and cheaper to dig a pond on sites with low elevation. Transporting the fish once harvested is also affected by sites with a higher elevation, this then contributes to the fish perishing (Pers.Com.20193).



**Figure 5.18: Kafue District elevation map**

Source: Field data, 2019.

Hossain et al. (2007) were of the view that highly suitable sites with regard to topography have elevation of less than 6m. This so because it is cheap to dig up a pond in such areas. Findings in this study show that highly suitable sites have an elevation between 346m-570m as shown in Figure 5.19. Suitable sites have elevation ranging between 346m-794m and moderately suitable sites have an elevation of 570m-1466m above sea level. Not suitable sites have elevation ranging from 1242m-1466m hence requires well equipped machinery which is very expensive to purchase or hire in order to dig a pond. This is shown in Figure 5.20.



**Figure 5.19: Highly suitable site (site with low elevation)**

Source: Field data, 2019.



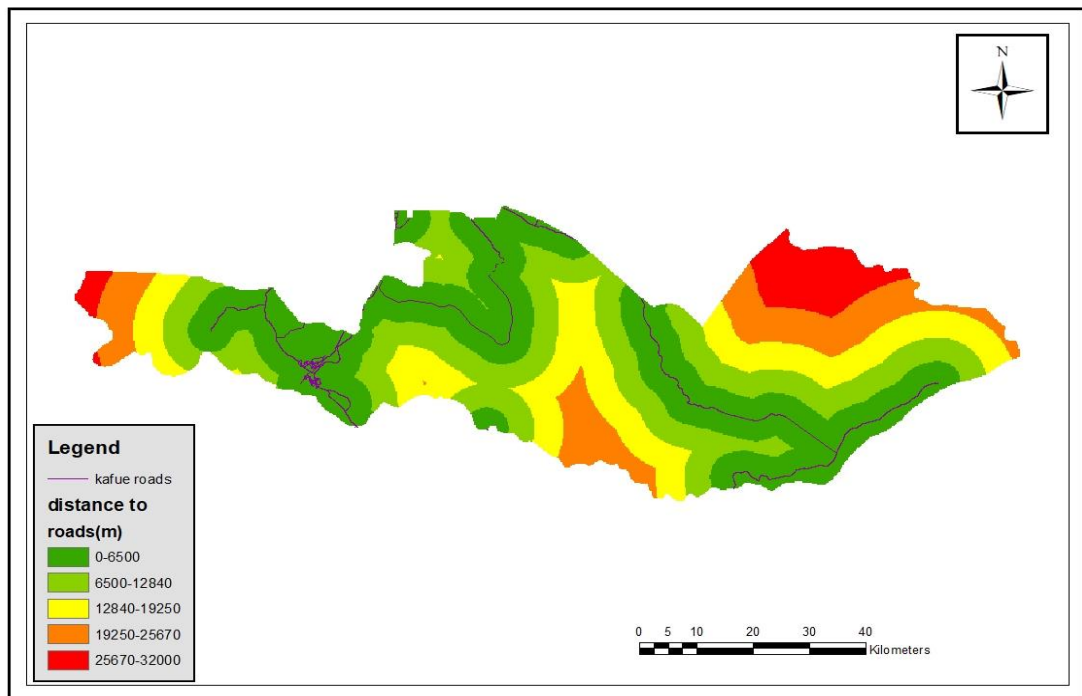
**Figure 5.20: Not suitable (high elevated rocky site)**

Source: Field data, 2019.

#### **5.4.5 Distance to roads**

Distance to motorable roads weighted 4% and is the second least important factor. Figure 5.21 shows the different distance ranges in meters. The reclassified distance to roads map had five (5) ranks as shown in Figure 5.22; distances of 0 - 6.5kms from motorable roads were ranked five and were the most suitable for fish pond farming. This is because transport cost is cheap, transportation of feed bought from Kafue town is cheap as well as fish after being harvested to be sold to the market. This is followed by distance of 6.5kms-12.84kms and were ranked four (4) and rank three (3) had 12.84kms-19.25kms. Rank two (2) and one (1) were the furthest from the roads hence transport cost would be very expensive with the former having distances of 19.25kms-25.67kms and the latter with 25.67kms-32kms.

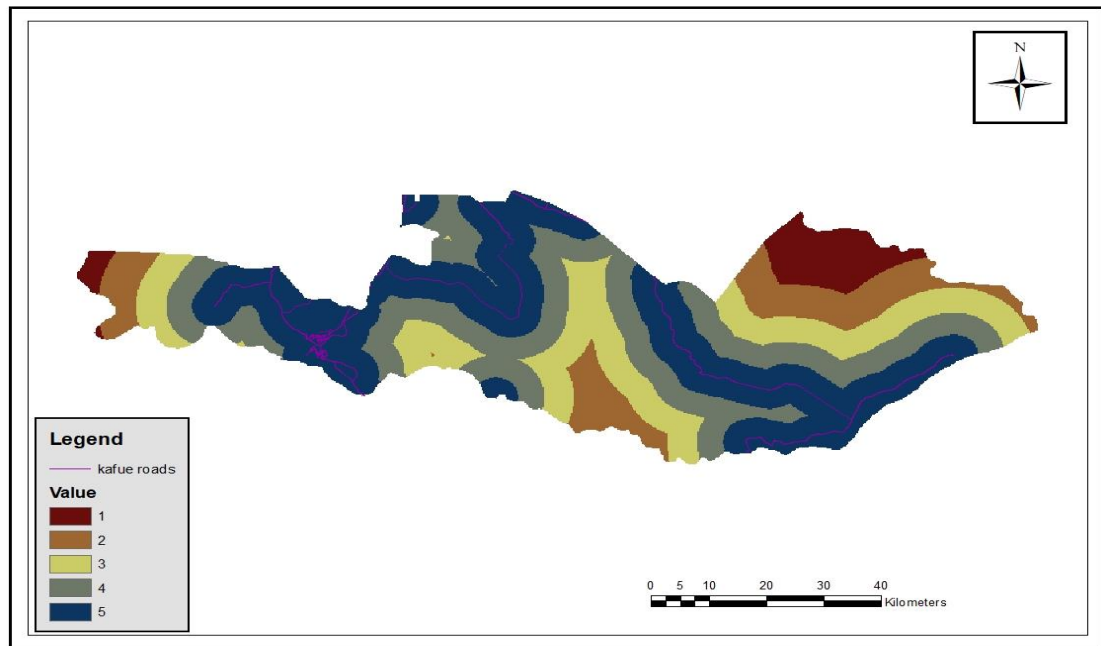
The most suitable areas with regard to distance to roads were those sites with a distance of 0–6.5 kilometers from the main roads. This is so because fish is a perishable produce and thus needs to be sold and transported as soon as it is harvested. The least suitable areas were those furthest from the roads with distances of 25,670–32,000 metres from the roads because transport cost for feed and customers would be expensive. Fish is a perishable good, the nearer a fish pond is to a motorable road, the less money spent to transport the fish to the market. It is easier to transport the fish once harvested, fish ponds that are near the road are easily accessible by customers. People who want to buy fresh fish straight from the pond, as some customers do, can easily access areas nearer to roads.



**Figure 5.21: Kafue district distance to roads map**

Source: Field data, 2019.

The reclassified distance to roads map had five ranks as shown in Figure 5.22.



**Figure 5.22: Reclassified Kafue district distance to roads map**

Source: Field data, 2019.

Key informant A had a view that a road that is in good condition is needed near the fish ponds. It might not be tarred but as long as it is passable by people and vehicles then it is good enough, this makes transportation of fish to the market easier and cheaper hence no losses resulting from perishing of fish (Pers.Com.20191). In confirmation, one of the discussant elaborated that the fish ponds for the cooperative are less than 100 metres from a motorable road. It is for this reason as to why the fish harvested is easily sold out. In 2018, about 100kgs was harvested and it was sold right at the fish ponds because customers did not have difficulties accessing to their pond, on the other hand, a few kilograms of fish that remained were easily transported to the market (Pers.Com.2019f).

Another discussant from the focus group discussion stated that:

When fish feed is bought from Kafue town, it is easily transported by any member of the cooperative using a bicycle because the fish ponds are less than 3kms from the town. This results into them spending less because in this case there is no need of booking a taxi to transport feed (Pers.Com.2019c).

Similarly, another discussant from the focus group discussion was of the view that although the cooperative does not have a fridge to store their fish, this is not a constraint because the fish ponds are close to the market and motorable roads. Once

the fish is harvested, it is sold at the fish ponds because customers are informed and go there to buy. Whatever remains is sold at the market and they have never experienced any fish getting rotten because the fish is sold out when it is still fresh (Pers.Com.2019a).

Highly suitable sites shown in Figure 5.23 have distance to motorable roads of less than 6.5kms because fish is perishable and so it needs to be sold as soon as it is harvested. Suitable sites have distances less than 6.5kms with a few having distances of 0 to 12.84 kms from motorable roads. Moderately suitable sites covered a distance of 0-19.25kms from motorable roads and not suitable sites are 19.25kms to 32kms away from motorable roads, this would result into the fish going bad before being transported to the market as well as customers having difficulties to buy fresh fish from the ponds for the distances from motorable roads is very far.



**Figure 5.23: Highly suitable site (distance less than 6.5km from the road)**

Source: Field data, 2019.

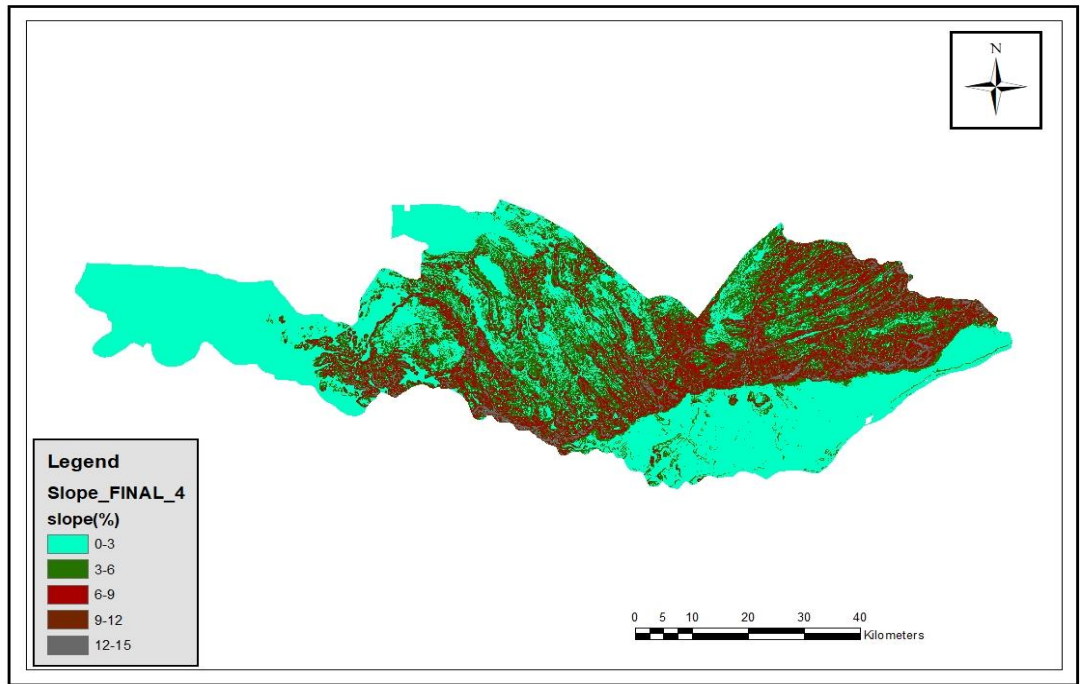
In terms of geographic sites and proximity to inputs, services and markets, Kaminski et al (2019) considered location as another important factor when profiling fish farmers. The location of farmers can both determine the environmental conditions needed for production, as well as the level of participation in the value chain. Location is also a decisive factor in determining farmers' integration in the value chain. Roads, electricity and access to other physical assets are very important for aquaculture growth and most people in their sample lived in very isolated places. Many farmers still lack the basic knowledge to fish farm. Experienced farmers lack the knowledge and skills to upgrade their farms i.e. incorporating commercial feeds or sex-reversed fingerlings, business skills, etc. A general lack of access to perennial rivers or streams and poor soil quality pose a challenge for fish farmers as they may incur additional

costs to secure water (e.g. by digging boreholes; or buying plastic liner to avoid seepage in their ponds). The findings of this study show that distance to motorable roads is vital in fish pond farming. The proximity to urban markets and access to transport are important considerations in farmers' participation in the value chain.

#### **5.4.6 Slope**

Slope weighted 3% from pairwise comparison using AHP. Hossain et al. (2007) suggested that the most suitable areas with regard to topography were those with low slope (0–3%). Similarly, to their study, sites with slope of zero to three (0-3%) were ranked one and were the most suitable for fish pond farming, such sites allow easy flowing of water to the pond hence pumping cost of water is low. These were followed by sites with slope of three to six (3-6%) given a rank of four (4) as it is cheap to dig up a pond on such sites and pumping cost of water is cheap as well as transport. Sites with slope of six to nine (6-9%) were ranked three (3) and rank two (2) had sites with slope of nine to twelve (9-12%). The least suitable sites were ranked one (1) with slope of (12–15%). These sites had a higher slope hence it was difficult and expensive to dig up a pond on such sites. Expensive in that there is need for well-equipped machinery to be used for such areas are a bit mountainous, this therefore implies that digging a fish pond in sites with a lower slope is cheaper than in areas of higher slope. Figure 5.24 shows the Kafue district slope map.

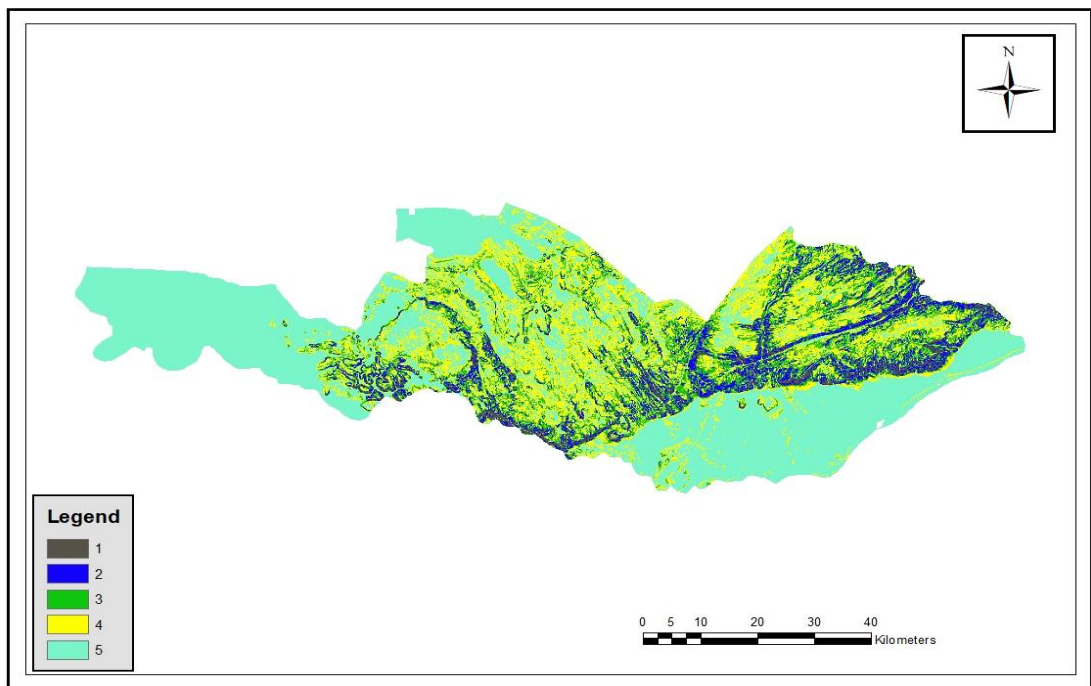
Hossain et al. (2007) in their study further found that the unsuitable zone is located mainly in areas with higher slope and elevation. Availability of sources of fish fry and easily accessible well-established marketing facilities favour tilapia farming development in the study area. In conformity to this study, their study took into consideration the existing land-use pattern and topographic conditions. The unsuitable zone is located mainly in areas with higher slope and elevation.



**Figure 5.24: Kafue district slope map**

Source: Field data, 2019.

Reclassification of the slope map in Figure 5.25 was done in order to assign ranks.



**Figure 5.25: Reclassified Kafue district slope map**

Source: Field data, 2019.

Key informant A stated the following:

It is expensive to dig a pond on sites with a high slope, therefore sites with low slope are more suitable for pond construction and both fish ponds were dug on sites with a slope of less than 3% hence it was cheaper to dig these ponds (Pers.Com.20191).

Likewise, key informant C was of a view of that the higher the slope the least suitable a site is for fish farming and vice versa (Pers.Com.20193).

Highly suitable site have slope less than three (3%), Suitable ones have slope ranging from 0-6%. Moderately suitable ones have slope between 6 to 12 % with not suitable sites having slope between 12-15% as shown in Figure 5.26.



**Figure 5.26: Not Suitable sites (hilly sites have higher slopes)**

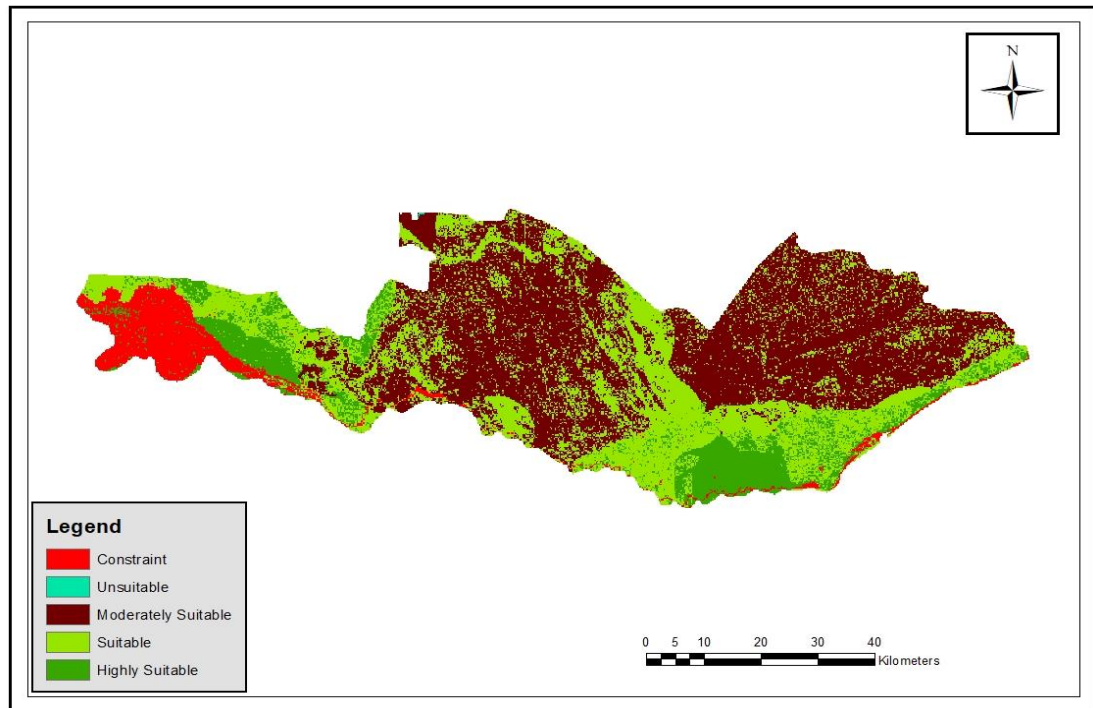
Source: Field data, 2019.

### **5.5 Suitability map for fish pond farming in Kafue district.**

The overall evaluation in Figure 5.27 shows that Kafue district is mainly moderately suitable (49%) for fish pond farming. This is followed by suitable sites (33%), highly suitable sites (10.99%) and constraints (7%). The least area is covered by unsuitable sites (0.01) implying that fish pond farming cannot be completely practiced in a few sites in the district.

Kabede et al. (2015) gave weight according to the effectiveness of the criteria based on previous studies, experts' opinion. Each class was given a score according to suitability that is: most suitable score 4, suitable score 3, moderately suitable score 2,

and unsuitable score 1. In addition to the classes given, this study had constraint with the least score given to it and highly suitable with the highest score assigned to it.



**Figure 5.27: Kafue district fish pond farming suitability map**

Source: Field data, 2019.

Table 5.8 entails that of the total area (459,890 ha), 50353 ha (11%) was highly suitable for aquaculture development, 153,040 ha (33%) was suitable, 223,770 ha (49%) was moderately suitable implying that a larger part of Kafue district is moderately suitable for fish pond farming. In sum, therefore, fish ponds can be dug in most different sites of the district. Wetland was a constraint and it covered an area of 32,674 ha (7%), fish ponds cannot be completely dug on these sites. The area of 53 ha (0.01%) was not suitable for fish pond farming, sites that are completely not suitable for fish farming had the lowest percentage of the total area hence fish pond farming cannot be completely practiced only in a few areas. Highly suitable sites, suitable ones, moderately suitable, not suitable and constraints had different criteria coinciding with each other.

**Table 5.8: Suitability classes and area in Ha and percentages**

Class	Area (Ha)	Area (%)
Constraint	32674	7
Unsuitable	53	0.01
Moderately Suitable	223770	49
Suitable	153040	33
Highly Suitable	50353	10.99
Total area	459,890	100

Source: Field data, 2019.

A fish pond dug on a highly suitable site would look like the one shown in Figure 5.28 or better. Such a pond was dug on a site meeting all the requirements of the six criteria discussed.



**Figure 5.28: A fish pond dug on a highly suitable site**

Source: Field data, 2019.

The consistency ratio was finally derived and shown in Table 5.9

**Table 5.9: Consistency ratio**

SUM of weighted value /criteria weight	37.03326
Lambda Matrix (sum/n)	6.17721
Lambda Matrix - n	0.17221
n-1	5
Consistency index = Lambda matrix – n/ n-1	0.0344
Random index	1.25
Consistency Ratio = CI/RI	0.0344/1.25
<b>CR</b>	<b>0.027</b>

Source: Field data, 2019.

If CR is smaller than 0.10, the degree of consistency is satisfactory; if, however, the CR is larger than 0.10, there are inconsistencies and the AHP method may not yield meaningful results. In this study CR was 0.027 (2%) which is less than 0.1 (10%) implying that the results are trustworthy. This means that the most important criteria in this study was land use/cover type with 43%, followed by soil type (30%) and distance to river (16%), elevation (4%), distance to roads (4%) and the least being slope (3%).

Liberatore et al. (1992) suggested that the structured approach of AHP could better capture the subjective judgments. Subjectivity of AHP is later dealt with by the structured approach. There are different steps followed in AHP calculations, these combine all the rankings from different experts and different formulas in each step are used. Hence AHP calculations later become objective by sticking to the existing formulas thereby incorporating the subjective judgements into the objective structured approach. For instance, despite the difference in the ranks assigned to LULC and soil type being minimal in the pairwise comparison, the weights derived at the end of the AHP calculations have a difference of 13% which is bigger than the values of the ranks differences.

Study limitations are that during image classification, extracting training sites was laborious as well as calculating of criteria weights using AHP because after assigning ranks from experts' opinion, if the consistency ration was more than 0.1 there was need to re-assign the ranks again and start doing the calculations all over. In order to obtain a consistency ration of 0.027 calculating of criteria weight was redone using AHP so as to have a consistency ratio that is accepted. The subjectivity of AHP was dealt with by its structured approach. Ranking is subjective but as the calculations were being done in different stages, AHP's subjectivity was later dealt with.

Table 5.10 shows a summary of results from different key informants.

**Table 5.10: Summary of results from key informants on Criteria**

Parameter	Key Informant 1	Key Informant 2	Key Informant 3	Key Informant 4	Key Informant 5	Key Informant 6
Factors considered in fish pond farming	Water Soil type Slope Market Land Use	Soil type Land use Elevation Slope Source of water Distance to roads	Land ownership Soil type Source of water topology	Water source Soil type Rainfall / Temperature Proximity to the market	Distance to source of fingerlings Distance to market Soil type Water source	Distance to source of feed Water source Soil type topology
Constraints considered in fish pond farming	Industrial areas Overpopulated areas	Water bodies Industrial areas	Built up Water bodies	National park	Built up	Settlements Water bodies
Challenges experienced	Technical Financial	Financial	Technical knowledge	Source of inputs Technical financial	Financial Predation Source of inputs	Theft Predation Pond maintenance
Measures to be taken	GIS training	Offer financial support	Training fish farmers	Find other sources of income other than fish farming to source inputs	Fence ponds Find source of income	Find tight security at the ponds Pond maintenance to be done frequently

Source: Field data, 2019.

## **CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS**

### **7.0 Introduction**

This study aimed at determining sites for on-land fish pond farming in Kafue district using multi-criteria evaluation approach. It further determined the criteria for selecting suitable fish pond sites in the district and finally developed a suitability map showing fish pond sites. This chapter therefore gives a summary of the study and recommendations based on the findings and discussions.

### **7.1 Conclusion**

The factors considered for fish pond farming were soil type, slope, elevation, land use/cover type, distance to roads and water. AHP was used for ranking and assigning weights using pairwise comparison. ArcGIS 10.1 was the software used for analysis and producing the suitability maps. The consistency ratio was 0.027 which is less than 0.1 implying that the results were trustworthy. The study combined geographic information and remote sensing data to select highly suitable, suitable, moderately suitable and not suitable sites using multi-criteria evaluation to help the farmers and authorities to achieve the efficiency in fish pond farming. The usefulness of GIS-based tools in site selection for fish pond farming for sustainable aquaculture has been demonstrated in this study.

The output raster had four categories, highly suitable, suitable, moderately suitable and unsuitable, this raster was called Kafue fish pond farming suitability map. The study finds that highly suitable sites for fish pond farming are those in which most of the variables that had the highest ranks coincide with each other. When site selection for fish pond farming is done effectively using multi-Criteria evaluation method, challenges faced by fish farmers such as seepage and fish mortalities can be reduced. The establishment of aquaculture ponds using GIS will reduce challenges currently faced by fish farmers due to siting using conventional methods, increase protein intake from the consumption of fish, provide employment opportunities and also reduce pressure on capture fisheries hence attain sustainability in the fisheries sector. Identifying suitable and productive sites is vital for environmental sustainability and economic efficiency of aquaculture ventures because it considers critical issues in fish farming. The usefulness and accuracy of this tool increases for optimum site selection as more data become available.

## **7.2 Recommendations**

Based on the findings of this study, the following recommendations were made:

1. Site selection using GIS and remote sensing can be a valuable tool in solving problems at a regional level. There is need of offering GIS training programmes in the Department of Fisheries so that officers attain knowledge in site selection for fish farming using multi-Criteria evaluation method instead of the conventional method that is currently used. This will result into fish farmers facing less challenges and reduce labour for fisheries officers
2. The government should integrate aquaculture site selection into its programmes by directly investing into the Department of Fisheries or granting of loans to individual that can use GIS skills in fish pond site selection.
3. There is need to engage GIS and Remote sensing experts in site selection for fish pond farming.
4. In cases where a pond is dug on bare land, there is need to add a lot of clay soil so as to make the soil fertile enough and reduce water permeability.
5. The model can be used by fish farmers and stake holders to make progressing decisions for their suitable site plan. The Department of Fisheries officers, after being trained on how to use the model, will guide fish farmers they want to dig the fish pond on their land.

## REFERENCES

- Al-Ahmadi, F, S. and Hames, A, S. 2009. Comparison of Four Classification Methods to Extract Land Use and Land Cover from Raw Satellite Images for Some Remote Arid Areas. Kingdom of Saudi Arabia”, *Journal of King Abdulaziz University-Earth Sciences* 1 (20):167-191.
- Al-Mashreki, M.H., 2011a. GIS-based sensitivity analysis of multi-criteria weights for land suitability evaluation of sorghum crop in the Ibb Governorate Republic of Yemen. *Journal of basic and applied scientific research*, 1 (9):1102–1111.
- Auditor General Zambia., 2015. *Report of the Auditor General on sustainable management of fish resources in natural water*.
- Bakhtiar, F. and T. Blaschke .2012. Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS, *Journal of Environmental Planning and Management*, DOI:10.1080/09640568.2011.646964.
- Bernard, H.R., 2002. *Research Methods in Anthropology: Qualitative and quantitative methods*. 3rd edition. Altamira Press, Walnut Creek.
- Boghen, A.D., 2005. *Cold water aquaculture in Atlantic Canada*. 2<sup>nd</sup> Ed. The Canadian Institute for research on Regional Development. ISBN: 0886590175. Moncton
- Borouhaki, S., and J. Malczewski., 2008. *Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS*. *Computers & Geosciences*, 34:399-410. Cairns, Australia.
- Briney, A., 2014. *An Overview of Remote Sensing*, May 16, 2014.  
<http://geography.about.com/od/geographictechnology/a/remotesensing.htm>
- Chen, Y., J. Yu, and S. Khan., 2010b. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental modelling and software*, 25, 1582–1591.
- Chikowo, R., 2018. *Description of cropping systems, climate and soils in Zambia*. Global yield gap Atlas. *Argic Ecosystem Environ* 102:119–13
- Chow, T.F. and R. Sadler., 2010. The consensus of local stakeholders and outside experts in Suitability modelling for future camp development. *Landscape and urban planning*, 94, 9–19.
- Deng, H., 1999. Multi-criteria analysis with fuzzy pairwise comparisons. *Int J Approx. Reason* 21:215–231.

- Congalton, R.G., 2001. *Accuracy Assessment and validation of Remotely Sensed and other spatial Information*. University of New Hampshire, Department of Natural Resources. 1(4): 1-6, Durham.
- Congalton, R.G. and Green, K. 2009. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. 2nd Edition, Lewis Publishers, Boca Raton
- Elaalem, M., A. Comberm, and P. Fisher., 2011. A comparison of fuzzy AHP and ideal point Methods for evaluating land suitability. *Transactions in GIS*, 15 (3), 329–346.
- FAO, 1976. *A framework for land evaluation*. Food and Agriculture Organization of the United Nations, Rome.
- FAO, 1976. *A framework for land evaluation*. Food and Agriculture Organization of the United Nations, Rome.
- FAO, 1993. *Guidelines for land use planning. FAO Development Series 1*. Food and Agriculture Organization of the United Nations, Rome.
- Fisheries Act No.22 of 2011. Accessed on 25<sup>th</sup> November, 2014 <http://www.parliament.gov.zm>
- Fisheries and Aquaculture Department, 2007. *GIS, Remote sensing and mapping for the development and management of marine aquaculture*. FAO Technical paper 458, Rome.
- Fisheries and Aquaculture Department, (FAO), 2005. *Putting into Practices the ecosystem approach to Fisheries*. FAO Rome 76p.
- Genschick, S., A.M. Kaminski, A.S. Kefi, and S.M. Cole., 2017. *Aquaculture in Zambia: An overview and evaluation of the sector's responsiveness to the needs of the poor*. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems and Lusaka, Zambia: Department of Fisheries. Working Paper: FISH-2017-08.
- Geoff, C., 2014. *Practical strategy AHP* Pearson education limited. London
- GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP), 2001. Joint group of experts on the scientific aspects of marine environmental Protection. *Planning and management for sustainable coastal aquaculture development*. FAO Rep. Stud. GESAMP. 68: 90.
- Giap, D.H., 2005. *GIS for land evaluation for shrimp farming in Haiphong of Vietnam*, *Ocean & Coastal Management* 1(48): 51-63, Vietnam.

- Guiqin, W, Q. Li, and L.M. Guerue., 2009. Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. *J Environ Manage* 90:2414–242. *Hierarchy Process*. 2<sup>nd</sup> ed. Springer, New York (XIV + 346 p.)
- Hobson, R.H., A.D. Roberts, and G.J. Williams., 2019. *Northern Rhodesia, Republic of Zambia*. Encyclopaedia Britannica. Zambia.
- Hora, S.L, and T.V.R. Pillay., 1962. *Handbook on fish culture in the Indo-Pacific region*. FAO Fish. Tech. Pap. (14):204
- Hossain M.S., S.R. Chowdburry, and G.D. Dass., 2008. Integration of GIS and Multi-Criteria decision analysis for urban aquaculture development in Bangladesh. *Landscape and urban planning*, 90 (3-4):119-133.
- Hossain, M. S., S.R. Chowdhury., N.G. Dass, and M.M. Rahman., 2007. Multi criteria evaluation approach to GIS-based land-suitability classification for tilapia farming in Bangladesh. *Aquaculture International* 15(6): 425–443.
- Hossain, M. S., S.R. Chowdhury., N.G. Das., S.M. Sharifuzzaman, and A. Sultana., 2009. Integration of GIS and Multi criteria Decision Analysis for Urban Aquaculture Development in Bangladesh. *Landscape Urban Plan*. 90 (3-4): 119-133.
- Hossain, M.S, and N.G Das., 2010. GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (*Macro brachium rosenbergii*) farming in Companigonj Upazila of Noakhali, Bangladesh. *Institute of Marine Sciences and Fisheries, University of Chittagong*, Chittagong 4331, Bangladesh.
- Hsieh, H. F, and S.E. Shannon., 2005. Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9):1277-1288.
- Jiang H, J.R. Eastman., 2000. Application of fuzzy measures in multi-criteria evaluation in GIS. *Int J Geo INF Sci* 14(2):173–184.
- Kabede, L., A. Kassahun, and P. Natarajan., 2015. *Gis Based Site Suitability Analysis for Pond Production of Nile Tilapia (Oreochromis)* Ambo University, West Shoa.
- Kaminski, A.M., M. Gellner, D. Giese, S. Jabbrov, M. Lootz, M. Lundeba, B. Nyika, N. Patt, A. Sadeghi, and M.M Siachinga., 2019. *Opportunities and Challenges for small Scale Aquaculture in Zambia*. Centre for Rural Development (SLE) Berlin. SLE publication scenes.

- Kapetsky, J.M., 1994. *A strategic assessment of warm-water fish farming potential in Africa*, CIFA Technical Paper, No. 27 edn. FAO, Rome.
- Karlsson, A., 2003. *Classification of high resolution satellite images*, August 2003, available at [http://infoscience.epfl.ch/record/63248/files/TPD\\_Karlsson.pdf](http://infoscience.epfl.ch/record/63248/files/TPD_Karlsson.pdf).
- Karthik, M., 2005. Brackish water aquaculture site selection in Palghar Taluk, Thane district of Maharashtra, India, using the techniques of remote sensing and geographical information system *Aqua cultural Engineering* 32.
- Kövári, J., 1984. *Inland Aquaculture Engineering. Aquaculture Development and Coordination Programme*. Budapest, 6 June-3 September 1983.
- Kuo, R.J, G.S. Liang, and W.C. Huang., 2006. Extensions of the multi criteria analysis with pairwise comparison under a fuzzy environment. *Int J Approx. Reason* 43:268–285.
- Kutty, M.N., 1987 *Selection for Aquaculture*. African Regional Aquaculture Centre, P.M.B.6165. Nigerian Institute for Oceanography and Marine. Research. Port Harcourt.
- Lewis, J.L, and S.R.J. Sheppard., 2006. Culture and communication: can landscape visualization improve forest management consultation with indigenous communities? *Landscape and Urban Planning* 77:291–313.
- Liberatore, M.J., R.L. Nydick, and P.M. Sanchez., 1992. The evaluation of research papers (or how to get an academic committee to agree on something). *Interfaces* 22(2):92–100
- Liberatore, M.J., R.L. Nydick., 1997. Group decision making in higher education using the analytic hierarchy process. *Res High Educ* 38(5):593–614.
- Lung, T., and G. Schaab., 2009. Assessing fragmentation and disturbance of West Kenyan rainforests by means of remotely-sensed imagery time series data and landscape metrics. *African Journal of Ecology* 44(4):491-506
- Lin, S., 2010. *Gis based multi-criteria analysis for aquaculture site selection*. University of Gavle. Department of industrial development, IT and land management. Yingpan, China
- Dolores, M.A., and C. Tongco., 2013. *Ethnobotany Research & Applications* 5:147-158 *purposive sampling as a tool for informant selection*. department of Botany, University of Hawai'i at Manoa, 3190 Maile Way, Honolulu, HI, 96822 U.S.A. and Institute of Biology, University of the Philippines, Diliman, Quezon City.

- Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. *Prog Plann* 62:3–65.
- Malczewski, J., 2006. GIS-based multi-criteria decision analysis: a survey of the literature. *Int J Geogr INF Sci* 20:703–726.
- Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. Progress in Methods for evaluating land suitability. *Transactions in GIS*, 15 (3):329–346.
- Mukami, N.M., 2010. *Assessing the potential of small scale Aquaculture in Embu district, Kenya using GIS and remote sensing*. Environmental information systems, Moi University.
- Nath, S.S., 2000 Applications of geographical information systems (GIS) for spatial decision support aquaculture, *Aqua cultural Engineering* 23(1): 233-278. Application of Geography Information System for spatial decision support in Aquaculture.
- Naylor, R.L., R.L. Goldburg., J.H. Primavera., N. Kautsky., M.C.M. Beveridge, and J. Clay., 2000. Effect of aquaculture on world fish supplies. *Nature* 2000; 405 (29):1017–24.
- Nekhay, O., M. Arriaza., and J.R. Guzmán-A´lvarez., 2008. *Spatial analysis of the suitability Niloticus in West Shoa Zone, Central Ethiopia*.
- Oscar, M.P., C.T. Trevor, and G.R. Lindsay., 2005. Aquaculture Research, - *GIS based models for offshore floating marine fish cage aquaculture site selection in Tenerife, Canary Island*. 31 (36):946-961., Coastal management.
- Peter, C., T.R. Longdill, and K.P. Healy., 2008. *An integrated GIS approach for sustainable aquaculture management area site selection a Coastal Marine Group*, Department of Earth and Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton. Marine Consulting and Research, Raglan, New Zealand
- Pillay, T. V. R, and M.N. Kutty., 2005. *Aquaculture: Principles and Practices*, 2nd Edition Wiley-Blackwell, Oxford.
- Prakash, T.N., 2003. Land suitability analysis for agricultural crops: a fuzzy multi criteria decision making approach. Thesis (MSc). (ITC) *International Institute for Geo information Science and Earth Observation*, Enschede.

- Richard J. U., and C. Ogba., (2016) “Site Selection Analysis for Suitable Aquaculture Fish Pond in Andoni L.G.A. Rivers State, Nigeria” *International Journal of Research – Granthaalayah* 4 (3):219-232.
- Saaty, T.L., 1980. *The analytic hierarchy process: planning, priority setting and resource allocation*. McGraw-Hill, New York.
- Saaty, T.L., 1980. *The analytic hierarchy process*. McGraw-Hill, New York.
- Saaty, T.L., and L.G. Vargas., 1991. *Prediction, Projection and Forecasting*. Kluwer Academic Publishers, Boston.
- Saaty, T.L., 1994. How to make a decision: the analytic hierarchy process. *Interfaces* 24(6):19–43
- Saaty, T.L., and L.G. Vargas., 2012. *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*. Springer Science & Business Media, New York.
- Shamilenge, D., 2019. *Fish deficit to be narrowed by Aquaculture*. Zambia business times.
- Shree S. N., P.B. John., G.R. Lindsay, and A.M. Jose., 2000. *Application of Geographic Information Systems (GIS) for Spatial Decision Support in Aquaculture*. *Aquaculture Engineering* 23:233 – 278.
- Sililo, S., C.G. Musuka, and A.S. Kefi, A.S., 2017. Fish Imports and Their Contribution towards Feeding an Ever-Growing Population in Zambia. *Innovative Techniques in Agriculture* 1 (2):4-10.
- Ssegane, H., E.W. Tollner, and K.L. Verenca., 2014. Geospatial modelling of site suitability for pond based Tilapia farming in Uganda. *Journal of applied Aquaculture* 24 (2): 147-169.
- Steer, L.A., 2010. Site selection for the small scale Aquaculture farming systems in the Western Cape: *A Gis application*. University of Stellenbosch. Rural Aquaculture Development Programme. Western Cape.
- Valavanis, V., and F. Taylor., 2002. *Geographic information systems in oceanography and fisheries*. Taylor & Francis London.
- Wanganeo, A., V.R. Chandran, and A. Kumar., 2009. *Aquaculture site selection in Midnapur district (west Bengal) using remote sensing and GIS*. Department of Limnology, Barkatullah University, Bhopal, M.P, India, Regional Remote Sensing

Service Centre, Indian Space Research Organization (ISRO), Kharagpur, India.  
28(3):395-398

William, A.W., 2013. Aquaculture Site Selection State Specialist for Aquaculture. Kentucky State University Cooperative Extension Program Princeton, *World Aquaculture*, 23(3): 42-43

Yu, J., Y. Chean., and P. Wu., 2009. *Cellular automata and GIS based land use suitability*

Zambia Statistics accessed 20 July 2013. Camera pix: "Spectrum Guide to Zambia." Camera pix International Publishing, Nairobi.

Zurbrugg, R., J. Wamulume., N. Nyambe., B. Wehrli and D.B. Senn., 2010. *Effects of river floodplain exchange on water quality and nutrient export in the dam impacted Kafue River (Zambia)*, Nasa Astrophysics Data System (ADS). 117(3):

[www.zambiatourism.com](http://www.zambiatourism.com)>about Zambia climate.

[www.zambiatourism.com/destinations/national-parks/kafue-national-park](http://www.zambiatourism.com/destinations/national-parks/kafue-national-park)

Zambia central statistics office (2010) Zambia Census of Population and Housing projections.

Zambia central statistics office (2016) Zambia Census of Population and Housing projections.

## APPENDICES

### Appendix A: Interview guide for the Department of fisheries Officer (DOF)

My name is Muzamba Martha Siachinga. I am conducting research on site selection analysis for fish pond farming in Kafue district: a multi-criteria evaluation approach. You have been purposely chosen for this interview so that I can get your views. The information provided will be for academic purposes only and will be kept confidential and anonymous. Is it ok for me to interview you?

Interviewer's Name: .....

District .....

Date of Interview: .....

#### A. BACKGROUND INFORMATION ON FISH POND FARMING IN KAFUE DISTRICT

1. When did fish farming begin in Kafue district?
2. How did it begin?
3. What is the purpose of fish farming?
4. What are the benefits of fish farming?

#### B. CRITERIA FOR SELECTING SUITABLE FISH POND SITES

5. What factors are considered when selecting suitable fish ponds sites?
6. How are these factors important from each other? (Pairwise comparison)? Use the table below to rank how important each factor is in comparison with the others.

Criteria	LULC	Soil type	D.river	Slope	Elevation	D. roads
LULC						
Soil type						
D.river						
Slope						
Elevation						
D. roads						

7. What constraints are considered when selecting suitable fish ponds sites?
8. Which areas are most suitable, suitable, moderately suitable and not suitable for fish pond farming and why?

**C. ACCEPTABILITY AND EFFECTIVENESS OF THE GIS METHODOLOGY**

9. How are suitable sites for fish pond farming selected?
10. How effective is the conventional method?
11. Have these sites been selected using the GIS methodology before? If not, why?

**D. CHALLENGES FACED IN FISH POND FARMING AND SITE SELECTION?**

12. What challenges are experienced in fish farming?
13. What challenges are faced in relation to selecting suitable fish ponds sites using the conventional method?
14. What challenges are experienced in selecting highly suitable, moderately suitable, suitable and not suitable sites?

**E. MEASURES AND SUGGESTIONS ON HOW TO MAKE THE GIS METHODOLOGY EFFECTIVE**

15. What measures are put in place to select suitable sites using GIS and remote sensing?
16. Are there any stakeholders involved in putting these measures in place?
17. How best can suitable sites be selected using GIS and remote sensing?
18. How can the GIS method be more accepted in fish farming?

**End of interview**

**Thank you for your response**

**Appendix B: Interview guide for experts in fish pond farming**

My name is Muzamba Martha Siachinga. I am conducting research on site selection analysis for fish pond farming in Kafue district: a multi-criteria evaluation approach. You have been purposely chosen for this interview so that I can get your views. The information provided will be for academic purposes only and will be kept confidential and anonymous. Is it ok for me to interview you?

Interviewer’s Name: .....

District .....

Date of Interview: .....

**A. CRITERIA FOR SELECTING SUITABLE FISH POND SITES**

1. What factors are considered when selecting suitable fish ponds sites?
2. What constraints are considered when selecting suitable fish ponds sites?
3. Which areas are highly suitable, suitable, moderately suitable and not suitable for fish farming and why?
4. From the criteria given in question 5 above, which one do you consider the most and least important?
5. How are these factors important from each other? (Pairwise comparison)

Criteria	LULC	Soil type	D.river	Slope	Elevation	D. roads
LULC						
Soil type						
D.river						
Slope						
Elevation						
D. roads						

**B. ACCEPTABILITY AND EFFECTIVENESS OF THE GIS METHODOLOGY**

6. How are suitable sites for fish pond farming selected?
7. How effective is the conventional method?
8. Have these sites been selected using the GIS methodology before? If not, why?
9. What are the benefits of selecting these sites using the GIS methodology?
10. Can people accept the GIS methodology? If Yes why and if No why?
11. Is the GIS methodology more effective compared to the conventional method?
12. Give reasons for your answer in 13 above

**C. CHALLENGES FACED IN FISH POND FARMING AND SITE SELECTION?**

13. What challenges are experienced in fish farming?
14. What challenges are faced in relation to selecting suitable fish ponds sites using the conventional method?
15. What challenges are experienced in selecting highly suitable, moderately suitable, suitable and not suitable sites?

**D. MEASURES AND SUGGESTIONS ON HOW TO MAKE THE GIS METHODOLOGY EFFECTIVE**

16. What measures are put in place to select suitable sites using GIS and remote sensing?
17. Are there any stakeholders involved in putting these measures in place?
18. How best can suitable sites be selected using GIS and remote sensing?
19. How can the GIS method be accepted in fish farming?

**End of interview**

**Thank you for your response**

## **Appendix C: Interview guide for fish farmers**

My name is Muzamba Martha Siachinga. I am conducting research on site selection analysis for fish pond farming in Kafue district: a multi-criteria evaluation approach. You have been purposely chosen for this interview so that I can get your views. The information provided will be for academic purposes only and will be kept confidential and anonymous. Is it ok for me to interview you?

Interviewer's Name: .....

District .....

Date of Interview: .....

### **A. BACKGROUND INFORMATION ON FISH POND FARMING**

1. When did you venture into fish pond farming?
2. Why did you start fish pond farming?
3. What are the benefits of fish pond farming?
4. Have you received any kind of training with regard to fish farming?
5. How many ponds do you have and what is the size/s of the pond?
6. What type of fish do you stock and where do you buy your fingerlings?
7. How much fish do you harvest per cycle?
8. Where do you sell your fish once harvested?

### **B. CRITERIA FOR SELECTING SUITABLE FISH POND SITES**

9. What factors did you consider when selecting suitable fish ponds sites?
10. What are the constraints when selecting suitable fish ponds sites?
11. What is the source of water for fish pond farming?
12. What is the distance between source of water and fish pond?
13. Which areas are most suitable for fish farming?
14. Which areas are suitable for fish farming?

15. Which areas are moderately suitable for fish farming?

16. Which areas are not suitable for fish farming?

17. What is the soil type where your pond is?

18. Do you experience any seepage and fish mortalities?

**C. CHALLENGES FACED IN FISH POND FARMING AND SITE SELECTION?**

19. What challenges have you experienced in fish pond farming?

20. What challenges are faced in relation to selecting suitable fish ponds sites using the conventional method?

21. Do you face any challenges in relation to fish market?

**D. MEASURES AND RECCOMENDATIONS**

22. What measures have you taken to overcome these challenges?

23. What would you recommend to be considered in successful site selection for fish pond farming?

**End of interview**

**Thank you for your response**

**Appendix D: Interview guide for focus group discussion (fish farmers)**

My name is Muzamba Martha Siachinga. I am conducting research on site selection analysis for fish pond farming in Kafue district: a multi-criteria evaluation approach. You have been purposely chosen for this interview so that I can get your views. The information provided will be for academic purposes only and will be kept confidential and anonymous. Is it ok for me to interview you?

Interviewer's Name: .....

District .....

Date of Interview: .....

**A. BACKGROUND INFORMATION ON FISH POND FARMING**

1. When and why did you venture into fish pond farming?
2. What are the benefits of fish pond farming to your households?
3. How many years have you been practicing fish pond farming?
4. What kind of fish ponds do you have?
5. Which fish species do you culture?
6. Do you have more than one type of fish in your pond?

**B. CRITERIA FOR SELECTING SUITABLE FISH POND SITES**

7. What factors do you consider when selecting suitable fish pond sites?
8. What are the constraints in selecting suitable fish pond sites?
9. Where do you get the water for fish farming?
10. Is water permanently available for fish farming?
12. What is the distance between your fish ponds and your source of water?
13. What type of soil is on the site where your fish pond is dug?
14. Do you experience seepage from the pond and how often?
15. How many fish mortalities do you experience per cycle and what are the causes?

### **C. FISH FARM CHARACTERISTIC**

16. How many fish ponds are you currently operating?
17. What do you feed your fish?
18. What is the source of your fish feed?
19. How often do you feed your fish?
20. How do you fertilise the pond?
21. What is the source of your fertilizer?
22. How much fish do you harvest per cycle and per year?
23. Which months do you usually harvest?
24. What is your harvest strategy?
25. Where do you sell your fish?
26. What is the source of your fingerlings?
27. What kind of tools do you have available for your pond?

### **D. CHALLENGES EXPERIENCED IN FISH FARMING**

28. Are there any challenges that you face in fish pond farming?
29. What are these challenges?
30. What are the causes of these challenges?

### **E. MEASURES AND RECCOMENDATIONS**

31. What measures have you taken to overcome these challenges?
32. What would you recommend to be considered in successful site selection for fish pond farming?

**Thank you for your response**

## Appendix E: Location of training polygons

