# ASSESSING THE POTENTIAL OF SMALL-SCALE AQUACULTURE IN EMBU DISTRICT, KENYA USING GIS AND REMOTE SENSING

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# DECLARATION

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# DEDICATION

I dedicate this thesis to my beloved parents Mr. Jamleck Njagi Ngarari and Mrs. Mary Ngarari, sister Winfred and my brothers Haniel and Edwin for their moral and financial support during the entire period of the preparation and writing of this thesis. To my friend, Kinyua Mburung'a for his encouragement in my quest for knowledge.

# ABSTRACT

Site selection for aquaculture development is a complex task involving identification of areas that are economically, socially and environmentally suitable, which can also be available for aquaculture. 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. This study used these technologies to identify sites suitable for aquaculture development in Embu District and assessed its potential contribution to food security and economic development in the area. The study developed map-based site selection criteria, using soil quality, water availability and socio-economic factors. These criteria were then implemented, aquaculture potential sites identified, the total area estimated and the economic impact assessed. The study predicted that about 20% (9,563 ha) of the total arable area of 47,800 ha in Embu District is suitable for aquaculture development. The study estimates that if aquaculture is optimally combined with other existing land use activities, it can contribute over Kshs. 9 billion per annum to the district's revenue. Comparing this with the current 7 ha under aquaculture, Embu District has potential for improving its economic status through aquaculture development. The study recommends that similar studies be carried out throughout the country so as to improve food security and wealth creation.

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# LIST OF ABBREVIATIONS

$^oC$ – Degrees Centigrade

DEM – Digital Elevation Model

ENVI – Environment for Visualizing Images

ESRI – Environment Systems Research Institute

ETM+ – Enhanced Thematic Mapper Plus

FAO – Food and Agricultural Organisation

GCPs – Ground Control Points

GIS – Geographical Information System

GOK – Government of Kenya

GPS – Global Positioning System

$H^+$ - Hydrogen Ions

ha – Hectares

IAA – Integrated Aquaculture - Agriculture

ILRI – International Livestock Research Institute

JICA – Japanese International Cooperation Agency

$km^2$ – Square Kilometres

m - Metres

mg/l – Milligrams per Litre

mm – Millimetres

NTU – Nephelometric Turbidity Units

$OH^-$ - Hydroxyl Ions

p.a – Per Annum

pH – Potential Hydrogen

RCMRD – Regional Centre for Mapping of Resources for Development

RGB – Red, Green and Blue

TIN – Triangulated Irregular Network

UTM – Universal Transverse Mercator

# OPERATIONAL DEFINITION OF TERMS

**Attribute –** A characteristic of a geographic feature described by numbers or characters, typically stored in tabular format, and linked to the feature. For example, attributes of a well, represented by a point, might include depth, pump type, location and gallons-per-minute.

**Band –** One layer of a multispectral image representing data values for a specific range of the electromagnetic spectrum of reflected light or heat (e.g., ultraviolet, blue, green, red, near-infrared, infrared, thermal, radar, etc.). A standard colour display of a multispectral image displays three bands, one each for red, green and blue. Satellite imagery such as LANDSAT TM provides multispectral images of the earth, some containing seven or more bands.

**Boolean analysis** - Analyses based on the use of logical operators to represent symbolic relationships. The operations include AND, OR, XOR (exclusive OR), IMP (implication) and EQV (equivalence).

**Buffer –** A zone of a specified distance around features. Buffers are useful for proximity analysis (e.g., find all river segments within 250 metres of a study area).

**Class –** A description of a group of objects with similar properties, common behaviour, common relationships, and common semantics.

**Classification –** Any technique whereby data are grouped into a smaller number of more general integer categories. It’s a procedure whereby data cells are assigned to one of a broad group of landcover classes according to the nature of the specific reflectances found at that place.

**Command** – A specific instruction and its parameters issued by the user to perform a specific action of the software.

**Constraint** – A criterion, which serves to limit the alternatives under consideration.

**Coverage** – A data set pertaining to a single theme. In a coverage, map features are stored as primary features such as arcs, nodes, polygons and label points as well as secondary features such as tics, extent and annotation.

**Criterion** – It is some basis for a decision that can be measured and evaluated. It is the evidence upon which a decision is based.

**Database** – A logical collection of interrelated information managed and stored as a unit, usually on some form of mass-storage system such as magnetic tape or disk.

**GIS database** – It includes data about the spatial location and shape of geographic features recorded as points, lines, areas, pixels, grid cells or tins as well as their attributes.

**Digital Elevation model (DEM)** – An image which stores data that can be envisioned as heights on a surface.

**Digitizer** – A device consisting of a table and a cursor with cross hairs and keys used for encoding vector graphic data (point locations) into plane (X, Y) coordinates.

**Digitizing** – It is a process of encoding geographic features from analog maps into a digital format usable by a computer e.g. x, y coordinates. It is carried out in order to create spatial data from existing hardcopy maps and documents.

**Editing** – Inserting, deleting and changing attribute and geometric elements to correct and/ update a model or database.

**Export** – The process of transferring data from one computer system to another system or storage media.

**Factor** – A criterion, which enhances or detracts from the suitability of a specific alternative for the activity under consideration.

**False colour composite** – A colour image that appears abnormal to the eye.

**Features** – A set of data with common attributes and relationship. The concept of feature encompasses both entity and object.

**Ground control points** - Any point or location with a known position and/ magnitude.

**Geographical Information Systems (GIS)** – A computer system designed to efficiently capture, store, update, analyse and display all forms of geographically referenced data.

**Geometric correction** – The adjustment of the geometry of a digital image for scaling, skewing and other spatial distortions.

**Geo-reference** – To establish the relationship between an image (row, column) coordinate system and a map (x,y) coordinate referencing system e.g. latitude/longitude.

**Geo-reference system** – A coordinate system with which the location of a point on the earth's surface may be identified.

**Grid** – A fully integrated grid (cell-based) geo-processing system for use with ArcView GIS 3.3. GRID supports a map algebra spatial language that allows sophisticated spatial modelling and analysis.

**Image** – A representation of an object that results from its reflection or emission of energy being recorded by chemical, mechanical, optical or electronic means.

**Image registration** – The process of geometrically aligning two or more cartographic data sets or images in vertical juxtaposition, while maintaining true geographic referencing.

**Import** – A process of loading data to a computer system from another system or storage media.

**Layer** – A logical set of thematic data described and stored in a geographic database in a single theme. A layer is organised by the subject matter (e.g. roads, rivers, soils etc) and extent over the geographic area of the database.

**Line** –A single geometric line segment defined by two points (a combination of two numbers used to represent either a planar (X-Y) or spherical (longitude-latitude) point).

**Mask –** A mask is a binary image that consists of values of 0 and 1. When a mask is used in a processing function, the areas with values of 1 are processed and the masked 0 values are not included in the calculations.

**Overlay** – A process that merges overlapping features and attributes from the two coverages to create a new coverage.

**Pixel** – A Short form of the words "picture element". A pixel strictly refers to the smallest resolvable (usually rectangular or square) element in an image. A pixel has both a spatial location and a value component.

**Polygon** – An area of space delineated by a boundary composed of straight line segments. It is stored in a vector system as a list of points (each with X and Y coordinate values), with the last point identical to the first.

**Polygon locators** – Nodes attached to enclosed areas that identify them as true features.

**Projection** – A representation on a plane of the surface of a round body.

**Raster data** – This is a grid cell based data structure used to represent images. The attributes are associated with grid cells. The order of image storage is typically by scan lines, progressing from left to right along scan lines and then from top to bottom from one scan line to the next.

**Re-sampling** – interpolation of pixels on a source digital image to new locations of transformed pixels usually coinciding with a geo-referenced grid.

**Root Mean Square (RMS) error** – It is a measure of the variability of measurements about their true values. The RMS error is estimated by taking a sample of measurements and comparing them to their true values. These differences are then squared and summed. The sum is then divided by the number of measurements to achieve a mean square deviation. The square root of the mean square deviation is then taken to produce a characteristic error measure in the same units as the original measurements.

**Spatial data** – Information about a location, shape and relationships among the geographic features, usually stored as co-ordinates and topology.

**Suitability** – It is appropriateness according to preordained conditions, requirements or circumstance. It is a common term in decision making or allocation situations where tracts of land are to be allocated according to their suitability for one or more purposes (objectives). Suitability for a purpose is determined by whether or not certain criteria are met by the piece of land under consideration.

**Supervised Classification** – A technique for the computer-assisted interpretation of remotely sensed imagery. The operator trains the computer to look for surface features with similar reflectance characteristics to a set of examples of known interpretation within the image.

**TIN** – A spatial data structure that describes a three dimensional surface as a series of irregular exclusive triangles.

**Topographic map –** A map depicting terrain relief.

**Training sites –** Areas the analyst identifies that exemplify each land-cover type in the image to be classified. These sites are used to "train" the software classifier to "recognize" each cover type so that all pixels in the image may be assigned to their appropriate cover class.

**Vector data –** A co-ordinate based data structure commonly used to represent map features. Each linear feature is represented as a list of ordered x and y co-ordinates. The attributes are associated with co-ordinates. Vector is any variable quantity that can be described as having magnitude and direction and which can be resolved into components. In computer-assisted cartography, complex lines can be described by a series of smaller line segments, each having magnitude (length) and direction.

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To the Almighty God, be praise, glory and honour now and forever. Amen.

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I'll never forget the inspirations of my colleagues Gladys, Angela, Florence, Carol, Jack, Simon, Moses, Songok and all my classmates. May the Lord guide all of you through 'calm waters and sheltered bays' in the quest for knowledge.

# CHAPTER ONE: INTRODUCTION

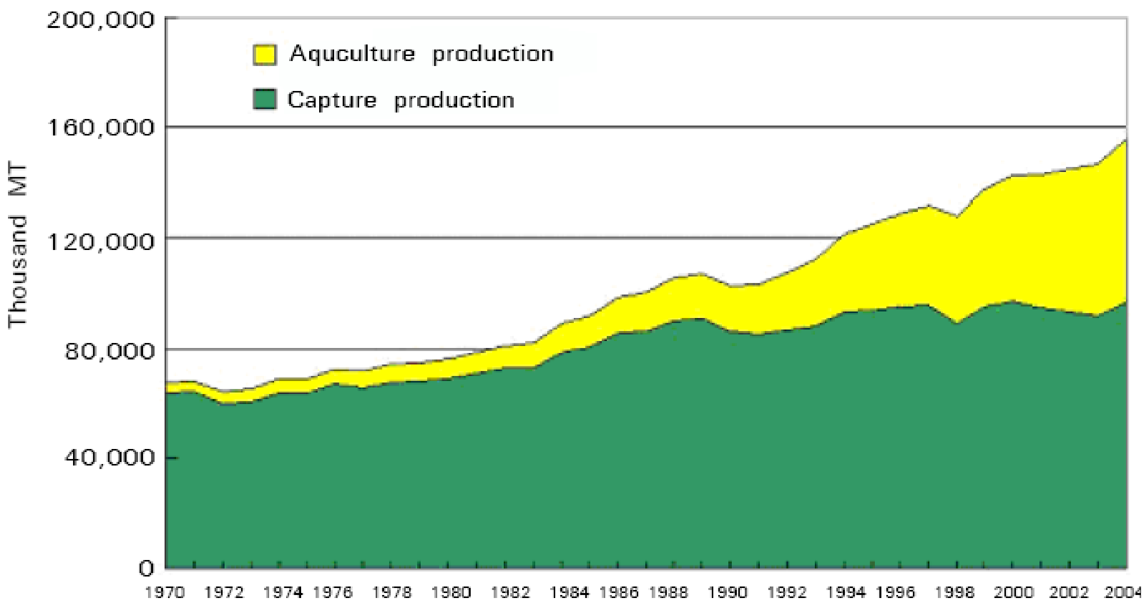
## 1.0 Background of the study

Aquaculture is concerned with propagation and rearing of aquatic organisms under complete human control (Stickney, 1994). Against a background of stabilizing or even falling catches from capture fisheries, increasing human population and an ever increasing demand for food, there is a major challenge to re-examine the nature and potential of the aquaculture sector (Muir, 1995). Marine and many inland fishery resources are heavily exploited. The state of global fishing stocks is in accelerating severe decline and the world's marine species may collapse by 2048 because of overfishing, pollution, habitat loss and climate change (Worm, 2006). However there is potential for increasing production from inland fisheries through intensified development of aquaculture. This practice holds a great promise in the long term for improving food security through increasing the supply of fish (Kapetsky and Nath, 1997).

**Aquaculture status in the world**

Aquaculture production is increasing worldwide and it is expected that its activities will be expanding significantly in the near future as practices are further improved and diversified (FAO, 2004). Aquaculture is the fastest growing animal-based food producing sector particularly in developing countries in the world with 27% of sea food produced coming from it (Stone *et al.*, 2000). Estimated total annual production increased by 4.2 million tonnes, from nearly 55.2 million tonnes in 2003 to 59.4 million tonnes in 2004 (Anroovy *et al.,* 2006). At that time, the total value of world aquaculture production was estimated at US$70.3 billion with the total annual value of aquaculture production increasing by over 7 percent from 2003 to 2004 (Anroovy *et al.,* 2006).

FAO State of Fisheries and Aquaculture (SOFIA) reported that 3% of marine stocks are under exploited, 21% moderately exploited and could support modest increases in fishing while 52% are fully exploited which means that they are being fished at their maximum biological activity and therefore any increase in effort would be unsustainable (Okumu, 2006). The remaining 24% are over exploited, out of which 16% are depleted, 7% recovering from depletion and 1% need rebuilding. This shows that the global maximum potential for capture fisheries has been reached. Figure 1.1 and 1.2 below show how capture fisheries is levelling off or decreasing while aquaculture production is increasing worldwide.




**Source: FAO statistics series**

**Figure 1.1:** Global Fisheries production, 1970-2004


**Source: FAO statistics series**

**Figure 1.2:** Aquaculture production in the world, 1990-2004

**Aquaculture in Africa**

Aquaculture is an industry in its early development stages in Africa showing that the continent has not utilised its immense fish farming potential (Omolo, 2003). Africa contributes only 0.1% of the total global aquaculture production (Rabuor *et al.*, 2006). Aquaculture production in sub-Saharan Africa in 2004 was estimated at around 93,000 tonnes (FAO, 2006). This implies that there is a considerable increase compared to the 39,000 tonnes estimated in 1995.

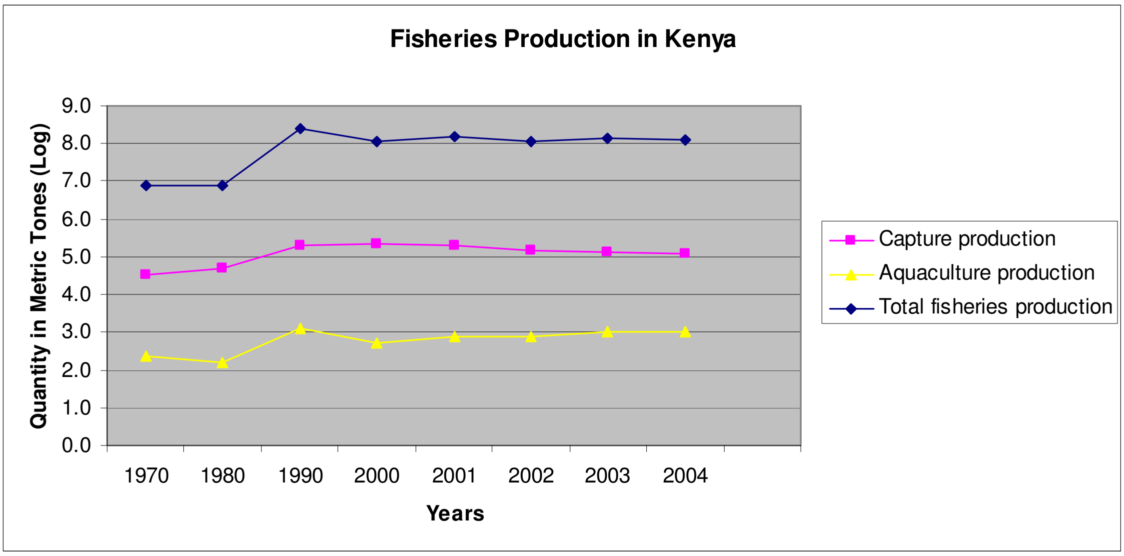
**Aquaculture in Kenya**

Following the Ministerial Rationalisation of 1999 and the Poverty Strategy Paper of 2001, fisheries is one of the sectors that the Kenya government has targeted in its poverty reduction strategies (Gitonga, 2003). At the same time its potential contribution to the Millennium Development Goals is likely to be significant.

Kenya's fisheries sub-sector contributes to the national economy through creation of employment, foreign exchange earnings and food security support (Gitonga and Achoki, 2004). Kenya produces fish from two major sources namely capture and aquaculture fisheries (Nzungi, 2003). Capture fisheries covers fresh water lakes, rivers, dams and marine waters of the Indian Ocean and accounts for the bulk (70%) of the production (Habib, 2003). Aquaculture provides the rest of the production through rearing of fish under controlled conditions in both fresh and marine waters.

In Kenya, capture fisheries resources have been on the decline (Ngugi *et al.*, 2003). This is as a result of increase in fishing pressure and demand for fish products caused by rural urban migration, increased population, adverse effects of climate change, introduction of alien species and the general failure by fishing communities to take up viable alternative sources of proteins such as pork, beans, chicken and beef (Gitonga, 2006). The steady increase in the fishing effort in the 1980's and 1990's initially increased fish production in the Kenyan waters, reaching its peak in 1999 before declining steadily in the subsequent years. The analysis of fish production data between 1999 and 2002 indicates that there was an accumulative decline in fish production by about 43% (Okumu, 2006). The corresponding annual production declines were 3.7% (2000), 21.2% (2001), 24.4% (2002) and 7.8% (2003) (Okumu, 2006).

According to Gitonga *et al.*, 2004, aquaculture was introduced in Kenya in the 1920's and has significantly contributed to sustainable utilisation of capture fisheries by offering an alternative source of fish both in consumption and trade. They continue to say further that it also assists in easing fishing pressure from the natural resources. At the same time it creates employment and promotes food security. Aquaculture also complements the fishing activities by providing bait for the long-line fishery. Aquaculture which currently occupies only an area of 0.014% of the land in Kenya, contributes about 0.5% of the total national fish production. If developed and commercialised it has a much higher potential that can be tapped (Gitonga *et al.*, 2004). The department of fisheries predicted that fish farming will be the fastest growing agricultural sub-sector in Kenya in the next decade (Rabuor *et al.*, 2006).




**Source: FAO statistics series**

**Figure 1.3**: Fisheries production in Kenya, 1970-2004

In Kenya Aquaculture is increasing while the capture fishery continues to decline as shown in figure 1.3 above. Since there is little evidence that capture fisheries will increase, aquaculture should be practised to increase fish production. Although aquaculture has a high potential of improving both food security and economic growth, this can only be achieved if it is practiced in areas with optimal aquatic production characteristics. This will ensure that as the industry expands to meet future needs, it does so in an environmentally friendly way. To accomplish this, individuals, governments and financing institutions require scientific knowledge of where the prospects for aquaculture development are most promising before committing scarce resources to its development. This study sought to use GIS and remote sensing techniques to identify such sites and assess their economic potential.

## 1.1 Statement of the problem

The increasing number of aquaculture farms threatens to bring competition between fish farmers and other actual and potential users of the arable land, such as the agricultural sector. This mainly happens when aquaculture farms are set up before suitable sites are selected (Kapetsky *et al.*, 1990). Therefore, to ensure a sustainable development of the aquaculture industry, there is need to identify suitable sites. Despite ensuring the profitability and sustainability of the operation, this will also assist in resolving competing demands for the arable land and avoiding undesirable impacts on the environment (GESAMP, 1997).

Selecting suitable sites using conventional methods has been very ineffective because these traditional methods are slow, use a lot of money and cover a very small area, that is, only the sampled area is considered (Kapetsky *et al.*, 1990). Site selection requires ready access to appropriate, reliable and timely data and information, in suitable form for the task at hand (Urbanski, 1999). Since much of this information and data are likely to have a spatial component, Wright and Bartlett (2000) pointed out that Geographical

Information Systems (GIS) have relevance to this task. By using remote sensing and GIS, 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 (Kapetsky *et al.*, 1987).

This study therefore attempted to show how GIS and Remote Sensing methods can be utilized to speed up and make more efficient location optimising processes. It also demonstrated how a thorough examination of the many spatially variables might affect or control fish farming in Embu district Kenya.

## 1.2 Objectives

The overall objective of this study was to assess sites suitable for small-scale aquaculture in Embu District using GIS and remote sensing.

**Specific objectives**

- **i.** To develop the criteria for selecting aquaculture sites in Embu District.
- **ii.** To delineate sites and estimate the total area suitable for aquaculture development in Embu district.
- **iii.** To determine the potential contribution of aquaculture to the economy of the area.

## 1.3 Research Questions

- **i.** What are the suitable characteristics for aquaculture in Embu District?

ii. Which parts of Embu District have the most suitable sites?

iii. Which parts of Embu District have the least suitable sites?

iv. What percentage of Embu District is suitable for aquaculture?

v. What will be the economic impact of developing aquaculture in Embu District in the sited areas?

**1.4 Justification**

According to the 1989 population census, Embu District had a total population of 233,187 while in 1999 it had a population of 278,196. The annual growth rate was 3.08% (GOK, 2001) in 1999 meaning that the population increase is very high. It was projected that the population would increase to 325,491 by the year 2008.

The high growth rate has led to a high population density (564 persons per $km^2$) in the district (GOK, 2001) and increased demand for food leading to increased pressure to extend land under cultivation and to intensify food crop production. Since most of the arable land has already been utilised, further intensification of agricultural production has led to conversion of marginal lands. For example, Mt. Kenya forest, which is one of the five water towers in Kenya has been cleared for agriculture by the surrounding community. This is a clear sign that there is increased pressure on land leading to a threat on the environment.

Agriculture is the mainstay of the economy of Embu district (GOK, 2001). For it to continue supporting the economy, it is imperative that the limited high potential land available be optimally utilised through the appropriate farming technologies. The District Development Plan notes with concern how increasing population pressure is leading to the subdivision of the land into increasingly uneconomical units (GOK, 2001). It is recorded that large scale average farm size in Embu district is 4 hectares while small scale farm size is 1 hectare (GOK, 2001). Some families have less than one-quarter of an acre of land (0.1 hectares).

On the other hand, potential agricultural land in Embu District is almost at a "premium" therefore increasing food yields per hectare must be maintained or improved in order to stop people from invading the nearby Mt. Kenya Forest for farming. To overcome this problem, aquaculture would offer a suitable alternative source of protein, income and ease pressure on the land. This strategy also offers opportunities to improve land productivity in the study areaas well as being easily integrated with agriculture and livestock rearing. It requires a small area to produce high yield. This could diversify the district's economic activities, provide a constant fish supply and decrease pressure on the natural resources.

Embu district has a considerable potential for aquaculture and so far seven hectares of land are already under aquaculture (Fisheries Department, 2006). This is contributed by the very favourable conditions for rearing both cold and warm water fish species prevailing in the district. These conditions include clean and well-oxygenated waters as well as favourable temperatures (12–27.1ºC) for growth of fish. Although it is believed that fish farming potential in Embu District is high, site assessments for aquaculture have not been made (Fisheries Department, 2006). In this context, the establishment of a structured decision-making and planning scheme of where to set up aquaculture farms would be useful.

This study therefore applies GIS and remote sensing techniques to identify potential sites suitable for aquaculture in Embu District.

**1.5 Study area**

The study was carried out within Embu District in Eastern province of Kenya between October 2006 and April 2007. Mt. Kenya, which is a gazetted forest in the district, was not included in the study area. The sub-sections below describe the district in detail.

**1.5.1 Administrative Boundaries**

Embu District is one of the thirteen districts which make up the Eastern Province of Kenya. The district lies approximately between Latitudes $0^{o}$ 8' and $0^{o}$ 35' South and Longitudes $37^{o}$ 19' and $37^{o}$ 42' East (GoK, 2001). It borders Mbeere District to the east and south east, Kirinyaga District to the west and Tharaka District to the north (GoK, 2001). The district occupies an area of 729.4 $km^2$ of which the arable area is 478 $km^2$ while the rest 251.4 $km^2$ is non-arable land. The non-arable land includes 210.2 $km^2$ of the Mt. Kenya forest which is a gazetted forest (GoK, 2001). The forest is uninhabited and has therefore been disaggregated from the rest of the area.

### 1.5.2 Physiographic and natural condition

The landscape is characterised by typical highlands and midlands and other topographic features, which include hills and valleys. The altitude ranges between 1,200 m to 4,500 m above sea level. The highlands are found in areas whose altitudes range about 4,500m to 1,500m above sea level. The midlands dominate parts whose altitudinal range is from 1,200m to 1,500m above sea level. There are four major rivers which drain the district namely Rupingazi, Thambana, Thuci and Nyanjara (GoK, 2001).

### 1.5.3 Climatic patterns

Rainfall is bimodal with two distinct rainy seasons. The long rains fall between March and June while short rains come in October and December. The amount received varies with altitude but the average is 1,495 mm p.a. However areas above 1700m display a tri-modal pattern which has a peak in July/August Temperature ranges between 12ºC in July to 27.1ºC in March with an annual mean of 20.7 ºC (GOK, 2001).

### 1.5.4 Population

The district had a population of over 290,312 persons in 1999 with a population density of 564 persons per $km^2$. The population density though high is almost evenly distributed in the rural settlement areas. Above 63% of the people in the district live below the poverty line. The district contributes 0.95% to the national poverty (GOK, 2001).

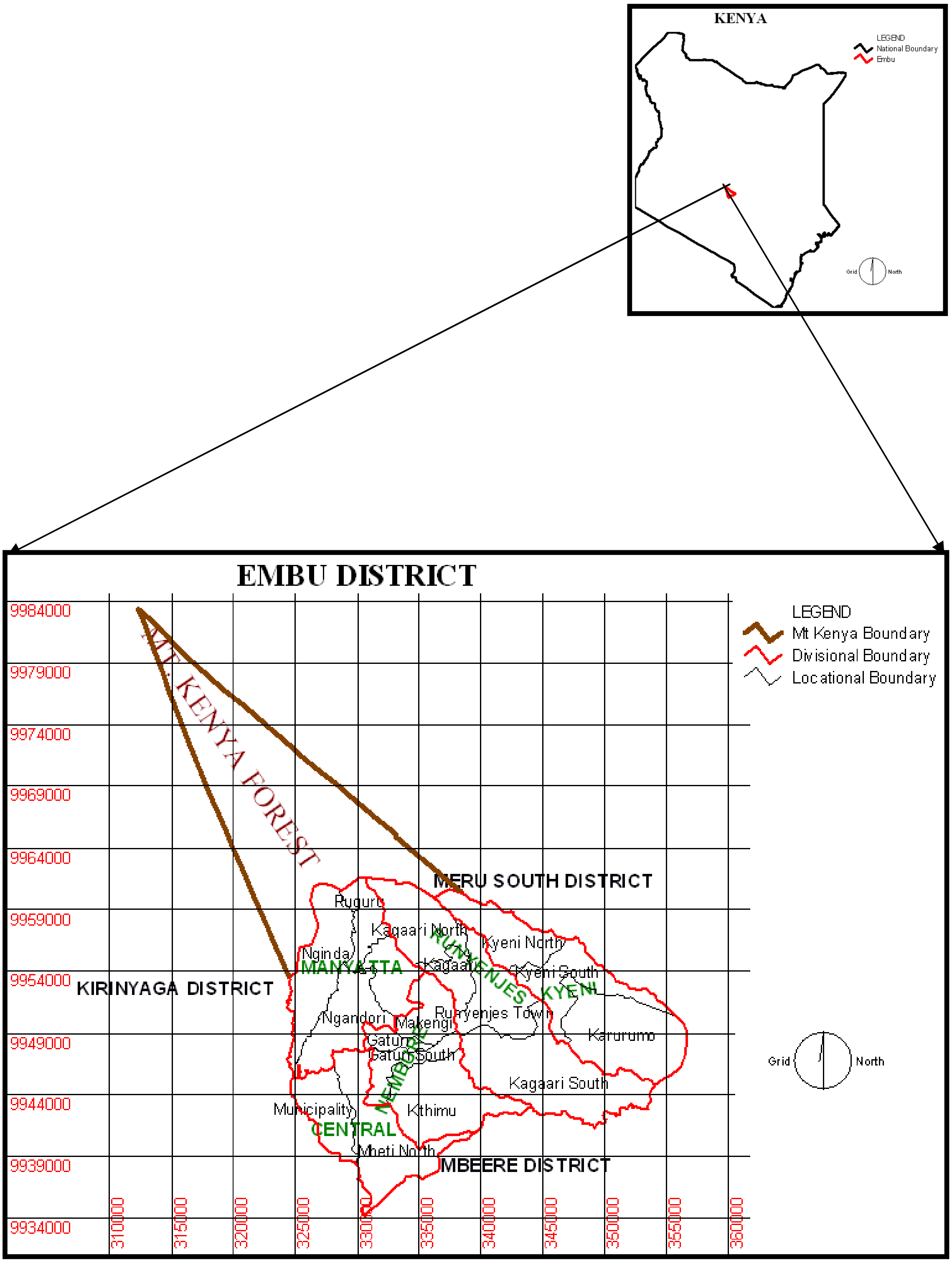



**Figure 1.4: Location of Embu District**

# CHAPTER TWO: LITERATURE REVIEW

## 2.0 Introduction

In the section that follows, issues regarding aquaculture development are discussed. First, the forms of aquaculture systems are discussed then a description of bio-physical and socio-economic requirements for aquaculture development. The section that discusses the methods used for selecting sites follows in the last two sections which discuss the use of GIS and remote sensing technologies in assessing the sites.

### 2.1 Aquaculture

Aquaculture is concerned with propagation and rearing of aquatic organisms under complete human control (Stickney, 1994). It involves the manipulation of at least one stage of an aquatic organisms' life before harvesting in order to increase its production (Ghittino, 1995). FAO (1996) also defined aquaculture as "the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants". Farming in this case implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators etc.

Aquaculture embraces the use and manipulation of natural and artificial water bodies to produce species required by man and thus concerns all activities concerned with breeding and culture of aquatic organisms which could be algae, molluscs, crustaceans and fish (Barnabe', 1990). It is a non-indigenous technology, which has received limited adoption in rural sub-Saharan Africa (Aquilar-Manjarrez and Nath, 1998).

Aquaculture practices are used world-wide in three types of environments (freshwater, brackish water and marine) for a great variety of culture organisms. Freshwater aquaculture is carried out either in fish ponds, fish pens, fish cages or, on a limited scale, in rice paddies. Brackish water aquaculture is done mainly in fish ponds located in coastal areas. Marine culture employs either fish cages or substrates for molluscs and seaweeds such as stakes, ropes, and rafts.

The primary role of aquaculture in a subsistence farming system is to provide edible fish thus contributing to food security and availing some income to vulnerable populations through sale of the surplus (Nzungi, 2002).

**2.2 Forms of Aquaculture**

In Kenya aquaculture is practised in various forms using different holding units which include, ponds, pens (enclosures) and re-circulating tanks (Mbugua, 2002). Pond aquaculture is most like farming. With this method, areas of land are enclosed by dikes and flooded. Fish are then added to the pond and are fed on a regular schedule and a clean source of water is used to keep the pond in the proper condition for healthy growth (Araki, 1992).

Floating pens are the most common methods for growing marine finfish, such as salmon, in protected coastal waters. One of the biggest concerns in this method is continuously providing fresh, clean water for the fish. In large enclosures made of netting, fish can enjoy a natural flow of water and all the food they can eat. This open-water approach is also used in growing marine shellfish, with the natural currents bringing both clean water and plenty of food for filter-feeding bivalves such as oysters, quahogs and scallops (Piedrahita, 2003).

The most recent kind of aquaculture uses recirculation systems to clean and re-use water. Recirculation systems are made up of several components that filter the culture water of waste and toxins as well as treating it to reduce its bacteria and viruses load. Because one can control the environmental parameters in this recycling system, it allows growers to carefully control water quality and eliminates them from the risk of weather-dependent ponds and pens (Piedrahita, 2003). Re-circulating systems also use far less water than other methods and any discharge water can be thoroughly treated to make sure that no waste is released into public waters (Timmons *et al.*, 2002).

## 2.3 Systems of Aquaculture

Aquaculture is practised at various levels namely, extensive (small-scale), semi-intensive (medium-scale) and intensive (large-scale) systems.

### a) Extensive Systems

These are the lowest management levels in aquaculture with very little or no input being directed into the production. Fish are stocked in earthen ponds and other water impoundments and let to fend for themselves. These systems are highly dependent on natural productivity and the physical conditions of the water (Payne, 1986). The main cultured species are *Oreochromis niloticus, Tilapia zilli, Clarias gariepinus and Cyprinus carpio*. This system can be integrated well with agriculture and is the focus of this study.

**b) Semi-intensive Systems**

These systems also use earthen ponds for fish culture but the ponds are fertilized using both chemical and organic fertilizers at varying proportions to enhance natural productivity. Exogenous feeding using cereals bran and other locally available feeds is done to supplement pond productivity (Payne, 1986). Polyculture of *Oreochromis niloticus, Tilapia zilli, Clarias gariepinus and Cyprinus carpio* is practiced with various combinations of the species. Veverica *et al.*, (1998) reported that this system yields about 4.0 ton $ha^{-1}$ $yr^{-1}$ while Liti *et al.,* (2002) reported yields of 5.0 ton $ha^{-1}$ $yr^{-1}$ for the same system. This system can also be integrated with agriculture.

**c) Intensive Systems**

These systems use raceways and various types of tanks as the holding units. In these systems, more fish are produced per unit area by substituting the natural productivity in the culture units by exogenous feeding, aeration and both mechanical and bio-filtration where necessary (Shepherd and Bromage, 1988).

## 2.4 Aquaculture Site Selection

The success or failure of an aquaculture system is dependent on many factors including the selection of a suitable site and the design and construction of facilities that enable efficient and economic operation (Wurts, 1992). In this study the main focus is on aquaculture site selection, specifically how this can be effectively done with the aid of GIS and remote sensing technologies. The sections that follow look at the literature on aquaculture practices i.e. what makes an area suitable for aquaculture, procedures for identifying such sites and the economic potential of aquaculture.

**Requirements for selecting aquaculture sites**

Site selection for aquaculture involves the assessment of numerous physical variables. From an aquaculture point of view, site selection or location decisions are important initially in the actual securing of production sites, or sites from which to function (Gifford *et al.*, 2002). Site selection affects both success and sustainability of an aquaculture operation. The prospects for securing a suitable site will vary greatly depending on existing land/water rights, land use planning controls, availability for purchase or rent, conflicting demands for access, etc. The fish farmer will then be concerned with securing sites where environmental parameters can be optimized, preferably in areas where pollution controls or qualitative environmental legislation exists.

It is important that sites or locations which allow for economic viability are secured (Born *et al.*, 1994). This could be in areas where optimum sustainable yields can be maintained or in areas where there is at least a reasonable potential for realizing production profits. Sites must also be reserved if future food yields are to be maintained and improved and in order to help the diversification of local employment. Since production requires so many critical physical and economic parameters, and with so many interests competing for the water/land interface "space", the fish producer will need to compete hard for any potential locations.

The success of a fish farm project therefore largely depends on one's project site conditions. The site conditions determine if one's fish farm will competitively produce. Correct selection of a site assists in designing a fish farm hence reduces costs to a fish farmer. Site selection also takes into account the biological traits of the target fish plus the intended capacity that will achieve optimal and cost effective production. In this study various bio-physical and socio-economic factors suitable for carrying out aquaculture practices were considered. These factors are: -

### 2.4.1 Water quantity

Water, the medium surrounding aquatic animals, is essential for all forms of aquaculture and is a key factor in determining where aquaculture may develop (Aguillar-Manjarrez and Nath, 1998). A regular, abundant water supply is essential for the maintenance of healthy fish stocks (Piper *et al.*, 1982). However, growing demands for water from an expanding aquaculture industry are resulting in increased competition with other water users for this limited resource (Nash, 1995).

When considering water quantity the fish producer must be concerned with the total water quantity available, potentially accessible and also the variability of water flow. The amount of water needed will vary according to: the total volume of fish being produced; the density of stocking; the age, size or the species of the fish or aquatic organism; the temperature of the water; the dissolved oxygen level of the water; the fertility of the water and the evaporation or seepage rates. Generally, the larger the quantity of water available, the larger will be the size potential for individual fish growth and for total fish production.

Water ponds may originate from several sources: precipitation, runoff, pumped or gravity water from perennial water bodies such as streams, rivers, lakes and reservoirs and pumped groundwater (Aguillar-Manjarrez and Nath, 1998). Precipitation is considered the main source of water for small-scale fish farming. Other water resources such as perennial streams and rivers would exceed the economic limitations associated with small-scale farming.

Planning an aquaculture system requires that adequate water be available for initial and future needs. Future needs include any planned expansion of the facility, changes in species cultured or management intensity. Fish ponds must be sited and designed to protect them from excessive runoff and flooding. The location and physical characteristics of the water body source should also be known, especially with regard to fluctuations in quality and quantity with season and rainfall. Sufficient water for filling ponds must be available at the appropriate times. Variations in water quality and quantity influence the location and siting of intake pumps, water distribution systems, design of the predator control filters and the need for storage reservoirs and sedimentation basins.

If underground water e.g. wells are the primary water source for the facility, information on depth, available volume and quality of subsurface water sources is needed. This information will influence production plans and the facility design: the number and location of wells, power sources for pumps, design of water distribution systems, need for water storage or settling lagoons and aeration requirements. Groundwater sources are the most desirable water supplies for aquaculture since they are usually free of pollutants, though some groundwater may contain toxic gases, with hydrogen and methane being the most common.

The cost of wells and pumping from deep wells and the deficiency of oxygen in groundwater are the most apparent disadvantages. All surface waters suffer from the disadvantages of being exposed to pollution, intermittently available (affected by seasons, weather, e.g. drought) or long-term changes in water quality characteristics and are inhabited by potential predators, competitors, and disease organisms, e.g. wild fish can be a source of disease and will often compete with cultured fish for feed. However, most sources tend to be well oxygenated and are usually less expensive to develop than groundwater sources. Surface water sources include streams and rivers, lakes and reservoirs and salt or brackish waters.

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. Well water contains little oxygen and high levels of carbon dioxide and nitrogen, necessitating aeration before use or pH testing. The need to pre-treat incoming water in order to improve its quality will affect site selection (Huguenin and Colt, 1989).

### 2.4.2 Water quality

Water quality is a relative term that depends on the use for which the water is intended (Wilson and Homziak, 1990). Water supply for aquaculture must possess several characteristics to be considered "good" quality water (Perez *et al.*, 2003). Characteristics of water can be defined by physical (temperature, turbidity, suspended solids) and chemical (salinity, dissolved gases) parameters.

Oxygen content, temperature, salinity, and hardness of the water supply should be at or near optimum levels for the type and number of aquatic organisms cultured (Homziak and Veal, 1990). Pollutants, especially organic wastes, chemical compounds, and toxic or pathogenic organisms, should not be allowed to contaminate the water supply. This is because poor water quality reduces fish growth and survival. Filters or provisions for water treatment should be made if the possibility of pollution of the water supply exists (Boyd, 1982).

Water quality varies over space due to natural causes and human influences. Natural causes relate primarily to three major factors: precipitation, rock weathering and evaporation (Payne, 1986). Water of higher temperature is more prone to qualitative degrading, e.g. reduced oxygen levels, excessive nutrient accumulations, etc., and heavy rainfall may significantly increase turbidity through excessive run-off (Gifford *et al.*, 2002).

Geology affects water quality by determining the rate of rock disintegration and the rock type through (or over) which water may flow. In so doing it can accumulate dissolved minerals, such as calcium or sodium, or more concentrated minerals seeping from specific natural sources. Total ionic concentrations will generally progressively get higher further downstream and be higher during the dry season when the influence of ground water is greater. More turbulent patterns of water flow will enhance the oxygen content. Human influence on water quality is largely through unregulated activities, which allow leakages or discharges from a diverse range of human activities, i.e. related to industry, mining, agriculture and urban sprawl.

### 2.4.3 Water Temperature

This is one of the most vital environmental variables for all aquatic organisms (Kahareri, 2003). Water temperature affects fish activity, behaviour, feeding, growth, and reproduction (Fritz *et al.*, 1980). Fish are cold-blooded, and their temperature is approximately the same as their surroundings (Barnabe', 1990). Therefore, they cannot tolerate rapid changes in temperature. Every aquatic organism has an optimum temperature at which it can survive or reproduce (Nath, 1996). Warm water species grow best at temperatures between 25° and 32° C (Celsius) while cold water species grow best at temperatures between 18°-22°C (Boyd, 1990). Embu district has favourable temperature for aquaculture since temperature ranges between 12ºC in to 27.1ºC.

Temperature also influences oxygen content of the water, which is essential for the reproduction and growth of aquatic organisms. A rise in water temperature increases the metabolic rate of aquatic organisms and therefore their energy requirements (Kahareri, 2003). Energy for reproduction and growth of aquatic organisms is created through the increased rate of photosynthetic activity as temperature rises (Payne, 1986). The cooler the water temperature, the more oxygen is soluble, that is, there is more oxygen in cool water than in warm water.

Water temperatures are determined by three groups of factors:

*Meteorological*, e.g. air temperature, intensity and duration of solar radiation, incidence of snow cover and surface wind velocity (Smith, 1975). Solar radiation will only be effective on the epilimnion (nearest to surface zone) of larger standing water bodies. Though water circulation may occur in these bodies, on average deeper water in the hypolimnion is markedly cooler. Standing water bodies usually exhibit a wider range of both diurnal and seasonal temperature variations (Smith and Lavis, 1975).

*Geophysical*, e.g. depth of water, volume of water discharge, degree of water mixing, height of banks and temperature of inflows. The temperature of stream inflow, or of the basal water flow, is the second most important influence on water temperature. Rivers which contain a large groundwater component have a small temperature range (Rodda *et al.*, 1976).

*Human intervention*, e.g. reservoirs and weirs, thermal effluent discharges and canopy alteration by logging or planting. As more of the world's rivers are being impounded, then temperature variations applicable to standing rather than flowing water bodies, become more common. Similarly, thermal effluents largely emanating from electricity generating plants are increasingly encountered. Though heated water in some rivers may be dissipated quickly, or simply form a heated layer on the surface, in others the total effect may be quite noticeable.

### 2.4.4 Dissolved oxygen

Dissolved oxygen refers to oxygen gas that is dissolved in water (Kahareri, 2003). Fish need oxygen just like land animals do and they absorb oxygen directly into their bloodstream using their gills. Oxygen depletion is the cause of many fish kills while low oxygen stress is the cause of disease outbreaks (Wurts, 1993).

The amount of oxygen in water decreases as temperature and altitude increases. As temperatures increase, fish metabolism will increase so they consume more oxygen. Therefore, both the increase in temperature and increase in fish metabolism may cause oxygen depletion during the hot season (Kahareri, 2003).

Oxygen is produced during the day when sunlight shines on the plants in the water through photosynthesis. Oxygen levels will drop at night because no photosynthesis is occurring and respiration continues (Kahareri, 2003). Typically, there is a balance between the oxygen produced and consumed during the day, however there are some events that upset this balance:

1. Increased organic wastes that enter the pond. Any organic material such as manure, septic tank waste, and excess fish feed increase the oxygen demand in the water. As these excess organic materials decay, oxygen is consumed.
2. Die-off of aquatic plants. Since aquatic plants are the primary source of oxygen through photosynthesis, a die-off can result in oxygen depletion. As these dead plants decompose, their decomposition requires oxygen.
3. Excess aquatic plants. Excess plants (phytoplankton and submersed aquatic vegetation) produce more oxygen than can be held in water. We call this super saturation. The oxygen demand by these plants will be great into the evening hours, which results in wide fluctuations in oxygen levels.
4. Turnovers. With stratification, the pond has two layers with a warm surface layer and cooler bottom layer. A layer is created that acts as a physical barrier between the two layers. Photosynthesis and oxygen production only occurs near the surface. Water in the deep layer becomes oxygen deficient. During heavy winds or cold rain, the barrier can be broken which causes the two layers to mix. If the oxygen demand is great in the oxygen-deficient layer, the dissolved oxygen that is present will be rapidly removed from the water. This may result in a fish kill.

### 2.4.5 Turbidity

Water turbidity is caused by the presence of solids in suspension (Boyd, 1990). These solids comprise mineral and organic particles from the detritus as well as phytoplankton and zooplankton. These are called suspended solids and are expressed in milligrams dry weight/litre of water filtered. It varies between 10-50 mg/l in water of low turbidity, but can reach many hundreds of mg/l in winter in estuarine waters (FAO, 1985).

Turbidity can be measured optically using a nephelometer in which comparison can be made between the intensity of light transmitted or diffused by the water sample being tested and a series of standards, the turbidity then being defined on an arbitrary scale. The most commonly used method requires the measurement of diffused light energy by passing a beam of light through the sample and measuring at right angles, results in nephelometric turbidity units (NTU) (FAO, 1985).

Turbidity has a quantitative and qualitative effect on the penetration of light into water. It can reduce the levels of photosynthesis in the euphotic zone and therefore phytoplankton production and in this way the availability of nutrients for herbivores.

### 2.4.6 pH

Potential Hydrogen (pH) is defined as the negative logarithm of the hydrogen ion $H^+$ concentration (Boyd, 1990). It is a measure of how acidic or alkaline water is. The range goes from 0-14, with 7 being neutral. pH less than 7 is an acid while that greater than 7 is a base. pH is a measure of the relative amount of free hydrogen ($H^+$) and hydroxyl ($OH^-$) ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since chemicals in the water can affect pH, pH is an important indicator of water that is changing chemically. Boyd also suggests that the acceptable range for most fish is from 6 to 9. pH of water can be raised using agricultural limestone but this is an extra economic cost on the fish farmer (FAO, 1985).

**2.4.7 Soil Quality**

Soils vary greatly in large scale because soils result from complex physical interactions which themselves take place in areas having different topographic, geologic, climatic, vegetation and human influences (FAO, 1985). A good understanding of soil and its characteristics is one of the most important factors for aquaculture site selection, development and management (Coche and Laughlin, 1985). This is particularly the case in pond farms, where soil quality has a great influence on construction and maintenance costs and on productivity. According to Yoo and Boyd (1994), the common soil properties most relevant for pond construction are slope, texture and pH.

The site must have soils that hold water and can be compacted (Hajek and Boyd, 1994). If pond levees are constructed with soil that has high water permeability (leakage or seepage), the cost of pumping water could become prohibitive. Excessive seepage often results from improper site selection. Therefore, soil properties should be clearly investigated and identified during site selection (Yoo and Boyd, 1994).

The amount of seepage will depend on the soil composition and on the structure of the pond bottom (Coche and Van der Waal, 1981). For example, if the composition of the soil is coarse, as in sandy soils, a great amount of water will be lost by seepage. Kapetsky (1994) identified areas suitable for pond construction in Africa on the basis of soil texture and topography. However there are some other factors that are also important for soil evaluation such as effective soil depth, gravel and stones percentages, salinity and pH.

Sandy clays to clay loam soils are best for pond construction and they should contain no less than 35% clay. Soils with high sand and silt compositions may erode easily and present a piping hazard - soil-water flow along pipes-, which could wash out a levee though anti-seep collars can help minimize that problem. Soils classified between sandy loam and sand do not contain enough clay for pond construction (Kapetsky, 1994). Silt loams and loams may or may not have adequate clay.

Texture classifications are based on per cent compositions of clay, silt and sand (FAO, 1974). It is the particle size that determines how soil is classified. Soil distribution, particle form and composition, uniformity and layer thickness are equally important (Boyd, 1990). Suitable soils should be close to the surface and extend deep enough so that construction, harvest activity or routine pond maintenance will not cut into a water permeable layer, causing a leak. Soils therefore should be good enough for construction of dikes, ease of piping, high degree of compaction, allowable flow velocities in canals and intake basins, avoiding losses through seepage at the bottom and on the dike, avoiding erosion and to reduce seepage.

Soil suitability is therefore important from both an engineering and a productivity view point. In this study the soil characteristics considered for aquaculture sites include pH and texture.

### 2.4.8 Topography

Pond layouts should account for the existing site topography in order to minimize pond construction costs, make use of gravity for water conveyance to and from the ponds and enable water exchange, waste dispersal and efficient drainage during harvesting. This should also be considered for facilities such as feed stores and office. Location of these facilities should facilitate the work, save energy and work. In excessively flat areas problems such as flooding, the inability to provide for gravity flow of water and poor drainage may occur. Additionally, sluggish water flows found in flat areas are associated with low dissolved oxygen levels, high summer water temperatures and near coastal areas' saline intrusions. Areas having steep slopes may be difficult to locate and develop. Areas of steep relief may also cause problems with other production functions such as transport accessibility, isolation from markets, high rainfall and run-off, etc.

According to ICLARM and GTZ (1991), the most suitable slopes for large ponds (1-5 ha) in Africa should not exceed 1-2% (1-2 feet for every 100 feet of length). However, for small-scale farms where most ponds will be from 0.01-0.05 ha, slopes up to 5% (5 feet for every 100 feet of length) are most favourable. Extensive earth moving machinery may be required on land with slopes greater than these thus increasing construction costs. Some innovative farmers use terracing - stair stepping - for pond layouts in hollows or on land with slopes greater than 2%. However, much money is required to accomplish this task. Therefore assessment of slopes is a very important aspect in aquaculture.

Areas with low slope, 1 to 5 percent, are suitable for pond construction, but slopes of 2 percent or less are most preferred. Moderate slopes simplify delivery of water and gravity drainage of ponds. Topography around ponds should allow gravity drainage of the pond in any season. Water heights in external ditches and adjacent water bodies should be lower than the pond drain, even under expected high-water conditions. It is also important that ponds have an adequate drainage area for harvest and this can only be realised where the slopes are moderate.

### 2.4.9 Land use

Land use should also be considered when selecting a site for aquaculture as well as agricultural activities in surrounding areas. Conditions encouraging agricultural production generally favour aquaculture and vice versa. Agriculture can be used as a good indicator of areas where aquaculture might flourish (Little and Muir, 1987).

Integrated aquaculture – agriculture (IAA) systems is a term used to describe farming systems where aquaculture has been combined with agriculture. The IAA systems have led to improved agricultural waste resource utilisation efficiency, enhanced soil fertility and increased food production in resource-poor small holdings (Ruddle and Zhong, 1985); as such they are potential sustainable methods of increasing food production for resource constrained farmers in an environmentally friendly manner. In this case, small-scale farming, agricultural by-products can contribute to higher yields than would be possible from the natural production of the pond (Kapetsky and Nath, 1997). For commercial fish farming, such by-products can reduce feed costs by replacing some of the formulated feeds needed.

### 2.4.10 Population Size

Kapetsky and Nath (1997) suggested that the market opportunities potential for farmed fishe is inferred from the population density (in individuals / $km^2$). Wide variations in population sizes and densities occur within a country. The most densely populated areas are found bordering the lakes, in the river basins, along the coastal areas, and in certain highland areas, while settlement is the most sparse in the desert and savannah areas. Differences in population size, density and surface area can also be interpreted in the context of availability of arable land and grazing areas and there will be concentration of people in areas of high productivity and favourable climate or centres of industrial or commercial activity. High populated areas are the best for aquaculture development.

From a land cost land use point of view, a very high population density may prohibit use of such populated areas for fish farming (Kapetsky and Nath, 1997). There is a tendency for products to flow towards concentrations of high population and population figures and actual distribution of inhabitants in terms of economic resource base must be seen in terms of population growth rates (Reynolds, 1993).

### 2.4.11 Market Accessibility

In order to achieve higher returns, many fish producers would endeavour to dispose of a high proportion of their production to markets, which are “closest” to the final purchaser

(Lewis, 1984). Highest returns can be achieved by selling via the "farm gate" or at the "dock side", i.e. direct to the public. The higher the population density in close proximity to the farm the greater the potential of "farm gate" sales. "Dock side" sales are only really possible where regular markets can be guaranteed at sites having public access (Kapetsky, 1994).

The next best return might be achieved by operating a fish delivery round or by selling to local hotels, restaurants, peddlers or caterers, i.e. outlets whose own "mark-ups" might be very high (Gifford *et al.*, 2002). Some larger producers have contracts to supply supermarkets direct and some might supply direct to fishmongers or other retailers. Transport routes or facilities can also determine the feasibility of using specific markets, especially in areas where fresh fish are demanded and/or where processing facilities are absent (Pathak, 1989).

It is therefore important to have fish farms around the market centres which provide services and market for goods produced on the farms. Urban market potential on the other hand is not a factor for estimating small-scale aquaculture potential. This is because all aquaculture products produced on small-scale are sold or bartered locally.

**2.4.12 Transport accessibility**

Transport costs per se frequently represent only a small proportion of total fish production operating costs (Muir and Kapetsky, 1988). However, accessibility to transport is important in a number of non-quantifiable ways (Kapetsky, 1989).

Firstly, transport can be seen in terms of relative access advantages, whereby cost savings are made by selecting sites which have advantages of good direct access from the water side (or pond bank) to the public highway system (Gifford *et al.*, 2002). Since fish products are highly perishable, they are nearly all transported by road. Relative access advantages help to reduce vehicle running costs, expedite inward and outward deliveries and reduce personnel time/travel costs.

Secondly, transport can be viewed in terms of a cost function associated with distance between the production site and the market place. If markets are at a distance then transport penalties would necessarily occur (Lindquist and Mikkola, 1989). The lack of transport routes presents a huge impediment to fish production development (FAO, 1975).

There are several other ways in which transport accessibility might control fish production, and ways in which transport costs themselves could be controlled. If a site is selected which involves the construction of an expensive transportation connection, then this could well make the site non-viable (Muir and Kapetsky, 1988). The best site for aquaculture should be within an area where the road is less than one kilometre away.

## 2.5 Methods for Identifying Sites Suitable for Aquaculture

### 2.5.1 Conventional Method

This method uses manpower (human beings) to demarcate the areas suitable for aquaculture. The method is not very competent because it is slow, uses a lot of money and it covers a very small area, which is, only the sampled area. For example, the method used to identify the soil suitability is quite cumbersome since one has to keep rolling out balls of soil in the area and check if the ball can easily roll. Various soils will be different when rolled out into a ball shape. This form of identification is quite tedious and uses a lot of time. GIS and remote sensing techniques can be used to site aquaculture areas economically using less time at a larger scale. On the other hand, the two techniques can be used to create a database of areas suitable for aquaculture development. This study used GIS and remote sensing to assess aquaculture sites instead of using the conventional methods. It is expected that this approach will save time and money for farmers which they could use to consult experts.

### 2.5.2 Geographic Information Systems (GIS)

GIS is an integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, store, manipulate, retrieve, analyse, display and report all forms of geographically referenced information geared towards a particular set of purposes (Kapetsky and Travaglia, 1995). A GIS can handle any type of data i.e. physical, social and economic. These data have common locational or geographic bases that are spatially referenced to the earth. They are also specialised data systems that preserve locational identities of the information they record. They involve a spatially referenced computer database and appropriate applications software.

GIS is especially useful in circumstances where many diverse factors have to be considered to reach a decision, where the factors themselves are quite variable spatially and where the factors differ in importance and in situations (Kapetsky, 1993). GIS can be used to couple spatial data with their attributes and overlay them. A GIS consists of a series of overlay for a specific geographical region. These overlays may depict raw data or may show thematic information (such as soils, land use or geology) but they must share common geographic qualities (including a common co-ordinate system) that permit them to be merged into a single system that allows use of the varied data as an integrated unit. A GIS requires specialised programmes tailored for manipulation of geographic data.

GIS provides the analyst the ability to solve the special problems that arise whenever maps or images are examined (DeSilva *et al.*, 2001). For example, the problems of changing coordinate systems, matching images and bringing different images into registration. GIS has the ability to perform certain operations related to the geographic character of the data. For example, it must be capable of identifying data by location or by specified characteristics in order to retrieve data in a map-like format so that the geographic patterns and inter-relationships are visible to the analyst. GIS can perform operations that relate values at one location to those at neighbouring locations.

GISs end product can be in form of tables, graphics or as geographically coordinated maps. GISs attempt to model the distribution of natural resources and socio-economic indicators in time and space. They are in essence tool boxes providing the means to access, manipulate and display data so as to produce meaningful information for end users such as planners, researchers and administrators. The input data may come from many sources such as field surveys, air photography, remote sensing, existing maps and records. A GIS is assessed primarily on its capabilities to analyse geo-referenced data (Burrough, 1986). Almost any discipline depending on or making use of information with a spatial component is a potential candidate for GIS applications (Linden, 1987).

GIS is a technology ideally suited for the analysis and presentation of a wide variety of sociological and environmental data. At the same time rapid advances have been made in the field of GIS software, especially on personal computer platforms and as a result, GIS can increasingly be viewed as an integral and necessary component in spatial problem analysis and assessment. Due to largely funding constraints, GIS is in its infancy in the majority of African countries. While there are urgent requirements for the development of GIS throughout sub-Saharan Africa, the current scarcity of GIS installations makes it possible for future developments in this field to be carried out in a coordinated and integrated manner throughout the region (Campbell, 1992).

GIS has become of increased significance for environmental planning and assessment mainly because of the need to compare a great number of spatially related data (Gismalla and Bruen, 1996). Extending the idea further, it is readily apparent that concern for the environment is common to aquaculture no matter where it is practiced. With adequate database GIS can serve as a powerful analytical and decision-making tool. It can spatially link and conceptually integrate the complex data that are needed for effective management and sustainable development of aquaculture development (Kapetsky, 1993).

GIS is a system specifically designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially referenced data, as well as a platform for analytical operations for working with the data (DeMers, 1997). GIS can allow for the analysis of both qualitative and quantitative data types, identify associations between components, and therefore, build a "living database" with exploratory data analysis, interpretative and mapping capabilities (Booth, 1998). GIS has several advantages for aquaculture development programs. It not only provides a visual inventory of the physical, biological, and economical characteristics of the environment, but also allows rational management without complex and time-consuming manipulations (Krieger & Sandor, 1990).

Nath *et al.*, (2000) concluded that there has been a limited range of aquaculture applications using GIS due to (1) a lack of appreciation of the benefits of such systems for this sector, (2) limited understanding about GIS principles and associated methodology, (3) inadequate administrative support to ensure GIS continuity among organizations and (4) poor levels of interaction among GIS analysts, subject matter specialists and end users of the technology. The first applications of GIS in aquaculture date from the late 1980s (Kapetsky, 1985).

GIS applications in aquaculture are surprisingly quite diverse, targeting a broad range of species (fish, crustacean, and mollusks) as well as geographical scales, ranging from local areas, i.e., small bays (Ross *et al.*, 1993) and big bays (Scott & Ross, 1999), to sub national regions (i.e., individual states/provinces; (Aguilar-Manjarrez & Ross, 1995), to national (Salam & Ross, 2000) and continental (Aguilar-Manjarrez & Nath, 1998) expanses. They also vary with regard to the degree to which GIS outcomes have been used for practical decision- making (Nath *et al.*, 2000).

At the present time, the extent of GIS applications in aquaculture include site selection for target species such as fish (Benetti *et al.*, 2001), oysters (Chenon *et al.*, 1992), mussels (Scott *et al.*, 1998), clams (Arnold *et al.*, 2000), scallop (Halvorson, 1997), shrimp (Alarcon & Villanueva, 2001), and seaweed (Brown *et al.*, 1999), environmental impact assessment (Gupta, 1998), conflicts and trade-offs among alternate uses of natural resources (Biradar & Abidi, 2000) and consideration of the potential for aquaculture from the perspectives of technical assistance and alleviation of food security problems (Kapetsky & Nath, 1997).

One of the barriers to enhancing the diffusion processes concerning aquacultural techniques has been the lack of data on, and methods for, optimising production locations. A reason for this is that we have generally failed to grasp the significant part, which spatial variations, in physical, economic or social factor play in the success of fish farming. In this study GIS was used in data input and encoding, data manipulation, data retrieval, data analysis, data display and for database management.

### 2.5.3 Remote Sensing

Remote sensing is "concerned with the collection of data by a sensing device not in contact with the object being sensed and the evaluation of the collected data which is then termed information and is presented in map form or as statistics (Howard, 1985). Remote sensing allows change to be monitored in a systematic and orderly way, it is efficient and very cost effective in per $km^2$ terms, overcomes many data collection problems and it also provides for instantaneous updating of information (Campbell, 1996).

**2.6 Relationship between Remote Sensing data and GIS**

Satellite systems e.g. Landsat or SPOT acquire data for larger areas in a short time period, thereby providing essentially uniform repeated coverage with respect to date and level of detail. Such data are already in digital form and are provided in more or less standard formats.

Remote sensing data are available for almost all of the earth's land areas and are inexpensive relative to alternative sources. Though satellite data are not planimetrically correct, pre-processing can often bring data to acceptable levels of geometric accuracy. Remotely sensed data has the potential to address some difficult problems encountered in formation of GIS.

Data are not always available for the desired dates or seasons. If a large area is to be examined, there may therefore be many problems in mosaicking data for separate dates arise. Accuracies of classification and analytical methods required to process the data before entering them in the GIS may not be consistently reliable. There are many avenues for incorporating remotely sensed data into the GIS. The most satisfactory procedures depend on the specific requirements of a particular project and the kinds of equipment and financial resources available.

1. Manual interpretation of aerial photographs or satellite images produces a map or set of maps that depicts boundaries between sets of categories (e.g. soil or land use classes); then these boundaries are digitised to provide the digital files suitable for entry into GIS.
2. Digital remotely sensed data are analysed or classified using automated methods to produce conventional paper maps and images, which are then digitised for entry into GIS.
3. Digital remotely sensed data are analysed or classified using automated methods and then retained in digital format for entry into the GIS using reformatting or geometric corrections as required.
4. Digital remotely sensed data are entered directly in their raw form as data for the GIS.

### 2.6.1 GIS and Remote Sensing in decision making

Decision making is the process that leads to a choice between a set of alternatives. Geographical decision-making means analysing and interpreting geographical information that is related to the alternatives in question. Decision making is often used in land suitability analysis, or site selection, as well as location allocation modelling. All decision making has a degree of uncertainty, ranging from a predictable (deterministic) situation to an uncertain situation (Malczewski, 1999). The latter one can be subdivided into stochastic decisions (which can be modelled by probability theory and statistics) and fuzzy decisions (which can modelled by fuzzy set theory and others).

Consequently, particularly in uncertain situations, decision making involves the risk of making a "wrong" decision, because the information acquired is insufficient or the approach used is inappropriate. When uncertainty is part of the process, this uncertainty may in some cases be quantified and as such add another decision criterion to the evaluation process.

A GIS has the capacity to integrate remote sensing data into a spatial context and is well suited to support decision making procedures. GIS can act as a tool in helping the decision-makers evaluate alternatives, visualise choices and explore certain alternatives. Mwasi (2004) established that the complex problem of allocating limited land to satisfy unlimited needs can be solved by such a system which allows incorporation of several criteria and offers a means for combining them into decision alternatives. The decision maker is the one who determines the criteria, the factors, the constraints, the individual weighting and the decision rules.

### 2.6.2 GIS and Remote Sensing applications in aquaculture

GIS and remote sensing, either singly or in combination, have been used as tools in fisheries (Butler *et al.*, 1988). GIS has been used in aquaculture since the mid-1980s Gifford *et al.*, 2002). Meaden and Kapetsky (1991) combined several of the earliest case studies in a FAO technical paper along with complete information on the use of GIS and remote sensing in inland fisheries and aquaculture.

These include the use of SPOT imagery to select shrimp farm sites, of remote sensing and limited GIS to find oyster culture sites, and of GIS for catfish farming development by mapping and analyzing the physical characteristics of soils, to assess the potential for salmonid sea cage culture in Camas Bruich Bay, west coast of Scotland and to find the best locations for fish farming in Ghana.

Another early study conducted by Meaden (1987) suggested the criteria necessary for GIS assessment of areas for culture of rainbow trout. Kapetsky *et al.,* (1987), described the use of GIS for site evaluation for mollusk, shrimp and fish culture in coastal areas of Costa Rica. Kapetsky (1994) used GIS and its applications to aquaculture to determine the warm water fish pond farming potential in Africa.

All of these studies involved relatively small areas that could be analyzed with large-scale data sets. Nath *et al.,* (2000) gave a detailed evaluation of the potential applications of GIS for spatial decision support (SDS) in aquaculture, emphasizing the constraints (primarily limited understanding of GIS principles and methodologies, plus inadequate commitment to ensure continuity of GIS use in SDS) that limit its application. Though GIS has been used in Kenya, there is no information on how GIS has been used to assess aquaculture sites. This may be due to the fact that GIS is still in its early stages of development in Kenya.

# CHAPTER THREE: MATERIALS AND METHODS

## 3.0 Introduction

The main objective of this study was to assess the potential for aquaculture in Embu district by using GIS and remote sensing technologies. This chapter presents the process followed to achieve this objective. The chapter is divided into four parts. Part one describes the criteria used for aquaculture site selection. Part two describes the data used and its sources. Part three shows how the database was developed. In the fourth part, the criteria were applied with GIS to identify suitable sites. Finally, the potential economic contribution of aquaculture in the district was assessed.

### 3.1 Criteria Identification

In order to plan for aquaculture development and to reduce economic risks, the areas with high prospects for aquaculture have to be spatially defined using a number of criteria. In this process, the basic step was to identify the essential criteria for aquaculture development i.e. the most important site factors and to specify the ranges of data that pertain to a desired level of suitability for each criterion.

Specification of the ranges was vitally important because they were the basis of evaluation. This is because from these ranges, factors and constraints to be involved in the GIS analysis would be selected.

Criteria identification was done from literature sources that provided criteria based on bio-physical and socio-economic factors. In the present study, nine criteria were grouped into four main sub-models for aquaculture site selection as in Huguenin and Colt (1989). The four categories are described in (Table 3.1) below.

**Table 3.1:** Criteria used in suitability assessment for integration of aquaculture in Embu District

| Goal | Sub-model | Criteria | Range |
|---|---|---|---|
| Sustainable aquaculture site selection that is environmentally and economically viable | Potential for pond construction | Slope | 0 – 5% |
| | | Landuse/cover type | Agriculture |
| | | Soil pH | 6-9 |
| | Soil quality | Soil texture (% clay) | >35 |
| | | Distance to water body (m) | <250 |
| | Water availability | Source of water | Rivers |
| | | Rainfall (mm/yr) | >800-2000 |
| | Socio-economic factors | Distance to a motorable road (km) | <1 |
| | | Distance to a market centre (km) | <3 |

### 3.1.1 Potential for pond construction

The suitability of a site is important and determines if there is potential to construct ponds. The aim of this objective was to identify areas suitable for the construction of ponds. Slope and landuse were the criteria employed in this category. For slope, the range of 0-5% was preferred. Agriculture was the best landuse/cover preferred since aquaculture can be profitably integrated with agriculture while it also does well in agricultural areas.

### 3.1.2 Soil quality

The type of soil is a very crucial aspect while selecting aquaculture sites. Porous sandy soil should be avoided hence soils with 35% clay and above clay were preferred. The range of acceptable soil pH is 6-9 with soils of pH closer to neutral being the best.

### 3.1.3 Water availability

Sources, quality and quantity of water are very important factors in aquaculture site selection because an aquaculture system requires water be available for initial and future needs. In this study two water sources, rainfall and perennial rivers, suitable for fish farming were assessed. Water from perennial rivers and rainfall was considered to be of good quality because these sources tend to be well oxygenated and are usually less expensive to develop than ground water sources. Mean annual rainfall range of 800 to 2000 is required. Water availability from rivers was assessed in terms of presence or absence of perennial rivers. Proximity to the rivers was considered so as to determine the most economic site.

### 3.1.4 Socio-economic factors

For aquaculture to have high economic returns, it has to be practised in areas with easy access to services and markets. This can be assessed in terms of nearness to high population concentration or proximity to roads. Roads offer easy access to services and market centres. In this study, proximity to all weather roads and markets were put into consideration in order to get sites where economic limitations are reduced.

## 3.2 Data used and its sources

The bio-physical and socio-economic data required for aquaculture siting in the study area was obtained from two main sources namely; primary and secondary sources. The primary data sources were field survey and Landsat ETM satellite imagery. Secondary data sources included topographic maps of the study area, ILRI database and publications mainly government publications such as development plans, statistical abstracts and economic survey reports. GIS and remote sensing software were used for data extraction and analysis. Table 3.2 summarises the data used and its sources.

**Table 3.2:** Data and their sources

| DATA | TYPE | SOURCE |
|---|---|---|
| Satellite imagery | Primary | RCMRD |
| Landuse/cover characteristics | Primary | Field survey |
| Topographic maps | Secondary | 1:50,000 Survey of Kenya |
| Soil texture and pH | Secondary | ILRI database |
| Rainfall | Secondary | ILRI database |
| Reference materials | Secondary | Books, journals, internet etc |

### 3.2.1 Land cover mapping

A field survey was carried out in April 2007 to collect primary data on land cover characteristics of the study area. This data was required in order to assist in developing a classification scheme, to provide ground truthing data and for classifying the satellite imagery. The primary data consisted of natural vegetation characteristics e.g. wetlands, forests etc and manmade land cover attributes e.g. land use, vegetation cover etc.

A Global Positioning System (GPS) was used to record the locations selected. The areas with land cover included in the criteria and accessibility of a place determined the areas to be visited. A total of 56 sites consisting of plantations, roads, water sources, bare and rocky areas, urban areas and swamps were visited. Simple random sampling was used to select the samples.

### 3.2.2 Remotely sensed data and thematic maps

The main data source for this study was a cloud-free Landsat image for path 168 row 60 of the worldwide reference system. The image was acquired on 21st February 2000 by Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor. The Landsat image which covered the Mt. Kenya region, within which the study area lies, was obtained from Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi.

### 3.2.3 Topographic map sheets

Four 1:50,000 topographic map sheets of Embu District were used in this study. The maps were obtained from Survey of Kenya in Nairobi. The topographic maps were used for creating a digital database of roads, hydrological (rivers) systems, markets, contours and the study area boundary as well as for geo-referencing the satellite imagery.

### 3.2.4 Other data

Rainfall data, Soil pH and soil texture for the study area were extracted from a Kenyan database prepared by the International Livestock Research Institute (ILRI).

### 3.2.5 GIS software used

The main GIS software used in this study was the raster-based IDRISI 32 for windows. CartaLinx software was used to digitise and edit vector layers from topographic map sheets. A remote sensing image analysis software, Environment for Visualizing Images (ENVI) version 3.5 was used to resize, geo-reference and extract the study area from the Landsat ETM satellite imagery. ArcView GIS for windows (version 3.3) software developed by Environment Systems Research Institute, Inc. (ESRI) was used to extract and clip data from the Kenya database prepared by ILRI.

### 3.3 Database development

Database development entails creation of relevant criteria maps. Basic maps for most of the identified criteria were available in analog form e.g. roads, rivers, elevation, slope and markets. The first step of the database development involved digitizing topographic maps to form base maps. This was followed by creating criteria maps for aquaculture development. The spatial data was synthesized from different sources having different resolution, projections and feature types. The last step was to geo-reference the spatial data by creating a common reference frame to standardize the criteria maps and hence avoid multi-dimensional spatial mismatching.

A database consisting of eight data layers namely; slope, distance to roads, distance to rivers, distance to markets, soil pH, soil texture, rainfall and landuse/cover was developed. The following sections explain the process followed to create each layer.

#### 3.3.1 Digitization

Contours, roads, rivers and the district's boundary were digitized from topographic maps of the study area. Though these maps had different contour intervals of 20m, 50ft and 100ft they were used to extract the contour data. The digitized data from the contours and the study area boundary were required in order to obtain a digital elevation model. The boundary had no significance in defining the surface morphology but it was maintained in the triangulation to prevent subsequent analysis like interpolation from occurring outside its boundary.

The CartaLinx software was used to carry out tablet digitization. Coordinates were mapped in order to establish the relationship between map coordinates and board coordinates by digitizing a set of control points and indicating their map coordinate values. Six such control points well distributed around the surface of the map were digitized and an RMS of 0.046 was obtained and accepted.

The contours, roads, rivers and the district's boundary were digitized from each map and the data entered using the stream mode. Each sheet was digitised as a unit coverage and transformed into Universal Transverse Mercator (UTM) grid system**.** A new field was created by using the add field option from the tables menu. For the contours a new field was created and named elevation and the elevation data was entered. Contour intervals in feet were converted into metres by multiplying the elevation value by 0.3040 by using the design calculation option. Data from the four sheets was then combined using the append command in CartaLinx and the elevation, roads, rivers and the district's boundary coverage layers were created. The irregular features in the coverages were edited.

Using the export function on the file menu, the coverages were exported to ArcView GIS 3.3 GIS software as lines for contours, roads and rivers. The boundary of the study area was digitized and all the arcs were joined to enclose the area. Using a polygon locator a polygon of the study area was built. The polygon was then exported as an ArcView GIS 3.3 shapefile.

### 3.3.2 Slope

The exported contours were analysed to create a digital elevation model (DEM) using the 3D Analyst extension in ArcView GIS 3.3. This was created using contour and boundary themes of the study area. TIN features were created under the surface menu. The height source of the active features was the elevation data. Since the contour features were polylines they were input as mass points while creating the TIN. The TIN theme created was then activated to convert it into a 3D scene by choosing convert to 3D Shapefile under the theme menu.

The digitized and edited contours were exported as lines with different user IDs to the main analysis software, Idrisi 32 for further analysis. The contours exported to Idrisi were in a vector format. The vector lines were converted into a raster format by using LINERAS raster/vector conversion command in the reformat module of Idrisi. The data type of the raster file was then converted from byte to integer. The intercon module was used to create DEM. Slopes in degrees were then formed using the slope module

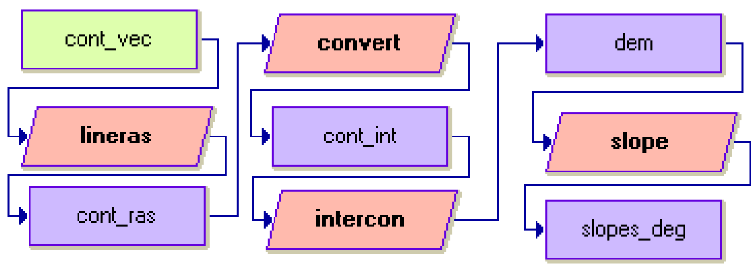



**Figure 3.1:** Slope criteria process model

### 3.3.3 Roads

The roads were digitized and edited in CartaLinx software. They were digitized from four topographic maps so the data was combined using the append command. The roads were identified using four classes of roads namely; motorable tracks, bound surface, loose surface and dry weather roads. The digitized data was exported to ArcView as a shapefile. Using the create buffer module under the theme menu, a buffer zone was drawn around the roads at a distance of 1km.

The buffer zone shapefile was then imported into Idrisi to form a vector file for further analysis. The vector file was then converted from vector to raster using LINERAS command.


**Figure 3.2:** Road vector to raster format conversion

### 3.3.4 Rivers

The rivers were digitized and edited in CartaLinx software. They were digitized from four topographic maps so the data was combined using the append command. The digitized data was exported to ArcView as a shapefile. Using the create buffer module under the theme menu, a buffer zone of 250m was drawn around the rivers.

The buffer zone shapefile file was then imported into Idrisi to form a vector file for further analysis. The vector file was then converted from vector to raster using LINERAS command


**Figure 3.3:** River vector to raster format conversion

### 3.3.5 Market centres

The market centres were digitized as points in Cartalinx. The market centre coverage was then exported as points into ArcView as a shapefile. In ArcView buffer zones with a distance of 3km around the market centres were created. The buffer zone shapefile was then exported into Idrisi by using shapeidr module. Polyras module was then used to convert the vector file into a raster file (Figure 3.4). This is because Idrisi uses images which are in raster format during analysis.


**Figure 3.4:** Market vector to raster format conversion

### 3.3.6 Soil

A digital soil map of the study area was obtained from the Kenya soils database compiled by ILRI through Kenya Soil Survey. Soil pH and soil texture attributes of the study area were extracted from this database. Since the shapefiles were not projected the ArcView projection utility was used to re-project them into the same projection as that of the digitized shapefiles. This was done in order to ensure that all the layers were in the same co-ordinate system. In this study the projected co-ordinate system WGS_1984_UTM_ Zone_37N in unit metres was used.

The projected layers were then clipped with the study area boundary shapefile using the geo-processing wizard in ArcView under view menu. The soil pH and texture layers extracted were imported as ArcView shapefiles in Idrisi. The vector files were then converted into a raster image by use of polyras to work best in Idrisi 32 which is a raster based system.

### 3.3.7 Rainfall

Digital rainfall data was extracted from Kenya rainfall distribution coverage created by JICA, National Water Master Plan and compiled by ILRI. The coverage stored as an ArcView rainfall shapefile of Kenya was extracted from the ILRI database. Since the shapefiles were not projected the ArcView GIS 3.3 projection utility was used to re-project them into the same projection as that of the digitized shapefiles. This was done in order to ensure that all the layers were in the same co-ordinate system. In this study the projected co-ordinate system WGS_1984_UTM_ Zone_37N in unit metres was used.

The projected layer was then clipped with the study area boundary shapefile using the geo-processing wizard in ArcView under view menu. The rainfall layer extracted was imported as an ArcView GIS 3.3 shapefile in Idrisi 3.2. The vector file was then converted into a raster image by use of polyras to work best in Idrisi 3.2 which is a raster based system.

### 3.3.8 Landuse

Landuse and land cover were classified by interpreting the Landsat imagery. The cloud free Landsat image purchased was unprocessed. In order to obtain landuse data of the study area the Landsat image had to be processed. The image processing was carried out as follows:-

**Image Processing**

ENVI software was used to process the image. First of all, the available nine bands were extracted from the unprocessed imagery. A new standard ENVI file was created from the available bands list. Out of the nine bands, only six (i.e. bands 1-5 and 7) which had the same spatial dimensions were used to create the new file. Each input file was imported one by one into the new file builder dialog and a new file was created.

To edit information in the new image file created, edit ENVI header was selected from the file menu. From the header files, the raw image data was converted into images by supplying relevant image dimensions namely; No. of rows and columns, the band name, pixel size, geographical location and the sensor type.

To aid in analysis, the unprocessed image was geo-referenced. The image co-ordinates were transformed into correct geographic co-ordinates and then projected to the UTM co-ordinate system. Using five ground control points obtained from 1:50,000 scale topographic maps of Embu the image was geometrically corrected as shown in table 4.1. Under the map menu in ENVI registration option was selected. Select GCPs: Image-to-

Map option was chosen in order to select ground control points (GCPs) for Image-to-Map registration. It was then re-sampled into a Universal Transverse Mercator (UTM) projection (zone 37N, WGS 84 datum) with 28.5m pixels using a nearest neighbour re-sampling method.

Ground control points from the image display window that could clearly be identified in the map were selected by pointing the cross hairs of the cursor at that point. The corresponding map X and Y co-ordinates of the selected points were entered manually. Once five points enough to define a warp polynomial were selected, GCP locations in the warp image were selected. The GCPs were used to perform a standard registration by selecting warp file under options menu in the Ground Control Points selection dialog. Under the input warp image dialog the file to be warped was selected and warped. Polynomial warping was used to warp the image with a polynomial degree of 1.

The study area was cut out of the geo-referenced image. To meet this objective, the study area boundary digitized from topographical maps using CartaLinx was exported to ArcView GIS 3.3 as a polygon shape file. The boundary was then overlain on the subset region of the already geo-referenced satellite imagery as a vector shape file from ArcView GIS 3.3. Using ground control points (GCPs) got from the reference points in topographic maps into the image the study area was warped. The study area was then masked out of the geo-registered image as a region of interest. The image masked out was with region bounds of minimum X: 324327.441m, minimum Y: 355221.441m, maximum X: 9934296.267m and maximum Y: 9961798.767m.

The images were exported from ENVI by saving the file of the masked out image as a TIFF/GeoTIFF file band by band into Idrisi software. Using the import command in Idrisi, the geo-referenced study area was imported into Idrisi in form of a Government/Data Provider Formats on the Landsat ETM module in the GeoTIFF data format type. The Landsat GeoTIFF bands were imported one by one and given a name for output Idrisi image. The bands were then enhanced by stretching using Histogram Equalisation and 1.0% Linear with Saturation points and this was done step by step for each band. Different band combinations such as Red, Green and Blue (RGB) were created after stretching in order to create a false colour composite of the study area. The three false colour composites formed were 345, 432 and 453 (RGB) in order to enhance classification of the satellite image. A true colour composite 321 (RGB) which helps one to view the normal colours of an area was also created.

Using the composite images created, land use classes were selected from the entire study area on the basis of variations in spectral characteristics (colour), spatial characteristics (size, shape, location etc) and background such as knowledge of existence of urban settlements, rivers, roads, forests etc from secondary sources such as topographic maps. Land use classification was done using supervised classification.

**Image Classification**

Any technique whereby data are grouped into a smaller number of more general integer categories is known as a classification. In remote sensing, a classification is a procedure whereby data cells are assigned to one of a broad group of landcover classes according to the nature of the specific reflectance found at that place. Supervised classification, which is a technique for the computer-assisted interpretation of remotely sensed imagery, was used to classify the 432 composite image. During this classification, training sites were first extracted, then the actual classification, spatial separation and lastly the final classification.

This procedure allowed for identifying training samples based on landuse types to guide the classifier in assigning land cover classes to individual pixels. Training sites were used to identify known features in the image using supervised classification. Training data was generated from a combination of prior knowledge of the study area, data from the field survey, ancillary information from existing maps (topographic) and other published sources.

Signature files were generated for seven different cover types by choosing training sites of known land cover. Well distributed training sites of each of the seven classes were well identified. About 100 pixels for each of the classes were digitized on-screen using the digitize module in Idrisi. Vector polygons were drawn on the raster false colour composite image that corresponded to land covers of as high purity as possible. Different classified land use and land cover map units were distinguished using different labels and colours.

This procedure was followed for each of seven different cover types, water, forests, bare surfaces, urban or built-up areas, subsistence farms, coffee plantations and tea plantations. Makesig was run using these seven cover types as represented in each of the six Landsat bands. After the signature files were developed, maximum likelihood classifier was run to classify each pixel in the image as to which signature it most closely resembled.

From this classification seven land use/land cover categories namely water (water sources), forests (i.e. exotic and indigenous forests), bare surfaces (non-vegetated land, sandy or rocky areas), urban or built-up areas (towns, sub-urbans, homesteads, transportation and communication facilities) were developed. Agricultural areas were divided into subsistence farms, coffee plantations and tea plantations. The image file created was then converted into a raster file using lineras.

### 3.4 Aquaculture site selection using GIS

The site selection criteria (Table 3.1) described earlier was executed with GIS environment to identify suitable sites for aquaculture development in the study area. The layers that created the database were used to extract information and construct layers of information to identify areas suitable for aquaculture. Idrisi 32, a raster based, GIS analysis system (Eastman, 1995) was employed to create information layers. In implementing the criteria, these relevant information layers were combined using the Boolean operations. This analysis is suitable for objective criterion but is not suitable to show gradational values (Kundu, 2000).

In these operations all the layers were considered as being equally important and were given an equal weight (Nath *et al.*, 2000). In this method different criteria were brought together for a single solution. Layers with different kinds of data (e.g. slope values, distance values and landcover categories) were first made comparable. This was done by standardizing the layers to some common scale of values. In this study the layers were standardized to a scale with just two possible values: 0 and 1. Once the criteria were reduced to constraint Boolean images of areas, which are suitable and not suitable, they were aggregated. Similarly to Jones (1997), all criteria were aggregated by multiplying them using the logical operator for intersection (AND). On each of the intermediate maps, there were just two themes or patterns, one in colour and the other in black, representing the idea of "good" or "appropriate" and "not suitable" respectively. The output had only two classes - "suitable" = 1 or "not suitable" = 0.

To get sites suitable for aquaculture in this study a GIS database query by attribute was performed. This was done by using reclass module to complete a query that involved only one attribute. For multiple attributes overlay was used.

### 3.4.1 Single attribute queries

Single attribute queries define the locations that meet only one condition. Boolean approach was used to produce Boolean images in the single attribute queries. In this approach, the criterion is either true or false. Areas are designated by a simple binary number, 1, including, or 0, excluding them from being suitable for consideration (Jiang and Eastman, 2000).

Reclass (in the GIS Analysis /Database query menu), which gives Boolean algebra values was used to produce Boolean images. Here, 1 was assigned to all values representing acceptable areas and 0 to all values representing unacceptable areas. It was therefore used to convert four landuse/cover classes of the Landsat image (water, forests, bare surfaces, urban or built-up areas) to 0 while subsistence farms, coffee plantations and tea plantations were converted to 1 so that a binary image named AGRIC was generated. This process was repeated for all thematic maps including slope, soil pH, soil texture, rainfall, water, roads and market images as in Figure 3.5 below. The values that met conditions described on the criteria were given the value of 1 while all other areas were given the value of 0.

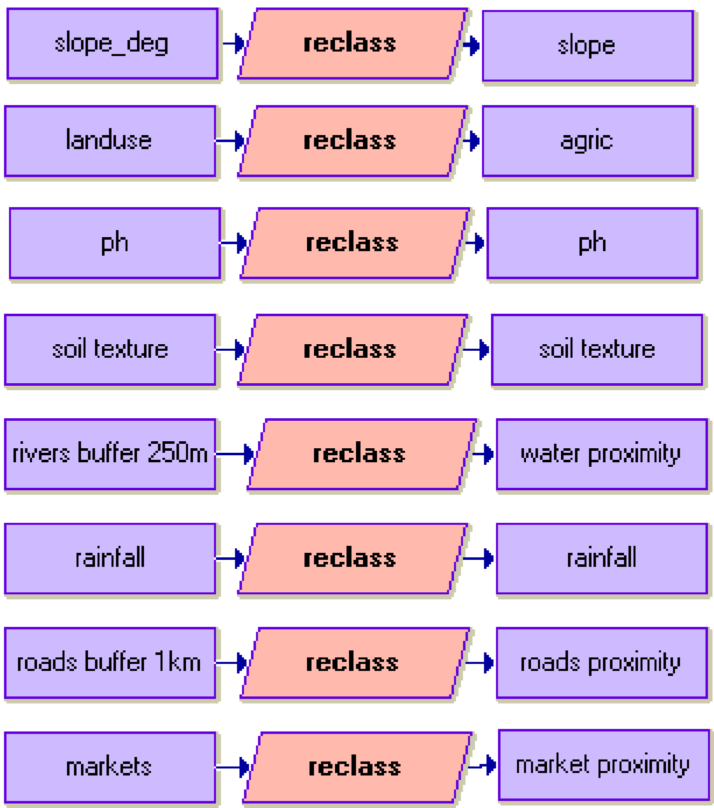



**Figure 3.5:** Various criteria reclassed to form Boolean images

### 3.4.2 Multiple attribute queries

Multiple attribute queries define locations that meet more than one condition. Boolean algebra was used to accomplish this task. After reclassification of thematic maps in terms of suitability was accomplished, a simple overlay was performed by applying logical operators to the layers. In other words, outputs of the single attribute queries were used as inputs for performing multiple attribute queries.

Logical AND operations were used to multiply one image with another. In this operation whenever a constraint layer was multiplied by one containing suitability data, the former was automatically excluded from the outcome. Multiplication operations for multiple images were performed to identify all locations that met all the conditions described in the criteria as shown in Figure 3.6 below.

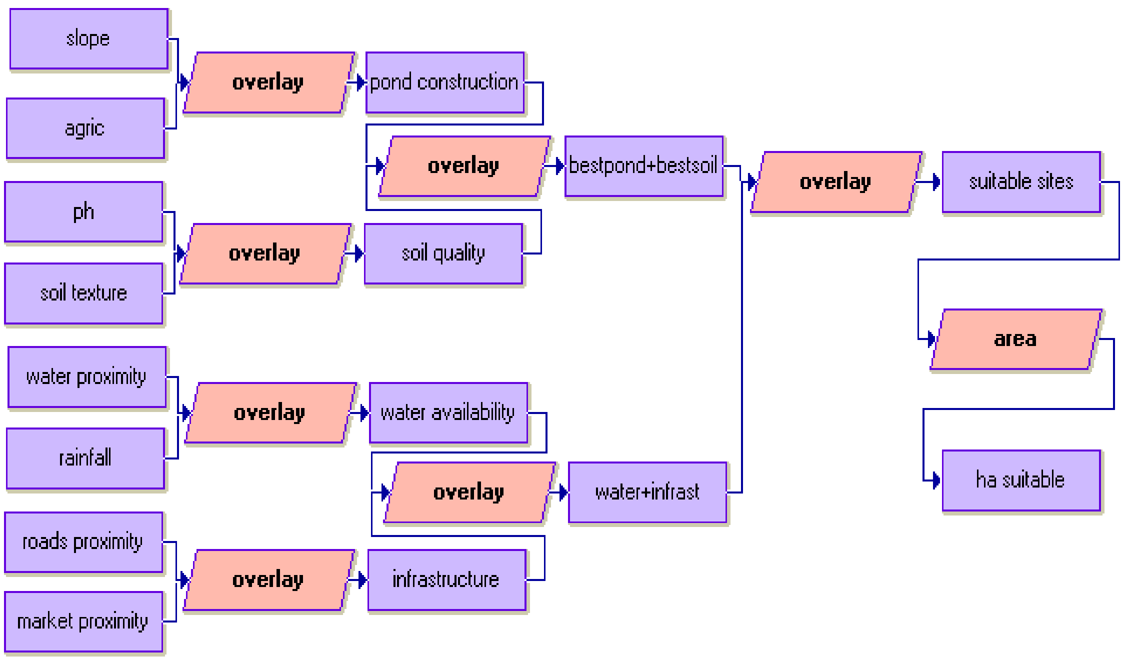



**Figure 3.6:** Boolean images used to create the suitable sites

As the flow chart indicates, the final step in the suitability process was to combine the information in the last two maps as an overlay to generate a decision end product map, called suitable sites. Each data cell for each map then had either a 1 or a 0 within it. Since the two intermediate maps were at the same scale and projection, they fit or registered in the overlay process.

Since the area of each cell was known, the total area associated with suitable conditions was the product of the number of cells times the unit area. The output image was achieved by using the area function of IDRISI. The area function was used to calculate the surface area for each group.

### 3.5 Assessment of Economic Impact

Aquaculture contributes to an economy in terms of employment and business. Veverica *et al.,* (1998) reported Nile tilapia yields of 4.0 ton $ha^{-1}yr^{-1}$ in fertilized static earthen ponds while Liti *et al.,* (2002) reported Nile tilapia yields of 5.0 ton $ha^{-1}yr^{-1}$ under similar conditions. According to the Kenya National Bureau of Statistics (2008) the price of one kilogram of fresh fish in Kenya was approximately Kshs.250 by January 2008. One hectare of a fish will therefore generate:-

I tonne = 1,000kgs

4 tonnes = 4,000kgs

5 tonnes = 5,000kgs

If one kilogram of fresh fish in Kenya is approximately Kshs. 250 then:-

According to Veverica *et al.*, (1998), 4 tonnes will cost (4,000*250) = Kshs. 1,000,000 pa while,

for Liti *et al.*, (2002) the 5 tonnes will cost (5,000*250) = Kshs 1,250,000 pa.

In this study Veverica *et al.*, (1998) findings was be used to estimate the economic impact of aquaculture development in Embu District. The suggestion was taken up in order to avoid an overestimation of the economic impact. Therefore, one million shillings was multiplied by the number of aquaculture hectares that were identified in the area of study.

# CHAPTER FOUR: RESULTS

## 4.0 Introduction

This chapter presents the main results of GIS analysis in figures and tables.

### 4.1 Secondary Data

#### 4.1.1 Data acquired from ILRI database

Soil pH, rainfall and soil texture data were extracted from the ILRI database.

**a) Soil pH**

Figure 4.1 shows the soil pH data extracted from ILRI database.

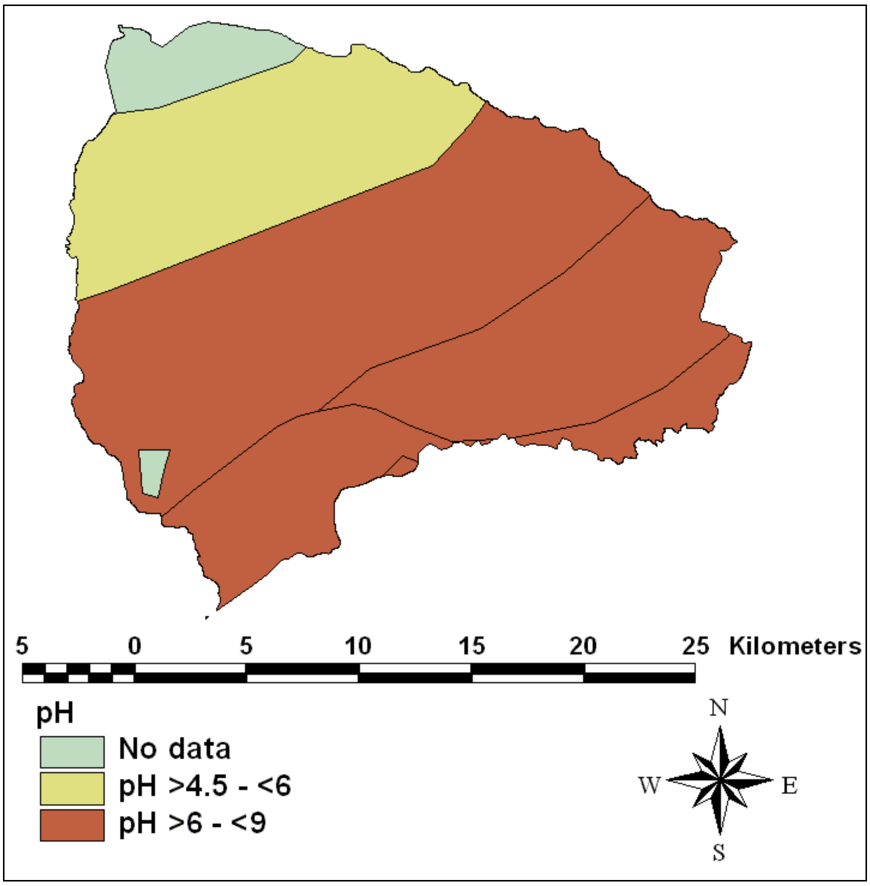



**Figure 4.1:** Soil pH for Embu district

From this figure it is evident that the soil pH in the study area decreases as one moves northwards. A part which covers an area of 2,596 ha has no data for its soil pH because the area is thickly forested and largely inaccessible. The middle part which covers an area of 11,422.4 ha of the study area has a pH range of 4.5 to 6.0 not suitable for aquaculture. The southern part which has a pH above 6.5 covers an area of 37,901.6 ha is suitable for fish farming. This is because it is within the pH range of 6-9 suitable for fish farming.

**b) Rainfall data**

Figure 4.2 shows the rainfall data extracted from ILRI database.

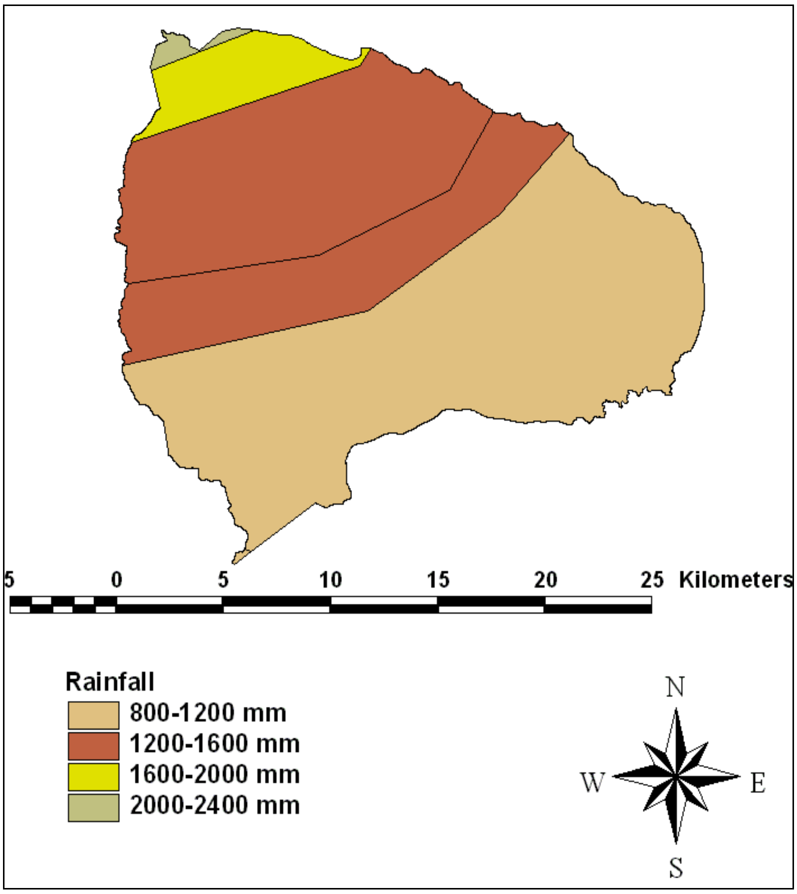



**Figure 4.2:** Rainfall data of Embu district

Rainfall in the study area increases as one moves towards the north. The area adjacent to Mt. Kenya forest receives the highest amount of rainfall i.e. between 2000 to 2400 mm. The rest of the area receives rainfall below 2000 mm with the least at 800 mm. The area receiving the highest amount of rainfall covers an area of 363.4 ha while the area receiving the least amount of rainfall covers the largest area of 33,228.8 ha. The middle parts of the study area which receive rainfall ranging 1200 to 1600 mm cover an area of 15,056 ha while that area whose rainfall ranges between 1600 to 2000 mm cover an area of 3,271 ha. The whole area receives enough rainfall for aquaculture development.

**c) Soil Texture**

Figure 4.3 below shows the soil texture data extracted from ILRI database.

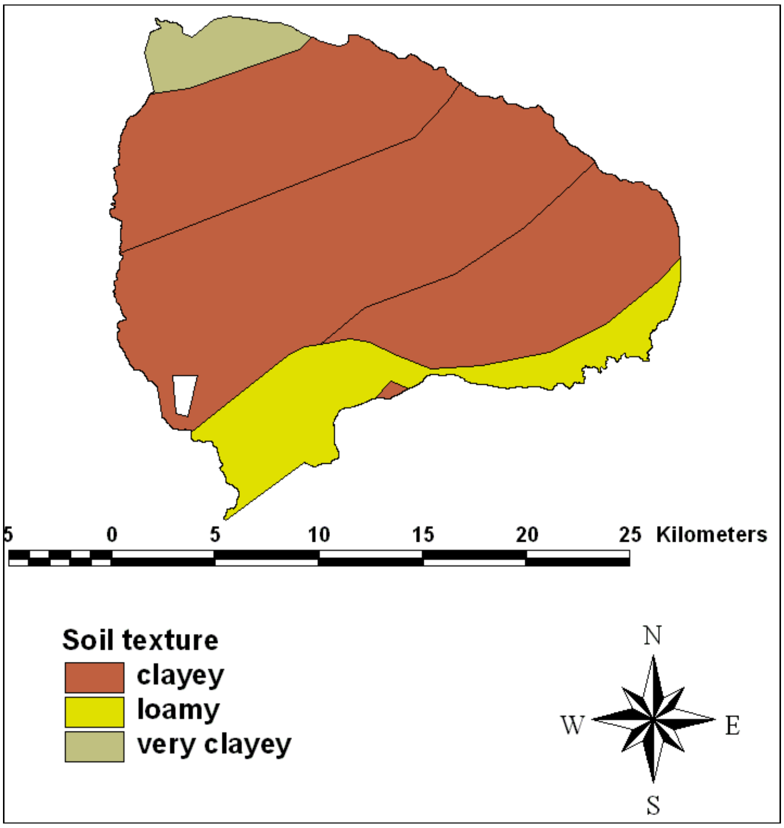



**Figure 4.3:** Soil Texture for Embu District

The clay content increases towards the north of the district. Most soils in the area are clay soils. The other soil type in the area is loamy soil which covers an area of 9,863.8 ha. Clay soils in the area are either clayey or very clayey. Clayey soils cover the largest area of 39,459.2 ha while the very clayey soils cover only an area of 2,596 ha.

### 4.1.2 Data from topographic maps

**a) Contours**

Topography of the study area is represented by the contour map (Fig 4.4) which shows various elevations of the area.

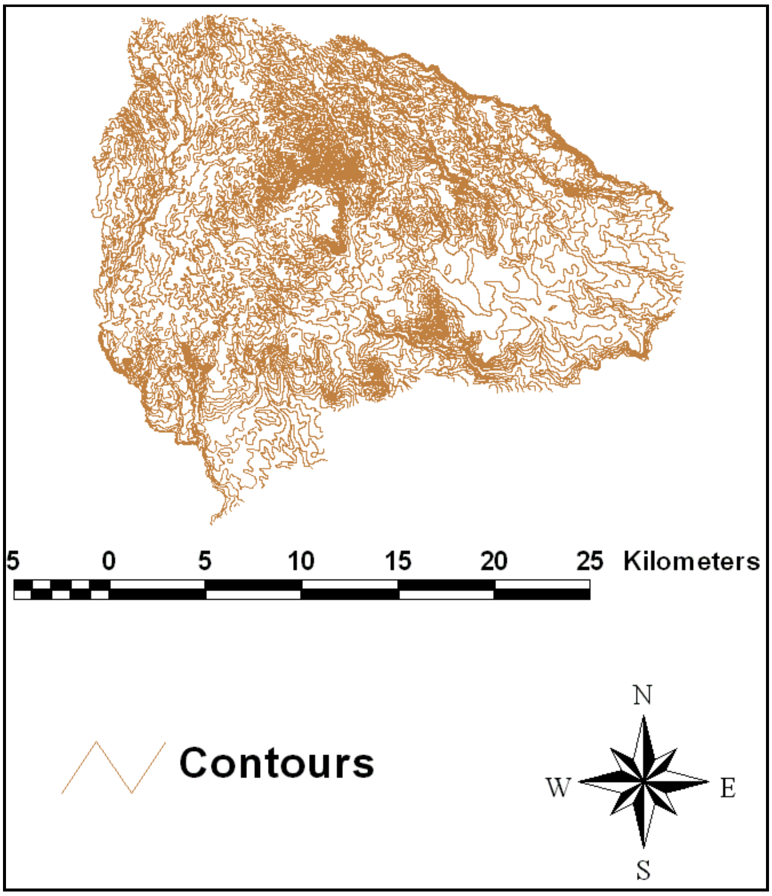



**Figure 4.4:** Contours

Elevation of the contours, range from 1060 metres to 2067 metres above sea level. This map shows variations in the closeness of the contours. For, example, in the northern part the contours are very close while those on the southern part are more sparse. Areas where the contours are close show steepness while the plains are characterised by contours that are distants apart. There are also some sections where contours almost overlay each other forming some dark spots within the map. These are mountainous areas or areas with deep river valleys.  From the Digital Elevation Model (DEM) of the study area, it is clear that the area slopes southwards.

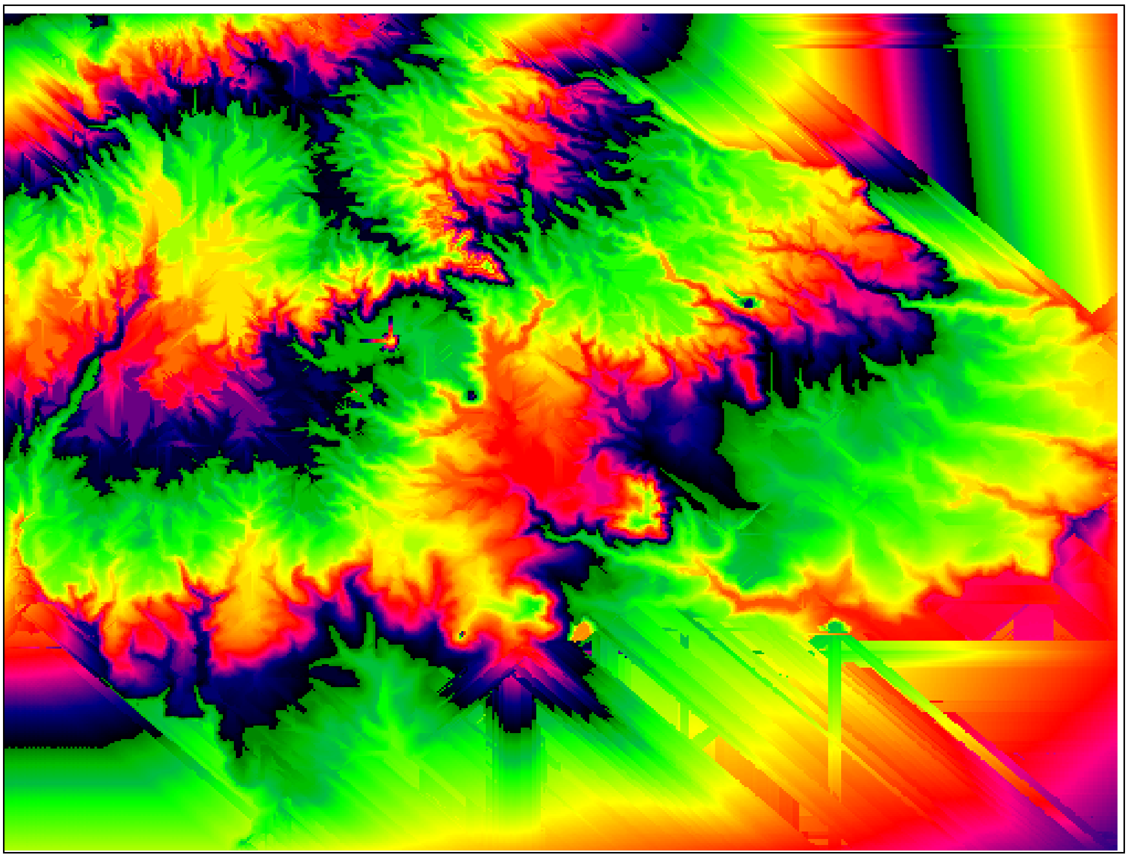


**Figure 4.5:** Digital Elevation Model (DEM)

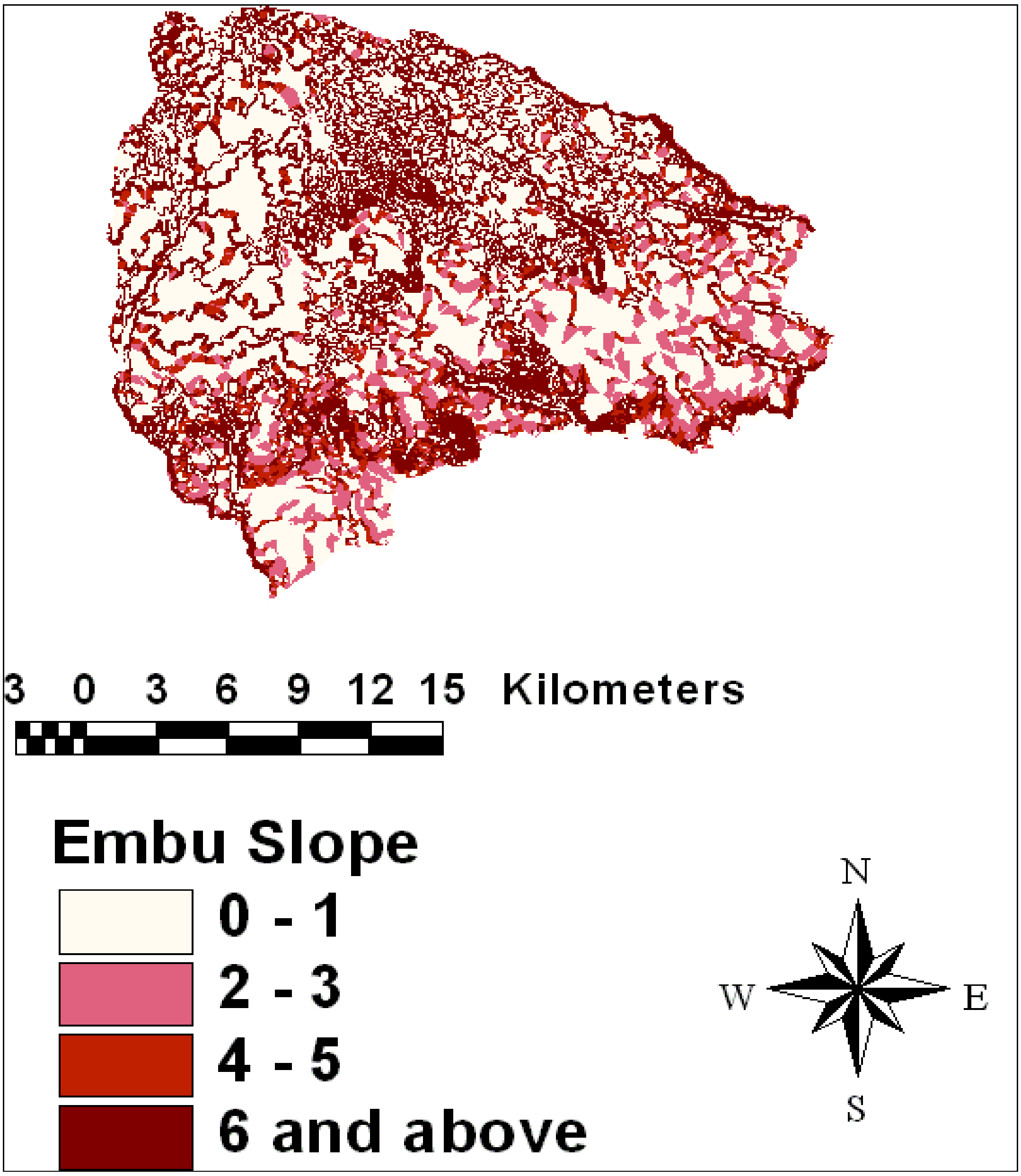



**Figure 4.6:** Embu slope in percentage

**b) Roads**

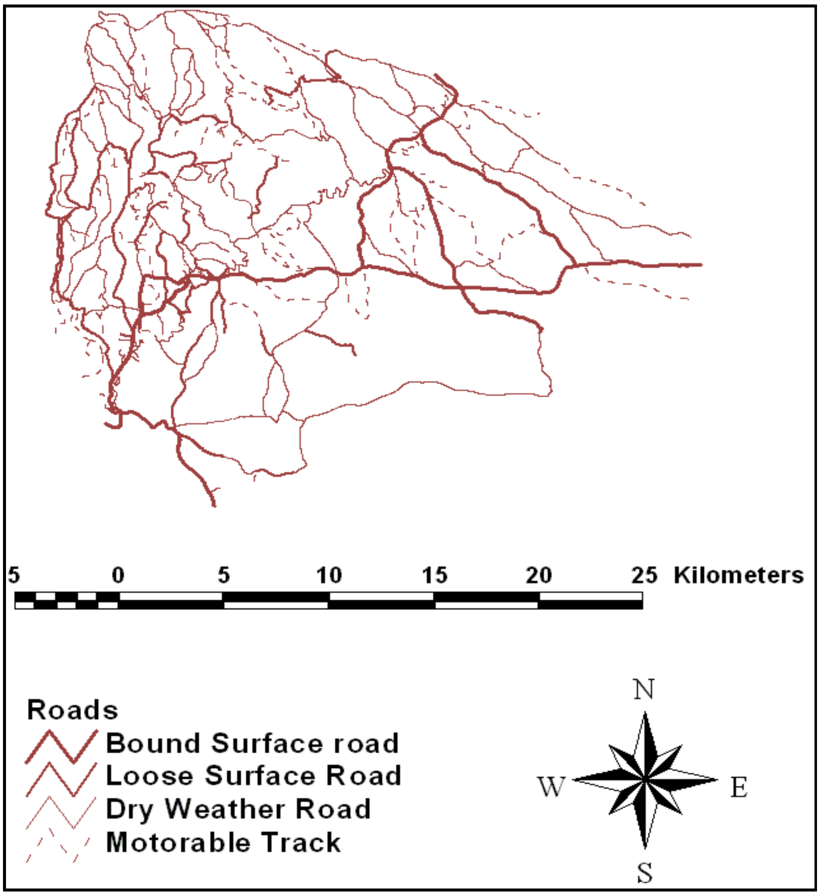



**Figure 4.7:** Roads layer

From the roads layer in fig 4.7, the study area has a good network of motorable roads. The northern and some middle parts have got many and closer roads unlike the southern part which has got fewer roads that are wide apart. The reason for many roads in the northern and middle areas could be for transporting the major cash crops, i.e. tea and coffee, grown in these regions unlike the southern part which is more of an ASAL.

Though the area has a bound surface road, the road passes only in the middle part of the district. Its construction was facilitated by the presence of Embu Town, which, despite having many activities, it is also the provincial capital of Eastern Province of Kenya. Though much of the area is accessible using the dry weather roads and the motorable tracks, they can only be used well during the dry season. Therefore in this study the most suitable roads for fish farming are the bound and loose surface roads which are indeed few in number.

The roads buffer zone shown below indicates that the area is easily accessible by motor vehicles. The northern and middle parts are more accessible than the southern part whose roads are wide apart.

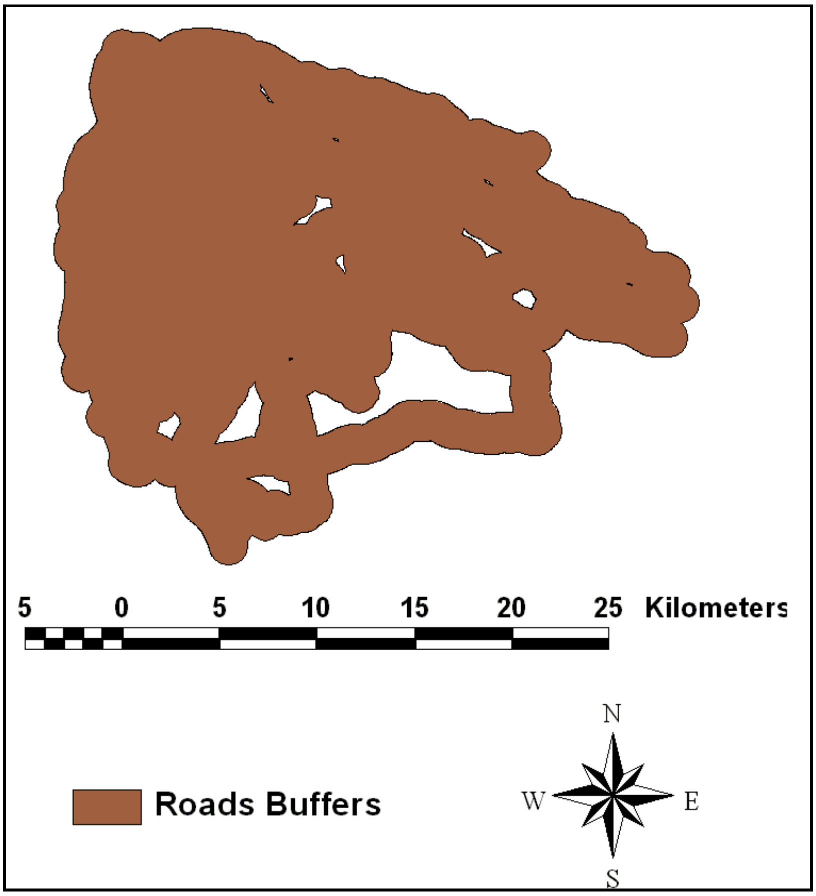



**Figure 4.8:** One kilometre Roads buffer zones

**c) Rivers**

Figure 4.9 below shows the rivers layer digitized from topographic maps.

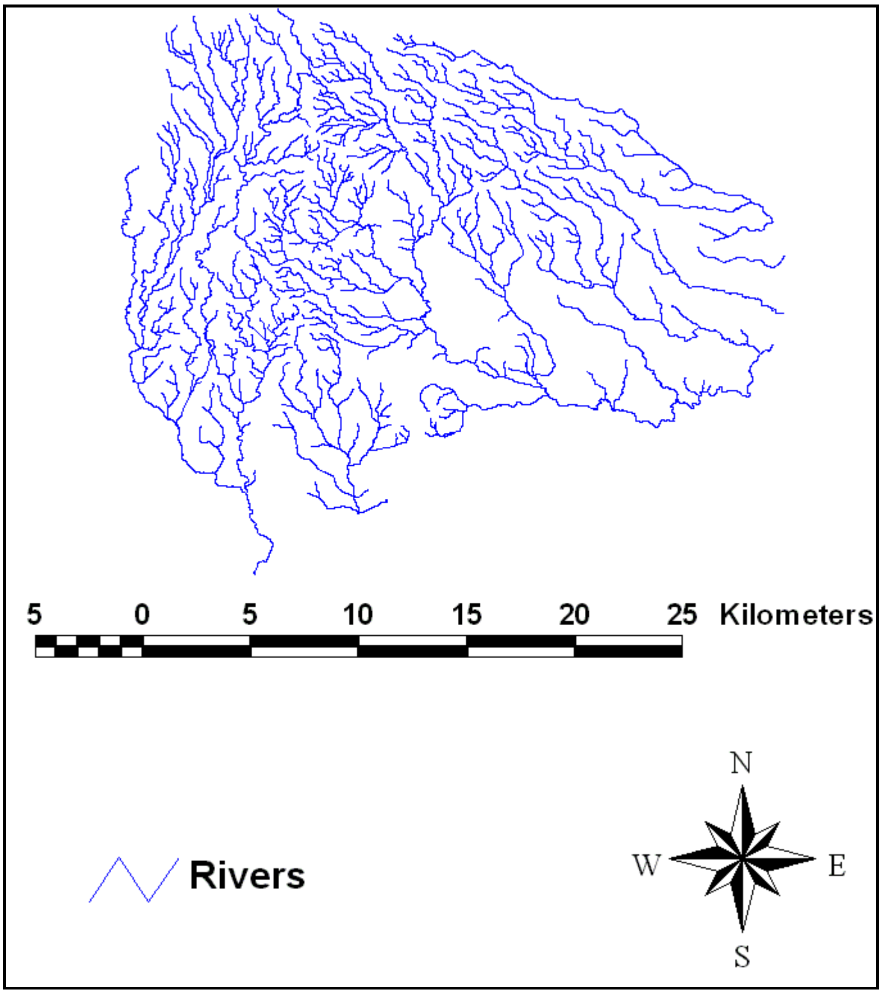



**Figure 4.9:** Water sources

From the rivers' layer, it is clear that the area has a dense network of rivers. The northern part, which is adjacent to Mt. Kenya, has got many rivers close to each other unlike the southern part where the rivers are wide apart. This is because Mount Kenya plays a critical role in water catchment for the area as well as the country and is one of the five main "water towers" of Kenya with Aberdare Range, Mau Complex, Cherangani Hills and Mt Elgon, all providing most of the nation's water. On the other hand runoff from rainfall in the northern part of the study area increases the number of rivers. Most of these rivers are permanent because they are served by Mt Kenya.

The buffer zone layer below shows that there is enough water on the northern and middle parts of the study area. The southern part where the buffers are wide apart reveals that this area does not have enough water for an aquaculture farm.

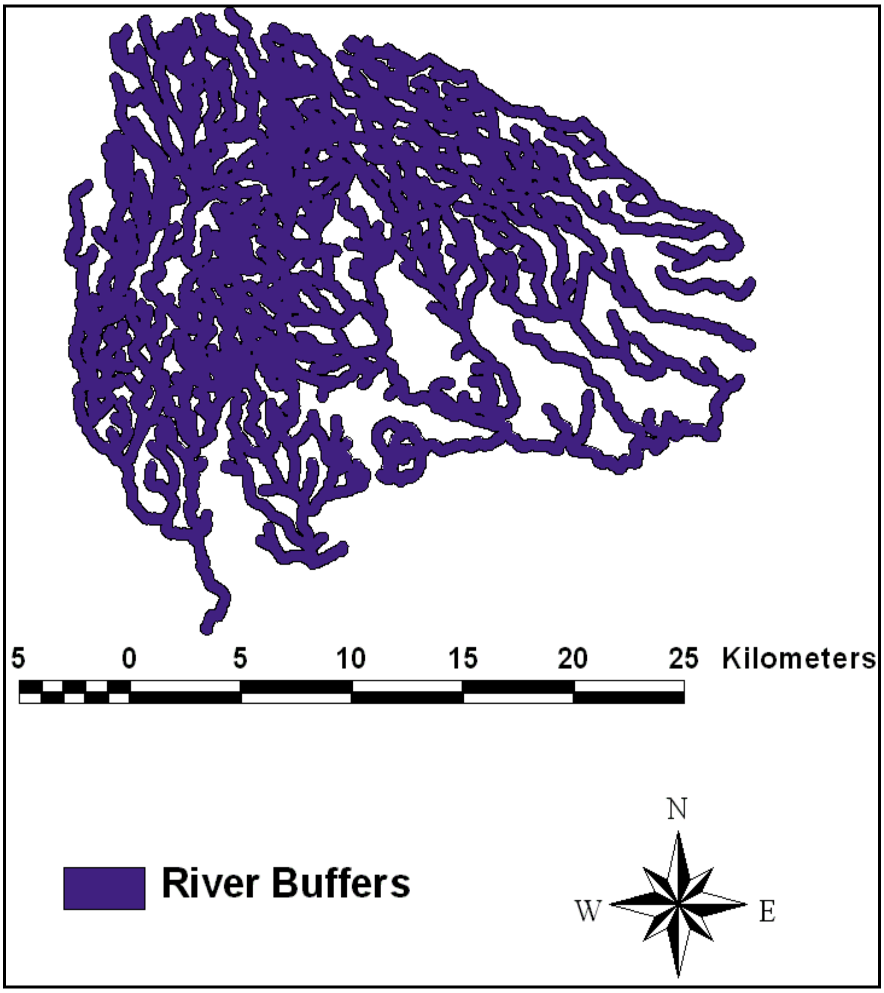



**Figure 4.10:** 250 m River buffer zones

**d) Market Centre**

Figure 4.11 below shows the market centers digitized from topographic maps.

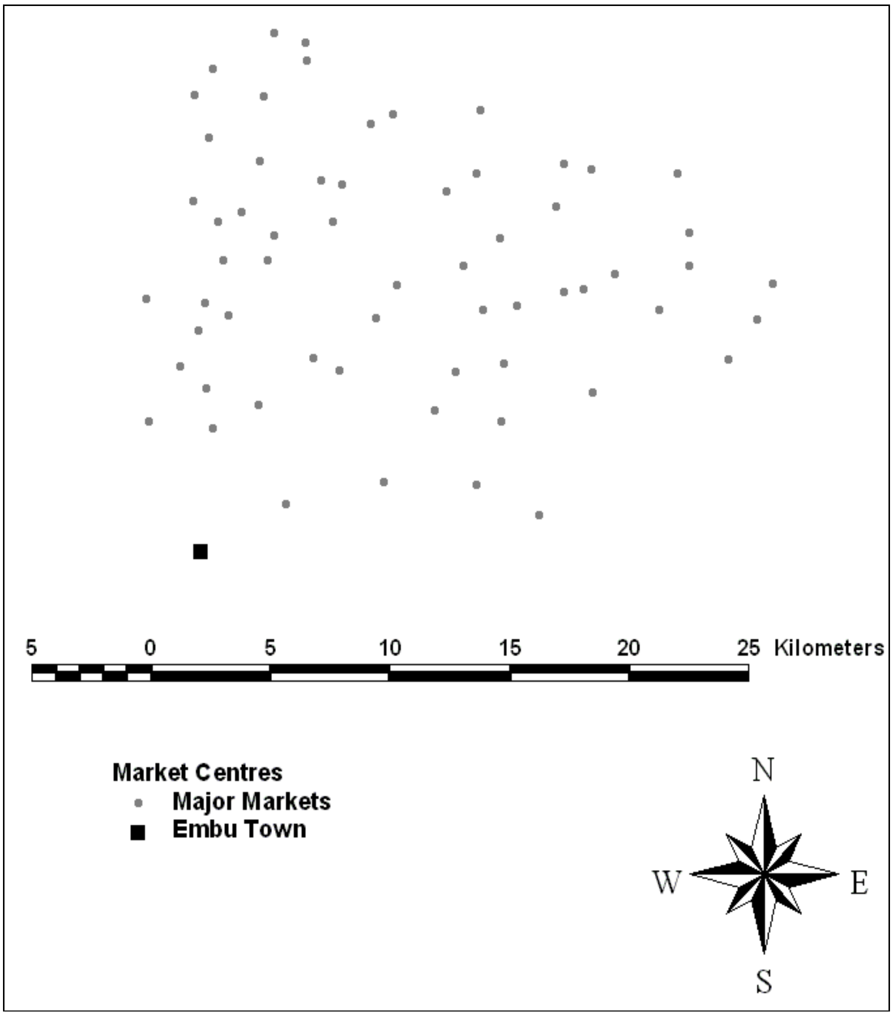



**Figure 4.11:** Market centres

It was found that the study area has market centres all around it. There are only a few centres located on the southern part of the district as a result of the sparse population in this part.

The buffer zone map shown in fig 4.12 indicates that the study area is within the reasonable (3 km) proximity of major markets that could be important for fish farming development. The markets are very important to the fish farming enterprises because they provide both labour and market.

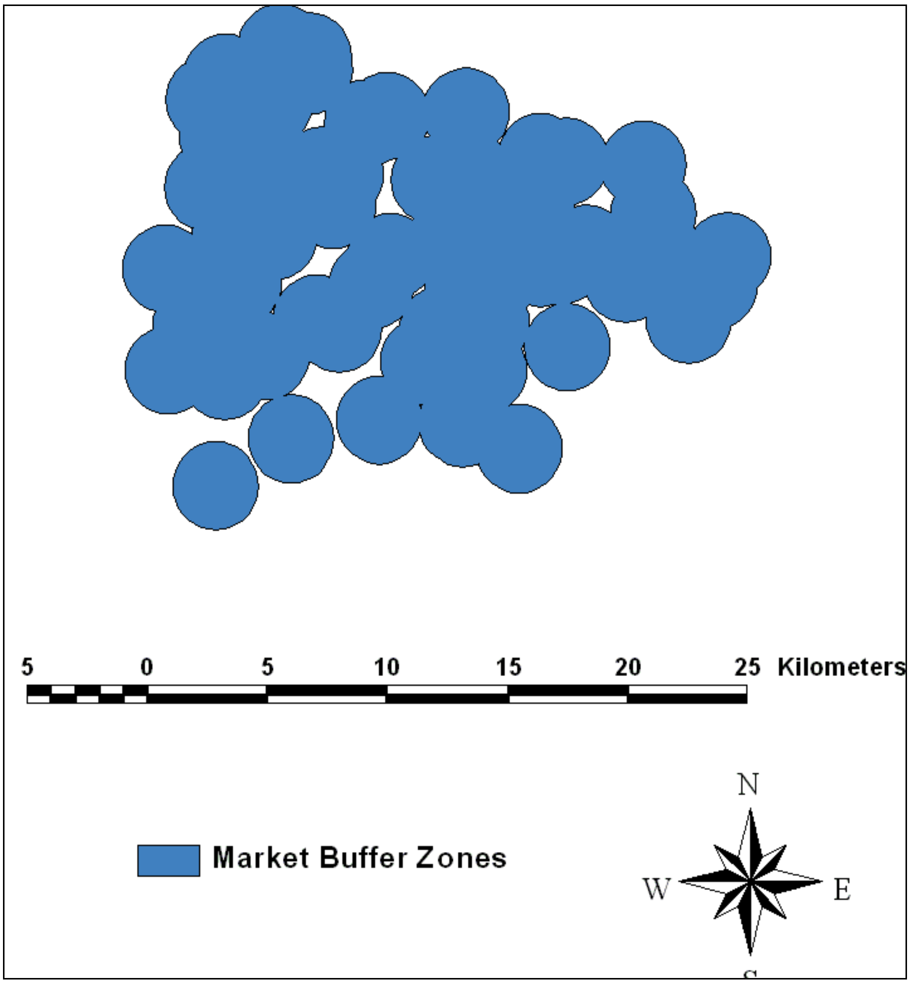



**Figure 4.12:** Three kilometre Market buffer zones

## 4.2 Image data analysis

### a) True colour composite

The true colour composite below was used during the image classification. This image allowed one to view the area as it was. For example, plantations are light green to dark green in colour while bare surfaces are brown as they usually are in reality.

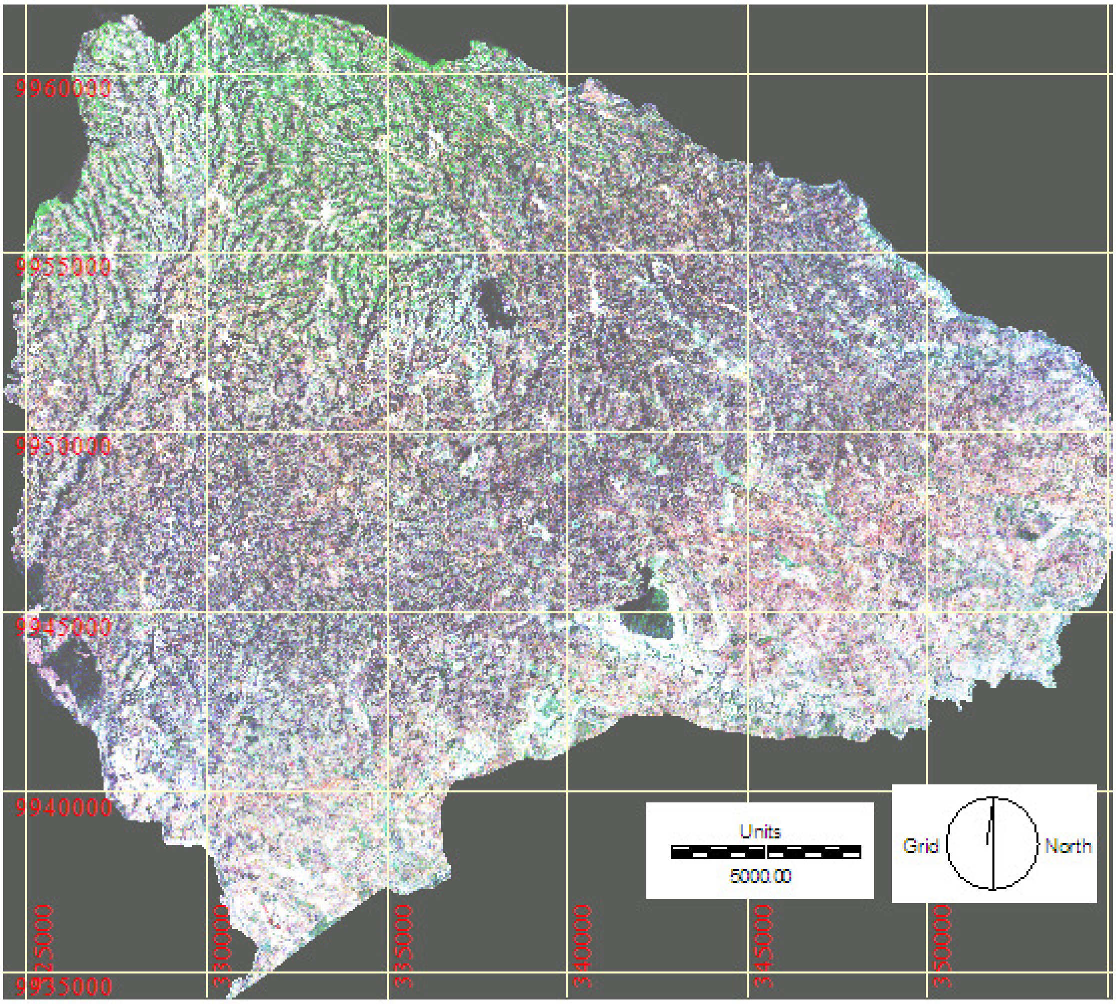



**Figure 4.13:** True colour composite (RGB=321)

**b) False colour composite**

The false colour composite (RGB=432) showed the greatest amount of land cover details in the study area as shown in fig 4.14. Band 432 took care of most of the information carried by all the nine reflective bands. Secondly the 432 combination produces an image dominated by red and green hues to which the human eye is more sensitive and hence more information can be visually derived (Richards, 1993).

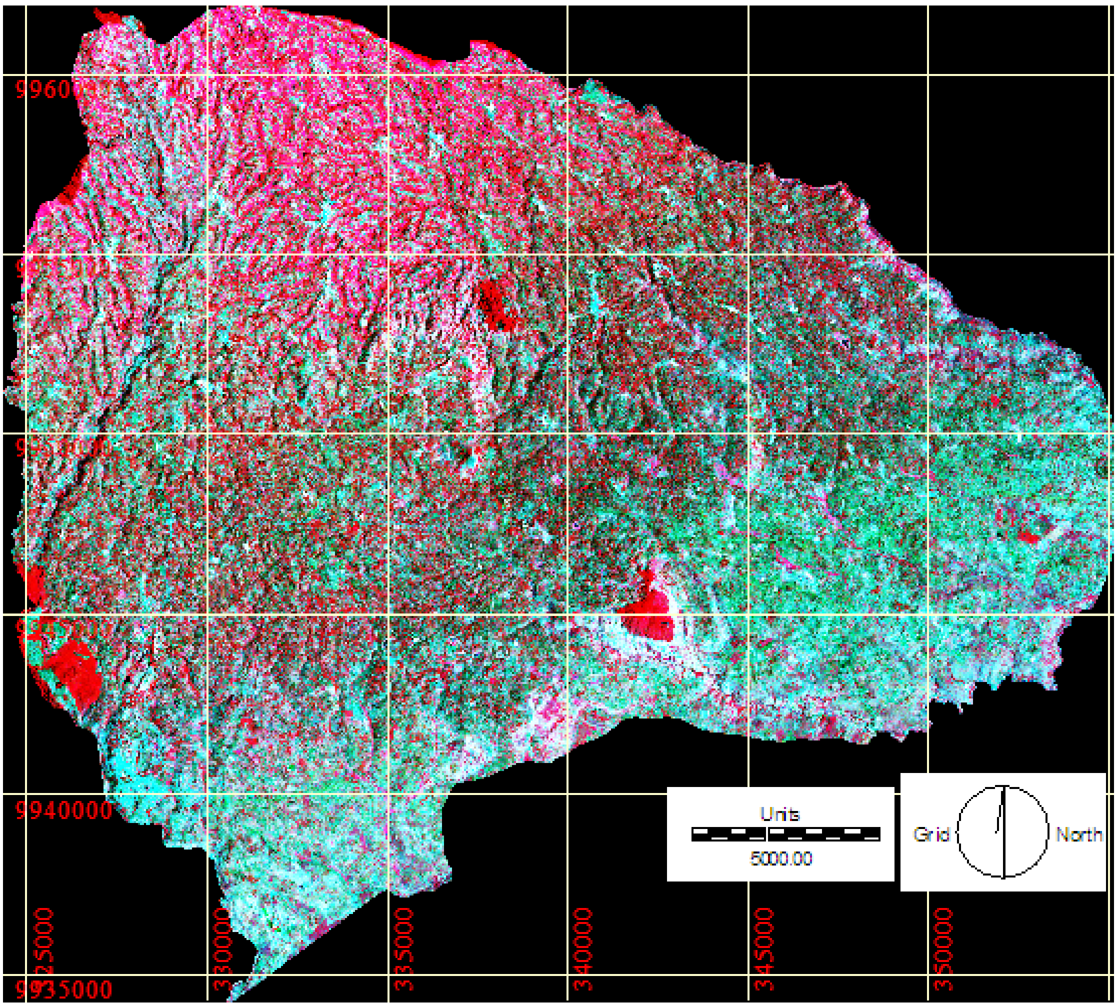



Figure 4.14: **False colour composite (RGB=432)**

The seven distinct landuse types required for this study were identified. Fron this image, clear and deep water was represented by black while silty and shallow water appeared dark bluish. Built-up features (roads, urban and sub-urban centres) appeared light bluish. Swamps and forested areas appeared red. Sparse vegetation appeared light greenish, bare soils appeared white while moderately dense to high biomass vegetation appeared pinkish to maroon. The Nyayo tea zone plantations along Mt. Kenya (Irangi) forest in the northern part and dams near Embu town were discerned using a combination of spatial (location, shape and size) and spectral (colour) characteristics. On the other hand, rivers were identified from very clearly formed river valleys.

During the image analysis the final projected imagery was geometrically accurate to within 0.024450 pixel root mean square error as shown in table 4.1 below. This means that the rectification was achieved at an accuracy of 0.02m.

**Table 4.1:** ENVI ground control points table showing ENVI Image to Map GCP Table

| **Map** | | **Image** | | **Predict** | | **Error** | | **RMS** |
|---|---|---|---|---|---|---|---|---|
| x | y | x | y | x | Y | x | y | **Error** |
| 330725.00 | 9929450.00 | 4813.50 | 6281.50 | 4813.51 | 6281.50 | 0.01 | -0.00 | 0.01 |
| 325300.00 | 9946150.00 | 4622.75 | 5700.50 | 4622.71 | 5700.51 | -0.04 | 0.01 | 0.04 |
| 321250.00 | 9948100.00 | 4480.00 | 5632.75 | 4480.03 | 5632.74 | 0.03 | -0.01 | 0.03 |
| 336200.00 | 9960125.00 | 5007.00 | 5214.00 | 5007.01 | 5214.00 | 0.01 | -0.00 | 0.01 |
| 349225.00 | 9941500.00 | 5462.00 | 5862.25 | 5462.00 | 5862.25 | -0.00 | 0.00 | 0.00 |

**Total RMS Error: 0.024450**

**c) Classified image**

The figure below shows the classified image.

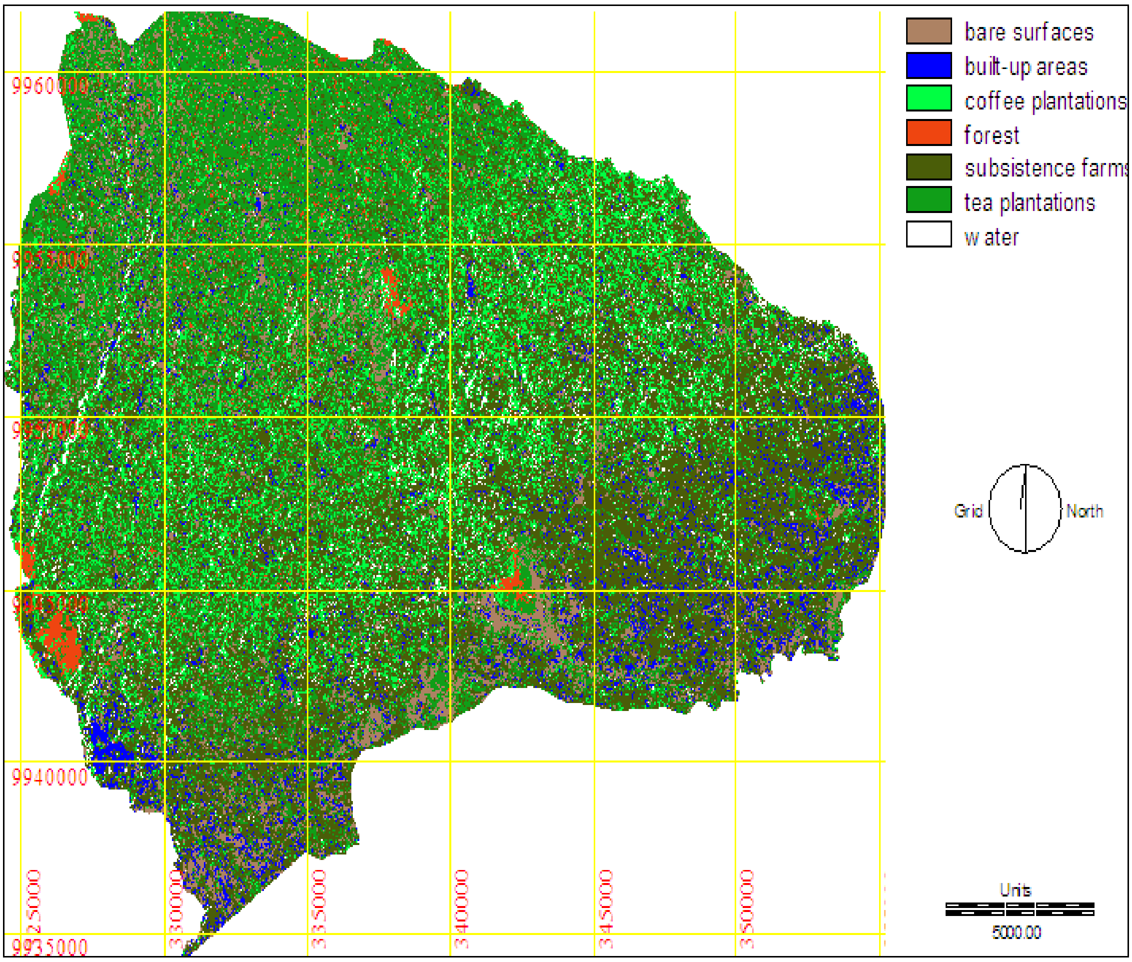



**Figure 4.15:** Maximum likelihood classification of the Landsat ETM image into landuse/cover classes

Agriculture occupies the largest area in Embu District with a total of 434 km$^2$. It is fairly distributed in all regions of the study area. Bare surfaces were mainly found on the lower part of the study area and they occupied an area of 34.6 km$^2$. Built-up areas which cover an area of 21.8 km$^2$ are scattered around the area. Water and forests take the smallest areas of 8.9 $km^2$ and 11 $km^2$ respectively. The class extracted from this image for further analysis was the agricultural area.

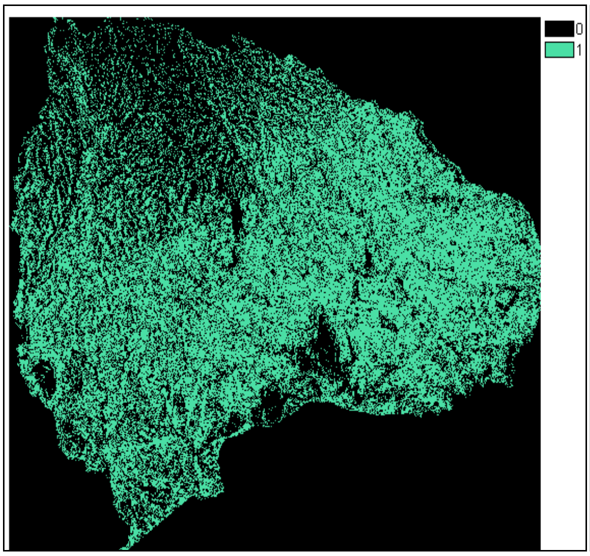
**Table 4.2:** Area of landuse/cover classes in square kilometres and percentages

| Landuse/cover Type | Area (Square Kilometres) | % of total area |
|---|---|---|
| Bare surfaces | 34.58 | 6.8 |
| Built-up areas | 21.82 | 4.3 |
| Coffee plantations | 78.71 | 15.4 |
| Forests | 11.04 | 2.2 |
| Subsistence farms | 214.98 | 42.1 |
| Tea plantations | 140.49 | 27.5 |
| Water sources | 8.93 | 1.7 |
| Total | 510.55 | 100 |

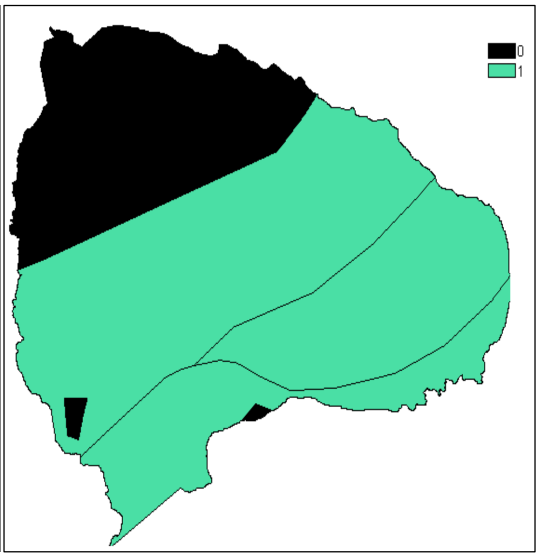
## 4.3 Land suitability assessment

Figure 4.16 shows the outcome of the land suitability assessment in eight aquaculture criteria maps. The maps show the areas which are most suitable in the green colour and the black areas represent the unsuitable locations.

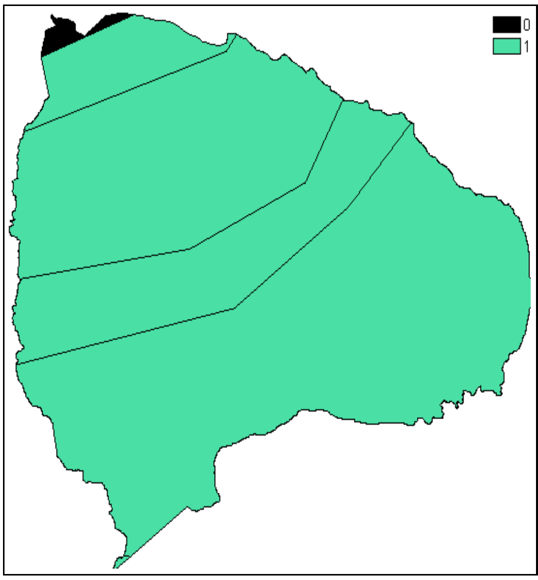
a) **Boolean images**



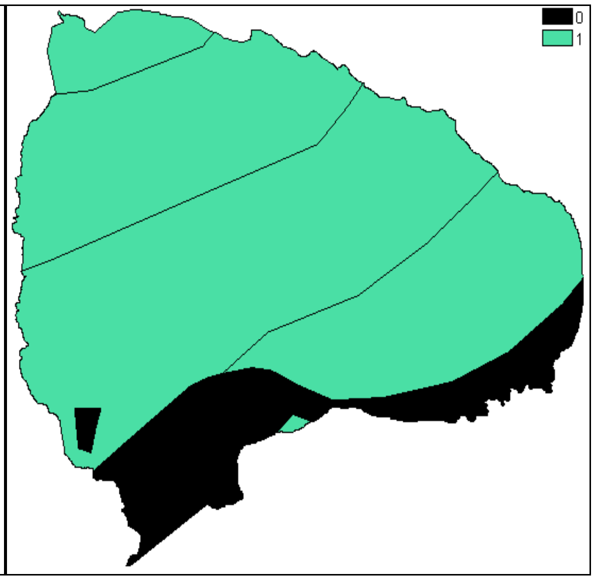

Areas under agriculture



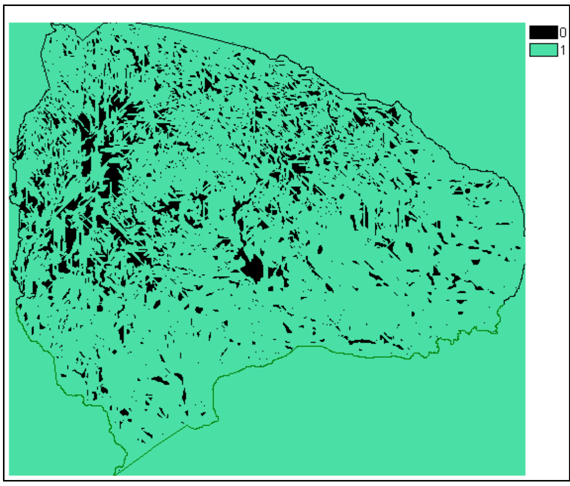

Soil pH map



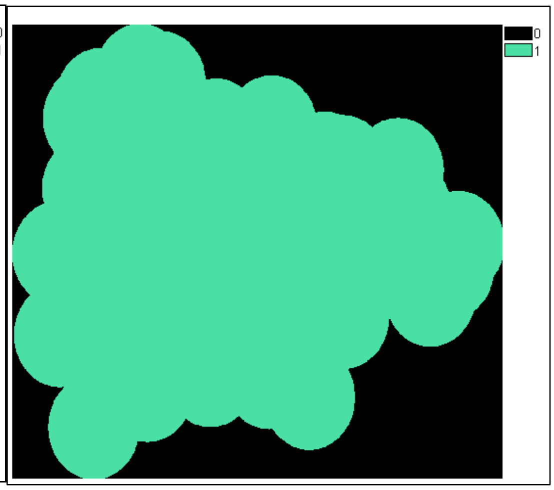

Rainfall map



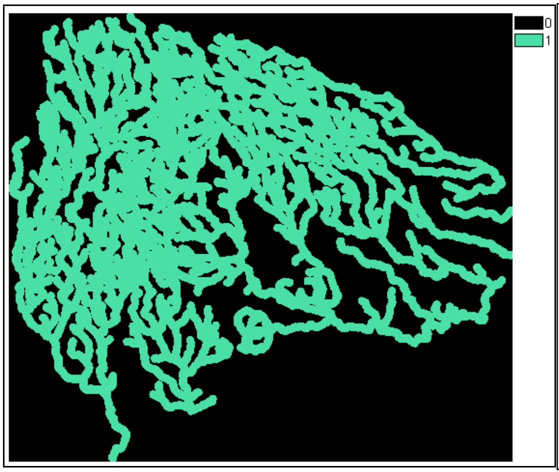

Soil texture map



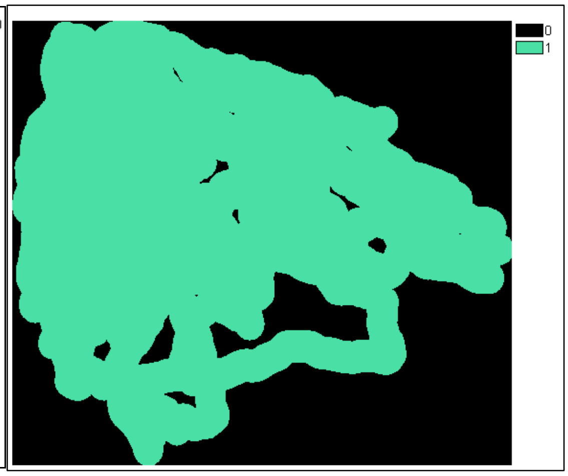

Slope map




Proximity to market centres map




Proximity to rivers




Proximity to roads

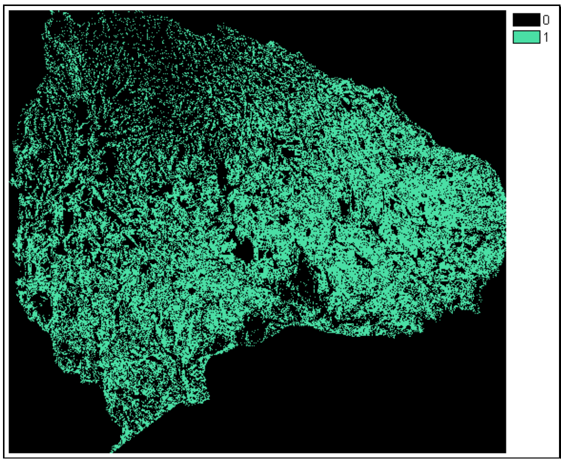
**Figure 4.16:** Boolean images of various criteria

The largest aquaculture suitability scores were obtained from proximity to markets (99.7% of the study area), followed by rainfall (99.3%), proximity to roads (94.4%), slope (87%), agriculture (82%), soil texture (81%), soil pH (73%) and proximity to rivers (67%).

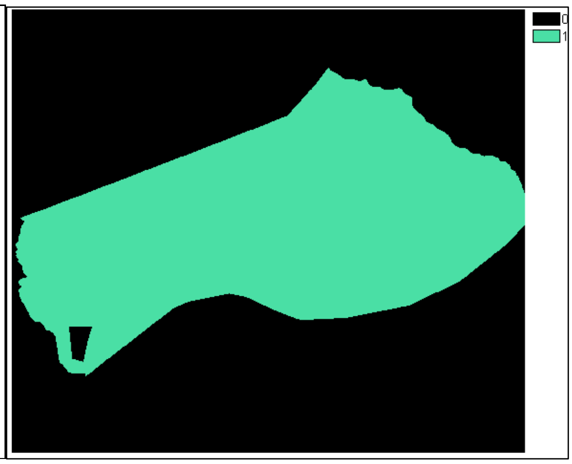
The optimum suitability scores were located as follows: for proximity to markets, around the whole area; for rainfall, almost the whole area except the northern part of the study area; for proximity to roads, the northern and middle parts of the district and some parts of the southern region; for slope, the southern part and some parts of the northern and middle regions; for agriculture, the middle and southern regions and some parts of the northern region; for soil texture, the northern and middle regions; for soil pH, the middle and southern parts and for proximity to rivers, along the rivers which are located mainly on the northern and middle regions.

## b) Suitability maps

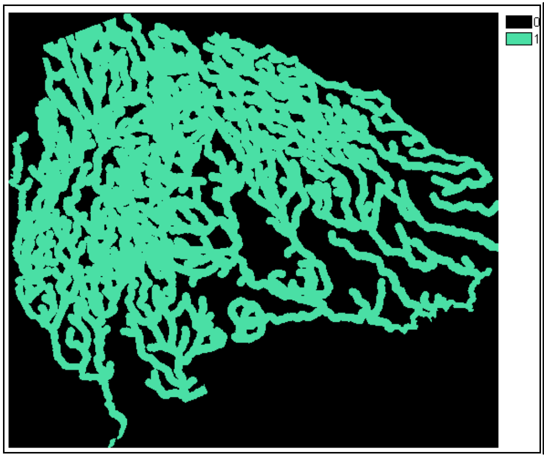
Figure 4.17 shows the suitability maps for various land use requirements that make up the criteria. This is as a result of overlaying the Boolean images.




Suitability map for pond construction




Suitability map for soil quality





Suitability map for water availability

Suitability map for socio-economics

**Figure 4.17:** Suitability maps for the four landuse classes

These maps were as a result of combining the criteria maps by means of GIS to investigate site selection in terms of potential for pond construction (slope and landuse), soil quality (soil pH and texture), water availability (rainfall, water sources and proximity) and socio-economic factors (proximity to roads and markets).

From the suitability map, the socio-economic factors largely favour aquaculture in the study area since they take an area of 86%. On the other hand the potential for pond construction is a major limitation. This is because the area that has a high potential to construct ponds takes the minimum percentage (48%) of the study area as compared to the other factors. Areas with suitable water availability cover an area of 67.3 %. These were distributed in the whole region due to extensive river systems and high precipitation rate. Soil quality suitability for aquaculture takes 59% of the study area.

**c) Suitable sites**

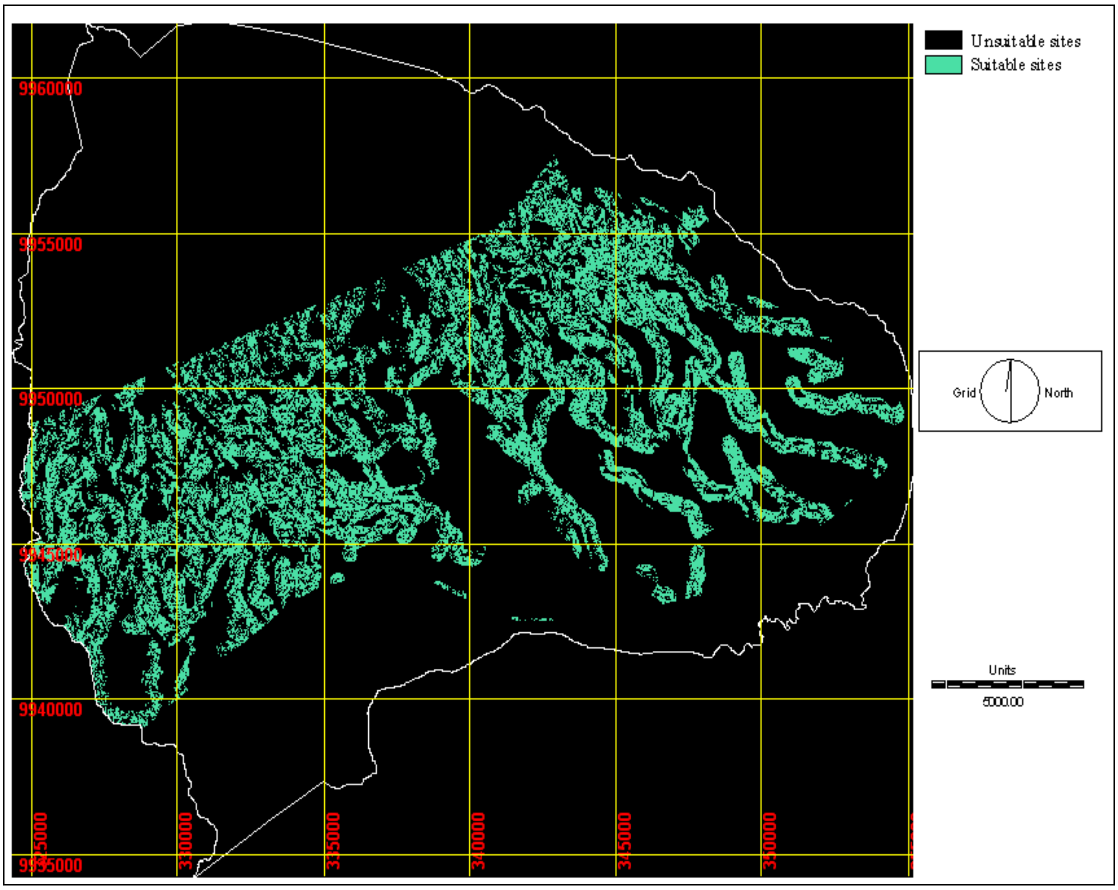



**Figure 4.18:** Areas showing suitable and unsuitable areas of aquaculture sites of the study area.

When the four main suitability maps were overlain the overall sites suitable displayed in figure 4.18 (green in colour) were attained. From the 51,920 ha of the study area, 9,563 ha (20%) were identified as being suitable for aquaculture development.

**4.4 Economic growth contribution of aquaculture**

Veverica *et al.,* (1998) reported Nile tilapia yields of 4.0 ton $ha^{-1}$ $yr^{-1}$ in fertilized static earthen ponds while Liti *et al.,* (2002) reported Nile tilapia yields of 5.0 ton $ha^{-1}$ $yr^{-1}$ under similar conditions. According to the Kenya National Bureau of Statistics (2008) the price of one kilogram of fresh fish in Kenya was approximately Kshs.250 by January 2008. One hectare of a fish will therefore generate between Kshs.1,000,000 (250*4,000kgs) to Kshs.1, 250,000 (250*5,000kgs) per annum. The 9,563 hectares in Embu will therefore contribute over Kshs 9 billion per annum.

# CHAPTER FIVE: DISCUSSION

From the field study various natural and manmade land cover patterns were noticeable in the study area. Two main cash crop plantations i.e. tea and coffee plantations were identified. Tea plantations were found on the northern part of Embu district whose cold climate and high rainfall favours tea growing. Coffee plantations were concentrated inthe middle part of Embu. On the other hand, subsistence farming was found to be more established in the northern and middle parts of the study area unlike the southern regions. The southern part has some areas that are still virgin i.e. some parts of the land have never been cultivated. This is because this is the arid and semi arid land (ASAL) area of the district which is characterised by a sparse population thus less cultivation and development.

Large urban centres were found along busy roads while small market and centres were found in the interior parts due to the differences in population densities. The former were densely populated than the latter. Two large stillwater swamps were also identified within Embu town. These swamps can be a major source of water for any aquaculture enterprise around the area since they never dry up.

During image classification, extracting the training sites was a laborious task due to considerable within-class variability and it was impossible to be entirely certain that a comprehensive set of training samples for each class had been specified. It was impossible to obtain homogenous sites, for example, in urban areas there was a mixture of cover types such as bare soil/concrete, buildings, vegetation and a high degree of shadows.

It was also difficult to map the wetlands since the permanent and evergreen vegetation of wetlands were spectrally similar to forests. Their spatial locations also coincide with riverrine vegetation. In the forests the shadows could not be spectrally distinguished from the water. Bare surfaces were confused with seasonal swamps on the false colour composite. This is because the image used was acquired in February when most seasonal swamps had already dried up. Tea plantations which were part of the agricultural class were confused with swamp vegetation. This is because tea has the same spectral reflectance with papyrus which is the main vegetation of the swamps.

As a result of the confusion described above for various classes, some classes were over-represented while others were under-represented. For example the bare surfaces and tea plantations were over-represented since they were confused with seasonal swamps and swamp vegetation respectively.

The Boolean constraints left no room for prioritisation, hence all suitable areas were of equal value, regardless of their position in reference to their factors. In the Boolean intersection all criteria were assumed to be constraints. Suitability in one constraint does not compensate for non-suitability in any other constraint. However, this procedure carries the lowest possible uncertainty since only areas considered suitable in all criteria are entered into the result.

A total 9,563 ha (20%) out of the 51,920 ha of the study area were identified as being suitable for aquaculture development. Many of the areas ranked as most suitable were distributed in the middle region of Embu district. These areas occurred along the main roads, rivers systems, in the middle elevation, lower slopes, major markets, good soil quality with appropriate landuse/cover types and good precipitation.

Areas with constraints for aquaculture development in this district were mainly mountainous, hilly, natural forests, and rocky areas. The areas not suitable for aquaculture (80%) were mainly the upper and lower parts of the district.

Much of the study area was limited by soil quality. The main constraint in the northern part of the district was low pH hence farmers would require high initial investment to improve the soil quality. The southern part of the district had loamy soil. This was a constraint because farmers may have to buy liners to ensure that the water does not seep through the soil, increasing the cost.

There is rapid growth in aquaculture production both globally and locally since farmed fish has become an important food source. This is as a result of population increase and changes in food consumption patterns. Consumption of fisheries products has increased and therefore there is need to develop aquaculture to ensure that its full potential is maximized. This can only be done by ensuring that farmers have access to data that enables them to know if their farms are suitable areas for aquaculture to thrive.

The Kshs 9 billion expected to be acquired from the 9,563 ha once the results are implemented will make great contributions to the economy of the district. It will increase food production, alleviate poverty, provide business and create employment in the district. Development of aquaculture in Embu district will maximize its full potential contribution to the area since sites have already been identified. This will ensure that aquaculture will be a socially acceptable and an environmentally responsible industry in the district.

# CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

## 6.1 Conclusion

The advantage of using remote sensing technique and GIS was not only time and cost effectiveness but it also helped to achieve a more comprehensive and integrated treatment for aquaculture development criteria, which is difficult through conventional techniques alone. There is considerable potential for further exploitation of GIS for optimisation of aquaculture activities in Kenya. The GIS planning process has an important role especially where land use patterns are intensive and where developments must be environmentally sustainable as in the case of Embu District.

The results of this study demonstrated the usefulness of integration of remote sensing and GIS to select suitable sites for development of aquaculture. Furthermore, it demonstrated the effectiveness of using remotely sensed data in providing the necessary spectral and spatial information for generating information layers required for the study. Using this approach, planning of aquaculture development could effectively be adapted to local contexts in order to introduce appropriate aquaculture related livelihood options and help alleviate rural poverty in Kenya.

GIS predicted that 9,563 ha (20%) of land were suitable for aquaculture development. The present status of aquaculture in Embu district is only 7 ha (1.5%). The study therefore revealed that there is a high potential for aquaculture that has not yet been exploited in this area. With this in mind, the expansion of aquaculture in the study area is necessary since the results indicate that the possibilities of expanding aquaculture in the area are high.

With the areas suitable for aquaculture having been sited, aquaculture development in Embu should now be encouraged as a means for local people to earn a living while minimizing their impact on the environment. Unlike subsistence agriculture and cattle grazing which require forest clearing and usually generate little revenue for poor farmers, aquaculture offers a sustainable income with low start up costs. Aquaculture can offer a great potential for sustainable poverty alleviation in this region. It will reduce the need to clear land for subsistence agriculture while generating significant economic and nutritional benefits for the Embu community. As such, fish like the tilapia (*Oreochromis niloticus*) and catfish (*Clarias gariepinus*) may be the best hope for this region.

## 6.2 Recommendations

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

1. The present study showed that GIS can be efficiently used to analyze complex spatial data to evaluate suitable sites for aquaculture development. An economic component should therefore be incorporated into GIS applications to determine economic suitability in addition to physical suitability.

2. This study used the Boolean approach which is very conservative. Weighted Linear Combination technique is recommended for use. This is because it is flexible in

assigning factors allowing them to compensate for each other thus giving them more allowance and effectiveness in the suitability analysis of aquaculture site selection.

3. Lack of knowledge of suitable sites for aquaculture is one of the major constraints of aquaculture development in Kenya. On this note, the Ministry of Fisheries should carry out similar studies throughout the country to save the cost and time that is wasted using conventional surveys.

4. The Ministry of Fisheries should use GIS to expedite growth of aquaculture through development of a fish farming information base in the country.

5. Though the study has proved that Embu District has a high aquaculture potential that is yet to be exploited, the decision to convert agricultural areas into fish farms will be related to social aspects. In order to maintain a balance between social and economic aspects, integrated aquaculture – agriculture (IAA) systems should be promoted in order to improve the economy of the highly populated area.

6. The infrastructure of Embu District should be improved in order to improve the fish farming potential in the area. For example, the motorable tracks and the dry weather roads should be constructed into all weather roads so that they can be used during all seasons.

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