UNIVERSITY OF NAIROBI

USING GIS TO DEVELOP A MANAGEMENT PLAN FOR ENA RIVER BASIN IN EMBU AND MBEERE DISTRICTS

By

NGAMAU J. KAMAU

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DECLARATION

I declare this work as original and not been presented before for similar assessment.

Kamau Ngamau

F56/7758/2006

Signature…………………..   Date……………………….

This project was submitted for examination with my approval as a university supervisor

Name……………………………………………..

Signature…………………………………………..   Date…………………………

DEDICATION

I dedicate this work to all my colleagues in the Mt. Kenya East Pilot Project (IFAD/MKEPP) who assisted me greatly by providing relevant information to complete this project.

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I would wish to appreciate all my lecturers, Department of Geospatial and Space Technology for their patience in imparting these skills in my professional and academic life.

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Special regards also to my family, friends and workmates for their understanding all through.

ACRONYMS AND ABBREVIATIONS

AEZ	-	Agro ecological zones
AGNPS	-	Agricultural Non-Point Source Pollution Model
ANSWERS	-	Areal Non-point Source Watershed Environment Simulation
ASL	-	Above Sea Level
ASAL	-	Arid and Semi Arid Lands
CAP	-	Community Action Plan
CBO	-	Community Based Organization
DDC	-	District Development Committees
DDO	-	District Development Officer
DFRD	-	District Focus for Rural Development
DRSRS	-	Department of Resource Surveys and Remote Sensing
DWO	-	District Water Office
EIA	-	Environmental Impact Assessment
EMCA	-	Environmental Management and Coordination Act
ERBMP	-	Ena River Basin Management Plan
ERIBAM	-	Ena River Basin Model
ERS	-	Economic Recovery Strategy
FDAs	-	Focal Development Areas
GIS	-	Geographical Information System
GoK	-	Government of Kenya
Ha	-	Hectares
IFAD	-	International Fund for Agricultural Development
IGAs	-	Income Generating Activities
IRBM	-	Integrated River Basin Management
Km	-	Kilometre
Ksh	-	Kenya Shilling
M&E	-	Monitoring and Evaluation
MDGs	-	Millennium Development Goals
MKEPP	-	Mount Kenya East Pilot Project for Natural Resources Management
MUSLE	-	Modified Universal Soil Loss Equation

NEMA	-	National Environmental Management Authority
NGO	-	Non-Governmental Organisation
PMU	-	Project Management Unit
PRA	-	Participatory Rural Appraisal
PRSP	-	Poverty Reduction Strategy Paper
RGS	-	River Gauging Stations
RUSLE	-	Revised Universal Soil Loss Equation
RWUAs	-	River Water-User Associations
SHESED	-	Système Hydrologique Européen Hydrological Modeling System
SRTM	-	Shuttle Radar Topography Mission
USLE	-	Universal Soil Loss Equation
WEPP	-	Water Erosion Prediction Project
WRMA	-	Water Resources Management Authority
WUA	-	Water Users Association

ABSTRACT

This study revolves around Ena River Basin, one of the significant basins on the Eastern side of the renowned Mt. Kenya that lies between 0^0E, 33^0N and 0^0E, 37^0N, and contributes to the catchment for Tana River, Kenya's largest river that is used for among other purposes, hydro-electric power generation. In the recent past, the Tana basin has experienced significant flow reductions, caused by among other issues, massive degradation in the basin area. The objective of the study is to therefore identify causes to this issue, and to use a GIS based analytical model to spatially analyze the basin, with a particular emphasis on the coffee zone that falls in the middle stage of the Ena River development.

Using the Ena River Basin Management Model (ERIBAM), a GIS based management tool that combines River flow data, Sediment Load, Soil pH and Slope and Elevation units, the study results spatially represent in a cellular form areas affected by this degradation, with suggested recommendations on how to deal with the resultant issues. This model has borrowed heavily from the Revised Universal Soil Loss Equation (RUSLE), developed by Renard *et al,* in 1991 and is an accepted worldwide GIS-based analytical model. As with process-based models however, the ERIBAM model has limitations due to temporal variations in its inputs as discussed in the study.

Keywords: ERIBAM, River flow, Sediment load, Soil pH, Topography.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The Forests of Mt. Kenya, the Aberdares Range, the Mau Complex, Mt. Elgon and Cherangani Hills are the important water catchment areas for Kenya. In total, they cover over 1 Million Ha and form the upper catchments of all main rivers of Kenya except Tsavo River (DRSRS, 2004).

The rivers serve as sources of water for hydroelectric generation, irrigation, agriculture and industrial processes. The forests protect soil and water on which agriculture depends and form habitats for our wildlife on which our tourism industry depends. They act as reservoirs for biodiversity and serve as sinks for carbon. Their importance in supply of timber and non-timber products to the communities living within their surroundings cannot be over emphasized. As such these forests are important and support the livelihoods of all Kenyans in one way or another.

According to the 1994 National Water Master Plan, the annual quantity of renewable freshwater resources was 20.2 Billion Cubic Meters (BCM) of ground and surface water. Based on current population of 30.1 million, the per capita endowment of water is about 650 m^3 per year, placing Kenya among the chronically water scarce countries (Globally, a country is categorized as 'water scarce' if its renewable freshwater supplies are less than 1 000 cubic meters per capita). The water demand for essential uses is projected to increase significantly from 2.1 BCM per year in 1990 to 5.8 BCM per year in 2010, or 28% of available water resources (*Water Act, 2002*). The occurrences of ground and surface water resources are unevenly distributed both in space and time, due to the variability in rainfall and the diverse climatic and geological conditions. In order to provide for this increasing demand, more effective conservation and management of water resources will be necessary, especially since, according to the Master Plan, these needs cannot be met without regulation works in rivers and creation of a storage capacity of more than 30 times of what is currently available in the country (dams and reservoirs).

In 2001, irrigated agriculture accounted for only 1.5% of the cultivated area (or about 82,000 Ha), which is about 14% of the potentially irrigable area (540,000 Ha). Private farmers cultivated 40% of irrigated land for horticulture and export crops, and smallholder farmers and government managed schemes cultivated 42% and 18 % of the irrigated land, respectively, mainly for food crops and vegetables. Irrigation water accounts for 73% of total water use in the country and is thus the highest user. In general, irrigation efficiencies are low and therefore their improvement will result in the highest gains in water conservation (*Water Act, 2002*).

At present, the formal domestic water supply coverage is 70% for an urban population of 7.5 million and 46% of a rural population of 23.7 million. Many urban and rural centres that are supplied with piped water have unaccounted for losses of up to 50% of the supply. A combination of inadequate water resources management, especially in conservation, and poor management of supply functions has led to water shortages in most utilities (*National Policy on Water Dev., 1999*).

A need has therefore been identified for the development of River Basin Management Plans that will explore water management guidelines, priorities and strategies that will provide direction for future planning and management within the basin aimed at increased crop production, increased income levels to households, reduced pollution to water bodies and increased river base flow for down stream users. This particular research study is aimed at the development of a Basin Management Plan for the Ena River Basin.

1.2 STATEMENT OF THE PROBLEM

The proposal to design River Basin Management Plans within the Mt. Kenya catchment basins was initiated by the Government of Kenya and stakeholders with a view to reversing the vicious degradation cycle, which currently threatens to impair hydrological regulative functions of the ecosystem. The Mt Kenya catchment is the most critical water tower in Kenya accounting for close to 49% of the flow of Tana River and in its turn, the Tana Basin is crucial bedrock for economic development in Kenya; accounting for close to 50% of the national hydro-electric power output in addition to supporting irrigated agriculture, livestock production, fisheries and biodiversity conservation all of which are strategic to Kenya's economic development. Numerous streams originate from Mt Kenya to form major rivers. The main rivers around this area are Kathita, Mutonga, Ena and Thiba among others. These streams finally join Tana River, with a mean annual flow of 178m^3/sec, to form Kenya's main river that finally drains south-eastwards into the Indian Ocean (*Water Act, 2002*).

Over the years, however, there have been growing concerns that these life-supporting functions of the Tana River are systematically being lost due to degradation within the upper and middle reaches of the basin where the river derives the bulk of its water supply. In its catchment, a combination of increasing exploitation of the forest resources over and inappropriate land use practices in the farmlands have triggered an increasing soil erosion menace that continues to contribute high sediment inputs to the Tana and its tributaries.

With an incisive study along Ena River basin an increase in soil erosion and environmental degradation has subsequently caused agricultural productivity to decline and therefore contribute to ecologically volatile areas being opened for cultivation, a process that has further interfered with natural water channels to the streams, hence aggravating incidence of peak floods in the river during the rains and also depressing the base flow during the dry season. The end result is a process, which if not checked will quite likely impair the hydrological balance with a potential to radically interfere with local water supplies. With time, it is feared that allocation of water resources will become a sensitive issue with potential to trigger ethnic tension and conflict. Moreover, the issue of resource degradation has emerged as both a result of and contributor to rural poverty which therefore brings the imperative need to manage water resources in a sustainable way.

According to the studies conducted for the National Water Master Plan, the total low-flow discharge into the Tana River from the Mt. Kenya basin catchments is estimated at 4.7 million m^3 per day (*JICA, 1992*). It is apparent that flood flows in the main rivers have remained consistently high over the years, especially during April and November when the area receives the heaviest rainfall thus generating the highest flood flows. Water demand is lowest during the months of highest flood flows, when there is little or no demand for irrigation. It is however notable that flood flows are estimated to provide over 70% of the total annual river discharge (*Water Act, 2002*). The overall flow, however, has been on a declining trend.

The trend is based on low-flow data for some of the tributaries of the Tana River and gives an indication of the decline in the low-flow over a period of over 25 - 35 years prior to 1995(*Decurtins,1992*). A number of reasons have been advanced for the declining trend observed in all rivers, yet in different degrees. Heavy water abstraction is noted to be the most significant factor. The decline has also been attributed to increased cultivation with poor canopy cover, such as in abandoned coffee farms and environmental degradation in the upper catchment, resulting in increased run-off at the expense of river base flow. Plate 1.1 shows at a glimpse the broad landuse practices along the basin area which shows high utilization in the agricultural, woodland and bushland regions, where the Ena River courses through.

The total water demand in the Tana basin area is estimated at 1.2million m^3/day. This includes provision for existing 'illegal use' and represents approximately 80% of the total surface water available (1.5million m^3/day). Water consumption in the area is dominated by irrigation, which accounts for over 75% of total demand (*Water Act, 2002*). Increasing population pressure in all zones and increased livestock numbers in the lower zone have led to a rise in water demand for domestic and livestock use, with a significant increase in urban water consumption.

With these issues in mind, a management plan ought to be implemented to stem further denudation of the remaining river basin infrastructure. Since the effect has to be initially documented before interventions are finally executed, a GIS oriented approach would help to determine the extent of this degradation and identify the spatial locations of hotspots that would benefit from this management strategy. Use of modern GPS technology, raster analysis and layer comparison would best identify these areas.

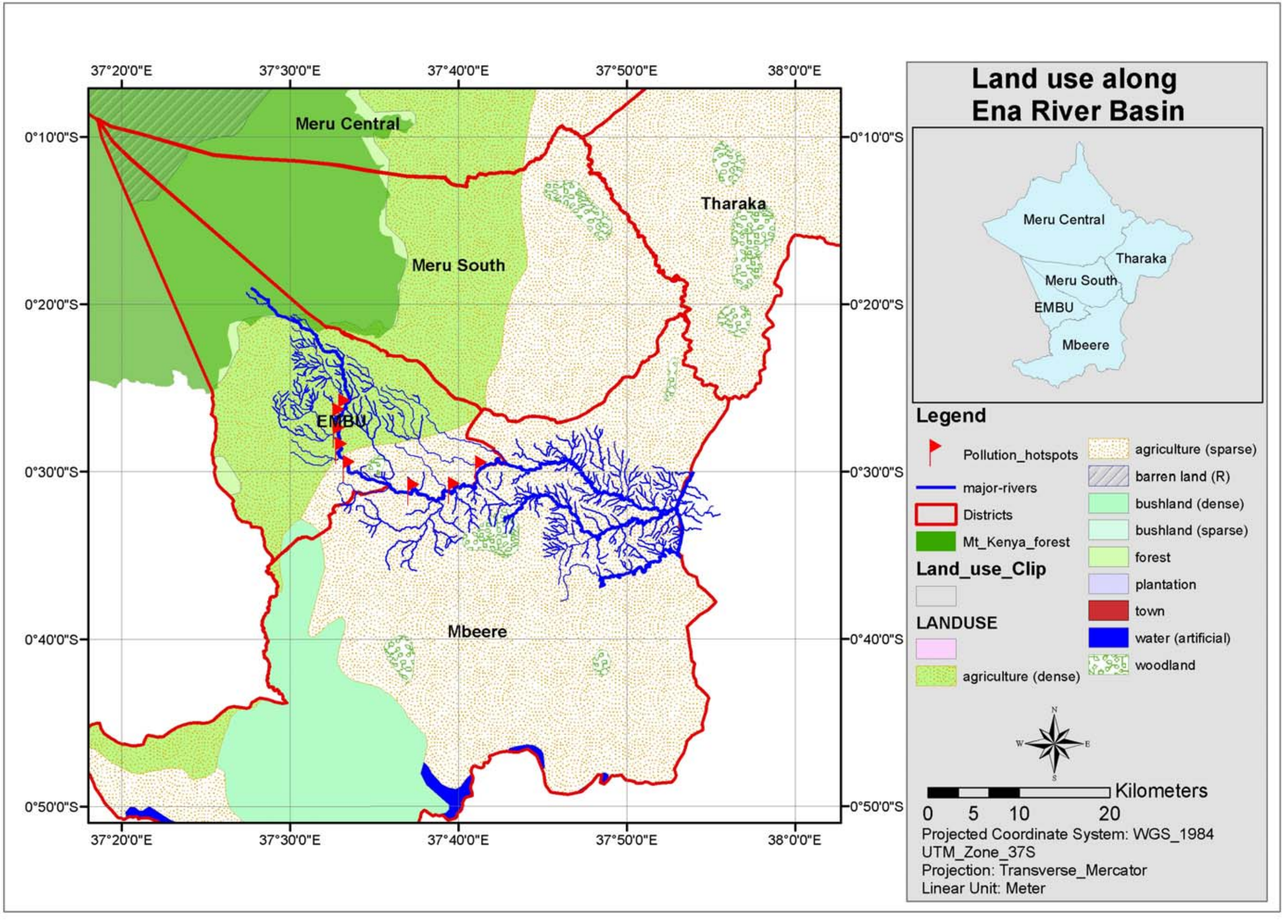


Plate 1.1 Main Land use activities along the Ena river basin

1.3 OBJECTIVES OF THE STUDY

The purpose of this study is to develop a GIS based river basin management strategy for the Ena River Basin based in Embu and Mbeere districts in Kenya. The specific objectives of this study are namely:

- ❖ Investigate the state of environmental degradation along the Ena River basin.
- ❖ Establish the causes of this basin degradation
- ❖ Use a GIS based model to analyze the basin area
- ❖ Spatially document the causes of this degradation and propose a schematic management plan for the basin restoration.

1.4 SCOPE OF THE STUDY

The extent of this study will be covering the coffee zone along the river basin in question, which straddles two districts and is about 15 km in length. GIS analysis will only be possible through analysis of representative areas along the basin.

The study will assume that:

i. Spatial and numerical data collected will have an insignificant degree of error
ii. Spatial data will be available in a uniform coordinate system
iii. Representative sites chosen will adequately assist in the drawing of valid conclusions for the entire basin

Use of high spectral resolution data along the river basin where available will assist in visually identifying such factors especially denudation and biomass cover.

1.5 OVERVIEW OF THE METHODOLOGY

The study involved a case study design of problem analysis which included development of a numerical model to determine degradation specifically on the coffee zone of the Ena River basin. The study site falls between 0^0E, 33^0 N and 0^0E, 35^0N and data was collected on 8 sites along the basin for representative analysis. The model combined several identified attributes determined through quantitative and qualitative analysis of the study area and borrowed heavily from existing soil loss geographical analysis models. The resultant degradation coefficients were then analyzed on a gridded raster map of the study area to determine the extent of degradation in order to assist in determining appropriate intervention measures.

1.6 PROJECT ORGANIZATION

Chapter 1 of this study defines the study background, statement of the problem, specific objectives and the scope of the study. Chapter 2 defines the literature review on the theory behind the study and its justification while Chapter 3 defines the methodology. The methodology defines the study site, materials and tools, research design, study population sampling techniques and validation.

Chapter 4 is quite significant since it details the study results and continues to discuss the analytical aspect of this study in relation to the results. The discussion gives possibilities available in achieving what the management model envisaged and the realistic nature of the results in line with the assumptions held. Chapter 5 then concludes the study and gives recommendations on the results and possible improvements in future from weaknesses observed.

CHAPTER 2 LITERATURE REVIEW

The Government of Kenya has identified a need for the development of River Basin Management Plans that will explore water management guidelines, priorities and strategies that will provide direction for future planning and management within the basin aimed at increased crop production, increased income levels to households, reduced pollution to water bodies and increased river base flow for down stream users. This particular study is aimed at the development of a River Basin Management Plan for the Ena River Basin.

Through these plans, the government will address issues of the river banks protection, water catchment areas protection, rehabilitation of degraded roads embankment and in protection and restoration of wetlands and river banks. It will also identify hotspots, which have negative impacts to the natural environment. Development of River Basin Management Plans is aimed at supporting and enhancing the overall goal of Poverty Reduction in Kenya as envisaged in various Government policy documents such as the Economic Recovery Strategy for Wealth and Employment Creation (ERS), Poverty Reduction Strategy Paper's (PRSP) and the Millennium Development Goals (MDGs).

Overall, the design will have inbuilt mechanisms to facilitate compliance with requirements of the Environmental Management and Coordination Act (*NEMA, 2004*), particularly with regard to environmental screening for proposed projects and will favour devolution of responsibilities to the District, Divisional and community levels as a strategy for building capacity for local governance as envisioned in the Water Act 2002. In this respect the proposed capacity building for Focal Development Areas (FDAs) and Community Based Organisations (CBOs) such as River Water-User Associations (RWUAs) and Water User Associations (WUAs) therein resonates well with current GoK policy on resources management. Also to be strengthened, are other stakeholders operating in the basin area such as staff from line ministries, River Basin Authorities and other Statutory Bodies.

The Ena river basin covers the two administrative districts; Embu and Mbeere Districts. Embu District has two parliamentary constituencies, Manyatta and Runyenjes and also has 6 divisions, 15 locations, 52 sub-locations and 3 Local Authorities with a total of 26 wards. Mbeere District has two parliamentary constituencies, Gachoka and Siakago and also has 4 divisions, 19 locations, 41 sub-locations and 1 Local Authority with a total of 9 wards (*DFRD, 1983*).

The basin area is characterized by a varied relief profile as shown by Plate 2.1 where the altitude rises from an elevation of 500 meters above sea level (asl) at the Tana River Channel to over 1896 meters asl at the point where Ena River emerges from the forest.

This high altitudinal variability results in a succession of five distinct agro-climatic zones in east-west direction, varying from semi-arid (almost arid), fairly hot to hot lowlands in the eastern part to humid, cool temperate/fairy cool highlands in the northwestern part of the area.

The basin area has been stratified into two zones of similar climatic potential forming three broad ecological zones: High, Medium and Low Potential Areas.

The High Potential Zone generally receives rainfall upwards of 1000mm per annum increasing up to 2300mm annually on the most easterly exposed slopes of Mt. Kenya. Annual rainfall generally occurs in a double maxima pattern with a long wet season in April to June and a short rains season in October to December. The wet seasons are separated by two short, dry periods whole length increases towards the lowlands. Daily rainfall is normally concentrated between late afternoon and early evening with minimal rainfall occurring in the period between 8.00 am and 10.00 am. Potential evapo-transpiration as influenced by net radiation generally decreases with increase in altitude from a high of about 4mm per day in the lowlands to a low of 0.5mm per day in the alpine zone (*Gikonyo, 1998*).

Away from the highland masses, the moderating effect of altitude on climate becomes less prominent with consequent reductions in seasonal and annual rainfall. Annual rainfall ranges from about 550mm and increases to over 1000mm towards the volcanic foot ridges. Annual rainfall is mainly concentrated in two wet seasons (April-May and October-November) whose length and rainfall content decreases with increasing distance from the highland masses of Mt. Kenya. Similarly, the length and severity of dry spells in between the wet season increases towards the plateau and lowlands.

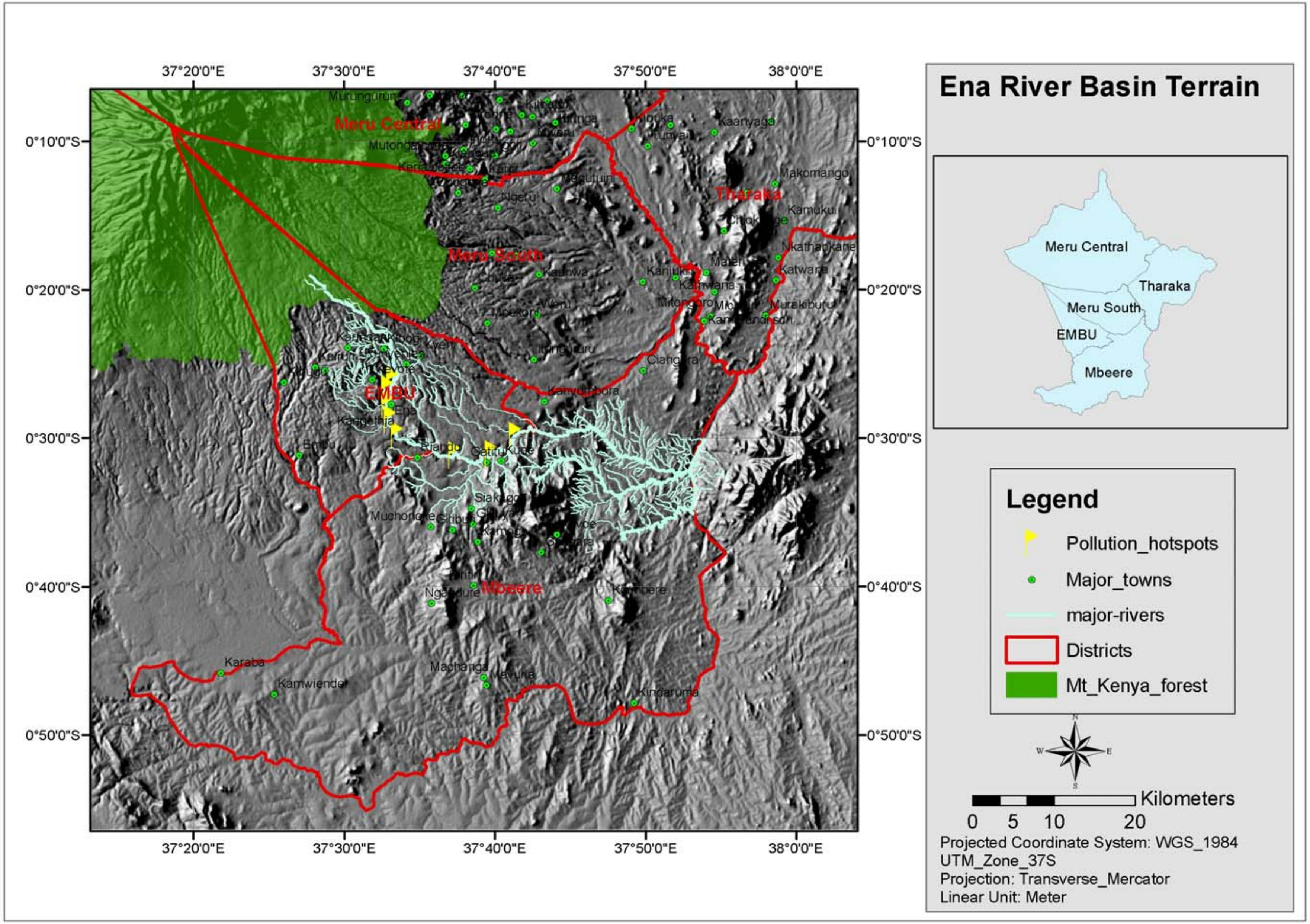


Plate 2.1 A representation of the relief profile of the Ena basin area

Major factors of climate namely rainfall, temperature and evapo-transpiration, all of which determine ecological potential are influenced by the altitude. Annual rainfall increases from a low of 550 mm in the lowlands of Tharaka to a high of over 2100mm in the most easterly exposed slopes of Mt. Kenya. Mean annual temperatures range from very cold (below freezing point) on Mt. Kenya to over 30^0C in the lowlands.

In the basin area, the average annual potential evaporation varies from about 2225 mm at Tana River to 1650mm in the north-eastern side (*Embu District Development Plan 2002-2008*). Compared to rainfall, the potential evaporation is fairly constant throughout the year at different sites due to only slight variations in temperature, air humidity and wind.

The *upper catchment* zone comprises the afro alpine zone, which is protected in the Mt. Kenya National Park and the National Forest Reserve which is more or less uninhabited. The middle catchment includes the high potential agricultural land comprising the tea, coffee and cotton tobacco zones. This land has been cleared of its natural vegetation and is now covered by cultivation and post cultivation vegetation, human settlements and farmlands. In some areas, remnants of natural vegetation are found along riverine corridors and some indigenous trees are also found in the farmlands. The Ena River emerges from the forest at an altitude of 1896 metres above seal level at the Kianjakoma-Kanja rough road near Kaikama tea leaf base in Kaikama location.

The local environmental conditions have been greatly affected by increased rainfall fluctuations, droughts, soil erosion, hot temperatures and declining water resources among others. The spatial and temporal distribution pattern of seasonal rainfall in the middle catchment has important implications for river water management in the basin. Inadequate wet seasons in the cultivated area causes the local farming community to turn to supplementary irrigation as security against early rainfall cessation, while surface water from the well watered foothills has been extensively tapped to supply areas of scarcity. As a result there is over abstraction of surface water to support activities in areas within vicinity of Mt. Kenya and this is an issue of critical concern. Efforts towards improvement of the local environment are seen in widespread tree planting, soil conservation and water harvesting (*State of Environment Report, 2003*).

Within the Ena river basin, minor wetlands will be found perched on impervious bedrock within the upper reaches of the Ena valley. Though the original vegetation has been lost in most cases, many wetlands have been reclaimed either under Napier grass for fodder or under horticultural crops. Riverbanks within this system are however better preserved with permanent vegetation cover which greatly reduces chances of erosion.

The *middle reaches* of the Ena just below the Embu-Runyenjes Road have sections with impeded drainage on account of occurrence of pockets of planosols. Extensive planosols are encountered along the Runyenjes-Siakago earth road just after Ugweli and these are under intensive cultivation of subsistence crops-maize, beans, potatoes etc. Some pockets of planosols are however under increasing exploitation for brick making clay, leaving behind extensive quarries which are no longer suitable for crop production. Some pockets of vertic soils are encountered within the valleys of some tributaries of the Ena but all have been reclaimed under horticulture for both home consumption and sale (*NEMA, 2004).*

The Ena Catchment area comprises three sub-catchment areas:-

1) Sub-catchment 1(Ena) which drains Kanja and Lokorire areas
2) Sub-catchment 2 (Kaena) which drains Kianjokoma area coming down to Kirimiri area
3) Sub-catchment 3 (Kirurumwe) which drains Makengi, Manyatta, Kevote and Nembure areas

The land in the upper catchment zone has been cleared of its natural vegetation and is now covered by cultivation and post cultivation vegetation, human settlements and farmlands. In some areas, remnants of natural vegetation are found along riverine corridors and some indigenous trees are also found in the farmlands.

The middle reaches of the Ena river basin form the coffee zone. The coffee plantations are neglected and soil conservation practices initially in place have since been abandoned leading to erosion. The farmers grow exotic tree species which they sell to tea factories in the area as firewood. The area is generally characterized by depleted vegetation cover leaving the soil exposed and increased exploitation for brick making clay, leaving behind extensive quarries which are no longer suitable for crop production.

Numerous streams originate from the mountain and feed into Ena River as tributaries. The tea and coffee zones are well watered due to proximity to the forest from where most of the streams originate. In the lower livestock zone Ena flows as one big river having been fed by a host of tributaries.

There is a high prevalence of water abstraction without the necessary permits, as well as water abstraction by those who have permits which far exceeds the authorised levels which has resulted in reduced water levels in the river. Further, there are no records of long term hydrological records to guide the approval of water abstractions for long term resource availability. A total of 119 intakes have been documented along the river course with 30 of these found in Embu district while 89 of these are found in Mbeere district (*MKEPP, 2003*).

According to a past literature review of GIS applications in computer modeling conducted by Heaney et al. (*1999)* for the U.S. Environmental Protection Agency (EPA), Shamsi (*1998, 1999*) offers a useful taxonomy to define the different ways a GIS can be linked to computer models. The three methods of GIS linkage defined by Shamsi (*2001*) as illustrated are:

1. Interchange method
2. Interface method
3. Integration method

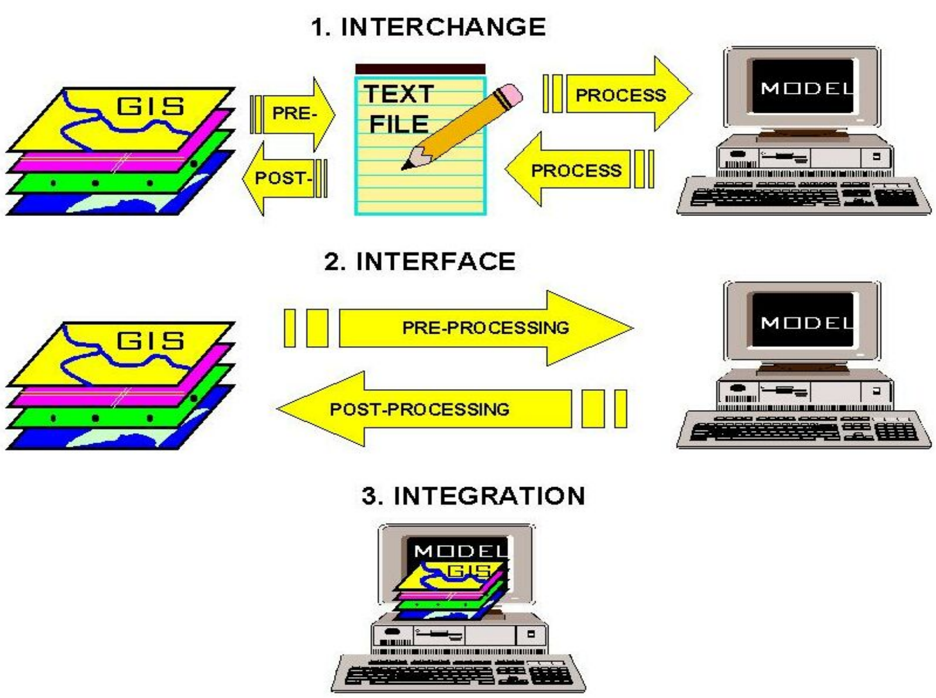


Figure 2.1 Methods of GIS Linkage to a computer model (Heaney et al., 1999)

Interchange Method

The interchange method employs a batch processing approach to interchange (transfer) data between a GIS and a computer model. In this method, there is no direct link between the GIS and the model. Both the GIS and the model are run separately and independently. The GIS database is pre-processed to extract model input parameters, which are manually copied into a model input file. Similarly, model output data are manually copied in the GIS to create a new layer for presentation mapping purposes. This is often the easiest method of using a GIS in computer models, and it is the method mostly used. Using GIS software to extract floodplain cross-sections from DEM data or runoff numbers from land use and soil layers are some examples of the interchange method.

Interface Method

The interface method provides a direct link to transfer information between the GIS and the model. The interface method consists of at least the following two components:

1. A pre-processor, which analyzes and exports the GIS data to create model input files; and
2. A post-processor, which imports the model output and displays it as a GIS layer.

The interface method basically automates the data interchange method. The automation is accomplished by adding model-specific menus or buttons to the GIS software interface. The model is executed independently from the GIS; however, the input file is created, at least partially, from within the GIS. The main difference between the interchange and interface methods is the automatic creation of a model input file.

Integration Method

GIS integration is a combination of a model and a GIS such that the combined program offers both the GIS and the modeling functions. This method represents the closest relationship between GIS and catchment models. Two integration approaches are possible:

1. GIS Based Integration: In this approach, modeling modules are developed in or are called from a GIS. All the four tasks of creating model input, editing data, running the

model, and displaying output results are available in GIS. There is no need to exit the GIS to edit the data file or run the model.

2. Model Based Integration: In this method GIS modules are developed in or are called from a computer model.

Methods available in literature for estimation of sediment yield and temporal variations can be grouped as either empirical or process-based. Empirical methods, which include, for example, the Universal Soil Loss Equation (USLE) (*Wischmeier & Smith, 1978*), the Modified Universal Soil Loss Equation (MUSLE) and the Revised Universal Soil Loss Equation (RUSLE), combine the soil erosion from all processes in the catchment into one equation. These methods are simple in application and hence frequently used in different parts of the world. Process-based methods attempt to solve the fundamental equations for transport of water and sediment. Some of the process-based models for soil erosion include ANSWERS, WEPP AGNPS and SHESED. These models are expected to simulate realistically the process of rainfall-runoff/soil erosion.

However, due to temporal variations in rainfall inputs and pronounced spatial heterogeneity prevalent in catchment areas, even the process-based models are found to produce unsatisfactory results. Through GIS analysis, an integrated model that uses various geographical and physical parameters can be developed for the basin. The model can then be used constructively to comprehend and evaluate the impact of point and non-point variables within the basin that then can be used by management to make decisions. A drainage basin model should describe a phenomenon of runoff, transport and transformation of substances under the basin conditions as realistically as possible. Many models have been developed in the past, such as the USLE (Universal Soil Loss Equation) by Wischmeier and Smith (1978) which is an accepted method worldwide and can be supported by GIS.

The study is therefore aimed at devising a simple model for the management of the basin incorporating 5 key inputs;

1. River flow data(m^3/s)
2. Sediment load(mg/l)
3. Soil pH
4. Slope(undulation) and
5. Elevation(metres)

The model incorporates the RUSLE approach which makes use of empirical coefficients to represent the rainfall characteristics, soil properties, ground surface conditions, etc. This approach incorporates 5 key factors in this relationship;

$$A = R*K*LS*C*P$$

Where;

A = Annual soil loss from erosion

R = rainfall erosivity factor

K = soil erodibility factor

LS = Slope length and steepness factor

C = Cover and management factor

P = Support practice factor

CHAPTER 3 METHODOLOGY

This chapter gives an insight on the study site, research design, study population, sampling techniques and sample size. Research instruments, data collection techniques, variables and data analysis are also reviewed.

3.1 STUDY SITE

This study was conducted along the Ena River basin as shown in Plate 3.1 which is identified by the drainage catchment for the particular river. This includes the river tributaries and sub-tributaries that assist in feeding the river. Since the average river basin is defined by the extent of it's tributaries and sub –tributaries, the spatial extent of this basin is expected to extend 5 kilometers on either side of the river basin measured from the centre of the river course. The study site falls on 0^0E, 37^0N and research data was collected on 8 sites for an approximate distance of 15 kilometers along the basin for representative analysis. This data included geographical coordinates, altitude, flow volumes, pH values, sediment load among others which was to be processed and modeled to determine degradation coefficients.

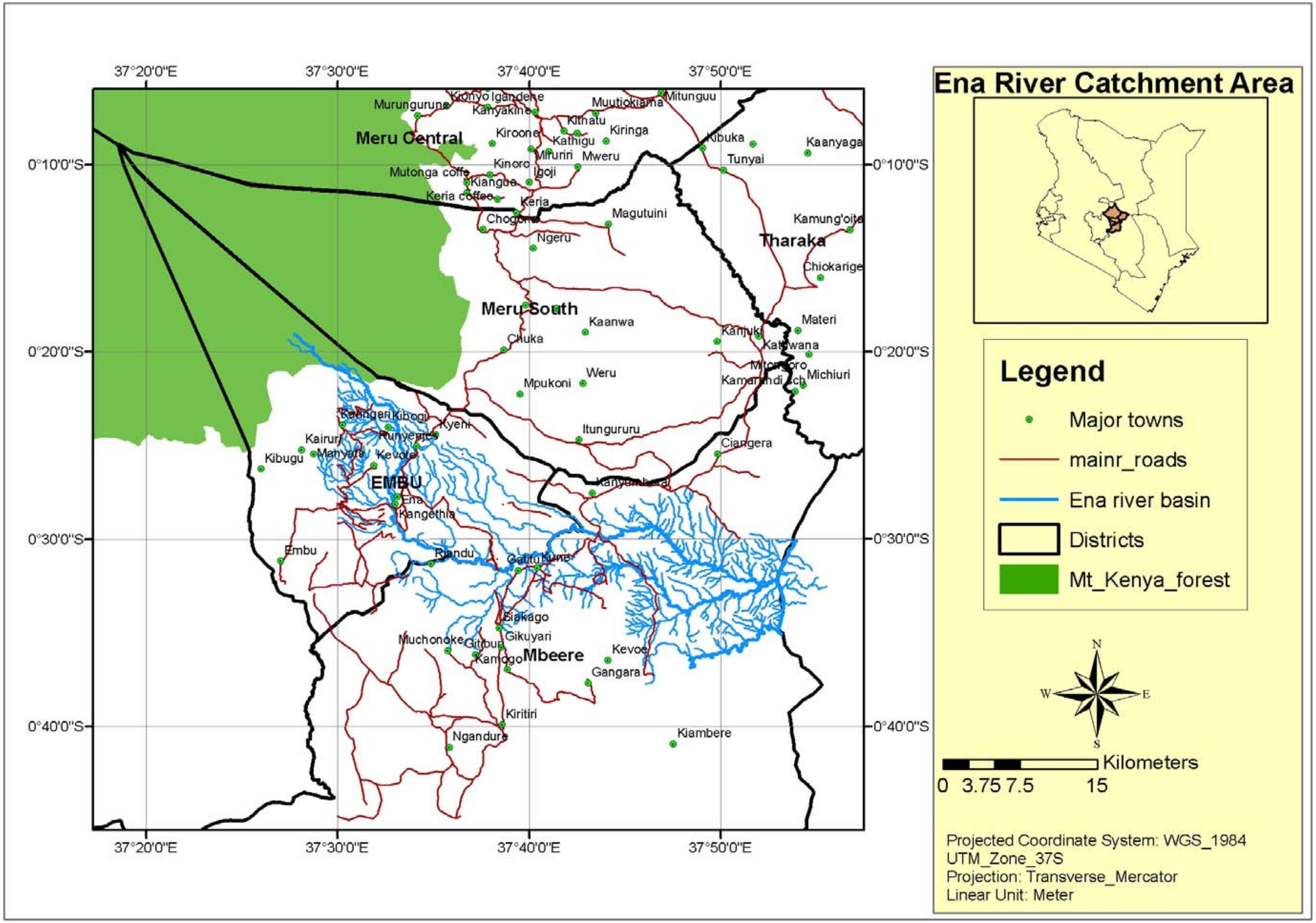


Plate *3.1 Ena River Catchment Area*

3.2 MATERIALS AND TOOLS

3.2.1 MATERIALS

Materials used in this study included but were not limited to existing topographic sheets for the area (Siakago, Embu and Chuka), Kenya administrative boundaries layers, 90 metres hillshade Digital Elevation Model (DEM) to analyze the study area. Secondary data desk review from basin related journals and past hydrological models was also employed. Specifications for these materials are given in Table 3.1.

Table 3.1 Description of main datasets used in the study

Data	Source	Data Specifications
Topographic sheets No. 121/4, 122/3, 135/2 and 136/1.	Survey of Kenya	Topographic representation of the basin area on a scale of 1: 50,000.
Kenya administrative boundary GIS layers, soil layer, landuse layer	Survey of Kenya	Administrative shapefiles for the area on a scale of 1: 250,000.
90 metres hillshade DEM	World Resources Institute	Captured from Shuttle Radar Topography Mission (SRTM) on Feb. 11^{th} 2000.

3.2.2 TOOLS

Tools mainly used included a laptop computer with installed GIS ArcView (Version 3.2) and ArcGIS (Version 9.2) software for spatial and IDRSI (Kilimanjaro Version) for raster analysis. For water quality data processing, a sediment sampler and a micro-weighing machine were used for hydrological analysis. River flow volumes were recorded from River Gauging Stations readings and hotspot spatial coordinates were taken using a GPS device (Model Garmin 60SCx) with a 5 metre accuracy level. Respondent based data recording instruments were not significantly used in this study.

3.3 RESEARCH DESIGN

This research adopted a case study design. This is research design used when studying a particular group of objects (Hugh, 1996). It does not necessarily have to encompass the whole subject's area and the findings can be used to apply to the whole area. This method assists the researcher to carry out a detailed study of the variables in the study area and use the findings to make informed recommendations to the identified problem. Use of research tools such as structured questionnaires assists in data collection for eventual compilation and analysis. The study area incorporated among others, the tributary catchment that drains into this basin at various stages of the river development.

Currently, GIS techniques have been interfaced with hydrological models, both distributed and empirical, to capture the spatial variation in computed quantities. Catchments are also subdivided into sub-areas to account for spatial heterogeneity using a cellular based approach which is quite adaptable to collection of input data in a regularized pattern using remote sensing and GIS.

3.3.1 ENA RIVER BASIN MODEL (ERIBAM)

The Ena basin model can then be customized from the RUSLE model to form a simple yet effective resultant model;

$$D = Q*L*P*SE$$

Where;

D = Total degradation (m^3 mg/sl)

Q = River flow data (m^3/s)

L = Sediment load (mg/l)

P = Soil pH (dimensionless)

SE = Slope and Elevation factor (dimensionless)

The customized model can then be christened ERIBAM (Ena River Basin Model).

The units for D can be represented as

$$D = m^{2} * mg/ s * cm^{3}$$

and since

$$10{,}000cm^2 = 1m^2$$

also

1000mg = 1g

Then it follows that;

$$D = 10{,}000cm^2 * mg/s * cm^3$$

And the units for D will therefore be;

D = 10g/cms.

Almost similar to the Rainfall Erosivity factor, R in RUSLE, the Q factor describes the River Flow factor that differs with the influence of among others, the gradient of the river course. The R factor was originally calculated in RUSLE to represent the total kinetic energy of the rainstorm at it's maximum intensity and since this data is never readily available, an equation generated by taking into account monthly and annual rainfall data. Used in the ERIBAM model, the Q factor takes into account the monthly and annual river flow data to compare favorably with RUSLE.

Used in the ERIBAM the sediment load factor, L is used to determine the amount of dissolved solids as determined using laboratory analysis of water samples collected from identified sampling sites along the course. This compares well with the soil erodibility factor, K in the RUSLE model that describes erosivity and the ease with which the soil is detached by the surface and splash flow.

The P factor, representing the water pH, is used in the model to reflect the diversity in the alkalinity of the water at various hotspots owing to pollution mainly from unkempt or abandoned farmlands or from socio-economic centres along the basin that would be discharging their effluent into the river. While the change may not be significant especially during the rainy season, it would be influential during off – rain seasons. Since pH is a scalar, dimensionless quantity, it would empirically add to the model the sensitivity of variation much needed to show dispersion and create a relationship between the variables that cumulatively will represent degradation per unit area.

Comparing favorably with the LS (Slope Length and Steepness factor) RUSLE model, the Slope and Elevation factor, SE would represent soil and water loss due to terrain undulation and the elevation of the unit area beyond sea level. The SE can be segmented to represent mean values dependent on the gradient and elevation to avoid a difficulty in determination. This factor can be isolated qualitatively from the Digital Elevation Model (DEM) of the study area and then processed to generate a slope layer.

3.3.2 STUDY POPULATION

The Ena river course traverses 50 Kms through the 2 districts with an estimated population of 65,000 people residing in the river basin. Within Embu District, Ena River traverses 25 km through Runyenjes and Nembure divisions of the district which have populations of 31,342 and 20,305 people respectively.

Mbeere district is sparsely populated with majority of the population concentrated around major market centres as shown in Plate 3.2. Ena River traverses 50 km through Siakago and Evurore divisions of Mbeere district which constitute the most densely populated divisions in the district with 100 and 96 persons per Km^2 respectively (JICA, 1997).

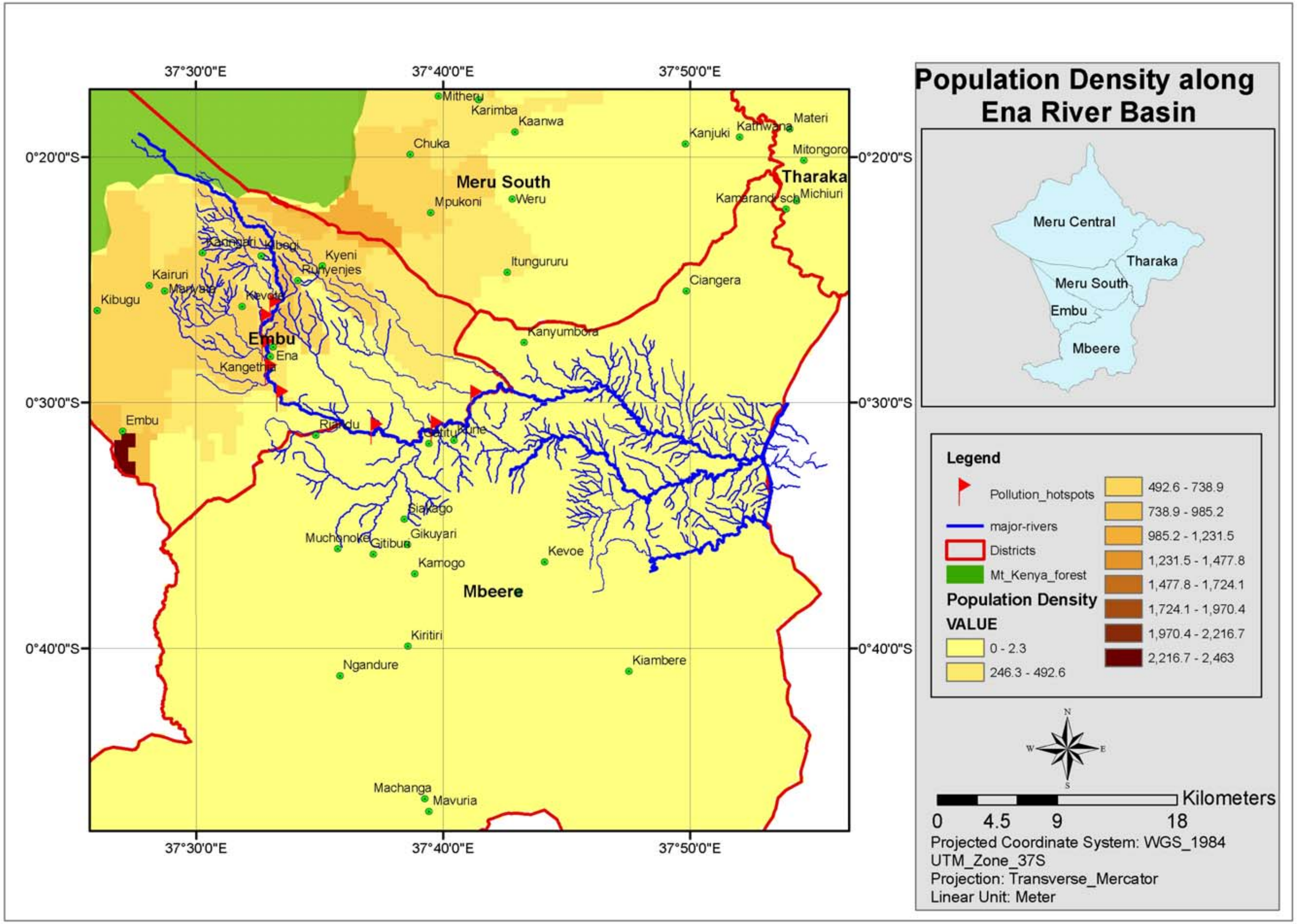


Plate *3.2 Average population density per km^2 for locations in Embu and Mbeere districts*

3.3.2 SAMPLING TECHNIQUE

Stratified random sampling was carried out along the river basin from the forest edge to delineate representative areas that would reflect particular characteristics of the adjacent basin infrastructure. Selected hotspots were used as representatives for the diverse basin ecological characteristics. This sampling also considers the three agro-ecological zones that the river passes through i.e.

i. The tea zone – marked by the initial stages of the river after the forest edge to about 10 km downstream.

ii. The coffee zone – represented by the middle stage of the river course where the river basin has undergone the worst degradation. It is approximately 15 km long.

iii. The marginal farming/livestock keeping zone – marks the final stages of the river course and is located in Mbeere district. It marks the longest river course and is approximately 25 km long to where the river enters the larger Tana basin.

Some selected hotspots along the basin are as follows;

Table 3.2 Earmarked hotspots along the Ena basin

No.	Hot Spot	Elevation (metres)	Criteria for selection
1.	Forest cutline	1884m	River Gauging Station
2.	Ena River (Tea Zone)	1741 m	Represents upper tea zone.
3.	Kanja Area	1714m	Extensive Quarrying along the river course
4.	Boundary between coffee and tea zones	1619m	Evidence of heavy siltation on the river basin.
5.	Kirurumwe Centre	1534m	Dumping and sewage pollution
6.	Intake for Rukira Irrigation scheme	1517m	Abstraction from the river
7.	Runyenjes town	1515m	Dumping and sewage pollution

8.	Kaena bridge	1481m	River Gauging Station
9.	Gatuanguo	1352m	A feeder spring to Ena.
10.	Siakago District Hospital	1206 m	Dumping and sewage pollution
11.	Ena Bridge (boundary between Mbeere and Embu districts)	1116 m	Domestic water abstraction

3.3.4 DATA PROCESSING TECHNIQUES

Data was collected at the same time while undertaking the identification of the hotspots. Data was also sought from the established offices mainly the WRMA (Tana Catchment Region), the District Water Office (DWO) and Mount Kenya East Pilot Project (MKEPP) offices which are already undertaking critical functions in the Ena river basin management. Data analysis was done using the available equipment e.g. a current meter for the collection of flow data, a sediment sampler that is used for collection and analysis of the water samples, an extracting machine for extracting the sediment volumes from the samples, an oven for dehydrating the samples and a bench weighing machine for measuring sample quantities.

Data processing was done using available tools and spreadsheets and the data types used are outlined in Table 3.3. The Model's inputs include the Flow (Q) data, pH values at the sampled hotspots, sediment load and Slope/Elevation factor. The variables were selected on account of their variability at different hotspots in order for the resultant model values to be sensitive to changes at short geographical intervals. Processing of this model is done using Microsoft Excel and average values were computed from the data collected for ease of processing. *Appendix 1* shows all the data collected at various hotspots along the river that was used on the model.

Table 3.3 Data types used in the ERIBAM Model

Factor/Variable	**Data Type**
Degradation	Real
River flow	Integer
Sediment Load	Integer
pH	Integer
Slope and Elevation	Real

3.3.5 VALIDATION

The study was specifically concentrated along the coffee zone in the basin area and validation of the model results was conducted by subjecting the model to the upper tea zone and the lower tea zone to evaluate the model's flexibility, with satisfactory results. Sample sites on the tea zone showed lower levels of the Degradation factor, D as opposed to areas on the cotton/marginal agriculture that showed increased D values. Extensive study can be conducted in future to corroborate available basin information from the responsible management offices and physical ground verification and therefore remains open as an area of further analysis.

Use of existing and available river basin management models can assist to favorably compare results and ascertain the degree of confidence on the results obtained from the ERIBAM model and assess the relevance of the results obtained against reality. Statistical analysis may then be applied to ascertain the confidence level of the observed result.

CHAPTER 4 RESULTS AND DISCUSSIONS

This chapter presents the study results as anticipated in the methodology and uses these results to apply them to the suggested model for suitability analysis. The results are then compared against the expected spatial extent and the outcome is discussed for interpretation.

4.1 RESULTS

Using data collected from the basin as shown in Table 4.1, we can derive the Degradation factor, D from various hotspots on a mean scale. The data can be initially determined from the coffee zone, where the model will be initially exposed before its applicability is tested in the other two zones.

Where sediment load data may not be readily available, it may be substituted with coliform load data, which is used to determine the amount of dissolved biohazards, specifically faecal material, which are an indicator of pollution. Where possible though, simulation of sediment load data may be done for theoretical purposes only, so as to achieve enough sample data for meaningful analysis and comparison. Such data will be simulated to follow expected trend lines in relation to other variables.

The basin network can then be discretized into distinct cellular blocks of a particular area size that can then be given values depending on the model's result and the different values can be presented in a histogram. Values of similar cells can be summed together against the rest to create diversity and the resultant pattern can be overlain on a digitized base map of the area.

Contour and basin layers from the study region, especially around the coffee sector where degradation is severe, can be rasterized using interpolations from isolines and converted into a DEM. Using this DEM, grids of flow directions are created for all the catchments, with unique flow direction for each cell representing the direction of steepest descent that enables determination of the *Slope and Elevation factor (SE)*.

Mean data from the selected hotspots along the basin collected on various dates between 2006 and 2008 is presented in Table 4.1.

Table 4.1 Mean data (2006-2008) for selected hotspots along Ena River (Source, WRMA, Embu)

Hotspot	**FLOW(Q)**	**PH**	**SEDIMENT LOAD (No./1000)**	**FEACAL COLI (No./1000)**
Kanja	0.196	6.247857	49.86667	120.5714
Kirimiri	0.180	6.325714	52	201.125
Kirurumwe	0.183	6.48	54.91667	224.9167
Githunguthia	0.166	6.288462	55.15385	371.3077
Karurumo	0.133	6.808421	57.15789	254.9474
Ena Bridge	0.175	6.55375	56.625	509.5625
Itimbogo	0.168	6.1	59.125	370.7143
Ena BAT	0.159	6.644167	62.08333	644.8333

The Slope and Elevation factor, ***SE,*** which is a product of elevation and the terrain undulation, can be calculated once the slope values are determined. Little empirical intervention can be expected since the procedure for determination of these values is still vague even in past hydrological and relief – based models. For known elevation data, the slope values can be qualitatively determined since gradient calculations for an irregular surface may not be easily determined. The SE factor is calculated using a cellular approach, where the DEM for the area is gridded into cells of uniform area. This method however considers the downhill slope angle which constrains the slope angle calculations to one cell length in a downhill direction. It is similar to the maximum slope method, but includes a directional component -- angles are constrained to a downhill direction (uphill angles are calculated as having a negative slope). This is to guard against the model generating negative values that might be a challenge when interpreting D-value results.

Having identified the sites, the elevation average for all the sample sites is noted with a view to determine the slope and elevation factor for the points of interest. As with Plate 4.2, the grids of equal cell sizes then assist in identification of an average value for the slope for each cell. The slope factor is then determined for a range of values from 1(steepest slope) to 0(level ground) as shown in table 4.2. Since empirical determination of these values is complicated, a simulation of values obtained from the digital elevation model would assist for the purposes of this study. While these values may not factually represent the grid terrain dynamism, they would be a rough estimator of the anticipated slope factor deduced from the tonal variations of the DEM.

The values in Table 4.2 therefore reflect the average slope factor for the grids as shown in Plate 4.2. These values are then divided with the elevation data for each hotspot to generate the Slope and Elevation factor, *SE* for the ERIBAM model. Table 4.3 shows the average *SE* values calculated for the same hotspots (figures are x 10^3 m).

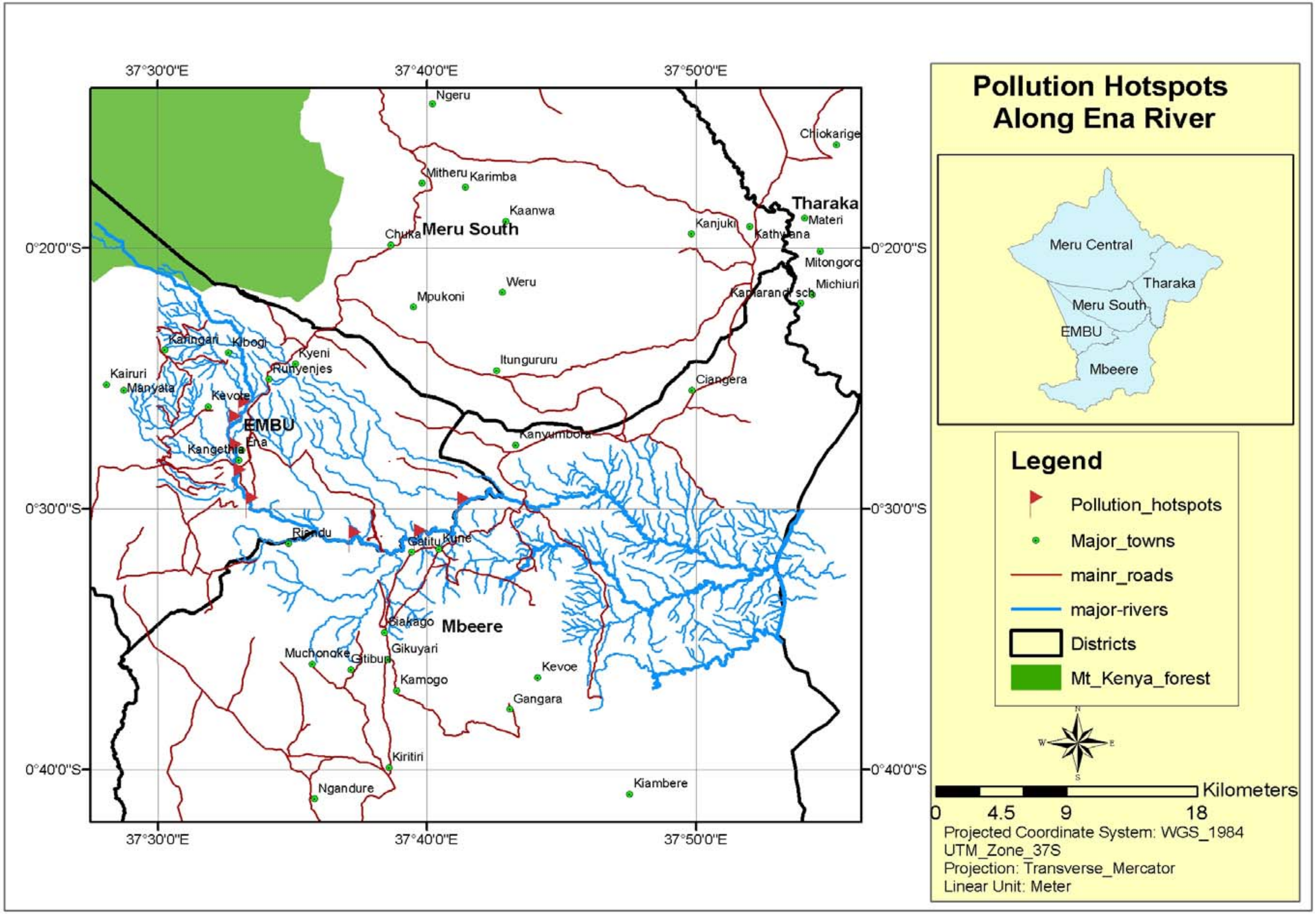


Plate 4.1 A representation of the coffee zone hotspots in the Ena basin

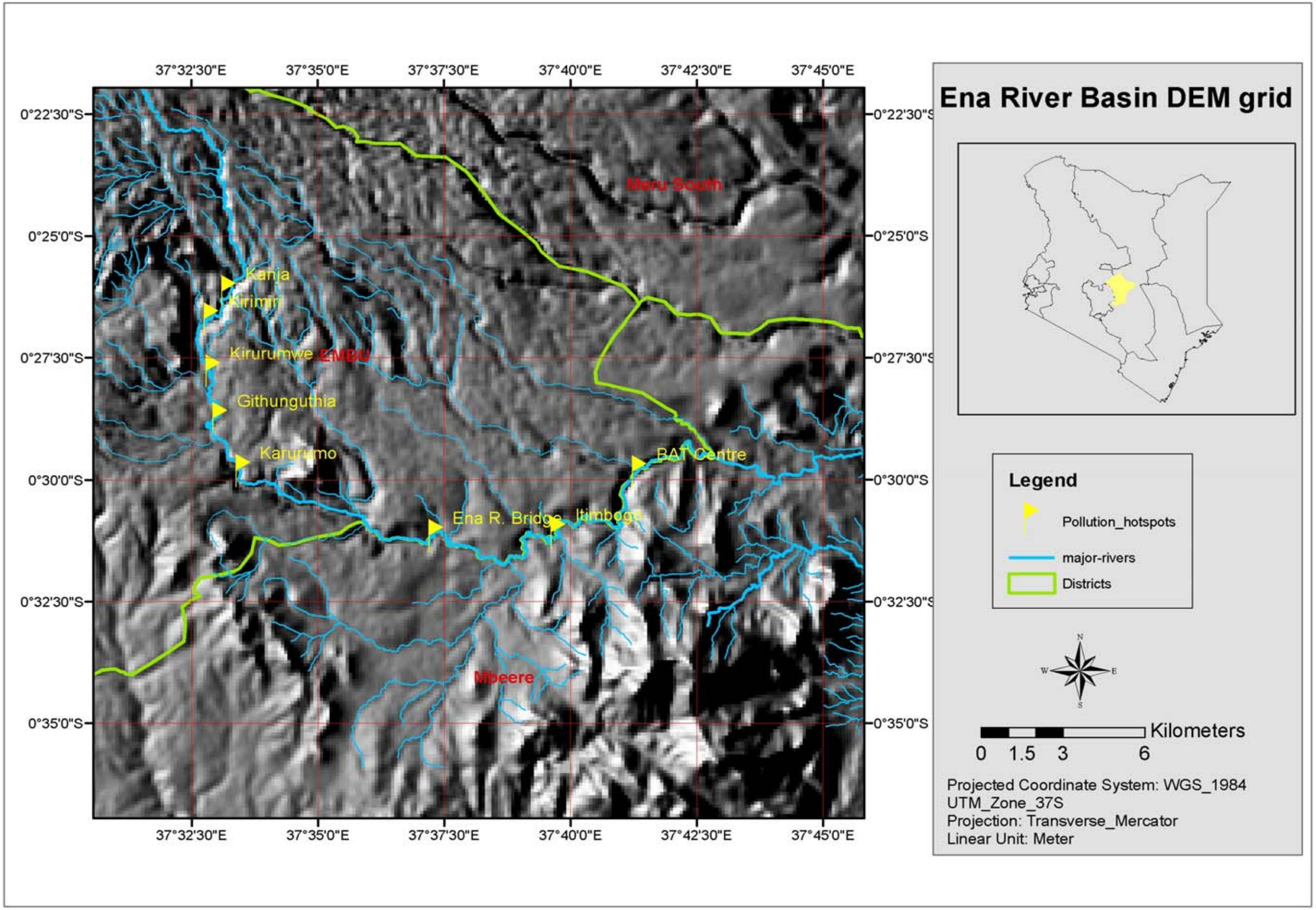


Plate 4.2 DEM gridded cells showing selected hotspot sites.

Table 4.2 Average slope factor (S) values for selected hotspot grid cells

0.55	0.65	0.50	0.40	0.35
0.50	0.55	0.45	0.60	0.50
0.65	0.70	0.40	0.50	0.40
0.40	0.45	0.35	0.40	0.45
0.60	0.55	0.50	0.60	0.70

Table 4.3 SE values for selected hotspots

	1.123	0.681		
		0.671	0.847	
			0.684	0.446

From the resulting D-values in Table 4.4, we can observe a sustained reduction in overall degradation as we move from the upper end of the coffee zone to the lower boundary with the cotton zone. This can be attributed to the drop in elevation values which subsequently means that degradation and soil loss is more prevalent in the upper where the slopes are more pronounced than on the lower end of the zone where the terrain is more flat. A closer look at other values that contribute to the model, for example the sediment load (L) shows a sustained increase in the load factor for the samples of water analyzed at various points along the basin. This accurately confirms that degradation is prevalent across the basin and the higher values evident further down would be as a result of accumulated degradation as the river accelerates downstream. pH values for two randomly identified hotspots along the basin were also analyzed in Chart 4.1 to show a general increase in pH values as the river courses downstream, which is also an evidence of sustained and accumulated pollution from abandoned farms, trading and health centres along the basin that contribute by channeling their waste discharge into the basin catchment.

Table 4.4 Resultant D-values for the ERIBAM model

Hotspot	**Flow(Q)**	**pH**	**Sediment Load**	**SE factor** (x 10^3 m)	**D factor** (x 10^3 g/s)
Kanja	0.196	6.247857	49.86667	1.123	**68.5768**
Kirimiri	0.180	6.325714	52	1.123	**66.4914**
Kirurumwe	0.183	6.48	54.91667	0.681	**44.3483**
Githunguthia	0.166	6.288462	55.15385	0.671	**38.6323**
Karurumo	0.133	6.808421	57.15789	0.847	**43.8387**
Ena bridge	0.175	6.55375	56.625	0.684	**44.4214**
Itimbogo	0.168	6.1	59.125	0.684	**41.4444**
BAT Centre	0.159	6.644167	62.08333	0.446	**29.2515**

Chart 4.1 (a) and (b)   Comparison of pH scales for 2 hotspots, Kirimiri and Ena BAT centre

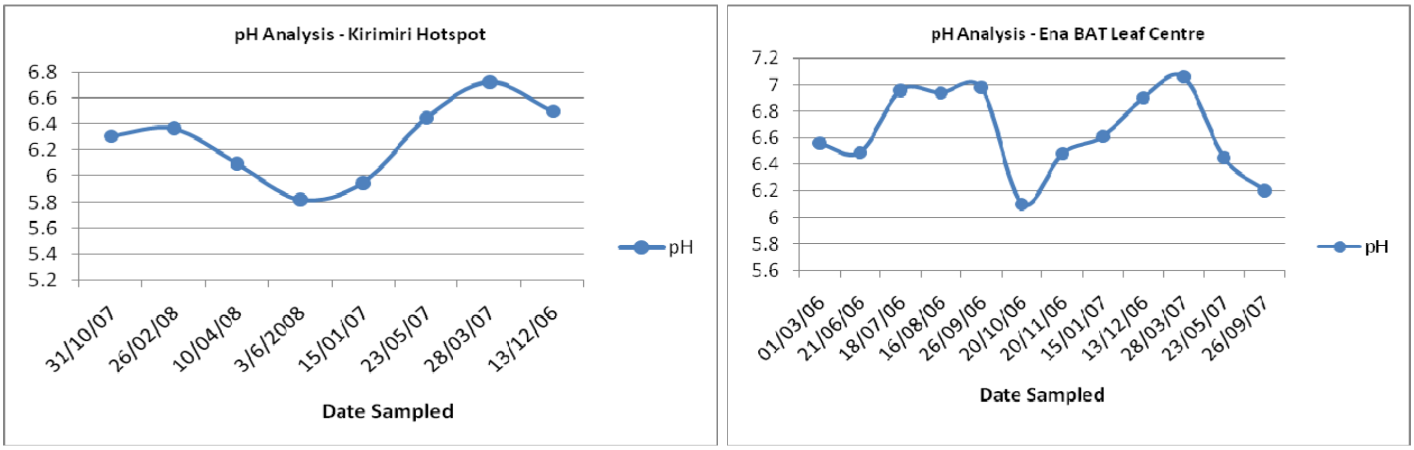
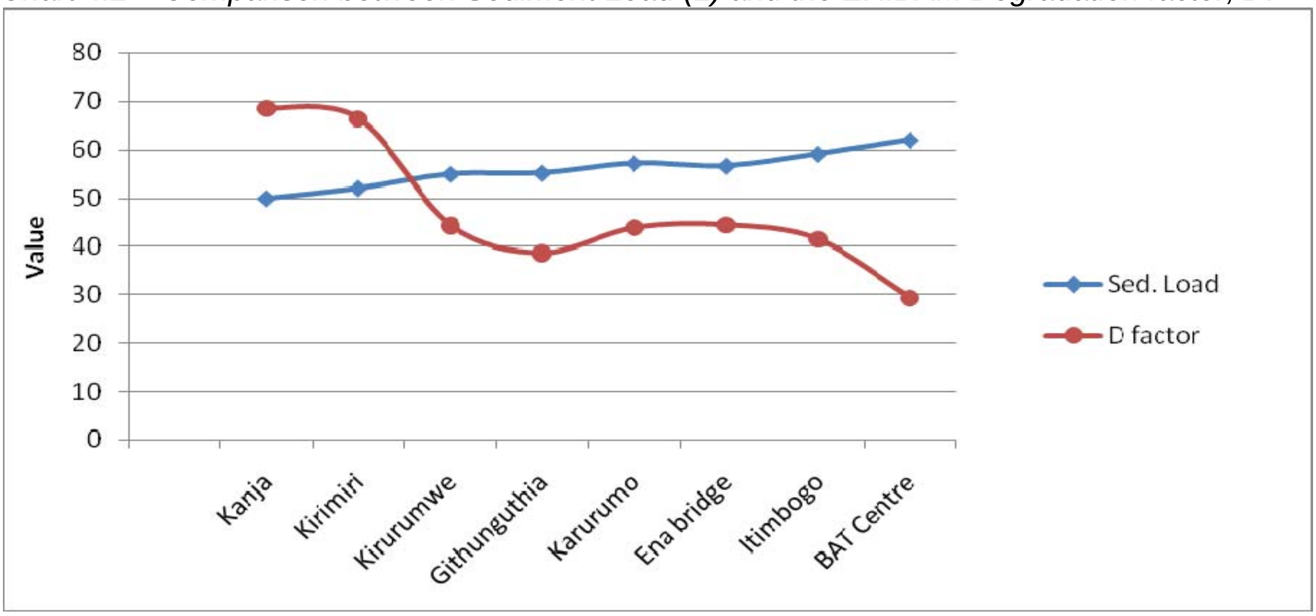


Chart 4.2   Comparison between Sediment Load (L) and the ERIBAM Degradation factor, D.



4.2 DISCUSSIONS

The use of remote sensing and GIS technology has proved successful in many fields of natural resources management. Its synoptism and large area extent as well as the ability of GIS to collect store and manipulate various types of data in unique spatial databases helps in performing various kinds of analysis and thus, extracting information about spatially distributed phenomena.

Using spatial comparison of the hotspot data along the coffee zone, there is revelation of increased degradation, caused by intense negative human activity. The ERIBAM model therefore provides a sufficient planning tool for comparing the Ena basin management alternatives. However the model, unlike RUSLE, has not been calibrated against a large database and little effort has actually been put into the ERIBAM model validation, specifically due to the limited dataset that constricts applicability to the basin in question. Reliance on hydrological data, usually collected for standard regulation and compliance purposes, only stifles the model's goodness of use and can only be used as a rough estimator. However, the results obtained from the model application look convincing, since they resonate properly with the argument that significant degradation is evident in the coffee zone, where abandoned coffee farms on substantially elevated slopy landforms has led to increased soil erosion and loss of vegetation cover.

Outputs from the ERIBAM model can be validated against other spatial databases from the area, specifically the Landsat image that can be processed through supervised classification to show landuse practices along the basin. This classification can then be used to add value to the derived information since it will reflect in the same grid the extent of vegetation land cover. Other useful information that can be used to add value includes the woody biomass cover extent that will show the proportion of landcover that might support conservation more than ordinary vegetation that might give a wrong impression.

Using this information, a basin restoration strategy can be developed with incorporation of the environmental and social scientists who can suggest restoration measures and methodology that are spatially specific to the results from the ERIBAM model. These measures would include among others, a sustained campaign on afforestation to restore the denuded surface to stem high runoff, sensitization on soil and water conservation practices and enforcement on available laws on pollution for institutions and trading centres that pollute the basin.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

We give credit to 3D modeling approach in enabling us design and use the ERIBAM numerical model with an easy and applicable manner to be used by policymakers for determination of qualitative and semi-quantitative degradation within an area of interest. The aim of this study was to devise a simple yet efficient degradation prediction model that would assist in resource planning and also assist local administration in determining the causes in the ecosystem.

As such, an integrated model that combines empirical formulation with GIS makes large scale monitoring simple and fast. As evident with the study area, the geological features of the land, coupled with extensive denudation of biomass cover and irrational soil management, causes huge quantities of sediment to be transported downslope into watercourses which increases the formation of big proportions of wasteland. However, spatial resolution is quite sensitive to estimation of degradation in the ERIBAM model and caution needs to be taken in selecting the grid size for numerical modeling. Data available however seems to inadequately support the model and possible reasons arising from:

i. the time lag between the data collected and the imagery,
ii. positioning errors surrounding the geographical locations of the fields and pixels in the raster GIS,
iii. potential mismatches between field sizes and pixel sizes and,
iv. qualitative and theoretical nature of the field evidence used to compute the Slope and Elevation factor(*SE*).

Comparison of a qualitative observation with a numerical prediction should perhaps assist in reducing the error margin. However, since the study has not been put to rigid testing, the relative spatial and qualitative data used can be treated as appropriate for the current investigation. In this regard, the study objectives can only be fulfilled in terms of the available data and while the 4 objectives were met to a confident level, limitations were encountered due to the size of the study area that could only allow the study to be concentrated along the coffee zone. Investigation of the state of degradation, causes of this degradation and model development were fully achieved (100%) but the objective to spatially document this degradation and develop a full management plan could only be partly achieved (50 %) since a complete management plan involves socio economic aspects beyond the scope of this study.

5.2 RECOMMENDATIONS

Due to the simplicity of the ERIBAM model, the procedure used could be applied for a best fit modeling approach that would eventually improve prediction of degradation in a basin area. However, extension of the model to other basins with different climatologic and hydrometric characteristics to determine the model's critical limit of applicability is recommended in order to test the model's flexibility towards variances across different river basins.

Since simulation data was used in some cases, especially for determining the sediment load where real data was not immediately available, there would be need to validate these results against future data collected on the same, which would assist in strengthening the model's accuracy. Where qualitative estimation was used, especially for slope factor(S) determination, empirically strong data needs to be used, and appropriately justifiable deterministic parameters identified to calculate the slope factor for the spatial grids.

The ERIBAM model would also be more sensitive if more variables would be incorporated e.g. the vegetation biomass cover. This would assist in resolving the contradiction between elevation and degradation especially when the model is applied in a high altitude area. In the upper tea zone of the Ena basin, a lot of degradation would not be expected, but high slope factor values as well as elevation above sea level might distort the model results to show an opposite phenomenon if other variables were to be held constant. The slope and elevation factor might then have to be determined against another factor on degradation to generate a unitary sensitive variable that will incorporate the two.

Since the ERIBAM model was not exposed to a large dataset, calibration of this model in future is highly recommended. Calibration would be greatly assisted if long term data were available for the basin, and more specifically in the upper tea zone and the lower cotton zone where model application is yet to be done.

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APPENDIX 1: DATA ON SELECTED HOTSPOTS ON ENA RIVER BASIN

(Source: WRMA, Embu)

ENA – KANJA – S $00^{0}22^{'}$48.2”; E 037^{0}, 31’, 2”, 1728m (Boundary of Tea and Coffee zones)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
1/03/06	0.188	-	24	40
21/06/06	0.191	6.96	46	43
18/07/06	0.194	5.87	37	240
16/08/06	0.187	6.32	57	43
26/09/06	0.20	6.31	39	11
20/10/06	0.199	6.1	40	210
20/11/06	0.177	6.96	48	24
15/01/07	0.167	-	37	26
13/12/06	0.189	6.3	56	28
28/03/07	0.183	6.71	58	64
32/05/07	0.190	6.45	46	39
26/09/07	0.175	5.64	61	39
31/10/07	0.212	6.24	59	93
26/02/08	0.201	6.23	61	28
10/04/08	0.199	5.73	54	800
3/06/08	0.287	5.65	49	Nil
Mean	**0.196**	**6.247857**	**49.86667**	**120.5714**

ENA – KIRIMIRI – S 00^{0} , 25’, 42.5”; E 37^{0}, 33’, 09.9”, 1492m (Marginal Tea and Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
31/10/07	0.177	6.31	56	210
26/02/08	0.167	6.37	47	150
10/04/08	0.189	6.10	58	1100
3/06/08	0.173	5.82	63	11
15/01/07	0.180	5.95	54	14
23/05/07	0.175	6.45	52	28
28/03/07	0.177	6.73	38	75
13/12/06	0.198	6.5	48	21
Mean	**0.180**	**6.325714**	**52**	**201.125**

ENA - KIRURUMWE – TRIBUTARY – S 00^{0} , 28’,25.5”; 037^{0}, 32’,50.9”, 1362m (Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
26/09/07	0.187	6.31	56	240
31/10/07	0.20	6.36	67	150
26/02/08	0.189	6.55	43	800
10/04/08	0.177	6.19	64	800
3/06/08	0.167	6.44	45	39
25/06/06	0.179	6.22	68	20
26/07/06	0.183	6.56	52	30
18/07/06	0.180	6.68	49	110
28/03/07	0.175	6.62	50	11
15/01/07	0.182	6.49	49	460
23/05/07	0.187	6.44	56	28

13/12/06	0.194	6.9	60	11
Mean	**0.183**	**6.48**	**54.91667**	**224.9167**

ENA - GITHUNGUTHIA S 00^0 , 25', 44.1"; E 037^0, 33', 09.9" 1482m (Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
31/10/07	0.147	6.33	40	800
26/02/08	0.50	6.65	54	120
10/04/08	0.149	6.48	57	800
3/06/08	0.157	6.13	61	7
26/09/07	0.136	5.84	63	39
31/10/07	0.139	6.24	58	1100
26/10/08	0.143	6.35	54	7
10/04/08	0.140	5.99	48	800
3/06/08	0.135	5.77	58	11
15/01/07	0.122	6.23	56	4
23/05/07	0.127	6.45	55	28
13/12/06	0.144	6.7	56	11
28/03/07	0.117	6.59	57	1100
Mean	**0.166**	**6.288462**	**55.15385**	**371.3077**

ENA - KARURUMO – TRIBUTARY S 00^0 , 28', 25.5"; E 037^0, 32', 50.9" (Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
26/09/07	0.127	6.70	56	210
31/10/07	0.120	6.24	62	800
26/02/08	0.139	6.37	34	240
10/04/08	0.147	6.17	45	120
28/03/07	0.127	7.12	43	75
23/05/07	0.119	6.7	56	240
26/09/07	0.123	6.85	67	20
31/10/07	0.140	6.57	63	800
26/02/08	0.125	6.50	60	210
10/04/08	0.142	6.59	58	800
03/06/08	0.127	6.33	61	11
25/07/06	0.154	6.99	60	11
01/03/06	0.117	7.55	57	28
26/07/06	0.120	7.61	59	28
13/12/06	0.159	6.8	62	28
23/05/07	0.118	6.8	64	1100
20/11/06	0.136	7.55	68	20
28/03/07	0.147	7.12	54	75
13/12/06	0.141	6.8	57	28
Mean	**0.133**	**6.808421**	**57.15789**	**254.9474**

ENA - ENA BRIDGE S 00^0 , 28', 28.0"; E 037^0, 32', 54.1" , 1367m (Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
1/03/06	0.177	6.6	65	150
21/06/06	0.157	6.5	68	240
18/07/06	0.169	6.64	54	460
16/08/06	0.143	6.68	56	1100
26/09/06	0.190	6.99	54	240
20/10/06	0.185	5.9	58	1100
20/11/06	0.212	6.97	52	1100
15/01/07	0.201	6.84	49	1100
13/12/06	0.169	6.7	51	1100

28/03/07	0.207	6.71	58	1200
23/05/07	0.156	6.42	54	210
26/09/07	0.164	6.67	48	21
31/10/07	0.179	6.07	65	75
26/02/08	0.133	6.54	58	43
10/04/08	0.170	6.41	57	7
3/06/08	0.185	6.22	59	7
Mean	**0.175**	**6.55375**	**56.625**	**509.5625**

ENA – ITIMBOGO – TRIBUTARY S 00^0 , 28', 58.8"; E 037^0, 38', 12.2", 1230m (Marginal Coffee Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
26/09/07	0.157	5.69	68	93
31/10/07	0.167	5.96	69	210
26/02/08	0.149	6.18	66	650
10/04/08	0.183	5.84	65	1100
03/06/008	0.160	5.63	49	43
15/11/07	0.175	6.2	50	
23/05/07	0.172	6.71	52	460
28/03/07	0.181	6.59	54	39
Mean	**0.168**	**6.1**	**59.125**	**370.7143**

ENA - B.A.T LEAF CENTRE S 00^0, 31', 43.7"; E 037^0, 38', 17.8", 1114m (Boundary of Coffee and Cotton Zone)

DATE	FLOW(Q)	PH	SEDIMENT LOAD	FEACAL COLI
1/03/06	0.145	6.56	66	460
21/06/06	0.138	6.49	69	460
18/07/06	0.149	6.96	69	110
16/08/06	0.157	6.94	68	1100
26/09/06	0.160	6.98	66	460
20/10/06	0.169	6.1	63	1300
20/11/06	0.143	6.48	60	1300
15/01/07	0.157	6.61	56	1000
13/12/06	0.161	6.9	58	28
28/03/07	0.183	7.06	58	1100
23/05/07	0.177	6.45	53	210
26/09/07	0.164	6.20	59	210
Mean	**0.159**	**6.644167**	**62.08333**	**644.8333**