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Themes

Main theme

Expanding Theoretical and Applied Roles of GIS in a Dynamic Global Environment

Sub-themes

GIS pedagogy

GIS in sustainable development

GIS in resource planning and management

GIS in agriculture

GIS in disaster management and security

Legal and policy issues in GIS

Trends in GIS technologies and instrumentation

Emerging issues in GIS

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Key Note Paper
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Imparting spatial thinking to university community: Kenyatta University experience in the use of ESRI campus-wide site license

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Abstract:

Kenyatta University (KU) took the challenge and applied for ESRI 100 African Universities Programme in March 2012 with the signing of a Memorandum of Understanding with ESRI Eastern Africa in June 2012 and the award of the licence in April 2013. The availability of the license aimed at improving learning, research and capacity development among the students and staff at KU. A strategy that lead to campus-wide accessibility of the software through six computer laboratories spread across campus was put in place by June 2014. Base support from Directorate of ICT and the presence of GIS proficient technicians was necessary to network and access the license and start the process of training in the software use and its application. In the intervening period, the hosted the 1st ESRI Education User Conference in September 2013 and mounted two workshops on "GIS applications in Hydrology and Water Resources Management" and "GIS and Remote Sensing for Disease and Landscape Dynamics Mapping" in early 2014. The software was also made available to students and staff for their research through off-site licensing protocol. To capacity build staff and students, KU launch a training campaign in 16 sessions that introduce geospatial knowledge use and application in a two-phased approach: Phase 1 of three days introduction to ArcGIS and remote sensing and Phase 2 of five days training on applications which involved using the university as a mapping unit and therefore enabling campus mapping. The process culminated in a spatially referenced digital map of KU and a showcase of map stories during the GIS Day 2014 and Esri Education User Conference held in Dar-Es-Salaam November 2014. To date close to 1000 participants from across all Schools in KU have been trained. There has been University top management support in the process and involvement of Deans of Schools and Heads of Departments with absolute interest from stakeholders and a dedicated GIS team. The facilities have also helped KU research staff implement projects such as "Mapping Extent and Impacts of 2011-2014, 50-year Flood Cycle in Lakes Baringo/Bogoria Basin, Kenya" which from the time series Landsat image analysis of January 2010, December 2010, January 2011, January 2012, May 2013, September 2013 and January 2014 document a rise in Lake Bogoria 26.3% aerial coverage between January 2010 and September 2013, while Lake Baringo increased its flood area by 61.3% over the same period. The GIS tools also helped the KU research teams put into context the "Risk, Hazard, Vulnerability and Capacity Assessment / Mapping of the Kenya"

1 OVERVIEW OF KENYATTA UNIVERSITY AND ITS RESEARCH AGENDA

Kenyatta University http://www.ku.ac.ke/index.php/about-ku/about-ku/ku-profile is the second largest public university in Kenya with a population of about 80,000 students. The university was established through an Act of Parliament in 1985 and is governed according to the Universities Act No. 42 of 2012. The university is accredited and affiliated to: the Commission of University Education

(CUE), Inter-University Council for East Africa (IUCEA), Africa Association of Universities (AAU), Association of Commonwealth Universities (ACU) and International Association of Universities (IAU), among other bodies. Kenyatta University purposes to actualize sensitivity and responsiveness to societal needs and the right of every person to knowledge.

The main campus sits on 1,000 acres of land just 16 Km from Nairobi Central Business District. Other campuses are at Ruiru, Parklands, Nairobi City Center, Kitui, Mombasa, Nyeri, Kericho, Nakuru, Embu and Arusha (Tanzania). As of 2014 the university had 952 academic and 1792 non-academic permanent staff working in 14 Schools supplemented by 67 teaching programmes.

The vision of Kenyatta University is to be a dynamic, inclusive and competitive centre of excellence in teaching, learning, research and service to humanity. The mission of Kenyatta University is to provide quality education and training, promote scholarship, service, innovation and creativity and inculcate moral values for sustainable individual and societal development. Kenyatta University's 2005-2015 Strategic Plan is the road map towards achieving this vision.

Kenyatta University's teaching, learning and research opportunities cut across diverse disciplines offered to diploma, undergraduate and postgraduate students in the following 16 Schools http://www.ku.ac.ke/index.php/academics/schools :

- 1) Agriculture and Enterprise; 2) Applied Human Sciences; 3) Business; 4) Economics; 5) Education and Human Resource Development; 6) Engineering; 7) Environmental Studies; 8) Medicine; 9) Humanities and Social Sciences; 10) Law; 11) Pure and Applied Sciences; 12) Visual and Performing Arts; and 13) Hospitality & Tourism Management, 14) Virtual and Open Learning, 15) Public Health, 16) Graduate School.
- In addition there are 45 directorates, centres and institutes in the University http://www.ku.ac.ke/index.php/about-ku/administration/directorates among which the Directorate of Grant Writing, Directorate of Intellectual Property Rights; Centre for Resources Mobilization and Consultancy Directorate of Grant Writing and Management, Centre for Career Development and Placement, Africa Centre for Transformative and Inclusive Leadership (ACTIL), Centre for Entrepreneurship and Enterprise Development, Center for Teaching Excellence and Research Training (CTERT), Centre for Institutional Based Programmes, Center for International Programmes and Collaboration(CIPC), Centre for Quality Assurance, Centre for Gender Equity & Empowerment, Center for Refugee Studies and Empowerment, Chandaria Business Innovations and Incubation Centre, Cisco Networking Academy, Community Outreach and Extension Programmes (COEP), Information Communication Technology, Intellectual Property Rights Unit, Institute of Peace and Security Studies (IPSS) and Institute of African Studies direct and document all researches and consultancies carried out by the University and ensure quality delivery of services.

The ultimate goal of Kenyatta University is to equip the students with adequate knowledge to face the challenges of the highly dynamic and competitive world. KU prides herself in providing high quality programmes that attract individuals who wish to be globally competitive. To achieve this, the university maintains a competent staff and has invested heavily in infrastructure and facilities for research and innovation http://www.ku.ac.ke/index.php/about-ku/about-ku/facilities-amenities. KU has also established meaningful links with industrial partners, who guide the University on practical, professional requirements which need to be built into programmes at the University.

The concept of global problems demanding Natural Resources Management (NRM), Integrated Water Resources Management (IWRM), Disaster Risk Management (DRM) Urban Assessment, Environmental Risk Assessment, Food security and their mapping are not alien to Kenyatta University. Indeed NRM, IWRM and DRM form some of the core courses offered in the departments of Geography, Sociology, Environmental Science; Environmental Planning and Management and Environment and Community Development, Water and Environmental Engineering. In particular, these departments teach courses that address issues dealing with NRM, IWRM, natural and anthropogenic hazards, environmental and urban risk assessment, and pollution monitoring. The departments have laboratory equipment where they train and equip graduates with capacities to deal with and to train others on the salient issues of resource management and planning.

Among the many areas of research in which the staff and students have been engaged over the years include: human settlement, population growth/pressure, watershed management, hydrological processes and water resources management, water resources aspects, coastal resource management, ecosystems and forest management, droughts and floods, HIV/AIDS and aging , food security, sediment and erosion processes, soil and water conservation droughts, food security, sediment and erosion processes, hydro-geomorphological studies, risk management and conservation in semi-arid zones, and integration of maize markets. The gender factor is also a major component of research in the university and a number of researches targeting gender and resource management have been conducted. Postgraduate students and staff are also continuously carrying out research in corporate social responsibility, agriculture and food security, medical sociology, environmental, rural, urban, community development, entrepreneurship, fish farming, drug abuse and rehabilitation, HIV/AIDS, community organization and development. Equipments are available for field work. Kenyatta University maintains a data base of climate data and satellite images and a number of statistical software for research e.g. ArcGIS, SYSTAT, INSTAT, IHACRES, IHFLOODS with a focus on environmental aspects of natural and human resources as desired in industry and society. The Department of Geography has a fully equipped and functional and recently automated weather station from which massive data has been collected. There is also a well equipped cartographic section.

Studies on environmental changes such as global warming, ozone depletion, pollution, and climate change, over-exploitation of natural resources, altered land use and loss of biodiversity are best-carried out and addressed through studies and researches that are cross cutting. In order to cope with increasing incidences and emergence of both slow and rapid on-set disasters in Kenya, Kenyatta University focuses on training programmes and research that build human capacity and provide a repository of information for planning, monitoring and management of earth resources. Further NRM, IWRM and DRM training programs are needed in response to the need to build capacities of local communities within watersheds to cope with emerging issues. Current efforts demand up-scaling on spatial mapping and spatial thinking that the Esri Site License is a critical teaching and research tool in that context.

Through the School of Education, Kenyatta University has been the premier educational training institution in Educational Psychology, Educational Administration Planning & Curriculum Development, Educational Communication & Technology, Educational Foundations. These programmes among others have enabled Kenyatta University to develop a vast majority of teachers and other education professionals for the country. Additionally, Kenyatta University education experts participate in the national curriculum development panels of the Kenya Institute of Education as well as providing research and capacity development support to the Ministry of Education, UN Agencies, and local and international NGOs through individual and team-based consultancies. Infusing GIS into the training programme will increase access and better understanding of community dynamics.

2 SYNOPSIS OF KENYATTA UNIVERSITY GIS PROJECT AND GOAL

Kenyatta University (KU) is a public institution of higher learning based in Nairobi Kenya. The dynamics of research and the current world’s demand for spatial oriented research and training for sustainable development has seen KU go through a metamorphosis in its research and teaching programs to fit in today’s needs of global problem solving. One such metamorphosis in KU is the inclusion of Geographic Information System (GIS) in some of the programs offered across the 14 Schools. Although for a long time GIS was being taught in a number of departments, it was not until the award of the Esri 100 African Universities Program with a Campus-wide Enterprise License that GIS has taken a drastic turn in the teaching and research program in KU.

The success of the implementation of the Esri 100 African Universities Program and license in KU intensified since June 2014 with the recruitment of 2 GIS Interns supported by the Community of Excellence for Research in Neglected Vector Borne and Zoonotic Diseases (CERNVEC) / ICIPE http://www.icipe.org/cernvec/ to coordinate an 8 day training program to jump-start staff and students to use ArcGIS Tools. The training module introduced participants to Esri ArcGIS and Exelis Envi software and imparted Spatial Knowledge to both teaching staff and KU students.

The teaching program was enrolled starting 11th of June, 2014 to 18th December, 2014. This saw introduction of GIS as an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.

The success of the GIS training saw the trained participants get to know how to use ArcCatalog to organize their GIS projects, use ArcMap to execute the projects in Geodatabase environment and produce their spatial maps using the hundred available tools within the ArcGIS 10.1 software. Mining of spatial data from Remotely Sensed images using Envi 5.0 was also a cutting edge as this brought the comprehensive complement of the two systems into one see http://www.ku.ac.ke/index.php/news-center/155-news-centre/796-geospatial-knowledge and http://www.ku.ac.ke/schools/environmental/index.php/component/content/article/109-gis/299-arc-gis-and-remote-sensing-programme under ArcGIS News and events Past Training.

Success stories of the training program was further enhanced by the successive hosting of the 2014 GIS Day on 18th November, 2014 and representation by 8 participants at the 2nd Esri Eastern Africa User Conference between 20th and 21st November, 2014 at the University of Dar es Salaam in Tanzania. GIS and Remote Sensing Training for Mapping of Neglected Tropical Diseases (NTDs) from 15th - 18th December 2014 at Kenyatta University's Business and Students Service Centre closed year's activities.

3 KENYATTA UNIVERSITY PARTNERSHIP WITH ESRI FOR PROBLEM YOU SOLVING

Whereas Kenyatta University's mission includes the provision of quality education, training and research; promotion of scholarship; services; innovation and creativity and inculcate moral values for sustainable individual and societal development, the objectives of KU are inter alia to provide, directly or in collaboration with other institutions, facilities for university education including:

- technological and professional education;
- training through research and development of specialized programs;
- discovery and transmission of knowledge;
- stimulation of life and cultural development of Kenya;
- facilitate the integration of knowledge and skills among others in geospatial techniques and the use of Geographic Information Systems (GIS);
- support the transfer of knowledge to the public and the private sector.

In view of this, Kenyatta University and Esri EA envisioned use of GIS to enhance research and teaching of spatial knowledge and in particular aimed to:

- To use GIS to nurture spatial thinking and as a key technology to help staff and students develop analytical and problem solving skills;
- To use GIS to provide staff and students with tools to develop a better understanding of the world's resources and challenges;
- To use GIS knowledge to promote geospatial education, training and research in developing countries in general and in Eastern Africa in particular.

This teaching and research oriented application of Esri product in GIS has seen the KU GIS Training Team implement and promote the use of the tool to over 1000 students and staff of Kenyatta University.

Kenyatta University's Strategy in getting ESRI Support with ArcGIS Campus-wide license through the 100 Africa University Programme and the implementation process has seen applications in a number of problem solving projects. The benefit of the 100 African Universities Program provides the opportunity for students and faculty throughout the university to use ArcGIS in their coursework and research. The other outcome of the many training activities conducted to sensitize students on GIS tools for spatial knowledge and research is that there has emerged the need to establish a Gis Training Centre at Kenyatta University

The demand for digital and spatial knowledge based data (geo-information) and mapping among Kenyatta University faculty is high and continues to increase. This has generated the need to gather, coordinate and develop the expertise required to support spatial knowledge for teaching and research in computer-based environment. The establishment of a GIS Training Centre at Kenyatta University will initiate better utilization of the full potential of the current Esri ArcGIS Site License awarded to the University through Esri's 100 African Universities Programme. It will also provide a better research environment for collaboration between departments their staff and students on the use of Geospatial Technology for teaching and research and start to move towards spatial thinking that is necessary for sustainable development. The Centre's main task will be to encourage and facilitate the use of GIS within the university. All Schools now acknowledge the usefulness of GIS within higher education and research.

The objectives of the Kenyatta University GIS Center are:

1. To provide an expanded GIS lab facility and utility for GIS Training and capacity building in the university.
2. To prepare skilled GIS personnel across the university who can participate in building Geo-information technology awareness and expertise for research and sustainable development.
3. To provide a basis to develop a GIS curriculum for the university to support the demand for geo-spatial knowledge for teaching and research.
4. To provide facilities for short GIS Certificate courses tailor-made for specific applications in an effort to expand spatial knowledge use for sustainable development.
5. To provide facilities and resources to support GIS input into the current short certificate course in Environmental Impact Assessment (EIA).
6. Provide facilities and resources to support GIS input into relevant spatial knowledge courses taught in various Departments at Kenyatta University.

The creation of an effective and operational Center requires suitable laboratory facilities with capacity to guide and deliver on the training, teaching and research needs of the university and an effective committed coordination. The following resources/structures are basic:

- Adequate computing environment with suitable GIS, remote sensing and statistical software
- Operational and effective local area network for campus-wide access to server based software
- Teaching and training curriculum that has infused GIS knowledge into them
- Geo-databases for digital spatial data (digital maps, data and statistics with spatial elements)
- Open Data portal for web applications and online map stories, information dissemination and science communication
- Offer a consultancy base able to provide services and support to the external stakeholders
- Coordination and initialization of research projects involving the use of geospatial knowledge and building a database on such projects for monitoring and evaluation
- Collaboration with organizations and institutions outside the university to grow spatial knowledge use.

KU Staff and Students (this is also true for external stakeholders) using the GIS Center's Facility and resources will be able to:

- Train on GIS and remote sensing basics and applications
- Work comfortably in a spatial environment to teach and research
- Use GIS, Remote Sensing and other software's to work with spatial data,
- Use GIS software and hardware to create customized spatial products and web applications,
- Use GIS, remote sensing software and programming tools to perform a variety of analytical tasks, modeling and database management system to develop GIS applications.

The GIS Centre will offer KU schools and students free access to information, short courses and software related to GIS modeled on the use of GIS as a system (Figure 1) and appreciating and understanding the data flow process (Figure 2). There will also be an opportunity to do online GIS training at the Centre and have access to free self-study-materials.

The GIS Laboratory provides an environment where schools, staff and students work together to advance knowledge in the application of geospatial technologies to;

- Integrate state-of-the-art remote sensing (RS), Geographic Information System (GIS), and Global Positioning (GPS) technologies with on-the-ground knowledge of earth systems and natural resource management to address environmental, socio-economic and developmental issues.
- Transfer knowledge and skills to the KU campus community, the local community, state agencies, local authorities and departments, the private sector and non-governmental organizations through education, outreach and training.
- Conduct scientific research focusing on sustainable development.
- Make geospatial data readily available to a variety of users through web-enabled distribution tools.

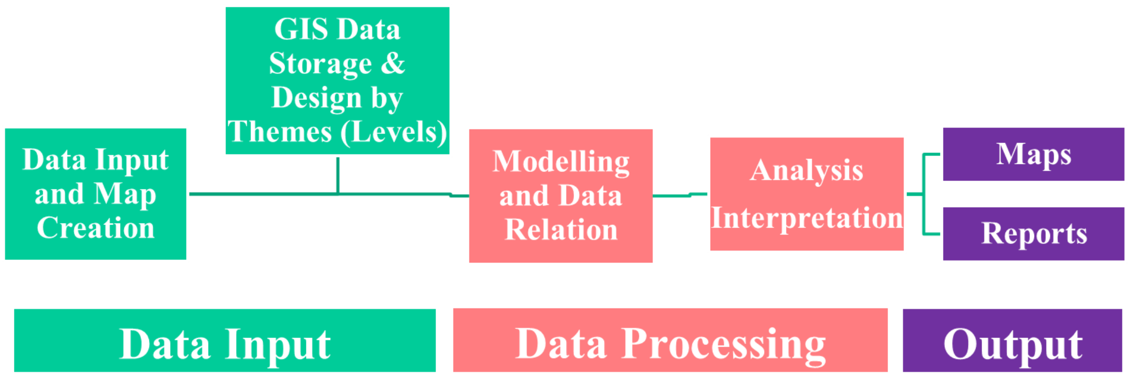


Figure 1: The Three Subsystems of GIS

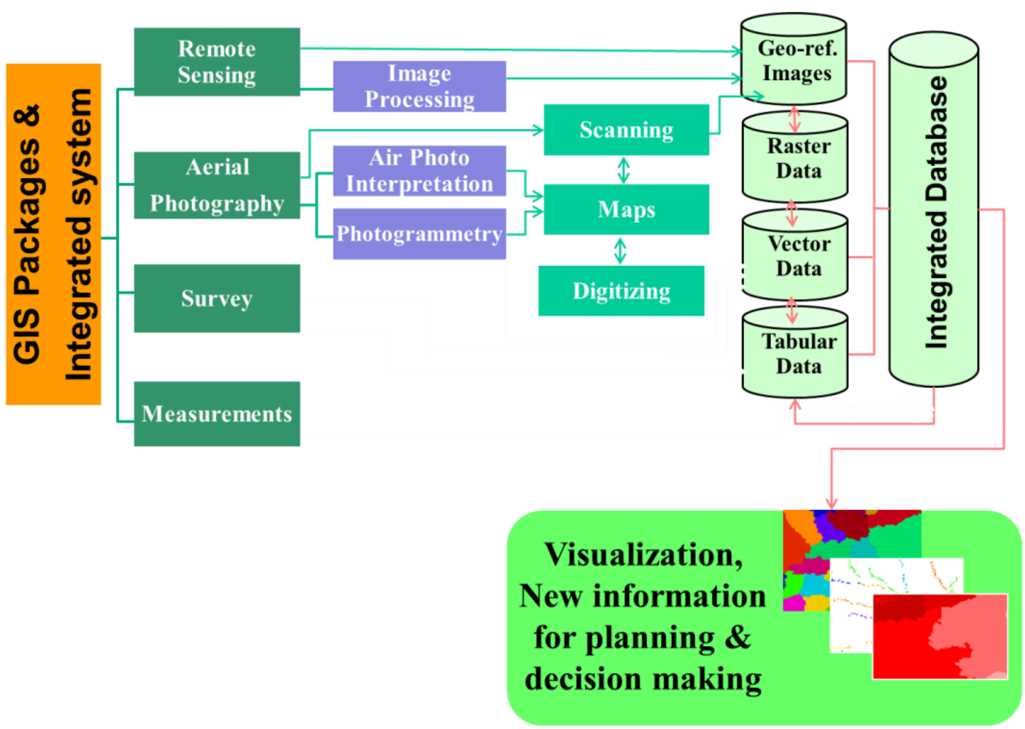


Figure 2: A Typical GIS Setup and flow process

The production of the KU Map by the Participants is one of the products now in use for location and information. The participants were able to collectively produce a map of KU main campus during their different group trainings. http://kuniversity.maps.arcgis.com/home/webmap/viewer.html?webmap=95ef9d489410401f8c82fc3b15921abe The finished product was printed and presented to the Vice Chancellor by the KU GIS team for administrative use.

4 ESRI GIS TECHNOLOGY USE FOR IMPLEMENTING AND DEPLOYING APPLICATIONS OR SOLUTIONS

To successively introduce the participants to Esri ArcGIS 10.1 technology, the KU_GIS team split the training into two phases; phase 1 being that of introduction to ArcGIS and phase 2 applications of ArcGIS. During the introduction phase, participants were introduced to ArcCatalog and what it does to organize and manage a GIS project. The pure basics of how to start the application from the start, all programme files was offered. This though very basic brought all the participant up to speed on how to use this application.

ArcMap as the main ArcGIS engine was then introduced and pre-copied data used to gradually train participants the rigor of this application. This was the core of the Esri software training as participants will spent their entire GIS life using this application.

ESRI ArcGIS Geodatabase, though embedded in the software was thought of as an independent application during KU-GIS trainings. This allowed a lot of emphasis to be given to data management and organization in a geospatial data model. The notion of geospatial data model has prompted key stakeholders to address Environmental issues affecting the world today in a more holistic geospatial approach.

GIS is now a catalyst for research and career advancement in the university. Being multidisciplinary, geospatial technology has given the students the skills they need for success in further education or their chosen discipline and research. Applications range from climate research modeling to retail site selection, environmental impact studies, and more. To the students "Geospatial data and tools are essential in almost everything they do and are excited with the opportunity to use spatial knowledge they have gained especially now the tools are accessible within a well-endowed side of the digital divide on campus." Increasing demand for readily available, consistent, accurate, complete and current geographic information and the widespread availability and use of advanced technologies offer great job opportunities.

The amount of data involved in GIS is vast, and the variety of location, topic and format very wide. Despite this all earth resources, problems can be reduced to answering one or the other of the two questions (Figure 3).

- Finding locations with specified properties (where is? – spatial related questions)
- Finding the properties in/of specified locations (what is there?– attribute related questions)

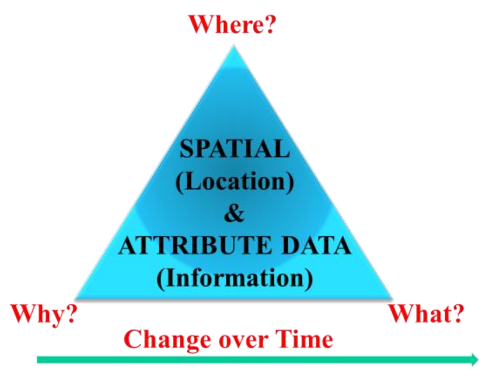


Figure 3: The GIS objects/features/phenomena Solutions model

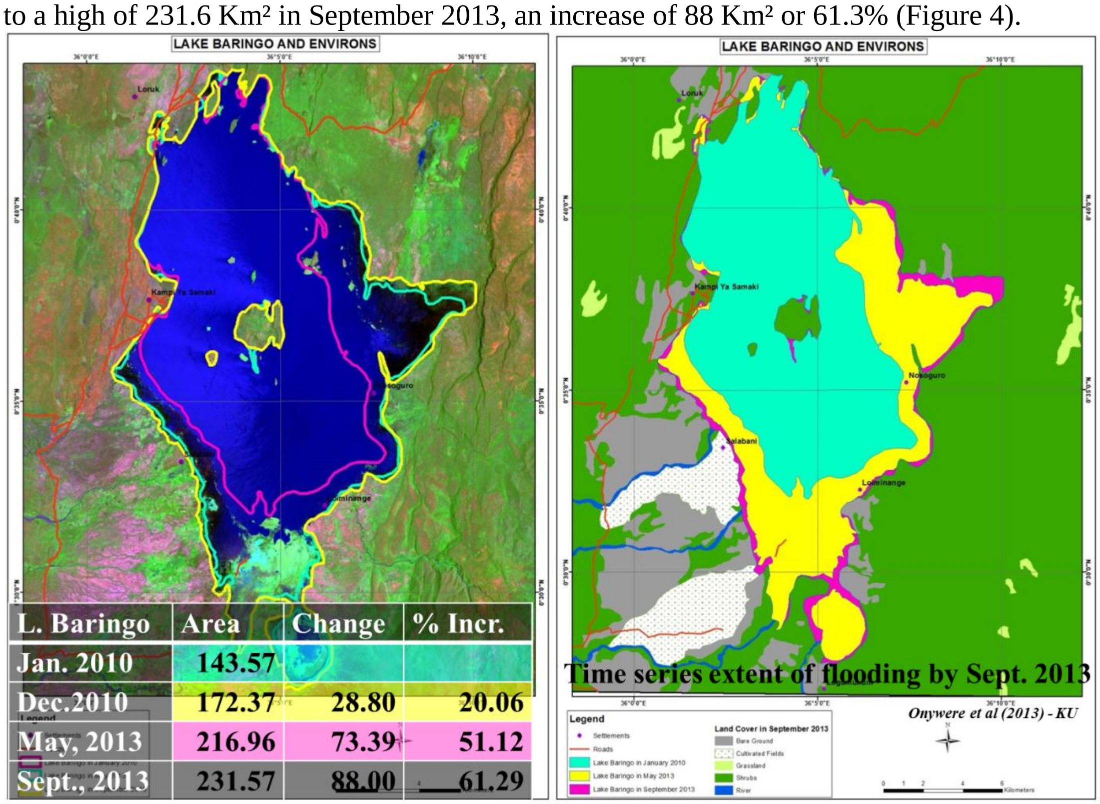
Leading to applications in all areas (earth resources, development activities, impacts of resources use and activities, Urban settlements, Health etc)

5 CONCLUSION ON RESEARCH AND DEVELOPMENT

The availability of the software has enabled the staff students to carry out their research properly and come up with products which can be sued for problem solving. The geospatial knowledge acquired has been applied to solve environmental problem and hazard management such as was evident in Lake Baringo-Bogoria basin.

The Lakes Baringo (145 Km^2) and Bogoria (32 Km^2) drainage basin lie at an altitude of 970m asl at the northern end of the Central Kenya Rift Valley. The two lakes are separated from each other by a 23 km stretch containing a low East-West trending escarpment. Lake Baringo has semi-fresh heavily silted waters and is recharged by Molo, Perkera and Endau rivers. Its freshness is maintained by underground seepage towards the northern end of the lake at Loruk into Suguta river recharging Lake Turkana. Lake Bogoria occupies a narrow enclosed graben and is characteristically alkaline. The two lakes are Ramseur sites that fluctuate with surface recharge and are greatly influenced by the rift valley faulting and fractures which also control the location of the groundwater aquifers and their intimate connection to the lakes. The basins lie within the arid and semi-arid area and are vulnerable to climate variability with occasional flush flooding.

Time series analysis of Landsat images was done using the Jan 2010, Dec 2010, Jan 2011, Jan 2012, May 2013, Sept 2013 and December 2014 scenes to assess the extent of flooding from the lake level rise recorded in that period. Maps of the spatial extent of the lakes show that the lakes rose and started flooding their riparian areas since September 2010. The lake level rise is attributed to the 50 year climatic cycle. The area experienced similar rises in 1902 and 1962/1963 periods. The 2010-2014 impact of the lake level rise saw Lake Baringo increase the area under flood water from 143.6 Km^2 in January 2010 to a high of 231.6 Km^2 in September 2013, an increase of 88 Km^2 or 61.3% (Figure 4).



L. Baringo	Area	Change	% Incr.
Jan. 2010	143.57		
Dec.2010	172.37	28.80	20.06
May, 2013	216.96	73.39	51.12
Sept., 2013	231.57	88.00	61.29

Figure 4: Extent of Flooding in Lake Baringo in 2013

Lake Bogoria increased its flood area from 32.56 Km² in January 2010 to 41.13 Km² in September 2013, an increase of 26.3% (Figure 5). The increased recharge of the lakes is from rivers draining the Central Rift Valley escarpments of Mau and Bahati and the Tugen Hills. The spread of the flood waters submerged the riparian vegetation and affected seven, displacing the communities and their livestock with loss of irrigation land in the lower parts of Perkerra Irrigation Scheme. The continued presence of flood waters will lead to restructuring of the soil character, and the vegetation community in the riparian areas. At least eight schools and three tourist lodges within the Baringo Tourist Circuit were submerged affecting the tourism income for Baringo County.

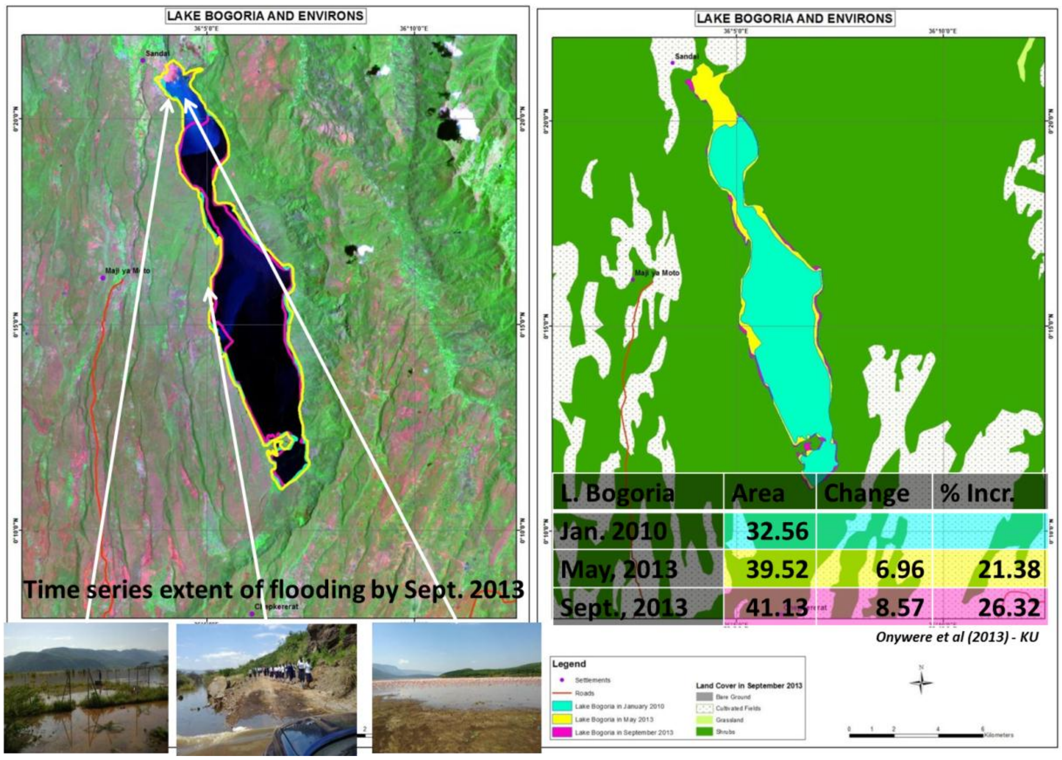


Figure 5: Extent of Flooding in Lake Bogoria in 2013

The availability of the ArcGIS tools have also gone a long way in solving education problems, i.e. applying the tools in the respective disciplines and departments where there was no awareness and only theoretical knowledge was taught. The establishment of a GIS training Centre will provide tools for students and staff to enable them carry out research and development and capacity building of various stakeholders for sustainable development and help achieve vision 2030.

The knowledge acquired in the University is an invaluable asset to the students and staff as they are able to apply it to the job market. Spatial knowledge is giving them a competitive edge against other graduates from other institutions. Some of these graduates are absorbed directly into the university while others go through advanced training programs from Tutorial fellow to full lecturers. This is essence helps the university to cut down on the cost of hiring new staff and also strengthens quality by employing staff with homegrown skills. However the University is a public institution hence does not run on profit.

The ArcGIS license is offering students with practical skills that they can employ directly in the job market. There are many opportunities currently in the GIS field and hence the students are benefiting greatly from these trainings.

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Paper No: 01
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Sub-theme: GIS in sustainable development

Geo-information technology in rainwater harvesting - Siaya county, Kenya

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Paper history:
Received on: 29 Jul 2015; Presented on: 13 Aug 2015; Revised on: 21 Oct 2015; Accepted on: 22 Oct 2015

Abstract:

Kenya is currently experiencing growing pressure on water resources caused by increasing water demand for agricultural, domestic and industrial consumption. This has been brought about due the effects of climate change and has necessitated the need to maximize and augment the use of existing or unexploited sources of fresh water. Rainwater Harvesting (RWH) has been considered as the most promising among others with efforts currently being made world over to provide water to meet the growing need. The focus of this study was to use geo-information technology in assessing the potential of rooftop rainwater harvesting (RRWH). RRWH is the technique through which rain water is captured from the roof catchments and stored in reservoirs for future use. The study was executed in Karapul sub-location in Siaya County, Kenya. A total of 8,024 rooftops were digitized in the ArcGIS environment from ortho-rectified aerial photography of 40cm spatial resolution. Three different classes of rooftop types were captured in the digitization process; these were, iron sheets, tiles and grass thatched rooftop types. Run-off coefficients of 0.85, 0.6 and 0.2 were respectively assigned to the three rooftop classes. Estimated rainfall surfaces from the year 2000 - 2012 were used to extract mean monthly and mean annual rainfall. A local model combining, mean annual rainfall, rooftop run-off co-efficient and average roof area was used to estimate the RWH potential. An estimate of 1,607,400 m^3/day RWH potential was found against 280m3 per capita water demand. The outcome of this study highlighted the relevance of geospatial methods and tools in assessing RWH potential. The study revealed that Karapul sub-location has a vast and untapped potential for RWH. The results from this work are intended to aid in planning water provision and to help address the water scarcity problem in Karapul Sub-location. In addition, the methodology outlined in this study can be replicated in other areas in Kenya and elsewhere to determine the potential of RWH and thus integrate rainwater as an alternative water source to ensure sustainable development.

KEY WORDS: Rainwater Harvesting, Runoff Coefficient, Siaya, Kenya

1 INTRODUCTION

Water scarcity has become a serious global threat due to the ever increasing population growth, frequent droughts and changing climate pattern. In most developing countries, lack of safe, clean drinking water often leads to waterborne diseases such as cholera, typhoid and dysentery. Kenya is currently experiencing growing pressure on water resources caused by increasing water demand for agricultural, domestic and industrial consumption that has brought about the need to maximize and augment the use of existing or unexploited sources of freshwater. Despite bordering Lake Victoria, the largest lake in Africa and the world's second largest fresh water lake, Siaya County often experiences water scarcity. The main water supplier is the Siaya and Bondo (SIBO) Water and Sanitation Company which can no longer meet the ever increasing water demand and this is evident from the dry taps in the area which remain so most of the time. Other sources of water include boreholes, water holes, rivers and wells. Existing report reveal that exploitation of underground water has only few prospects and when found, over 25 m deep, the water is saline (Ministry of Devolution and Planning, 2013). Furthermore, large number of water points cannot be used during the dry season because they are seasonal. There is only one permanent river in the study area, *Wadh Bar* which is located to the eastern side with high rural influence.

The *Siaya County Development Profile Report 2013* has cited inadequate water supply as one of the major challenges to county development. It has also emphasized the need for promotion of rainwater harvesting within the region by construction of roof catchment facilities, citing increased population, dropping groundwater levels in certain areas, low water quality and limited accessibility as well as many cases of water borne diseases as reasons for the urgency (Ministry of Devolution and Planning, 2013). RRWH is not widespread in this area and most inhabitants have resorted to haphazard digging of wells while those who cannot afford to do so purchase the scarce commodity from the well directly at a cost of Kshs. 5 per 20 litre jerrican or from vendors at a cost of between Kshs.10 to Kshs. 20 per 20 litre jerrican, depending on the distance and mode of transportation. In alleviating poverty in Siaya County and Kenya at large, water as a basic need is of priority. There is therefore need for an alternative water source to ensure the county's sustainable development. The focus of this study was to use geo-information technology in assessing the potential of RRWH.

1.1 Definition

Rainwater harvesting (RWH) is an alternative water supply method that has become popular in recent years in most parts of the world to provide water to meet the growing need in order to address the water scarcity problem.

The term RWH has been defined as direct collection of precipitation falling on the roof or on the ground without passing through the stage of surface run-off on land (Athavale, 2003).

1.2 Methods of Rainwater Harvesting

RWH can be classified into two broad classes, namely: Surface runoff harvesting and Rooftop harvesting. This is illustrated in Figure 1.

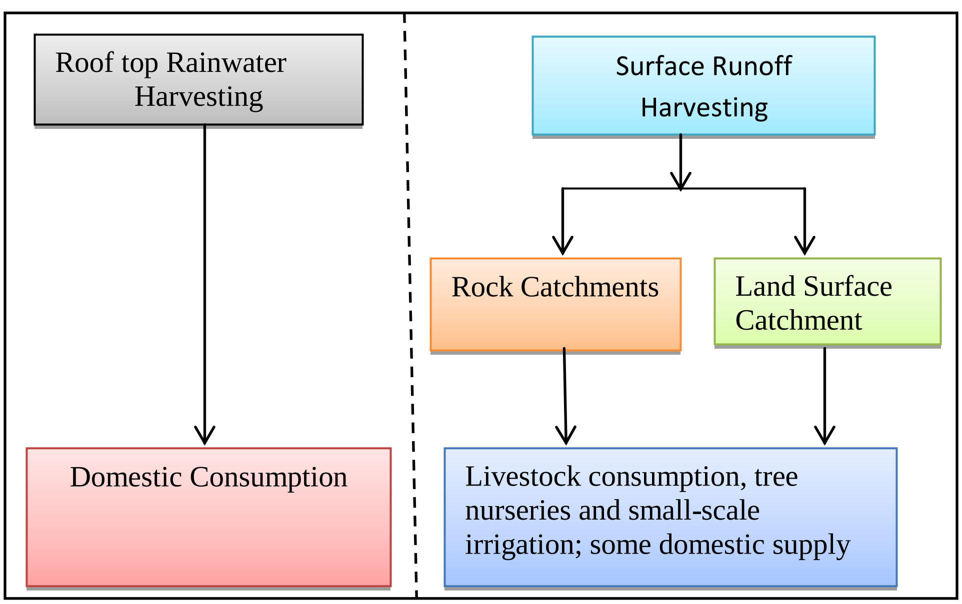


Figure 1: Rainwater harvesting systems and uses (After Wafler, 2010)

a) Surface runoff harvesting: Here, runoff refers to rainwater that flows off a surface other than roof (Awulachew and Lemperiere, 2009). The surface may be a rock, pavements, fields or roads. Some surfaces are permeable (e.g. field) while others are impermeable.

Rain that falls on the surface can be collected and used either for irrigation or domestic purposes. In some cases, depending on the quality, it has been used for flushing toilets and cleaning activities in household. It could even be used to recharge aquifers. The amount of water collected by this method depends on the amount of the rainfall, the permeability of the surface, the area of the surface and the slope of the surface among other factors.

b) Rooftop rainwater harvesting: In this method, rainwater is collected from the roof catchments and stored in reservoirs. Rain does not reach the surface of the earth and therefore, the water collected by this method is less contaminated as compared to the rainwater collected from the surface runoff (Thomas and Martinson, 2007). This project will focus more on this type of RWH.

1.3 Domestic Rooftop Rainwater Harvesting

Rainwater may be collected from any kind of roof. Tiled or metal roofs are easiest to use, and asbestos sheet roofs, especially when damaged, should not be used as poisonous asbestos fibres may be released into the harvested water (UNEP and OAS, 1995). This technology has been used where a more traditional reliable drinking water source has not been identified. In many developing countries, RWH is accomplished primarily through household rain catchment structures which are best suited for use in the villages in hilly areas, where people live in scattered huts or in small settlements. The technology also has been adopted in other areas, where polythene sheet covering is used as a rooftop catchment on thatched roofs. Storage of rainwater collected from rooftop catchments is typically informal. Buckets, basins, oil drums, etc. are commonly placed under the eaves in order to store water to supplement normal water supplies. Such water is rarely used for drinking purposes (UNEP and OAS, 1995).

Capturing, storing, and using rainwater where it falls has been known to conserve groundwater supplies; delay the need for costly water utility expansions by reducing dry spell water demand; slow down and even eliminate storm water runoff; and, reduce energy consumption compared to wells (Regional District of Nanaimo, 2013). RWH is listed among the specific adaptation measures that the water sector in Kenya and Africa at large needs to undertake, to cope with future climate change. At present, there is limited application of RWH, despite its high potential for alleviating the impacts of climate change on water security in many areas of Africa. In Kenya only 0.7 percent of the population in Kenya collects rain water (Ministry of Devolution and Planning, 2013). Inhabitants of Siaya County can benefit from RRWH projects to assist in the control of environmental disasters such as the negative impacts of flooding, landslides and soil erosion while at the same time harnessing the rainwater for use in households, agriculture, and industries as well as for livestock and environmental improvement.

1.4 Use of Geo-information Technology

Geo-information technology refers to the technology of measurement, analysis and graphic representation of earth phenomena using technologies such as GIS, Remote sensing and GNSS (eg. GPS). It involves the gathering, storing, processing, and delivering geographic information.

The global and geographic nature of climate systems has propelled geo-information technologies to the forefront particularly in the area of RWH. The value of geo-information technologies in water resources and Climate Change research cannot be overemphasized. Geo-information technology has been used to assess the impact of climate change to water resources by down scaling large-scale Global Climate Change Model (GCM) resolution to regional scale. Projected hydrological data has been used together with geospatial data such as Digital Elevation Model (DEM), river network and landuse map and a hydrologic model used to simulate future flood flow magnitude (Anam, n.d). A 2D hydraulic model, together with satellite imagery and population data can simulate the flood extent and subsequently map out the population affected and the economic loses of the projected floods. The outcome of such studies can be used to reduce water related disasters, enhance the resilience of water-related infrastructure and improve the resilience of communities in the context of climate change adaptation. Many assessments on the potentials of RWH using geo-information technology have also been done and are well documented. A large number of research- outputs, review and case studies have been reported. Athavale, (2003); Awulachew and Lemperiere (2009); Chao-Hsien and Yuchuan (2014); Cowden *et al.* (2008); Gould (1990); Kahinda *et al.* (2010); Pawar-Patil and Mali (2013); Waflar (2010); Fayez and Al-Shareef (2009); Mati *et al.* (2006); Nthuni *et al.* (2014) and Munyao (2010) among others, were useful in developing this study. All the past researches gave promising results and revealed the potential of RWH in different parts of the world.

1.5 Study Objectives

The broad objective of this study was to demonstrate the use of geo-information technology in assessing the potential of RWH. Specifically, this paper attempts to identify available water points in the study area, to assess and map the spatial distribution of the rooftop catchments for RWH and to develop a model for use in estimating rooftop rainwater potential.

2 METHODOLOGY

2.1 The Study Area

The research was based in Karapul Sub-location, located in Alego/Usonga constituency, Karemo Division in Siaya County, Kenya. It lies between Longitude 34°East and 34°30‘East and Latitude 00°30’ South and 00°20‘North. It is located in the western part of Kenya approximately 35 kilometres from the shores of Lake Victoria. Karapul Sub-location is one of the three sub-locations in Siaya Township location, others being Mulaha and Nyandiwa. Of the three Sub-locations, Karapul is the fastest growing in population due to its proximity to Siaya Town. The current population is estimated as 16,000 persons (KNBS, 2009), which is almost equivalent to the population of the other two sub-locations combined. It covers a spatial extent of about 14 square kilometers and the elevation ranges between 1,356.12- 1.392 metres at the highest points and 1,235 – 1.270 .83 metres above mean sea level. Temperatures range from between 21° C in the North East to about 22.5 ° C towards Lake Victoria.

The study area is a mixture of urban (towards Siaya town), and rural (away from the town) with different infrastructure. The main economic activities are mixed farming and trade. The majority of residents of Karapul Sub- Location collect their water for daily use from shallow wells, deep wells (boreholes) and streams. Most of the shallow wells are dug by individuals in their homes while the boreholes (deep wells) are dug by institutions after formal application and consequent approval by the Water Resource Management Authority (WRMA). Figure 2 shows the study area.

2.2 Key data sets

The key data sets identified for the study were Ortho-rectified imagery, rainfall data and existing water points. Ortho-rectified aerial photography of 40 cm spatial resolution provided the base map for extracting the rooftop catchment area. Human visual interpretation technique was adopted since the features were easily identified and digitized. The imagery is shown in Plate 1.

2.3 Existing Water Points

The official number of water points obtained from the Water Resources Management Authority (WRMA), Siaya County office was only five in form of boreholes (deep wells) to serve the residents. Existing records indicate that a borehole for a local primary school in the area failed while another experienced varying water struck levels from 35m, 60m, and then 80m. Each borehole is allocated a certain amount of water per day as indicated in Table 1.

The parameters considered for estimating the rooftop RWH potential for the study included: Roof Catchment area, Mean Annual Rainfall and Run-off Coefficient. The rooftop RWH conceptual model was developed to provide a framework for estimating RWH potential in the study area. This is illustrated in Figure 3.

The study strived to find a simpler approach to estimate the RWH potential within the study area as recommended by previous researchers such as Nthuni in Nthuni (2010).

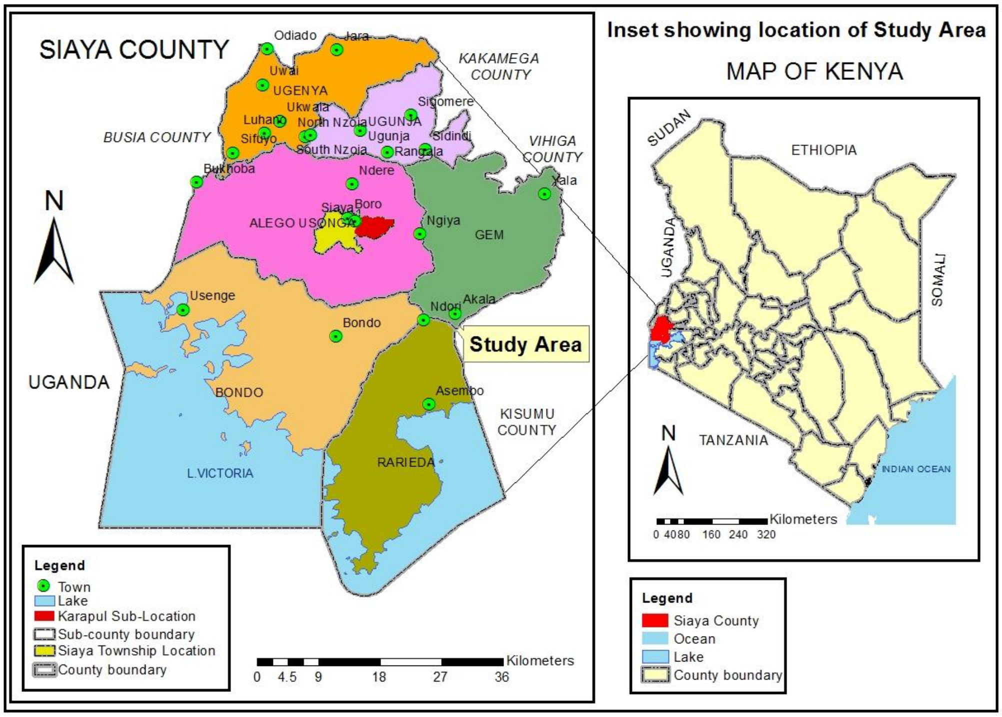


Figure 2: Location of the study area

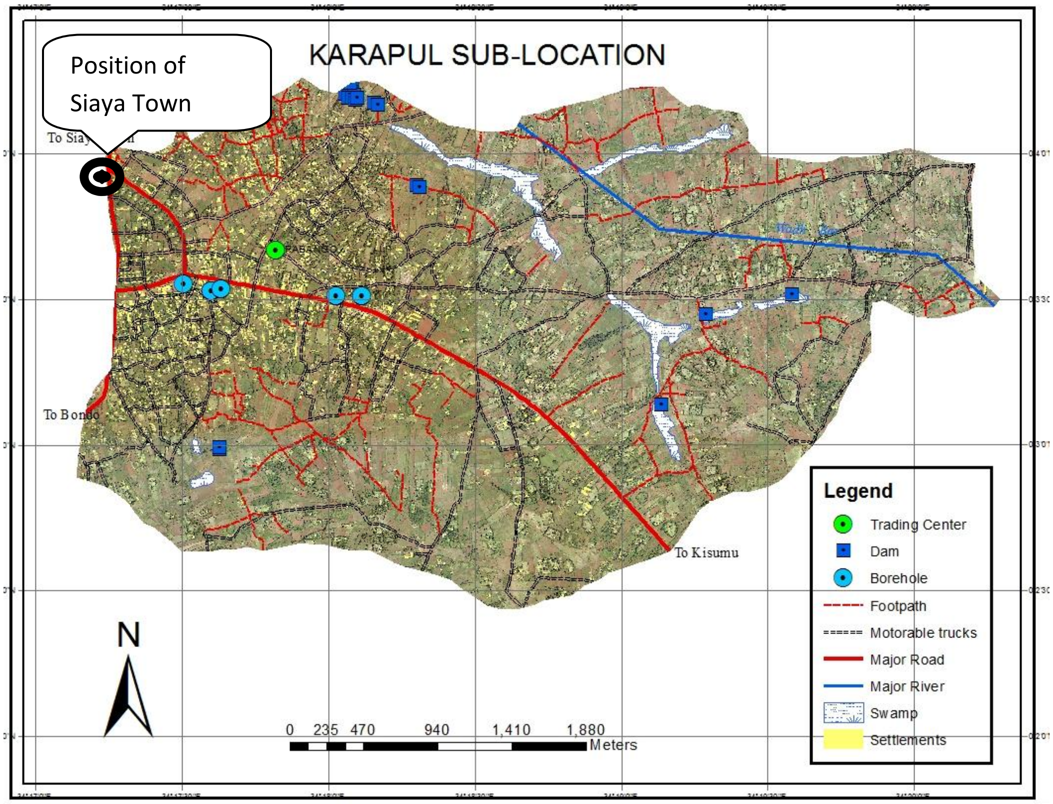


Plate 1: Ortho-rectified aerial photograph of the study area overlaid with existing water points and other vector data

Table 1: Existing water points- (boreholes) in the study area (Source: WRMA)

Applicant	Total Yield (m^3) per day	Alt_MSL	Total depth (m)	Water allocation/day (m^3)
Mwisho Mwisho Investment LTD	-	1325	65	30.000
Sussy Grand Hotel	-	-	-	-
Bama Hospital	5	1322	80	22.500
Karapul Filling Station	3	1311	80	30.000
Town Gate Plot	-	-	-	-

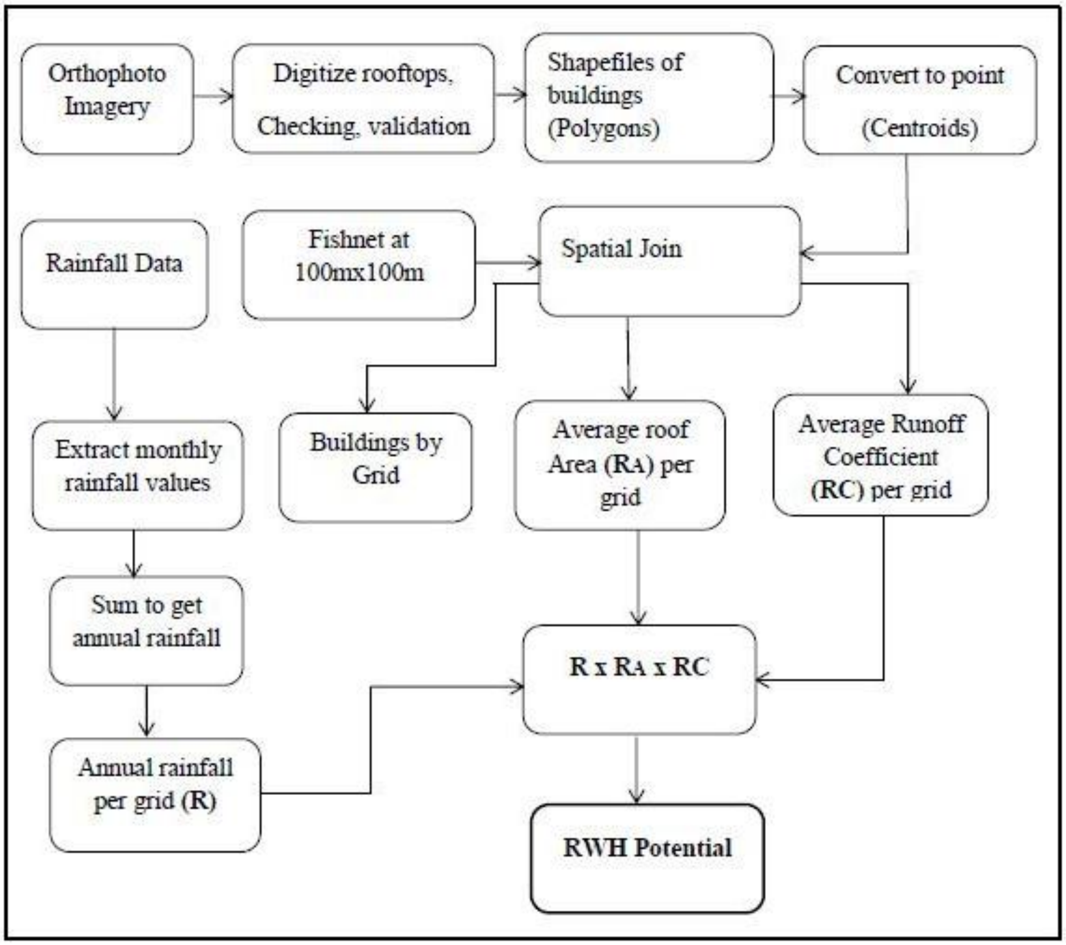


Figure 3: Conceptual model for implementation of RWH potential

2.4 Digitization of Rooftops

Three different classes of rooftop types were captured in the digitization process. These were, iron sheets, tiles and grass thatched rooftop types. Plate 2 shows enlarged sections of the imagery with digitized rooftops with A) showing urban side and B) showing rural influence respectively.

The average catchment area was then computed, based on the cell size.

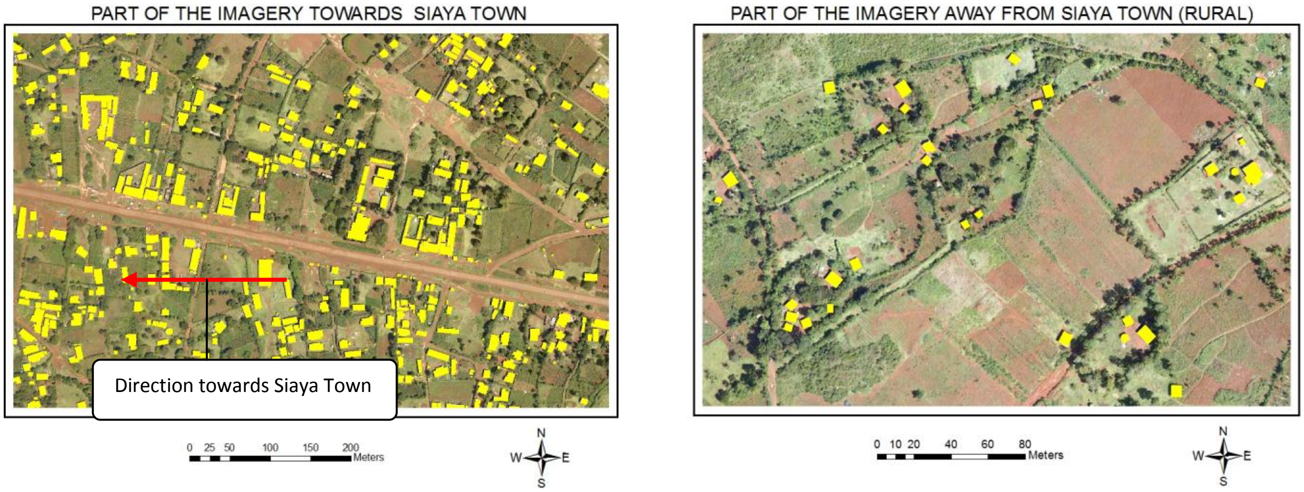


Plate 2: Sections of imagery with digitized roof tops: A) Urban influence; B) Rural

2.5 Roof Catchment Area (RA)

TWDB (2005) has defined roof catchment area as the “footprint” of the roof, i.e. the area covered by roof surface. It is calculated using Equation 1.

$$A = L \times W \,, \tag{1}$$

where: A is roof catchment area in m²; L is length of the roof and W is width of the roof.

2.6 Run-off coefficient (RC)

Runoff Coefficient (R_C) has been defined as the ratio of the volume of rainwater that runs off the catchment surface to the total volume of rain that falls on that particular catchment surface (Tripathi and Pandey, 2005). The model is illustrated in Equation 2.

$$R_c = \frac{V_t}{TR_t} \tag{2}$$

where V_t is the runoff volume and TR_t is the total volume of rain that falls on the roof catchment surface after time t respectively. *TRt* determined by multiplying the depth of rainfall after time t by the effective roof catchment area given by Equation 1.

For the purpose of this study, different Runoff Coefficient values of 0.85, 0.6 and 0.2 were assigned to the various roof classes according to their collection efficiency for iron sheet, tiled 0.6 and grass thatched roofs respectively. The areas without buildings adopted null (zero) values. The average Run-off Coefficient was then computed and used in the calculation of the Potential of rooftop RWH.

2.7 Mean Annual Rainfall (R)

The existing rain stations are located in Kisumu and Kakamega towns which are far away from the area of study and could not offer useful data for this study. The resolution, quantity and temporal aspects of the rainfall data were found to be critical for the study.

FEWS NET website (http://earlywarning.usgs.gov) provided rainfall estimates data for every 10 days (decadal) for the months of January to December. The data was for 13 years ranging from the year 2000 to 2012.

Estimated rainfall surfaces from the year 2000 - 2012 were used to extract mean monthly and mean annual rainfall. A gridded surface of 100m x 100m grid cell was generated ArcGIS environment to take care of the variations within the data sets and adopted as a basis for creating the models. The spatial extent was determined by the sub-location boundary of the study area. The model adopted is illustrated in Equation 3.

$$\sum_{k}^{n} R_i \qquad (3)$$

where: k is 2000; n is 2012 and R_i is estimated amount of rainfall received in mm during the year i

2.8 The Potential of Rooftop Rainwater Harvesting (Pt)

A local model combining, mean annual rainfall (R), rooftop run-off co-efficient (R_C) and average roof area (R_A) was used to estimate the rainwater harvesting potential. This is illustrated in Equation 4.

$$P_t = R \times R_c \times R_A \qquad (4)$$

where: P_t is potential of roof rainwater harvesting in cubic meters for a specific period of time *t;*
R is Average annual rainfall in mm; R_C is Coefficient of Runoff; R_A is average roof area in square meters.

3 RESULTS

3.1 Existing water points

According to the expected projection (Ministry of Water, 1988), Kenyans were not expected to walk for more than 500m to access water by the year 2010.

Results for proximity analysis performed on the existing official water points within the study area reveal that out of the 8,024 digitized rooftops, only 2,559 and 1,607 fall within the 500m buffer for boreholes and dams respectively. This is illustrated in Figure 4.

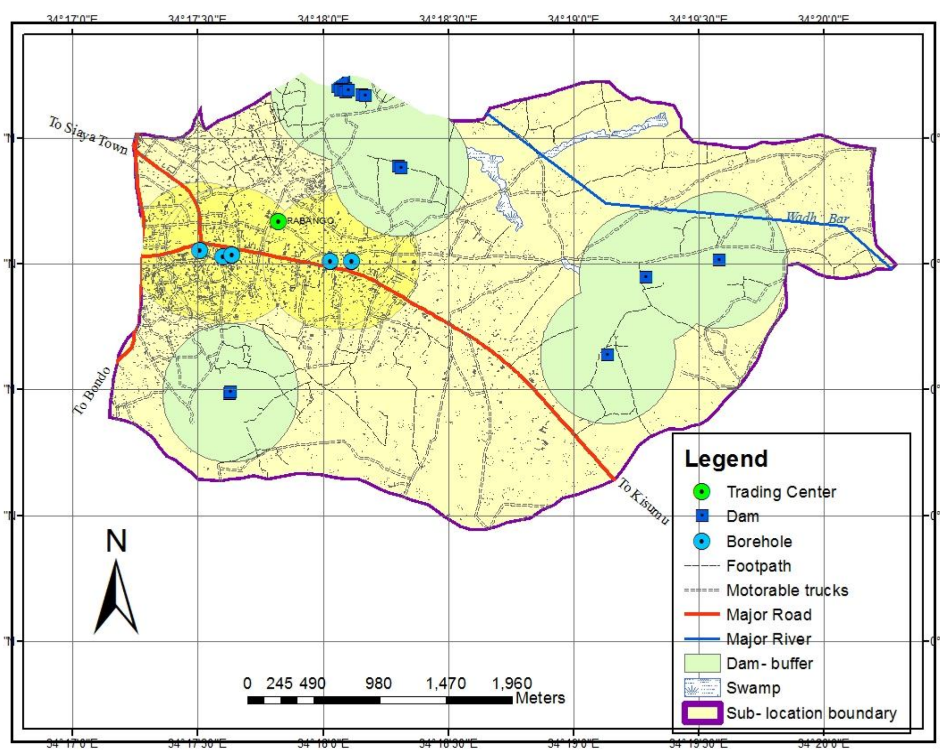


Figure 4: 500 m buffer on existing water points

3.2 Digitization of rooftops

A total of 8,024 rooftops were digitized in the ArcGIS environment comprising of 6,429 iron sheets, 1,503 grass thatched and 92 tiled roof tops respectively. The digitized rooftops were converted to points for ease of analysis before being used in the final model for estimating the RWH potential are shown in Figure 5.

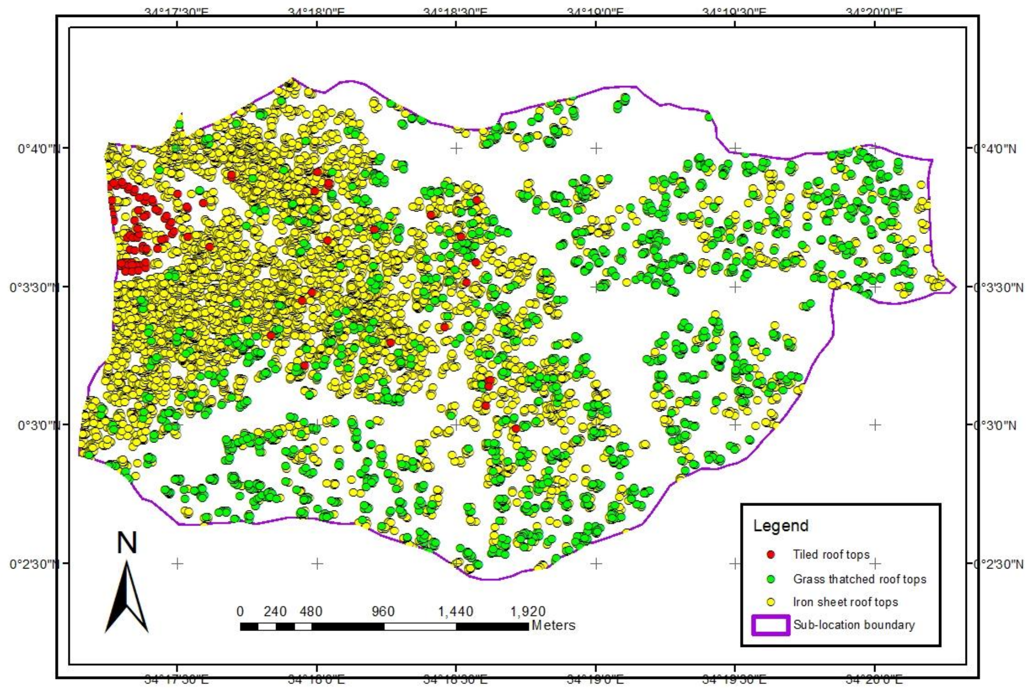


Figure 5: Map showing digitized rooftops

3.3 Mean Annual Rainfall

The rainfall variation is highest on the north-west part of the study area (1710mm-1722mm) and least on the eastern part (1689mm-1692mm). Moderate variations (1698mm-1704mm) are found mainly in the middle part of the study area. The rainfall variations were computed based on the 100m by 100m grid cell and are illustrated in Figure 6A and Figure 6B on the map and graph respectively.

3.4 Runoff Coefficient

A map of Coefficient of run-off was generated using average runoff coefficients for the different rooftops. The range of runoff coefficient is between 0-0.85. The results are displayed in Figures 7A and 7B. There are higher concentrations of runoff coefficient on the western side of the study area (0.75-0.85) than the eastern side except for a few patches to the extreme end on the eastern part. The regions with no (zero) runoff coefficient within the study area appear light grey on the map.

3.5 Total roof area

Out of the total of 8,024 digitized roof tops, iron sheet roofs took the majority catchment area (389,528.5321sqm.), taking 89%, followed by grass thatched roofs (35,755.1912sqm), taking 8%, while the tiled roofs were least with 13015.3281sqm occupying only 3% of the total digitized roof area.

Average roof area

The average area per grid cell of rooftops ranges from 3.24786 square metres for the lowest, to 766.0875 square metres for the highest average area respectively. The highest average areas are found on the western part of the study area whereas the lowest average areas are found on the upper, lower and eastern parts of the study area. The areas with zero values appear white on the map. The same is illustrated in Figures 8A and 8B

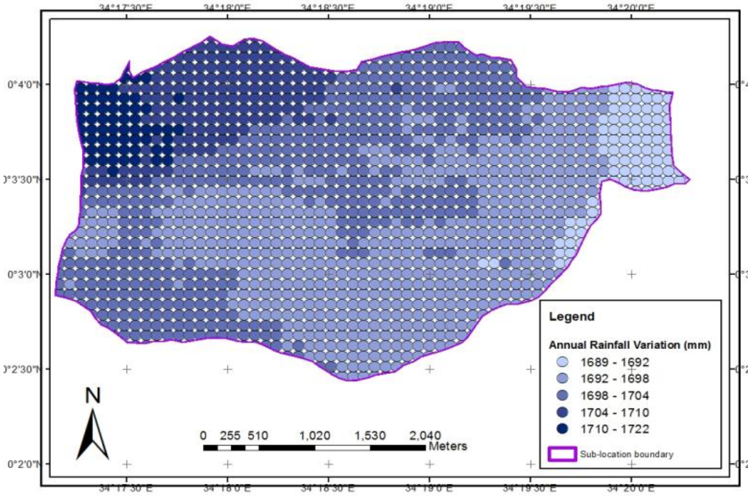


Figure 6a: Map showing mean annual Rainfall.

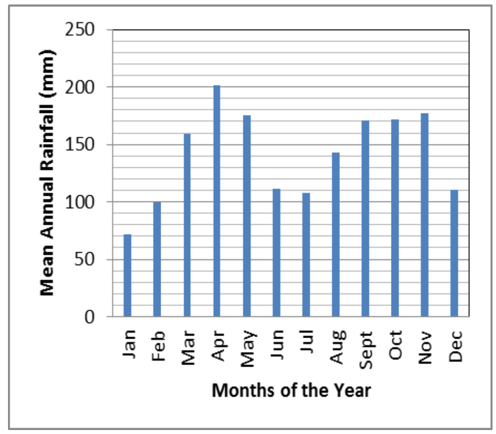


Figure 6b: Graph of mean monthly rainfall

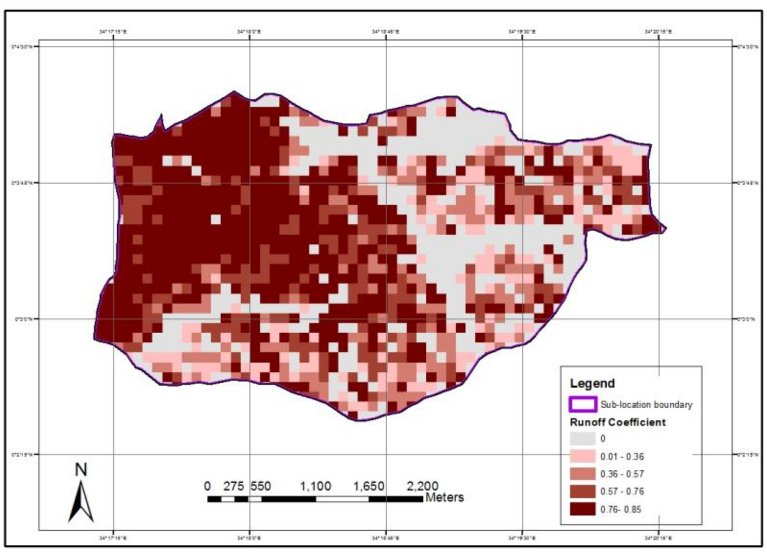


Figure 7a: Map of average Runoff Coefficient

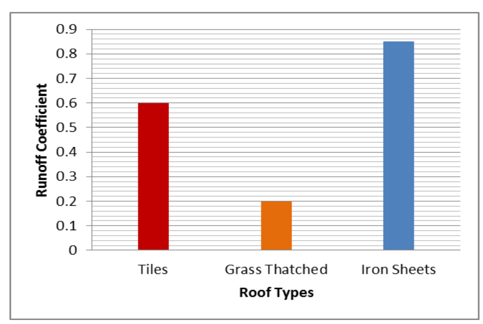


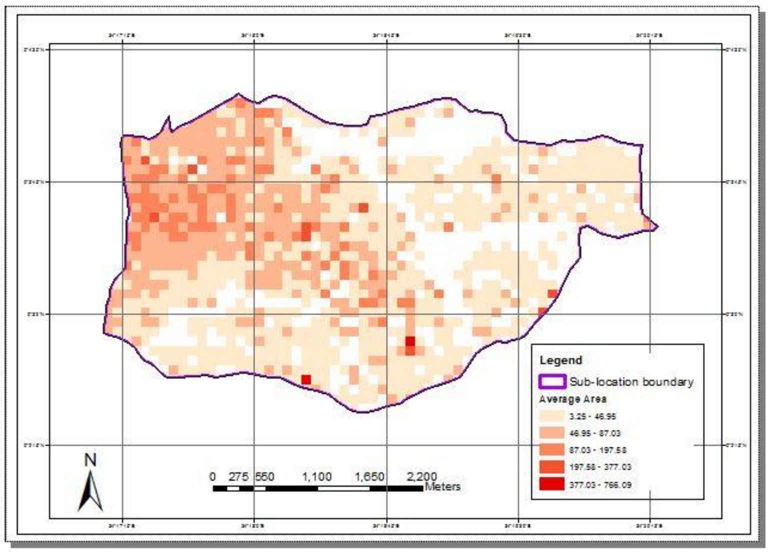
Figure 7b: Graph of average Runoff Coefficient

3.6 *Rainwater Harvesting Potential areas*

Figure 9A show the variation of RWH Potential over the study area. There are more dark red areas to the north-western part, and less on the eastern part, depicting high and low RWH potential respectively. The highest range is 100,000 – 1105694 litres on the western side, while the lowest range (0.000001- 10

000 liters) is found towards the eastern side of the study area. Areas without buildings adopted zero value. More of this is towards the eastern side of the study area. The estimated potential yields for the different roof types is illustrated in Figure 9B.

The percentage yields and the corresponding coverage are summarized in Table 2.



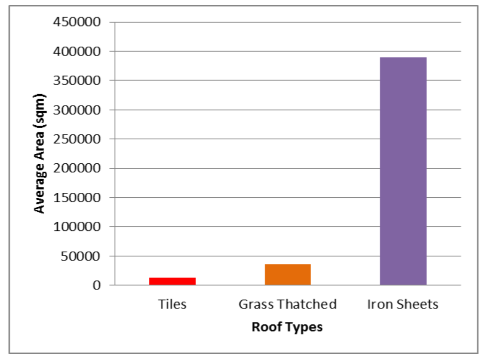
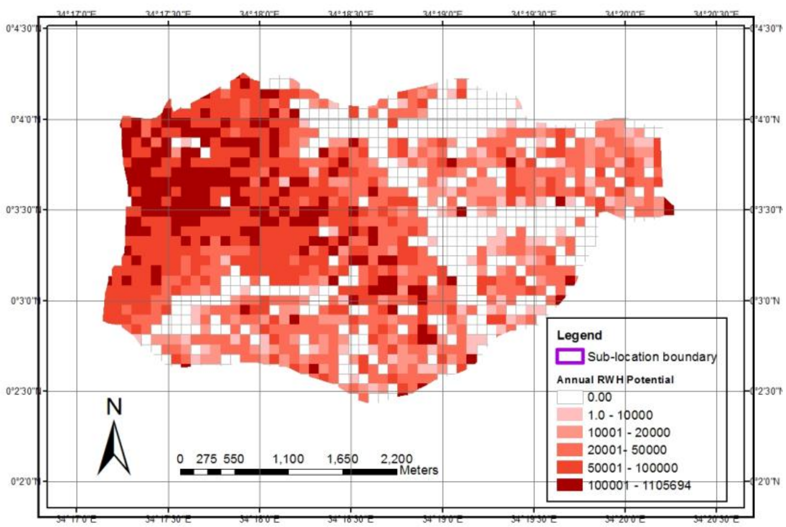


Figure 8a: Map of Average roof Area

Figure 8b: Graph of Average Area



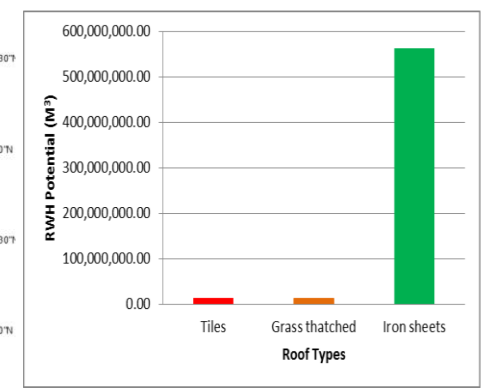


Figure 9a. Map of Mean annual RWH Potential

Figure 9b. Estimated potential yields

3.7 Correlation between Catchment Areas and RWH Potential

By using Geostatistical analyst tool and Inverse Distance Weighting (IDW) on roof area by type, it was observed that areas with high rainwater harvesting potential correspond to areas with high building density as illustrated in Figure 10. The high density areas are concentrated on the areas towards Siaya town located to the north-west of the study area while low density areas are found to the east with rural influence.

Table 2: Summary of final results

	Runoff Coefficient	Estimated Yield (m^3)	Percentage Yield	Coverage (sqm)
Tiles	0.6	13,276	2%	13,015
Grass thatched	0.2	12,157	2%	35,755
Iron sheets	0.85	562,869	96%	389,529
Total Yield		588,301		

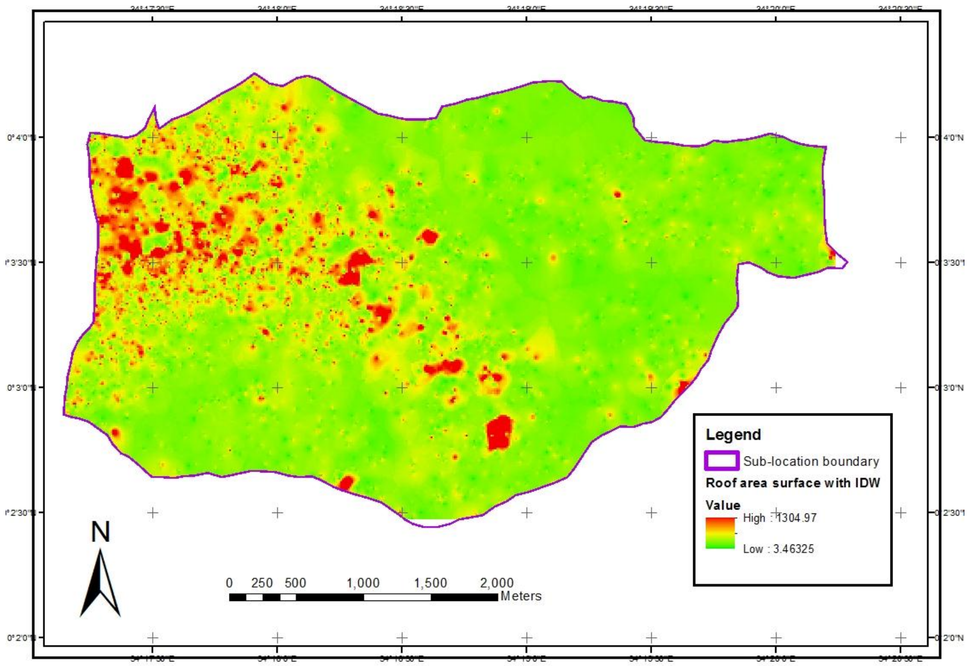


Figure 10: Geostatistical analysis surface of roof area by type.

3.7.1 *Potential yield versus demand*

Per capita water demand and availability were computed in order to further assess the adequacy of water in the study area. The computation was done based on the following assumptions:

- Total population = 14,000 persons (2009 census)
- Daily minimum water requirement per person (in rural areas) = 20 litres (WRMA)
- Water requirement for the population per day (Wd) = (20 x 14 000) = 280,000 liters = 280 m^3.
- Average water yields for each borehole per day = 4 m^3 = 4,000 litres
- Number of water points (bore holes) = 5 (Table 1)
- Water availability (Wa) = 5 x 4,000 = 20,000 litres
- Per capita water availability = (4 x 5 ÷ 14,000) = 1.4286 litres (0.0014286 m^3).
- Potential of RWH for the study area = 588,301 m^3 per year (Pt) (Table 2)
- Assuming that one year = 366 days (Dy), water demand per day is given by Equation 5

$$\frac{Pt}{Dy} = \frac{588{,}301{,}000}{366} = 1{,}607{,}379.781 \text{ litres per day} \quad (5)$$

Water surplus (Ws) = RWH potential (Pt)/day + yield from boreholes (Wa) – daily water requirements (Wd)

$$Ws = Pt + Wa - Wd \quad (6)$$

Ws = (1,607,380+20 000) – 280,000) = 1,347,380 litres per year

4 DISCUSSION

Proximity results in Figure 4 indicate that the majority of Karapul residents are disadvantaged in terms of water accessibility. Further more water from the existing dams is not suitable for drinking and can only be used for agriculture and for watering animals. Shallow wells in the study area are not recorded by the relevant authority, an indication of existing data gaps.

Results from this work have shown that 89% (389,528 km²) of the area of study has a high potential for RWH. The total estimated potential for the area of study was 588,301 m³ of rain water, with iron sheet rooftops accounting for 95.6% (562,869 m³) while grass-thatched rooftops accounted for 2.3% (13,276 m³) and tiled rooftop accounted for 2% (12,157 m³) of the potential as illustrated in 9.

Mean monthly Rainfall for 2000-2012 from January to December is very low (75mm-200mm) as shown in Figure 5B.Thus, there's need to augment with other water sources and also optimize on RWH during the rainy season. The prospects of borehole drilling are also very poor in the study area as mentioned elsewhere in this study, hence there's need for an alternative source of water for Karapul sub-location inhabitants.

Analysis of Run-off Coefficient reveal that the rooftops with iron sheets ranked highest followed by tiled roofs, while the grass thatched roofs ranked least. This is an indication that the estimated collection efficiency for the various roof types varies and this has a great influence on the outcome of the estimated RWH potential.

The results show that the RWH potential for iron sheet roofs is highest with 562,869 m^3 followed by grass thatched with 13,273 m^3 while tiled roofs has a potential of 12,157 m^3 .This is mainly because as much as the tiles have a runoff coefficient of 0.6, they were few in numbers hence the performing dismally in the analysis compared to the grass thatched roofs. These comparisons are summarized in Table 2.

From the geostatistical analysis results of roof area by type in Figure 10, the study has also shown that rooftops with large catchment areas are more privileged to harvest more rainwater. These are mainly educational and health institutions within the study area, an indication that such institutions could be sensitized and/ or assisted to install rainwater harvesting systems to save on water costs.

From the computations from Equations 5 and 6, it is clear that the per capita water availability is 1.4286 litres which is 18.57 below the daily water requirement of 20 litres per person hence very much inadequate. The results from existing boreholes with water demand per capita indicate that there is serious need to explore other alternative water sources. From the study, the potential of RWH is 588,301,000 litres which gives a water surplus of 1,347,380 litres per year and this can comfortably satisfy the water demand as well as be put to other uses.

5 CONCLUSIONS

This paper has documented the successful use of geo-information technologies in estimating the rainwater harvesting potential in Karapul sub-location of Siaya County, Kenya. The study found that this area, with average per capita water demand of 280m^3, can easily realize a per capita supply of 1,607m^3 from RWH. The results of this study should interest water supply planners and others who are interested in people's water security, since such security also impacts on food security and improved health.

6 RECOMMENDATIONS

It is recommended that for further study, the following should be considered:

- All the existing wells should be officially mapped by the responsible authority to avoid information gaps.
- The use of existing shallow wells to act as storage for rainwater could be explored.

- Geological studies to investigate the reason for drying wells and the fluctuating water struck levels.
- A model for calculating tank sizes could be developed and used to assist the residents who will adopt the RWH as an alternative water source.
- Roofing materials and roof conditions could be taken into consideration and health expert advice sought to enhance water quality and also to improve on the results.
- It is also recommended that the residents for Karapul sub-location should be sensitized to embrace RWH as an alternative to fresh water for domestic use.

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Paper No: 02
Page 27 - 33
Sub-theme: GIS in sustainable development

Characterization of watersheds in mountainous areas: A case of Mount Elgon, eastern Uganda

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Abstract:

Mount Elgon is a unique cross-border ecosystem between Uganda and Kenya. It is an important area for biodiversity and a ‘water tower’ for Uganda and Kenya. The Mt. Elgon ecosystem consists of several watersheds that serve many functions. However, the different functions are under an increasing threat of loss due to human activities. Promotion of sustainable ecosystem management requires detailed, accurate and up-to-date resource information, which is of benefitfor monitoring ecosystem changes to guide management decisions. This study aimed at characterizing watersheds in the Mt. Elgon ecosystem so as to enhance their sustainable management. The objectives were to delineate watersheds in the Mt. Elgon ecosystem and characterize the delineated watersheds. This was accomplished through hydrologic modelling and spatial analysis in Geographic Information Systems using several GIS datasets. The results show that Mt. Elgon region has a very wide stream network that is associated with a large number of watersheds varying in characteristics such assize, slope and elevation. It is recommended that these and other watershed specific characteristics be taken into consideration when designing interventions for sustainable management of these watersheds.

KEY WORDS: Watersheds, Sustainable Management, Mountain Elgon, Uganda

1 INTRODUCTION

Mount Elgon is a fragile cross-border montane ecosystem astride the Uganda and Kenya border. It is not only an important area for biodiversity but also a water tower for Uganda and Kenya serving as a catchment for the drainage systems of many lakes and rivers in Eastern Africa (IUCN, 2005).As a water tower, the Mt. Elgon ecosystem consists of several watersheds which are, for purposes of this study, areas of land that drain rain water into one location such as a stream, lake or wetland with various uses. These are resulting in unprecented pressure on the ecosystem. This is despite the fact that there has been increased vigilance with regard to management of the ecosystem, especially Mt. Elgon National Park which represents a significant proportion of the mountain ecosystem. The key threats arise from land use change and changes in lifestyle of local people among other drivers. Over the past 50 years, forest cover and the tree density in the Mount Elgon ecosystem have, for example, decreased due to extensive clear felling of plantations by large timber processing companies. There is also uncontrolled utilization of other forest products such as bamboo. It is therefore important that further efforts be put into management of the ecosystem, especially the watershed.

Promotion of sustainable ecosystem management requires detailed, accurate and up-to-date resource information (Coppin *et al.*, 2004; Odada *et al.*, 2009). This information is useful for monitoring ecosystem changes to establish linkages between policy decisions, regulatory actions and subsequent ecosystem-use activities (Lunetta *et al.*, 2006). However, information on such resources, is often either lacking, inadequate or not to update. This curtails the effective management of such fragile ecosystems in the montane zones. In the Mt. Elgon ecosystem, information about watersheds is inadequate. Watershed delineation offers the opportunity to characterize and investigate what goes on in one portion of the ecosystem compared to another.

This study was therefore aimed at characterizing watersheds in the Mountain Elgon ecosystem so as to enhance their sustainable management. The specific objectives were to: (i) delineate watersheds in the Mountain Elgon ecosystem and (ii) characterize the delineated watersheds. The research question under consideration was: What are the characteristics of the watersheds in Mount Elgon ecosystem? The acquired detailed, accurate and up-to-date information about watersheds in the Mt. Elgon ecosystem is hoped to play a vital role in enhancing sustainable management of watersheds through guiding management actions ultimately contributing to the integrity of the Mt. Elgon ecosystem.

2 METHODS

2.1 Study Area

The study was carried out in the region and covers five major administrative districts in the region which include Mbale, Manafwa, Bududa, Sironko, Kapchorwa and Bukwo districts (Figure 1). Mt Elgon is an important trans-boundary ecosystem that is rich in biodiversity, distributed across diverse habitats over a large altitudinal gradient. The Mt. Elgon ecosystem is characterized by montane forests, grasslands, bamboo and alpine vegetation. It supports large human and wildlife populations and is an important watershed feeding the Malaba, Sio, Turkwell Rivers, as well as Lake Turkana (in Kenya), the Lake Victoria Basin (Uganda and Kenya) and the Nile River Basin (via Lake Kyoga in Uganda). The Mt. Elgon ecosystem is therefore of high importance at local, national, regional and global levels. Like other mountain ecosystems, the Mt. Elgon ecosystem is important for its contribution to climate moderation.

The sample districts were selected because of their location in relation to Mt. Elgon where some of them are in the high elevations while others are in the lower elevations. The local population in these areas is also heavily dependent on the mountain and its resources. This area has the potential for the presence of a high number of watersheds. With a human population of about two million and annual population growth rate of up to 4%, the multiple functions of Mt Elgon ecosystem are under increasing threat from human activity (MWE, 2013; UNDP, 2013).

2.2 Data Management

Three datasets were used in this study and these included the Uganda elevation grid dataset at a spatial resolution of 110m x110 m, Uganda administrative boundaries shape file and the shape file of the study districts. Data analysis was done in ArcGIS version10.0. An elevation mask covering the study districts was created using the shape file of the study districts.There are several methods for delineating watersheds including automatic and manual delineation, but the automatic digital elevation model based delineation was chosenover the manual delineation approach becausethere weretoo fewunderlying data for the desired accuracy. This would make manual delineation inappropriate. In order to accomplish automatic delineation of watersheds, the hydrology tool in the ‘Spatial Analyst Tools’ of the ArcToolbox was used. This involved filling of sinks in the elevation mask followed by creation of flow direction and flow accumulation surfaces which were then used to develop a stream network. Subsequently the delineation of watersheds was based on pre-determined pour points. An ArcGIS imagery base layer was used in validating the stream network before delineating the watershed. The surface tool was then used to generate a slope surface in percentages from the elevation mask grid. The zonal tool within the same toolbox was thereafter used to compute zonal statistics (including area, mean slope and minimum, maximum and mean elevation associated with each delineated watershed so as to characterise each watershed.

Figure 1: Study districts including Mt. Elgon in eastern Uganda

3 RESULTS

3.1 Stream Networks and Watershed

The results show that the Mt. Elgon region has a very extensive stream network (Figure 2). It is clear that most of the streams originate from Mt. Elgon. It is, indeed considered a 'water tower' as it serves a catchment function for many lakes including Victoria, Turkana and Kyoga as well as rivers including Suam/Turkwel, Lwakhakha, Sipi, Malaba, Sio-Malakisi, Nzoia and Soloko (IUCN, 2005). This supports the present findings.

In association with the extensive stream network, the results show the Mt. Elgon area as consisting of several watersheds. Up to 15 watersheds were delineated (Figure 3). The delineated watersheds show the boundaries of the discrete areas of the bigger Mt. Elgon ecosystem that can be analysed to understand the distinct watershed characteristics and behaviour vital for the management of the watersheds. This relatively high number of watersheds was driven by the flow accumulation layer upon which the creation of pour points was based. The pour points were located at points that exhibited high flow accumulation values indicating that they were acting as collection and or receiving points for accumulation from different parts of the region. The region from which they received accumulation comprised the watersheds associated with each of the pour points.

3.2 Characterisation of Delineated Watersheds

The delineated watershed exhibited various differences in characteristics. In terms of extent or area (Figure 4), the delineated watersheds in the Mt. Elgon region ranged between about 40 and over 600Km^2.

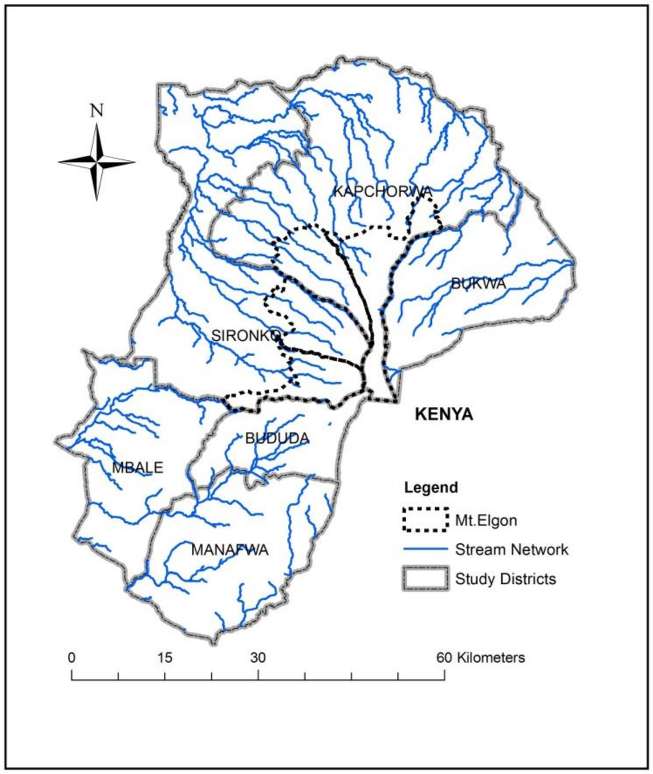

Figure 2: Stream networks in the Mt. Elgon region in Eastern Uganda

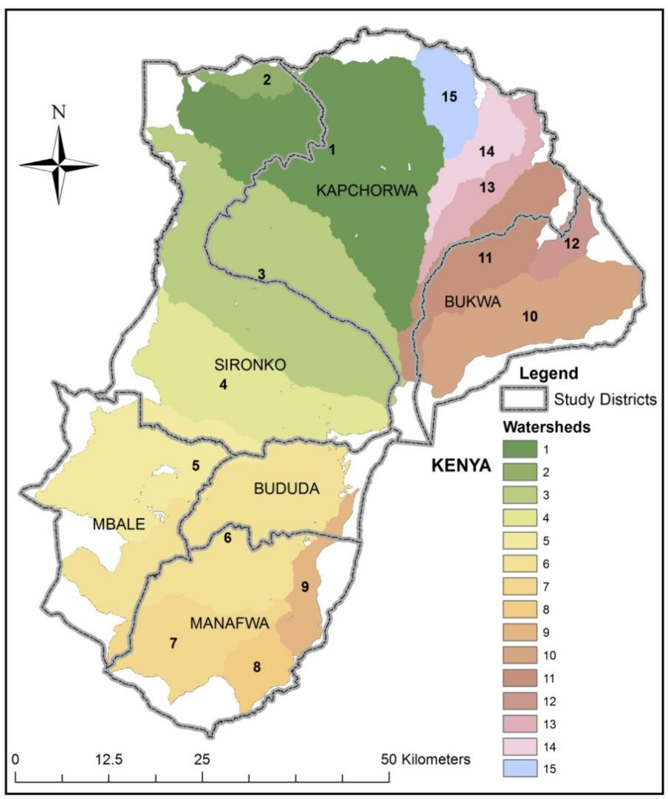

Figure 3: Watersheds delineated in the Mt. Elgon region of Eastern Uganda

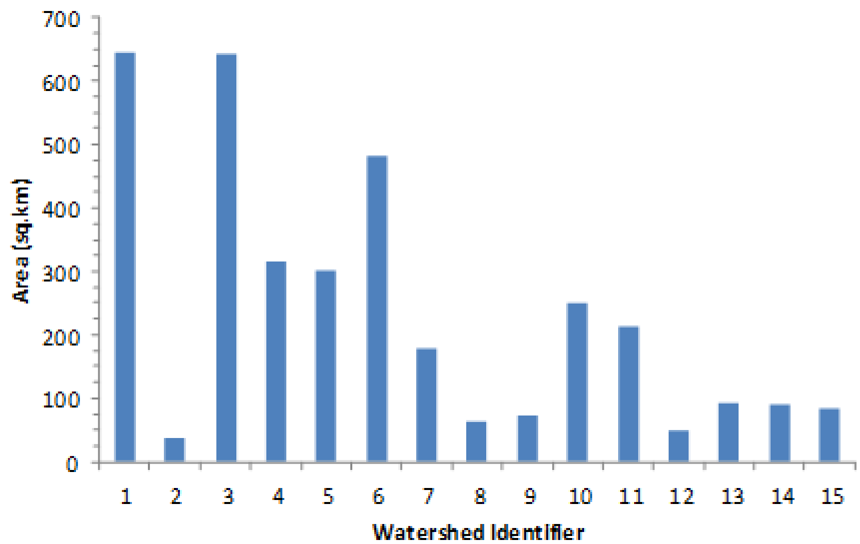

Figure 4: Characterisation of delineated watershed in terms of extent (area)

There is a wide variation in area of the watersheds with the smallest watershed (Watershed 2) measuring 39 km^2 while the largest watersheds (Watersheds 1 and 3) measure 644 and 642 km^2 respectively. The average size of watershed in Mt. Elgon region is 234.5 km^2.

The watersheds vary greatly in elevation (Figure 5). The minimum elevation ranges from 1046 m in watershed 1 to 1558 m in watershed 10 while the maximum elevation ranges from 1075 m in watershed 2 to 4268 m. On the other hand, the mean elevation among the watersheds rages from 109 m in watershed 2 to 2429 m in watershed 10.

The watersheds also exhibit variability in slope from one to the other (Figure 6). The mean slope ranges from 0.69% in watershed 2 to 24.72% in watershed 12.

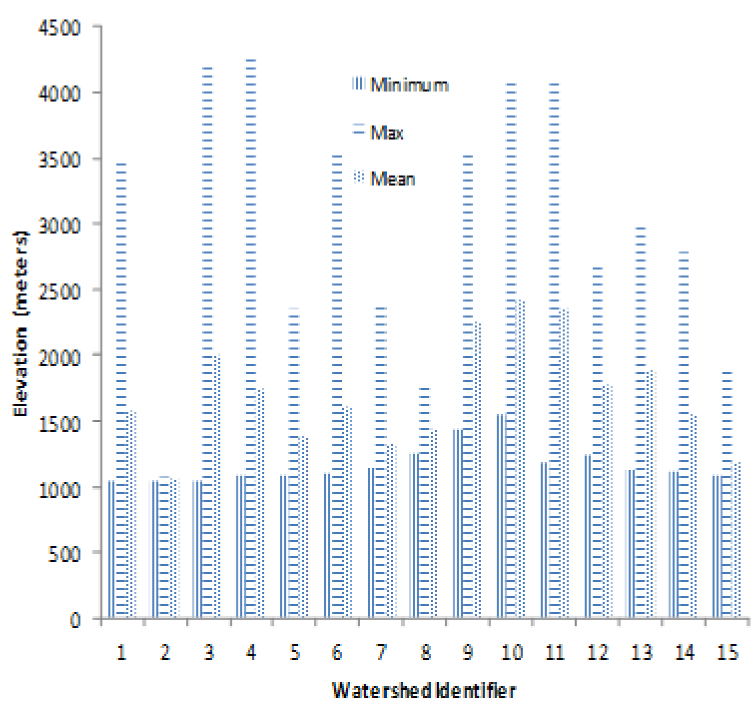

Figure 5: Characterisation of watershed in terms of minimum, maximum and mean elevation

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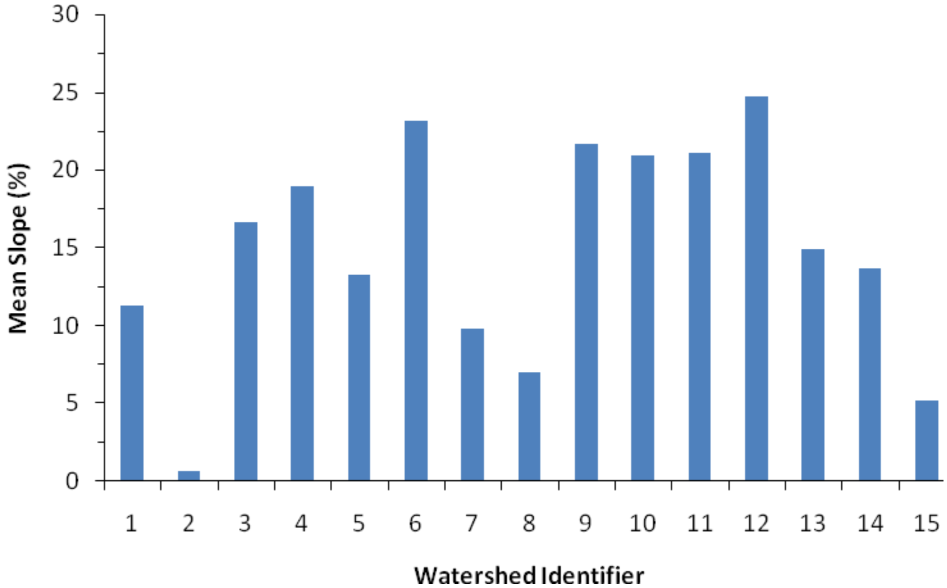

Figure 6: Characterisation of delineated watershed in terms of mean slope

3.3 Implications of the Characterisation

The characterisation of watershed has important implications with regard to their management. In terms of utilisation, size of the watershed has an influence on how easily it can be degraded. On the other hand, very steep slopes may indicate watersheds that can be susceptible to degradation activities like soil erosion. The steep slopes may also be good in watershed management as they may limit access, especially for people, who would otherwise degrade the watershed. Steep slopes and high elevations are also associated with very fragile conditions. An example, is the case of watershed 6 (Bududa) versus watershed 5 (Mbale) where the higher mean slope and mean elevation in Bududa could imply higher vulnerability to landslides. Watershed 6 would, therefore, require management interventions like tree or green vegetation establishment so as to have the slopes stabilised so as to avoid disasters such as landslides. The characterisation accomplished in this study, which incorporates slopes and elevation, can be augmented with other characteristics of watershed such as land use/land cover, population densities, rainfall distributions and soil conditions in order to reach concrete management decisions. However, since the resolution of elevation datasets used in delineating watersheds influences the delineation process (Cambareri and Eichner, 1998), efforts should always be made to acquire elevation datasets of higher resolution for delineating watersheds.

4 CONCLUSION AND RECOMMENDATIONS

Based on the results, we conclude that Mt .Elgon region has an extensive stream network that is associated with a large number of watersheds that vary greatly in characteristics such as watershed size, slope and elevation. It is recommended that where watersheds are under increasing pressure of degradation from human activities, watershed delineation and characterization be adopted. These approaches provide up-to-date information upon which interventions for the sustainable management of specific watersheds are designed. However, it is hoped that better characterization can be achieved if the elevation data on which the watersheds are delineated area at a higher resolution.

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Paper No: 03
Page 35 - 50
Sub-theme: GIS in sustainable development

Effects of increased land use changes on runoff and sediment yield in the upper river Nzoia catchment

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Abstract:

River Nzoia originates from three water towers namely Nandi hills, Cherengany Hills and Mount Elgon. With increased anthropogenic activities in Nzoia river catchments, land cover has continuously been altered. This scenario has resulted into increased quantity of physical parameters in runoff among them, sediment load and turbidity, during rainy season. This study modelled effects of increased land use changes on runoff and sediment loads. Digital Elevation Model, spatial soil data, sediment loads and meteorological data for the year 2000 to 2012 were the main input into the Soil Water Assessment Tool (SWAT 2012) model for calibration and validation. Data from 1990 to 2014 was as well collected for comparison purposes. Arc GIS 10.1 was used for spatial data analysis. Supervised Land classes were processed from satellite images for the year 2000 and 2010 using ENVI 4.7 software. The upper river catchment had an area of 10, 859 km^2 compared to 12,904 km^2 for entire watershed, has 27 catchments, and 36 Hydrologic Response Units. The sediment load during period of study went as high as 3767.9 tons/month in the projected year 2030 compared to 1400.79 tons /month in the year 1990. The study also revealed that 51% of rainfall received converted to surface runoff in the year 2014 compared to 44% as at the year 2000 implying reduction in base flow and ground water recharge. A 3.1% forest cover, 2.2% wetland, 15.3% tea, 5.5% sugarcane were destroyed for human settlement. Ground Water Delay, a lag between when water exits the soil profile to shallow aquifer was 31 days. In conclusion man's activities have put pressure on land altering its use. This has changed hydrology of the catchment putting sediment loads on increase. Threat for further increase in sediment load is real, base flow is diminishing as well as ground water recharge. Policies should be guided by this work to enhance good land use.

KEY WORDS: Catchments, modelling, sediments, runoff

1 INTRODUCTION

The cost of treating water for high volume abstractors is now higher than in the past years. This is not only due to higher costs of coagulants but as a result of degradation in the catchments resulting to poor quality of raw water abstracted. This is observed within the river Nzoia catchment especially where sediment loads and turbidity have increased to uneconomic limits in rain seasons. This study aims to close the gap between the expectations for a healthy watershed and realities that come with poor quality water in the river, and further points out areas that will guide policies to better management especially the Water Resources Users Associations (WRUAs).

1.1 Objectives

The goal of this research was to study the effects of land use change on runoff and sediment yield in the upper river Nzoia catchment using SWAT. The study determined in particular the relationship between the catchment use over time and sediment yield in the river as well as future scenarios.

1.2 Specific Objectives

To evaluate the runoff and sediment loads within river Nzoia as a result of increased land use changes.

1.3 Study area

The study area covered the upper part of river Nzoia. This majorly focused on the watersheds of the water towers that are drained by the trunk of river Nzoia.

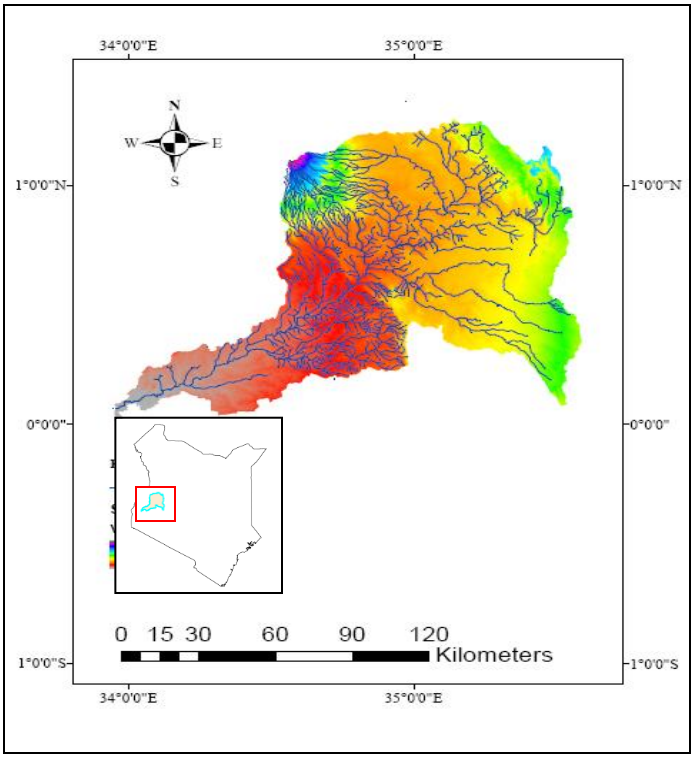

Figure 1. Deleneated study area

From Figure 1, Nzoia River Basin lies between latitudes 1º 30'N and 0º 05'S and longitudes 34º and 35º 45' E. The Nzoia River originates from Cherengany Hills at a mean elevation of 2300 m Above Sea Level (ASL) and drains into Lake Victoria at an altitude of 1000 m ASL. It runs approximately South-West and measures about 334 km with a catchment area of about 12,903 km^2, with a mean annual discharge of 1,777 x 106 m^3/year (WARMA, 2006). The study covers the upper part with an average area of 10,859 km^2 which is 84% of the river Nzoia catchment. It predominantly lies in 34º and 36º E and 0 to 1º N. The study shall focus on the highlighted part shown below the map of Kenya.

1.4 Topography

Nzoia River flows from the western side of the Elgeyo Escarpment (Sergoi, Sosiani and Kipkelion tributaries) and the Cherangani Hills (Chepkotet and Kaisungur tributaries) from an elevation of approximately 2,286 m above sea level. The tributaries, which flow from the high slopes of Mount Elgon attain maximum elevation in the river's basin and is estimated at about 4,300 m above mean sea level. The tributaries in Mt. Elgon include Kuywa, Sioso, Ewaso Rongai and Koitobos.

1.5 Rainfall

Highest rainfall occurs in the north-western parts of the basin, which gradually reduces in the south-eastern parts. The north-western part of the basin drained by the streams Malaba, Malikisi and Alupe receives an annual rainfall of 1682 mm with little spatial variation. In Sio sub-basin to the southeast the rainfall varies from 1802 mm in its upper catchment to 1589 mm in its outfall reaches. The Nzoia basin with its vast catchment witnesses a large variation in rainfall from a minimum of 1076 mm in the catchment of the left bank tributary Kipkarren to a maximum of 2235 mm in the south-western edge of the catchment.

1.6 Hydrology

The stretch of the longest Nzoia River channel is about 355 km, with a mean discharge of 118 m^3/s. However, the flow regime of the Nzoia is varied and is occasionally as low as 20 m^3/s, with extreme floods that may surpass 1,100 m^3/s. The discharge varies from a low flow of 2.8 m^3/s to a 100-year flood flow of 930 m^3/s. In its upper reaches from Km 135 to 257 in the highlands, the river flows in a slightly meandering V shaped valley. The width of the channel is about 40 m and bed gradient 1 in 240.

2 LITERATURE REVIEW

Sediment is ranked as the number one pollutant of surface waters in most parts of the world. The same applies to the case of Kenya. Excessive sediment in surface water causes problems to aquatic life, drinking water treatment plants, industry, Agriculture, and other users of the resource (Vellidis *et al*., 2003).

Water quality encompasses the physical, chemical and biological characteristics of water. Both natural water quality and human induced changes in quality are important consideration in river basin management. Sediment load is a geologic term referring to the solid matter carried by a stream or rivers (Strahler and Strahler, 2006). Erosion and bed shear stress continually remove mineral material from the river bed and banks of the stream channel, adding this material to the regular flow of water in a given reach.

Furthermore, at a global scale, Suspended Solid (SS) concentrations in many rivers have dramatically changed in recent years (Walling, 2006). Existing evidence suggests that natural sediment loadings have been substantially exceeded in many catchments in the UK, particularly since World War II (Evans, 2006).

Sediment load delivered to watercourses originate from a number of upstream primary and secondary sources, including cultivated fields and bank erosion (Collins *et al*., 1997). The land use part relates to the human activity or economic function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of the earth (Lillesand and Kiefer, 2000).

According to Githui (2009), there has been an increase of population over the last three decades with an estimated population density of about 221 persons/km^2 in 2002 within the River Nzoia basin. She also reports that the forest cover has decreased markedly from 12.3 to 7%, especially for the regions in the northwest and south of the catchment. This could be attributed to the cutting of trees in the forests for various uses such as firewood, timber and clearing for agricultural purposes. In contrast, the agricultural area is seen to have increased over the years from 39.6% in 1973 to 46.6% in 1986/1988 and to 64.3% in 2000/2001. Her study did not bring out evolution of land use in terms of settlement and built up area.

Runoff can be described as the part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating after a storm event. According to the U.S. Geological Survey (USGS), runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers.

From past research, the main anthropogenic activities increasing sediment supply to watercourses include, Changes in agricultural practices, for example, increased areas of arable cultivation, leading to greater areas of bare exposed soil susceptible to erosion by rainfall (Greig, *et al*., 2005), and mechanized farm practices which compact the soil and increase runoff and soil erosion (McMellin *et al*., 2002: Bilotta *et al*., 2007)

3 MATERIALS AND METHODS

3.1 Data and data sources

The Table 1 below shows the data that was used in the modeling study. Different data sets were obtained from different sources and processed prior to use. Processing entailed filling gaps or use of surrogate techniques to arrive at missing parameters.

3.2 Climate data

Climate data is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Climate data was obtained from Kenya Meteorological Department which was captured on monthly basis as well as weather stations within the catchments available at Water Resource Management Authority (WARMA) for a range of year 2000-2012. Climate data was an input in the model for calibration and validation purposes.

Table 1: Data format and sources

S/NO	Data Type	Data Format	Source
1	Climate Data	Daily data in excel sheet	Water Resource Management Authority- Kakamega Office
2	Stream Flow Data	Monthly data in excel sheet	Water Resource Management Authority- Kakamega office
3	Soil Data	Shape file	Kenya Soil and Terrain database. KENSOTER),http://www.isric.org /projects/soter-kenya-kensoter, 1mx1m
4	Digital Elevation Model	Raster file	Advanced Spaceborne Thermal Emission and Reflection, Radiometer (ASTER) Global Digital Elevation Model (GDEM) a 30m by 30m, https://wist.echo.nasa.gov
5	Sediment load data	Monthly data in excel sheet	Water Resource Management Authority- Kakamega Office
6	Land use data		This was Downloaded from http://glovis.usgs.gov as Tiff file

3.3 Stream flow data

This refers to the volume of water passing a given point of the river in m^3/day. It usually varies dependent on the rainfall intensity to particular catchment soil parameters, slopes, among others. This was obtained from WARMA offices in Kakamega). The span of years of interest is 2000 to 2012. Discharge data collected from the ground was in terms of months. The data was collected in m^3/sec and used for analysis as recorded without any alteration. The existing river gauging stations in the catchment used in data collection included Moi's bridge, Nzoia at Maili Tatu, Koitobos, Kamukuywa, and Nzoia at Webuye, Mumias and Rwambua. Stream flow data collected on the ground was compared with the model output and from the variances, sensitive parameters adjusted accordingly.

3.4 Land classification and change detection.

The land use changes map is derived from satellite images over the years and processed as per the steps below. Land classes followed Moderate Resolution Imaging Spectrometer (MODIS) approach. This follow Leaf Area Index (LAI) to do classification of land cover. Satellite images were downloaded from http://glovis.usgs.gov in tiff format for different set of years. Using ENVI 4.7 software the upper part of river nzoia basin was further reclassified using supervised classifaction, the same is done indetail in Table 3.

3.5 Soil map

Soil map gives the spatial variation of soil properties of a given basin. Soil data that will be required for SWAT to predict stream flow are those that describe hydraulic properties of the soil. The basin under study has six types of soils, namely clay light, heavy clay, loam, sandy clay, sandy clay loam, and sandy loam. The Loam soil composed mostly of sand and silt, and a smaller amount of clay (about 40%-40%-20% concentration, respectively). Mountainous regions like Mt. Elgon and Cherengany Hills have heavy clay with hydraulic conductivity of 0.1 m^3/year. The same soils are covered with forest and crops out of human encroachment.

The middle part of the catchment is predominantly covered by clay (light) which has a hydraulic conductivity of 0.0001 m^3/year. The same has enormous use as agricultural land mostly annual crops and settlements. The peak of Mt. Elgon has loam soils and covered by both forest and rock. Generally a large area of the catchment has sandy clay soils with Agriculture and settlement as the main land use.

3.6 Data processing

Data processing entailed the steps undertaken to make data usable for the model. SWAT does require that data sets such as meteorological data must be filled prior to use. In the study, documented and scientific approaches were used to fill the missing data where possible. Rainfall data had more gaps and documented scientific method was used to fill the gaps.

3.7 Estimating missing rainfall Data

Missing data in both rainfall and runoff was obtained using techniques of interpolation and surrogate as explained. Tobler 1st law of geography states that everything is related to everything else, but near things are more related than distant things'' (Tobler, 1970). The same can be correlated by their distance. Filling of missing data was not only embedded on the Inverse-distance weighting method (IDWM) equation 1 but also using the Tobler's law.

This method employs the Tobler's First Law of Geography by estimating unknown measurements as weighted averages over the known measurements at nearby points, giving the greatest weight to the nearest points (Longley *et al*., 2011). Inverse-distance weighting method was used to determine missing rainfall data. The inverse-distance (reciprocal-distance) weighting method (Simanton & Osborn 1980) is most commonly used for estimation of missing data. The weighting distance method for estimation of missing value of an observation, θm, using the observed values at other stations is given by

$$\theta_{\mathrm{m}} = \frac{\sum_{i=1}^{n} \theta_i d_{m,i}^{-k}}{\sum_{i=1}^{n} d_{m,i}^{-k}} \tag{1}$$

Where θ_{m} is the observation at the base station *m*; *n* is the number of stations; θ_{i} is the observation at station i, $d_{\mathrm{m,i}}$ is the distance from the location of station *i* to station *m*; and *k* is referred to as the friction distance (Vieux, 2001) that ranges from 1.0 to 6.0. The most commonly used value for *k* is 2. The distances were found using measure distance tool on ArcGIS 10.1 and inserted into excel sheet. The excel sheet was then programmed with the above formula for all dates when there was no data. Using distances and quantities of collected rainfall data for the neighboring stations, the missing rainfall data was estimated. Figure 2 shows how using ArcGIS, polygons were drawn around rain gauges with missing data mapped.

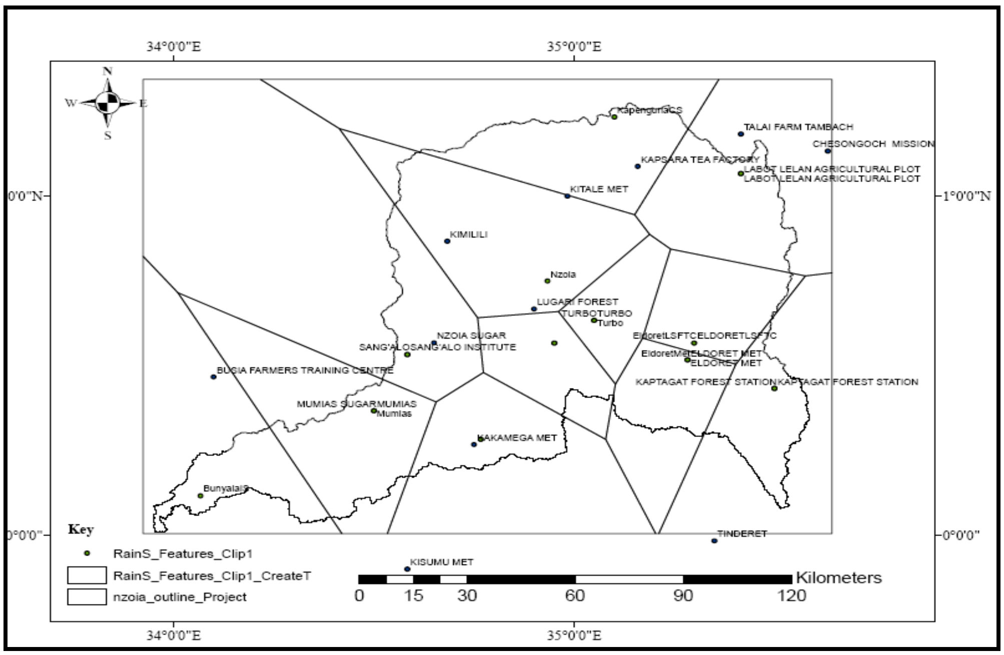

Figure 2: Thiessen polygons for for the study area

3.8 *Estimating missing turbidity in Nzoia river trunk mains*

Turbidity has been widely used as a surrogate for suspended sediment concentration since it is easily monitored and recorded, Jean *et al*. (2008). The form of turbidity-suspended sediment relationship was examined by Post *et al*. (1995). The relationship is given as:

$$c = 1.411t + 1.917 \tag{2}$$

Where: *c* is sediment concentration (mg/l) and *t* is urbidity of the water (NTU).

The sediment concentration in mg/L can then be converted into a sediment load in tonnes/day, thus:

$$s = \frac{cf}{11.57} \quad (3)$$

By use of the same equation for all the sites along the trunk main of river Nzoia, the relative sediment loads for sites were reasonably accurate and used to fill the gaps in the data collected.

3.9 Modelling in SWAT 2012

SWAT is a physically based, continuous time and public domain hydrologic model. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watershed with varying soils, land use and management conditions over long periods of time (Lijalem *et al*. 2007).

Hydrological cycle of a watershed is divided into land phase and the routing phase. Land phase controls the amount of water, sediments, nutrients and pesticides that enter the main channel in each sub-basin while the later deals with their movement through the channel network of the watershed to the outlet (Neitsch *et al*., 2005).

The land phase and hydrological cycle is based on equation below,

$$SW_{\mathrm{t}} = SW_{\mathrm{o}} + \sum_{t=1}^{t}\left(R - Q_{\mathrm{s}} - E_{\mathrm{a}} - W_{\mathrm{seep}} - Q\right) \quad (4)$$

SW_t is final water content in (mm), SW_o is initial water content on day i (mm), R is amount of precipitation on day i (mm), Q_s is Runoff on day i (mm), E_a is amount of evapo-transpiration on day i (mm), W_{seep} is amount of water entering the vadose zone from soil profile on day i, Q_{gw} is amount of return flow on day i (mm), and t is time in days

For water routing, SWAT used Manning's equation to define the rate and velocity of flow. Water was routed through the channel network using the variable storage routing method. Manning's equation for uniform flow in a channel was used to calculate the rate and velocity of flow in a reach segment for a given time step:

$$q_{\mathrm{ch}} = \frac{A_{\mathrm{ch}}.R_{\mathrm{ch}}^{2/3}.slp_{\mathrm{ch}}^{1/2}}{n} \quad (5)$$

$$v_{\mathrm{c}} = \frac{R_{\mathrm{ch.}}^{2/3}.slp_{\mathrm{ch}}^{1/2}}{n} \quad (6)$$

Where q_{ch} is the rate of flow in the channel (m^3/s), A is the cross section area of flow in the channel (m^2), R_{ch} is the hydraulic radius for a given depth of flow (m), *slp* is the slope along the channel length (m/m), n is Manning's coefficient for the channel and v is the flow velocity (m/s).

3.10 Entering meteorological data into SWAT

The input file storing the amount of daily precipitation data was in ASCII text file with one column. The period of precipitation measurement started on January 1st and ended on December 31st. In other words, the first precipitation value in the input file had the value of January 1st and the last value one of December 31st. Even though there was no limit to the number of years employed, calculations were based on the entire period of 2000-2005 for calibration and 2006-2012 for validation.

3.11 Land use land cover changes

River Nzoia basin has four distinct zones: a mountain zone which covers mount Elgon part, Cherengany hill and Nandi hills, plateau zone, transition zone and lowland zone. The mountain zone is forested but has suffered enormous land denudation and degradation; the plateau zone is the major farming zone with annual crops e.g. maize millet, beans, sunflower and perennial crops sugar cane and Napier grass being predominant.

3.12 Predicting Future Land Use

This research uses the CA-Markov analysis statistical technique combined with Markov chain and Cellular Automata (CA) theory frameworks. This was done via a module in software called IDRISI. Although the Markov chain model is easy to calculate using grid based GIS data and current land use change patterns, it does not accurately reflect actual land use changes because of the difficulty in processing of spatial data. The method uses fixed transition probabilities and is applied equally to all locations despite of temporal changes. To solve this problem, CA-Markov changes the states of adjacent grids consistently by applying common change patterns of temporal and spatial data to adjacent grids. Status of changed adjacent grids that are repeatedly practiced can simulate complex attributes and forms, and change the rules of adjacent grids so local characteristics are applied equally to local grids (Lee and Kim, 2007).

In processing for the future land use covers for the basin under study, the first land use cover image for the year 2000 was uploaded in IDRISI software in the CA markov module. The second image of 2010 was uploaded, followed by output conditional probability image of 85%. The number of periods between the images represented the difference in the years between the images, and in this case was set to 10years and proportional error put at 15%. The software has the ability of predicting the land use for the basin as at 2020 and 2030.

4 RESULTS AND DISCUSSION

From SWAT 2012, the images for sub basins, rivers and river gauge stations for the upper part of river Nzoia basin were developed as shown below.

Results of this study came from both the model and graphical interpretation of maps, tables and images. From a snap shot, one can tell the land cover in given water tower, soil and size of the sub basins. The watersheds were assigned numbers and sediment load from each analyzed. The figures for sediment loads were compared with the model output for the current state and future.

Predicted areas for different land use as at 2020 and 2030 shows that closed shrub land and urban built up area will experience positive change in the entire watershed. Evergreen needle leaf forest, deciduous broad leaf forest, evergreen broadleaf forest and mixed leaf forest are on the decline as indicated in the table above.

The output for the land use for the year 2020 and 2030 were given as in the figure above using CA Markov. Cropland and natural vegetation, woody savannas and grassland will have predominant area as per Table 2.

4.1 Expected future scenarios

It is expected that as the human activities intensify, search for more land for farming, wood for construction, land for brick making, settlements and livestock rearing, there shall be drastic changes in land use. As depicted in the predicted land classes as the year 2020 and 2030, the modelled responded as in a way that will leave rivers with more badly raw water quality in the rivers. Sediment loads for the year 2020 and 2030 showed an upward trend. By the year 2020 and 2030, it is expected that the average sediment loads will be 311.28 tonnes/month, 316.76 tones/month for the year 2020 and 2030respectively up from an average of 124.32, 161.72, and 163.96 tonnes/months for the year 2000, 2010 and 2014 respectively. This trend is worrying and affects the raw water even in terms of turbidity.

The Table 4 gives the land use change with the initial state on the horizontal and final state on the vertical axis. The changes have been discussed.

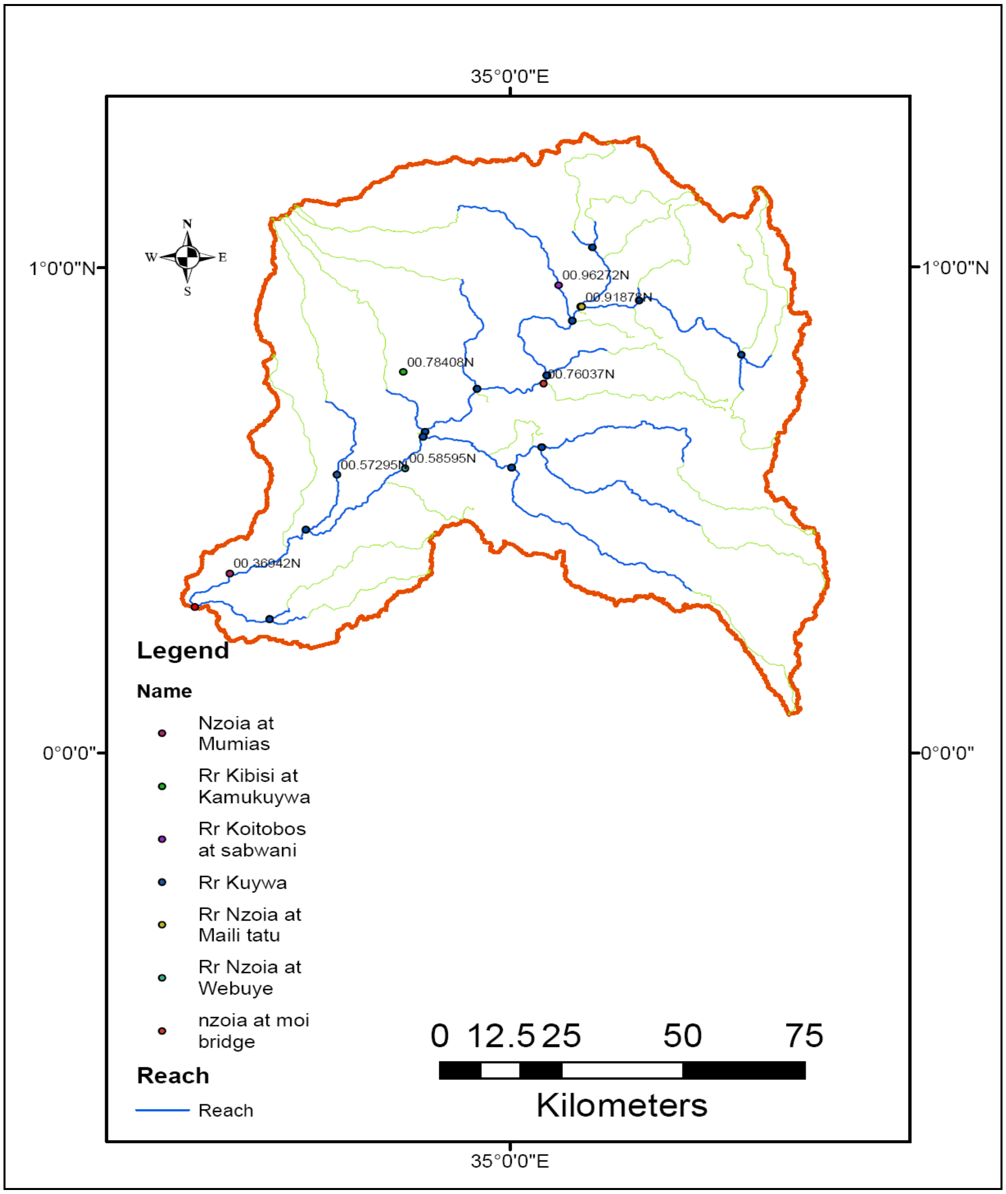

Figure 3: Watershed as delineated and sediment data collection points

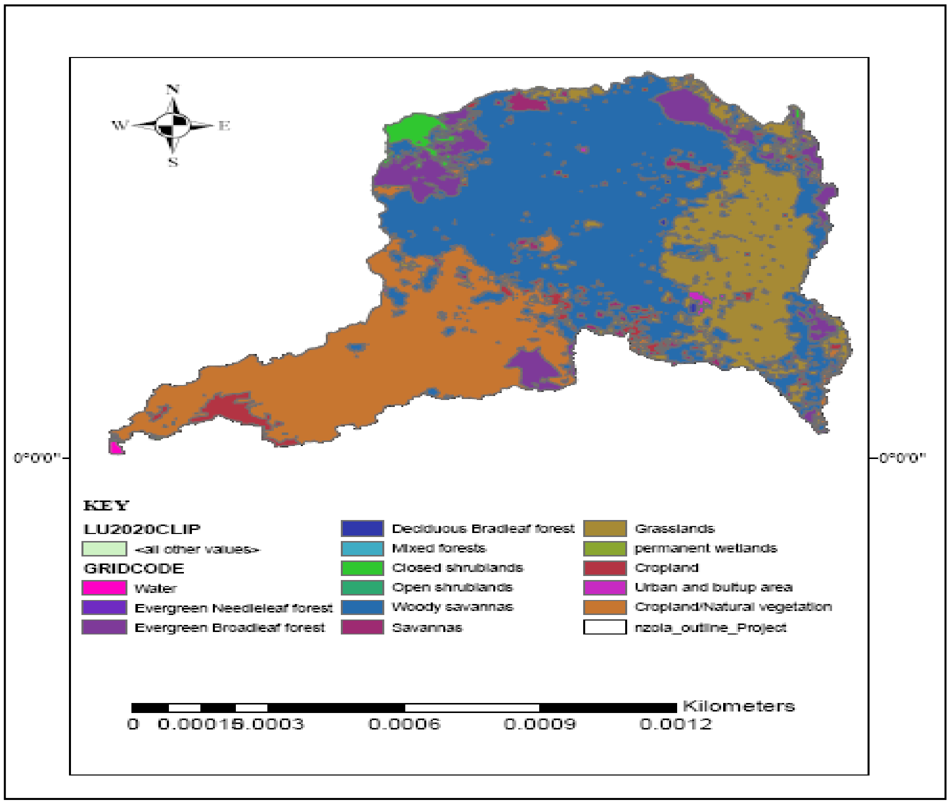

Figure 4a: Prediccted land use for thr year 2020

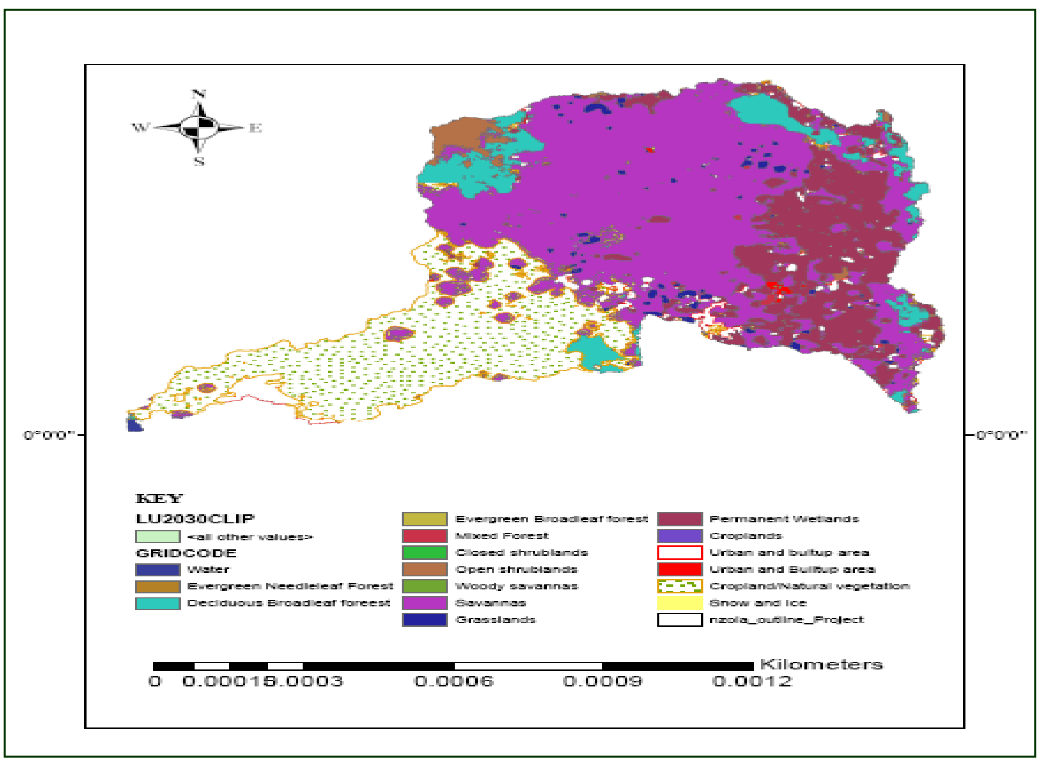

Figure 4b: Prediccted land use for thr year 2030

Table 2: MODIS Land Classes

Land cover	Area in km^2 at 2030	Area in km^2 at 2020	Projected % change 2020-2030	Area in km^2 at 2009	projected % change 2009-2020	Area in km^2 at 2001	% change 2001-2009
Water	35.21	34.36	2.47	35.78	-3.99	37.03	-3.38
Evergreen Needle leaf Forest	11.4	13.87	-17.81	22.70	-38.91	24.75	-8.28
Deciduous Broadleaf Forest	443	457.6	-3.19	293.20	56.07	185.35	58.18
Evergreen Broadleaf forest	10.4	10.85	-4.15	11.28	-3.79	11.45	-1.48
Mixed Forest	10.46	11.1	-5.77	11.28	-1.57	13.99	-19.39
Closed Shrub lands	1228.6	514.66	138.72	268.39	91.76	87.43	206.97
Open Shrub lands	618.64	519.66	19.05	400.13	29.87	332.11	20.48
Woody Savannas	2645.1	2468.28	7.16	2655.79	-7.06	2769.80	-4.12
Savannas	1246	1214.14	2.62	1299.10	-6.54	930.26	39.65
Grassland	727.81	2274.15	-68.00	2474.15	-8.08	2477.64	-0.14
Permanent Wetlands	23.18	25.47	-8.99	27.06	-5.89	27.98	-3.26
Croplands	2051.56	2037.05	0.71	2109.03	-3.41	2739.30	-23.01
Urban and Built-up Area	198.5	98.07	102.41	91.50	6.08	85.40	7.14
Cropland & Natural Vegetation	3648.68	3218.08	13.38	3203.43	0.46	3180.72	0.71
Snow/Ice	5.2	6.93	-24.96	1.75	296.51	1.75	-0.08
Total	12,904.13	12,903.26		12,904.57		12,904.96	

Table 3: Predicted sediment load as per the year 2020 and 2030

	Year					
Month	1990	2000	2010	2014	2020	2030
January	53.7	56.45	48.09	57.27	93.67	101.73
February	107.5	49.23	64.39	124.86	140.00	168.33
March	97.48	70.39	37.56	47.39	104.97	111.43
April	282.33	49.84	135.12	72.05	450.67	502.33
May	191.58	212.38	247.53	140.89	529.67	538.33
June	163.58	96.29	209.92	143	355.33	388.67
July	115.54	161.88	161.04	165	365.00	374.67
August	117.02	176.07	218.21	228	405.00	480.33
September	101.99	173.97	318.64	365	339.00	391.67
October	62.43	181.23	297.56	302	405.67	244.30
November	72.64	158.01	147.71	168	223.33	279.43
December	35	106.19	54.81	154	179.77	186.67
Total	1400.79	1491.93	1940.58	1967.46	3592.07	3767.90
Average	116.733	124.3275	161.715	163.955	299.3389	313.9917

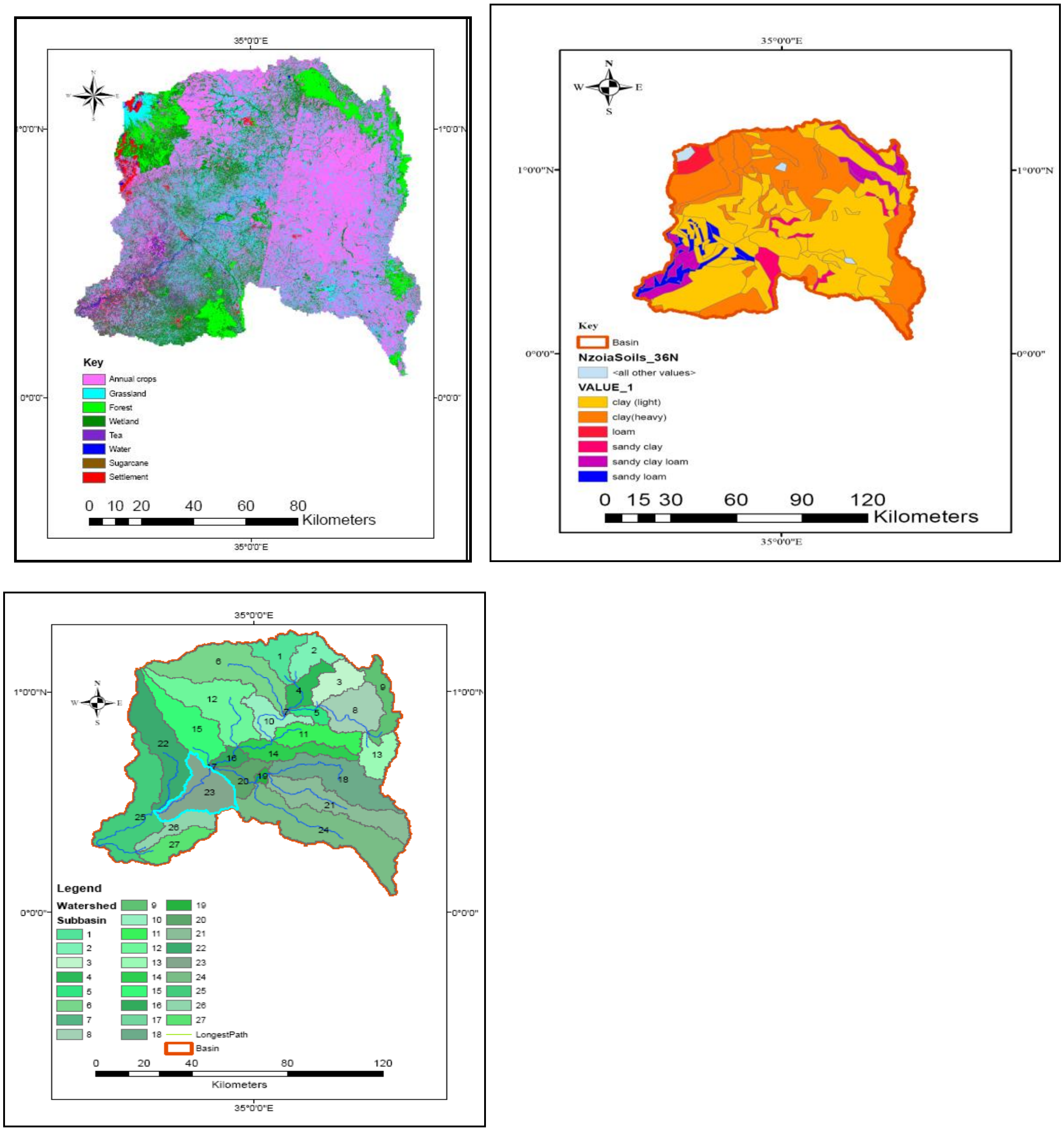

Figure 5. Land use, basinsoils and deleneated subbasins

4.2 *Change detection for different land uses*

a) Forest

83.1% of the forest area remained unchanged which represent 658.01 km^2. 1.6% (12.67 km^2) of forest cover due to anthropogenic activities changed to grassland, 2.8% representing 21.8 km^2 was destroyed and replaced with crops, 12.2% representing 96.58 km^2 was destroyed along the water bodies and wetlands, 1.86 km^2 to water body. In the period of study (2000-2010) a total of 16.9% of the forest cover in the upper river Nzoia water were destroyed to other use as per Table 4 above. Implying that these percentages especially in the water towers were changed to other usages. This exposed the soils to erosion causing an increase in the sediment load. The same increased chances of runoff as there was reduced percolation.

Table 4: Change detection matrix

	Area (Km²)							
	Forest	Grassland	Annual Crops	Wetland	Water Body	Tea	Sugarcane	Row Total
Unclassified	0.46 9.4%	0.51 10.5%	2.52 51.8%	0.58 11.8%	0.06 1.1%	0.64 0.0%	0.10 2.1%	4.87
Annual Crops	207.04 3.8%	392.14 7.1%	4,329.81 78.9%	125.07 2.3%	35.79 0.7%	335.88 6.1%	63.52 1.2%	5,489.24
Grassland	132.43 6.8%	208.78 10.7%	1,381.22 70.6%	56.36 2.9%	13.86 0.7%	152.18 7.8%	10.92 0.6%	1,955.75
Forest	658.01 83.1%	12.67 1.6%	21.80 2.8%	96.58 12.2%	1.86 0.2%	0.58 0.1%	0.63 0.1%	792.12
Wetland	334.93 14.5%	260.07 11.3%	1,090.16 47.2%	339.37 14.7%	76.98 3.3%	193.00 8.3%	16.39 0.7%	2,310.90
Water body	4.42 8.2%	4.28 7.9%	18.16 33.7%	1.77 3.3%	11.73 21.8%	11.55 21.4%	1.97 3.7%	53.87
Tea	11.33 3.4%	10.00 3.0%	93.80 28.4%	8.59 2.6%	8.78 2.7%	170.83 51.6%	27.27 8.2%	330.60
Sugarcane	4.52 2.7%	4.23 2.5%	44.01 25.9%	6.05 3.6%	2.91 1.7%	15.9 9.4%	892.30 54.3%	170.00
Settlement	3.41 3.1%	17.66 15.8%	63.38 56.9%	2.41 2.2%	1.37 1.2%	17.08 15.3%	6.13 5.5%	111.44
Clouds	16.86	,424.60	35.02	8.04	2.41	7.20	1.68	95.46
Shadows	8.02	6.98	14.47	4.14	1.50	0.32	0.21	35.65
Class Total	1,381.43	941.56	7,094.34	648.96	157.25	981.57	144.79	
Class Changes	723.42	732.78	2,764.53	309.58	145.53	810.74	128.81	-
Image Difference	(578.89)	1,021.46	(1,593.80)	1,675.3	(103.32)	(650.78)	25.74	-

b) *Grassland*

10.7% (208.78 km²) of total area under grassland remained the same. 6.8% (132.43 km²) changed to forest, 70.6% (1381.22 km²) was changed to annual cropland, 2.9% (56.36 km²) changed to wetland and 0.7% (13.86 km²) to the water body. A total of 7.8% (152.18 km²) changed to tea and 0.6% (10.92 km²) changed from grassland to sugarcane.

c) *Annual cropland*

A total of 78.9% (4329.89 km²) in the 10years of study (2000-2010) remained intact. A total of 3.8% (207.04 km²) under crops changed to wetland, 0.7% (35.79 km²) to water body, 6.1%(335.79 km²) was converted to fields for tea production and 1.2% (63.52 km²) changed sugarcane. During ground truthing, the photos were taken from the catchment to illustrate how man has altered the land use from the original land cover to mostly settlements and cropland. The photo was taken from around Cherengani hills (Kapolet forest). Despite high slopes in the parcels of land surrounding kapolet forest, encroachment on forest land is observed. Farming and livestock activities are on the increase thus posing the soils to more danger of erosion.

d) *Wetland*

A total of 339.37 km² of wetland remained intact in the period of study. 1090.16 km², 260.07 km², 334.93 km², 76.98 km² 193 km² and 16.39 km² changed from wetland to annual crops grassland, forest water body tea and sugarcane respectively.

4.2.1 Water body

Only 11.73 km^2 of the area under water body remained .the other land changed to unchanged. 4.42 km^2 4.28 km^2, 18.16km^2, 1.77 km^2,11.55 km^2 and 1.77 km^2 to forest, grassland, annual crops, wetland, tea and sugarcane respectively.

4.3 Tea and sugarcane

These two close grown crops have common characteristics of dense canopies. A total of 51.6% (170.83 km^2) of tea remained unchanged whereas 54.3% (892.3 km^2) of sugarcane remained unchanged. During ground truthing it was established that more sugarcane fields have been developed in Transnzoia and Bungoma North while the lower part of the watershed such as Mumias have had sugar cane field destroyed and either left to open fields annual crops or grassland.

In summary grassland area was adversely destroyed with a whopping 70.6% changing to annual cropland. A total of 3.41 km^2 (3.1%) of forest was destroyed for human settlement and 2.2% to wetland. Human activities such as pressure to increase land under agriculture and harvesting of forests have led to encroachments to the riparian land (water body) by 1.2% in the last 10 years, 15.3%of land under tea was destroyed for human settlement and finally 5.5%of sugarcane destroyed for human settlement. Grassland was most hit by human activities with only 10.7% remaining unchanged followed by water body at 14.7%.

4.4 Best model parameters

The model was calibrated with data for the year 2000 to 2005 daily meteorological data. One year was allowed as warm up period (Warm-up" is the very essential part of the simulation process that ensured the establishment of the basic flow conditions for the simulations to follow by converging the hydrologic processes to an equilibrium condition). The sensitive parameters were manipulated to ensure the modelled output is close to the observed value on the ground for runoff and sediment. The parameters are as in the Table 3 below.

Table 3: Best parameters effects and range

S/No	Parameter	Effect on simulation-increase/decrease	Minimum to maximum range	Modeled value
1	CN2	Increase In this figure increases surface runoff and vice versa	35-98	65
2	GWQMN	Increase in this figure Decrease base flow	0-5000	1000
3	ESCO	Decreases evaporation from the catchment	0-1	0.95
4	RCHRG-DP	Increases deep aquifer recharge	0-1	0.05
5	GW-REVAP	Decreases base flow by increasing water transfer aquifer to root zone	0.02-0.2	0.02
6	GW DELAY	Increase in this parameter increased the time it takes for water to exit soil profile and enter shallow aquifer	0-500	31
7	ALPHA BF	The higher it is the more rapid the response to ground water flow	0-1	0.048

4.5 Calibration for runoff and sediments

The model gave near accurate results for sediment loads

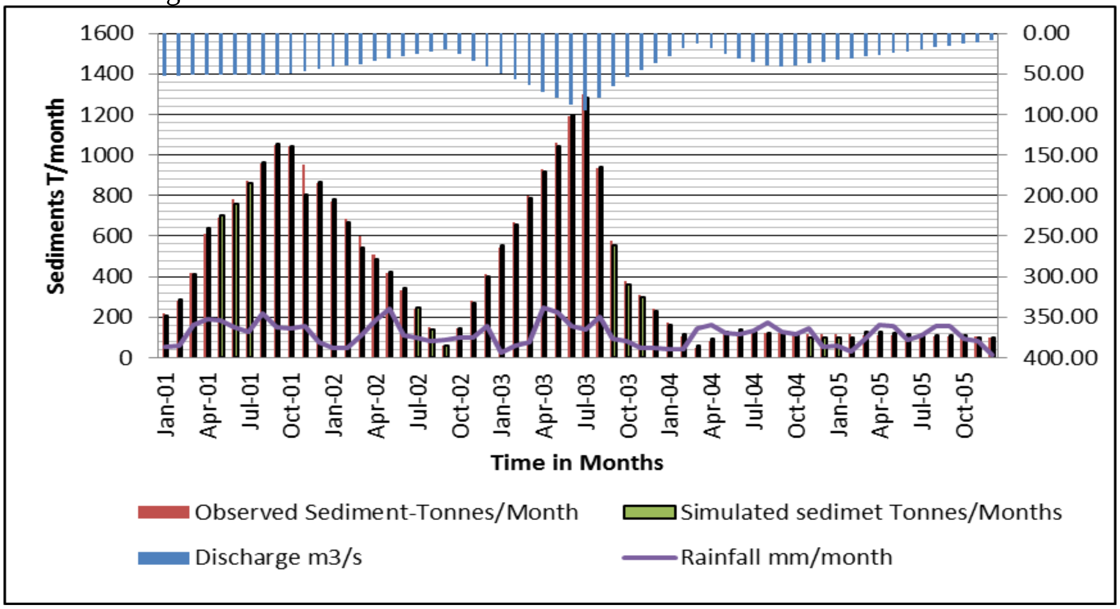

Figure 6: Calibrations for Discharge and Sediments

5 RESEARCH BENEFICIARIES

The immediate beneficiaries of this study are Water Resources Users Associations (WRUAs) who are mandated to take care of the catchment by the Water Resource Management Authority. The Kenya Forest Service will also be a beneficiary of the report. They will use the report's findings and recommendation as a decision support tool to improve the land cover especially in the mountainous region of the catchments which are the water towers of river Nzoia and other rivers that trickle from the same source.

6 CONCLUSION AND RECOMMENDATIONS

The model calibrated well to predict the sediment and runoff with up to 10% error. When subjected to long term prediction of over 10 years, the model over predicted sediments and runoff. It is therefore recommended that the study can further be scaled down for individual tributaries and smaller areas for more accurate results. It model should as well be validated using other watershed models so as to compare outputs from different models.

For studies related to this with missing sediment data, surrogate approaches that make use of turbidity from water treatment plants should be adopted.

Catchments with land use such forests, broad-leafed forests and low percentage of slope with long travel time of the runoff generates low sediment loads. Catchment 2, 27 and 26 had best abilities to resist generation sediment loads to its reaches. Zone number 2 even though has high slope of 15.25%, only 0.192tonnes/month of sediment load was generated. This tells that catchment with broad-leafed forest cover is excellent in reduction of sediment load. Broad-leafed cover forests reduce the rain impact to the soils, allow for maximum infiltration of rain water and enhance base flow to the reaches. This ensures that all the water reaching the reaches are free of sediment loads and hence better quality water to the users.

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Sub-theme: GIS in sustainable development

Impact of eucalyptus tree on water discharge in Kisii central sub-county, Kenya

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Abstract:

Eucalyptus tree was introduced in Kisii Central Sub-County in 1902 to increase forest cover and for commercial purposes. However, there have been concerns over the years regarding behavior of water levels in relation with eucalyptus tree plantations in the region. The impact of eucalyptus tree plantations on stream-flow water discharge in Kisii Central Sub-County have never been quantified. The objective of the study, therefore, was to quantify the impact of eucalyptus tree plantations on stream-flow water discharge in Kisii Central Sub-County. Stream-flow water discharges were obtained from the Water Resource Management Authority (WRMA) offices in Kisii town, for a 10-year period, 2005 to 2014. Area coverage of eucalyptus tree plantations in Kisii Central Sub-County, for a 25-year period, 1990 to 2014, were obtained from the Kenya Forest Service (KFS) offices in Kisii town. Results indicated that the area coverage of eucalyptus tree plantations have increased by over 80% over a period of 25 years. Annual stream-flow water discharges have reduced by over 70% over a period of 10 years. Therefore, the study found that stream-flow water discharge declined, with an increase in area coverage of eucalyptus tree plantations. Correlation coefficient of stream-flow water discharges in relation with area coverage of eucalyptus tree plantations was -0.8285. Although other factors were not investigated, these results indicate that eucalyptus tree plantations are negatively impacting on stream-flow water discharge. The study recommends further studies should be undertaken to distinguish how other factors affect stream-flow water discharge in Kisii Central Sub-county.

KEY WORDS: GIS; water discharges; eucalyptus tree plantation

1 INTRODUCTION

Eucalyptus is a controversial tree species globally due to its pros and cons. It is a fast growing tree species and adaptable to wide ranging ecological conditions. As a result, it is regarded as the most desirable tree species. However, eucalyptus is known to cause a number of environmental hazards like depletion of water resources, dominance over other species by allelopathic effects, loss of soil fertility and negative impacts on local food (Engel, 2005). Eucalyptus is a well known forest species of high water uptake ranging from 50 litres per plant per day to even 90 litres per plant per day, depending upon the adequacy of supply and age (Zahid *et al.,* 2007). According to Kenya Forest Service (2014), area coverage of eucalyptus tree plantations in the region is 349.7 hectares while the total land area of Kisii Central Sub-County is estimated at 23870 hectares (Kenya National Bureau of Statistics, 2012). Therefore, eucalyptus tree plantations occupy 1.47% of the total land area in Kisii Central Sub-County. According to Scott (1993), eucalyptus plantation can influence the ground water dynamics of a system by utilizing soil water and thereby preventing aquifer recharge or by extracting water directly from the capillary fringe. As a result, the ground water table is lowered. Eucalyptus plantations are effective in reducing ground water level because of high rate of transpiration and evaporation (White *et al*., 2002). Engel *et al*. (2005) showed that eucalyptus utilizes ground water from upper vadose zone, which is the source of supply to ground water.

In Kisii Central Sub-County, there have been concerns over the years regarding the behavior of water levels in relation with area coverage of eucalyptus tree plantations. The impact of eucalyptus tree plantations on stream-flow water discharge in Kisii Central sub-County have never been quantified. As a result, the main objective of the study, therefore, was to investigate the impact of eucalyptus tree plantations on stream water discharge in Kisii Central Sub-County, while the specific objective was to quantify the impact of eucalyptus tree plantations on Stream-flow water discharge in Kisii Central Sub-County.

2 METHODOLOGY

2.1 Study Area

Kisii Central Sub-County is located on latitude 0^0 41’ 0’’S and longitude 34^0 46’ 0’’E. It experience average annual rainfall of 1,500 mm with average temperature ranging from 16^0C to 27^0C. The area has an altitude of 1,800 m above sea level. The general slope of the land is from east to west characterized by a hilly topography. Seventy five per cent of the region has red volcanic soils which are deep in organic matter. The region is traversed by permanent rivers which flow westwards into Lake Victoria. They include: River Gucha, River Mogonga, River Nyangweta, River Riana, River Nyanturago, River Nyamache, River Mogusii and River Nyakomisaro.

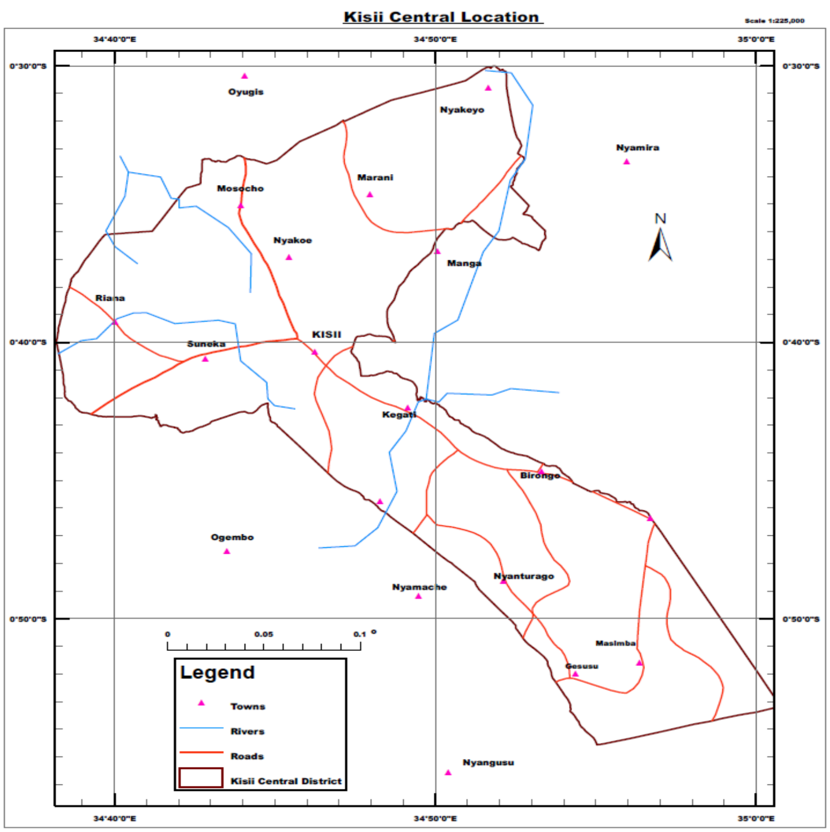


Figure 1: Map of Kisii Central Sub-County

2.2 Research Design

This study adopted Correlational research design. According to Privitera and Wallace (2011), Correlational research design is used determine the extent to which two or more variables are related. Therefore, this design was used to determine the degree of relationship between area coverage of eucalyptus tree plantations and stream-flow water discharges in Kisii Central Sub-County.

2.3 Data Collection Method

Stream-flow water discharges of River Nyakomisaro were collected from the Water Resource Management Authority (WRMA) offices in Kisii town, for a 10-year period, 2005 to 2014. Area coverage of eucalyptus tree plantations in Kisii Central Sub-County, for a 25-year period, 1990 to 2014, were obtained from the Kenya Forest Service (KFS) offices in Kisii town.

2.4 Data Analysis and Presentation

The relationship between area coverage of eucalyptus tree plantations and stream-flow water discharges was computed using Pearson correlation coefficient (r) for the period 2006 to 2014 at interval of two years, to determine whether the impact of eucalyptus tree plantations on Stream-flow water discharge in Kisii Central Sub-County was positive or negative. Basically, Pearson correlation coefficient was used because it shows the strength and direction of the relationship between area coverage of eucalyptus tree plantations and stream-flow water discharge in Kisii Central Sub-County. Results were presented by use of graphs. The following equation represents Pearson correlation coefficient (*r*) used during analyses:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - \left(\sum x\right)^2} \times \sqrt{n\sum y^2 - \left(\sum y\right)^2}} \qquad (1)$$

Where; y is the dependent variable (Stream-flow water discharge measurements) while x is the independent variable (Area Coverage of Eucalyptus tree Plantations in Kisii Central Sub-County).

3 RESULTS

3.1 Stream-flow Water Discharges of River Nyakomisaro from 2005 to 2014

Results from figure 2 shows that annual stream-flow water discharges of River Nyakomisaro have reduced by over 70% over a period of 10 years.

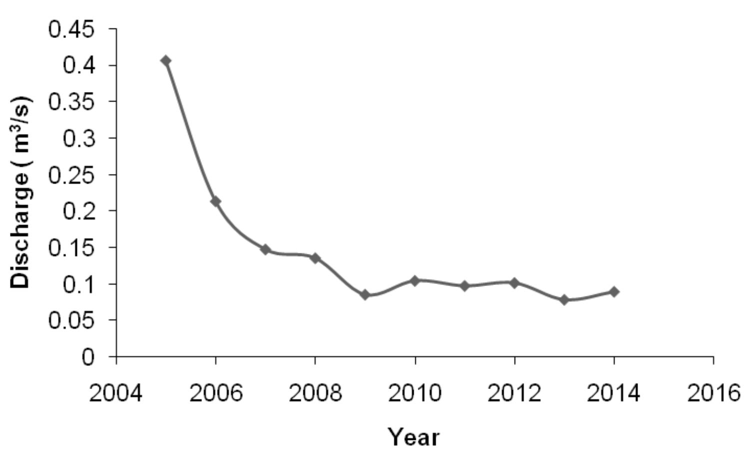


Figure 2: Stream-flow Water Discharges of River Nyakomisaro (Data Source: WRMA, Kisii)

3.2 Area Coverage of Eucalyptus Tree Plantations from 1990 to 2014

Results from figure 3 indicated that the area coverage of eucalyptus tree plantations have increased by over 80% over a period of 25 years.

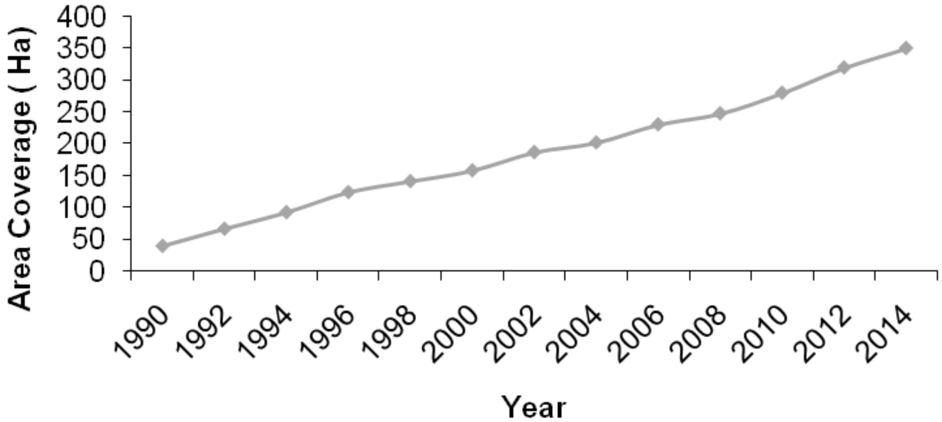


Figure 3: Area Coverage of Eucalyptus Tree Plantations in Kisii Central (Data Source: Kenya Forest Service, Kisii)

3.3 Area Coverage of Eucalyptus Tree Plantations and Stream-flow Water Discharges in Kisii Central Sub-County from 2006 to 2014

As area coverage of eucalyptus tree plantations increased, the stream-flow water discharges declined, clearly shown from figure 4. To determine the strength and direction of the relationship between stream-flow water discharges and area coverage of eucalyptus tree plantations, correlation coefficient (r) was calculated and found to be -0.8285 using equation 1. Correlation coefficient of area coverage of eucalyptus tree plantations and stream-flow water discharges was negative. This was an indication that there was an inverse relationship between area coverage of eucalyptus tree plantations and stream-flow water discharge. Correlation coefficient was close to -1, this shows that there is a strong negative correlation between area coverage of eucalyptus tree plantations and stream-flow water discharge in Kisii Central Sub-County.

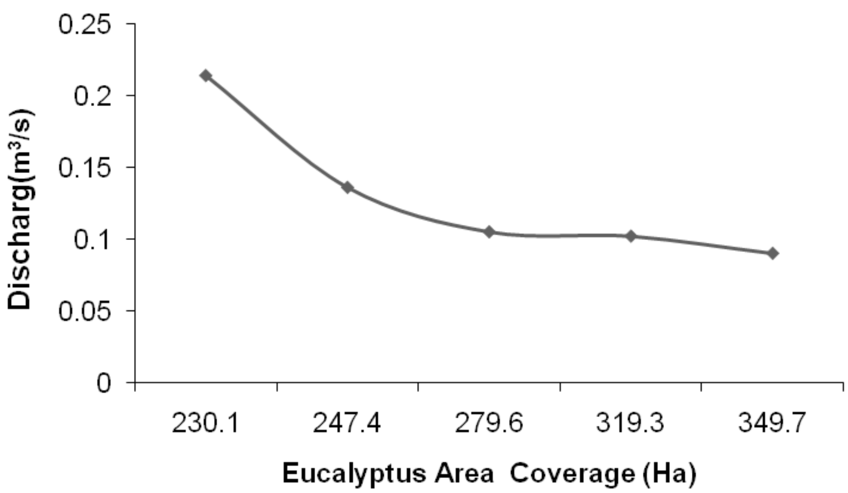


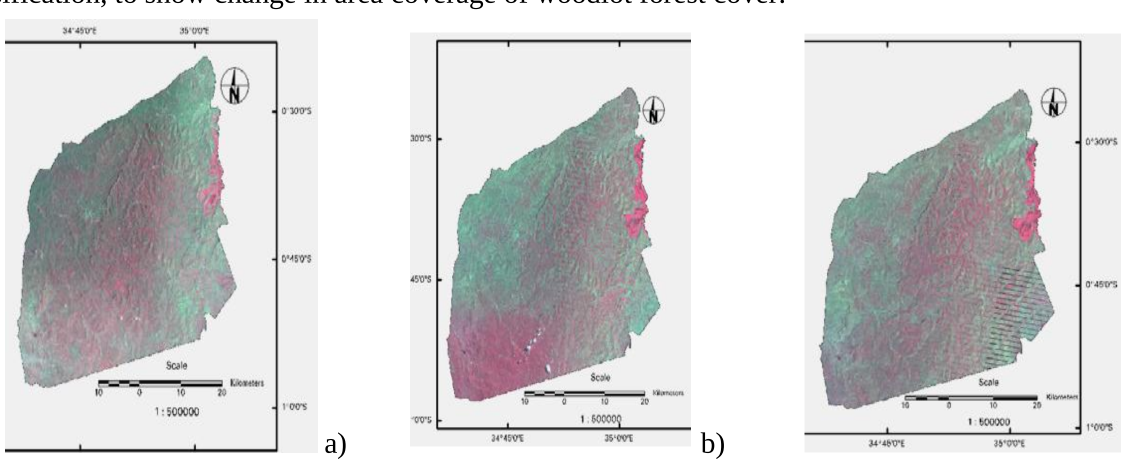
Figure 4: Relationship between Stream-flow Water Discharges and Area Coverage of Eucalyptus Tree Plantations

4 DISCUSSION

Based on findings of this study, there is an evident of negative correlation between area coverage of eucalyptus tree plantations and stream-flow water discharge in Kisii Central Sub-County. This indicates that eucalyptus tree plantations have negative impact on stream-flow water discharge in the region. This may be attributed by the ability of eucalyptus roots to penetrate deeper into soil layers, thus creating larger suction in the upper vadose zone, which seriously reduced the natural movement of water, hence affecting supply of water to the deeper aquifers, as found by Engel *et al*. (2005). Further, to support the findings of this study, Scott (1993) in his study, found that eucalyptus tree plantations can influence the ground water dynamics of a system, by utilizing soil water and thereby preventing aquifer recharge, or by extracting water directly from the capillary fringe. As a result, the ground water table is lowered. Eucalyptus tree plantations are effective in reducing ground water level, because of high rate of transpiration and evaporation (White *et al*., 2002). Engel (2005) during his study of hydrological consequences of eucalyptus tree plantations in Argentine pampas, he found that eucalyptus utilized ground water (67% of its total water use) as well as water from upper vadose zone, which is the source of supply to ground water. He also found that steeper hydraulic gradient induced by the eucalyptus plantation in 40 hectares land, forced the surrounding water to enter the plantation area, suggesting that it has capacity to make use of water from surrounding areas, by inducing water flow gradient towards the eucalyptus tree plantations area. In analyses conducted by Scott and Smith (1997), in their catchment experiment on eucalyptus plantation and pine plantation, close to a river system, they found that reduction in annual stream-flow due to pine was 47 mm while eucalyptus was 239 mm. Further, Scott and Lesch (1997) in their analyses, they found peak reductions of 470 mm per year for eucalyptus in the seventh and ninth years. The highest estimated flow reduction due to pine was 257 mm, recorded in the twentieth year of the rotation. These findings were verified by a study performed by Scott *et al*. (2000), who reported peak reductions in stream-flow between 5 and 10 years after planting eucalyptus and between 10 and 20 years after planting with Pines.

The findings of this study, therefore, corroborate the findings of the study conducted by National Environment Management Authority (2013), on rehabilitation of water resources in Kisii Central Sub-County, done along River Nyanturego and River Nyakomisaro. At the end of the study, they found that, after cutting down of eucalyptus trees in some parts of the rivers, and replacement of it with fodder crops, both the rivers responded positively by volume of water increasing. This showed that eucalyptus tree plantations had negative impact on both rivers.

Generally, the finding of this study on an increase in area coverage of eucalyptus tree plantations was supported by the finding of Mocha (2013). In his study, he found that, there was an increase in area coverage of woodlot forest cover from 912 hectares in 1986; 8,907 hectares in 2000 to 12,612.51 hectares in 2006 in the entire Gusii counties, this represents over 90% increase in the woodlot forest cover in the region. Mocha (2013) adopted the use of landsat remote sensing satellite images and land coverage classification, to show change in area coverage of woodlot forest cover.



a) b) c)

Figure 5: Landsat Remote Sensing Satellite Images of Gusii Counties, (a):1986, (b):2000 and (c):2006 (Source: Adopted from Mocha, 2013)

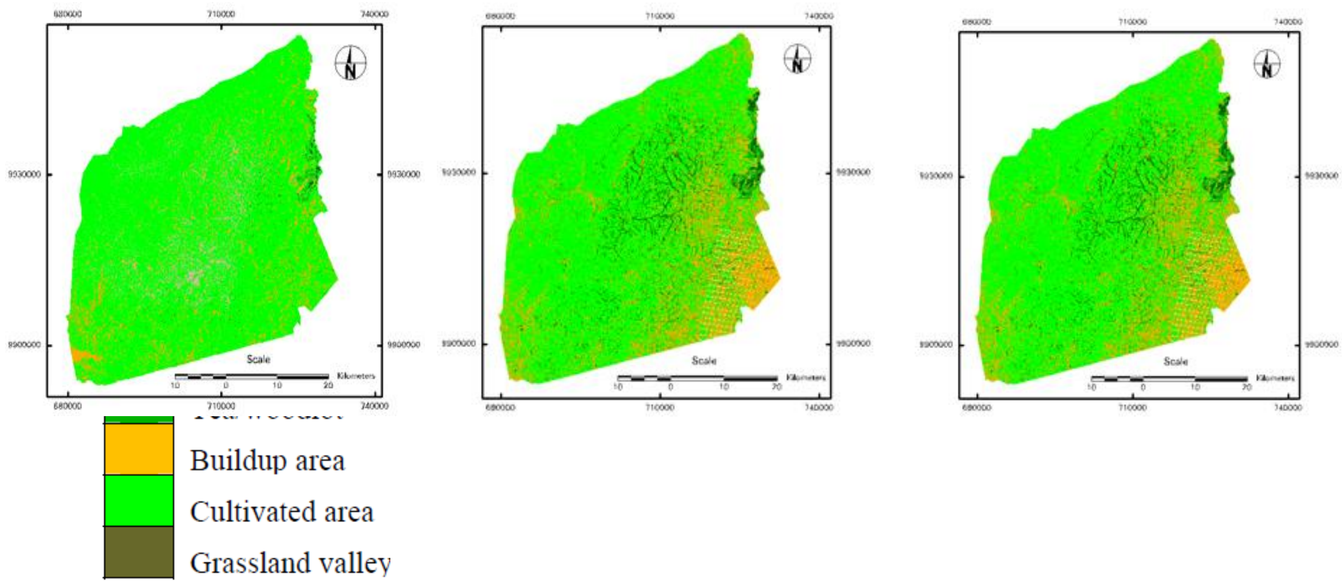


Figure 6: Classification Images of Land Coverage of Gusii Counties (a):1986, (b):2000 and (c):2006. (Source: Adopted from Mocha, 2013)

5 CONCLUSION AND RECOMMENDATION

The study found that stream-flow water discharge declined, with an increase in area coverage of eucalyptus tree plantations in Kisii Central Sub-County, during the period 2006-2014. Annual stream-flow water discharges of River Nyakomisaro reduced by over 70% over a period of 10 years, despite an increase in annual rainfall pattern in the region. Correlation coefficient of stream-flow water discharges in relation with area coverage of eucalyptus tree plantations in the study area was -0.8285. This suggests that eucalyptus tree plantations are negatively impacting on stream-flow water discharge in Kisii Central Sub-County. However, decline in stream-flow water discharge in the region, is also influenced by other factors apart from area coverage of eucalyptus tree plantations, which were not investigated. As a result, the study recommends further studies should be undertaken to distinguish how other factors affect stream-flow water discharge in Kisii Central Sub-county.

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Paper No: 05
Page 59 - 68
Sub-theme: GIS in sustainable development

Trends in land use and land cover changes; drivers and impacts on Kakamega forest block

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Abstract:

Information on Land Use and Land Cover changes that occurred from 1995 to 2015 in Kakamega forest and surrounding area was compared using remote sensing and geographic information system (GIS) with field verifications. The objective of this study was to understand the causes and to quantify the Land Use and Land Cover change around Kakamega forest and to analyze implications of Land Use and Land Cover changes in terms of biodiversity loss and wild life habitat destruction. Two sets of remotely sensed data, Land sat TM (1995) and Land sat OLI imagery (2015), with a time span of twenty years were used for the study. In addition to the 8 biophysical data, socio-economic characteristics of area were also used to interpret the causes of biophysical feature changes occurring in the study area. Generally the land use land cover of the study area were classified in to the six classes proposed by the Intergovernmental Panel on Climate Change namely forestland, cropland, grassland, wetlands, settlements, and other lands. If current trends are allowed to continue, biodiversity and wildlife in general endemic animals for Kakamega forest in particular will become endangered. In addition to this, overall ecosystem health will be under question. Forest cover of Kakamega has significantly increased, therefore selecting appropriate land use systems that are suitable to the conditions of the study area will be important.

KEY WORDS: Land use land cover change, Remote Sensing, GIS, Forest cover change.

1 INTRODUCTION

Land cover is defined by the attributes of the earth’s land surface captured in the distribution of vegetation, water, desert and ice and the immediate subsurface, including biota, soil, topography, surface and groundwater, and it also includes those structures created solely by human activities such as mine exposures and settlement (Chrysoulakis *et al*., 2004; Lambin *et al*., 2003; Baulies and Szejwach, 1998). On the other hand, land use is the intended employment of and management strategy placed on the land cover by human agents, or land managers to exploit the land cover and reflects human activities such as industrial zones, residential zones, agricultural fields, grazing, logging, and mining among many others (Zubair, 2006; Chrysoulakis *et al.*, 2004). Land use change is defined to be any physical, biological or chemical change attributable to management, which may include conversion of grazing to cropping, change in fertilizer use, drainage improvements, installation and use of irrigation, plantations, building farm dams, pollution and land degradation, vegetation removal, changed fire regime, spread of weeds and exotic species, and conversion to non-agricultural uses (Quentin et al, 2006). It is estimated that undisturbed (or wilderness) areas represent 46% of the earth’s land surface. Forests covered about 50% of the earth’s land area 8000 years ago, as opposed to 30% today. Agriculture has expanded into forests, savannas, and steppes in all parts of the world to meet the demand for food and fiber (Lambin *et al*., 2003). Based on data from diverse sources, the Global Forest Resources Assessment 2000 estimated that the world's natural forests decreased by 16.1 million hectares per year on average during the 1990s, which is a loss of 4.2% of the natural forest that existed in 1990 (Lambin *et al.*, 2003). Land use in East Africa has changed swiftly over the last half-century: expansion of mixed crop-livestock systems into former grazing land and other natural areas and intensification of agriculture are the two largest changes that have been detected (Olson and Maitima, 2006).

Accordingly, land cover classification has recently been a hot research topic for a variety of applications (Liang *et al*., 2002). Understanding the mechanisms leading to land use and land cover changes in the past is crucial to understand the current changes and predict future ones. These changes occurred at different time periods, paces, and degrees of magnitude and with diverse biophysical implications (Baulies and Szejwach, 1998).Therefore, Land use and land cover change (LUCC) research needs to deal with the identification, qualitative description and parameterization of factors which drive changes in land use and land cover, as well as the integration of their consequences and feedbacks (Baulies and Szejwach, 1998). However, one of the major challenges in LUCC analysis is to link behavior of people to biophysical information in the appropriate spatial and temporal scales (Codjoe, 2007). But, it is argued that land use and land cover change trends can be easily assessed and linked to population data, if the unit of analysis is the national, regional, district or municipal level.

Kakamega forest has received very considerable scientific interest and consequently many conservation initiatives have focused on this forest .This forest being the only tropical rain forest remaining in Kenya and the current alarming status of the natural resources being threatened with risks of extinction .Kakamega forest in particular could have undergone changes in land use and land cover changes for the reasons such as: Rapid population growth and land scarcity has forced farming families to expand their agricultural fields on to natural forests even in conserved areas like National Parks, as a result, large areas, which were under dense forest cover, are now exposed to deforestation, which leads into environmental degradation and serious threat to wild life habitat loss. Furthermore, the loss of the vegetative cover could result in biodiversity loss, which could lead to species extinction even though the rate differs with type of species due to its geographic distribution and abundance and finally local vegetation cover change, specifically forest cover change has significant and cumulative impact on regional and global climate changes, since environmental problems have no boundaries and are interrelated. The management of natural resources and the monitoring of environmental changes can easily be done through the monitoring of land use and land cover changes. Remote sensing and GIS can provide information on how to effectively manage specific ecosystems in Kenya. The main objective of the research was to quantify land use and land cover change and investigate the causes of land cover change of Kakamega forest block from 1995 to 2015. This was guided by specific objectives that included:To determine the types of land use around Kakamega Forest block; to investigate the extent of land cover change on Kakamega from 1995 to 2015 and to identify the cause and show the trend of the forest cover change of Kakamega forest.

2 MATERIALS AND METHODS

The study was conducted within Kakamega tropical rain forest block as in the figure 1.The forest is located between longitudes 34°40'00" and 35°9'30" East and latitudes 0°29'30" and 0°3'00" North in western Kenya. Its catchment function and the rivers of this area feed into Lake Victoria (Kamugisha *et al*. 1997). The area around Kakamega Forest has one of the highest levels of annual rainfall in Kenya with an annual average of 2,007 mm, as recorded at Isecheno Forest Station between 1982 and 2001 (Farwig *et al*., 2006). The forests are located in one of the world's most densely populated rural areas with an average population density of 515 people/km2 (Census 2009).

2.1 Methods used in land cover change detection

2.1.1 Field survey and data collection

The ultimate purpose of the field survey conducted was to collect qualitative and quantitative information to help to better understand, explain, and interpret the land use and land cover change, which was the core issue of this study. Hence, understanding trends in resource dynamics required historical information, which can be achieved using qualitative and quantitative data collected through interview and group discussion with selected informants believed to have a good understanding of the issues of interest. A purposive sampling technique, involving the targeting of individuals who suited the subject and nature of study using predetermined selection criterion, was used to select the participants through consultation with Kenya Forest Service (KFS) officers of that area. Both open ended and closed ended questionnaires were used covering a wide range of topics relevant to the central issue of interest. It was also pre-tested so as to evaluate the understandability of the questions and modifications were made accordingly. Besides this, field observations were made to have better information about the nature of the various land use and land cover classes prevailing in the area. Secondary data on land cover change detection was collected by downloading Landsat images from Landsat archive using www.glovis.usgs.gov site for downloading images for the years 1995 and 2015. Land use was categorised into six major land classes that have been proposed for National Green House Gas (GHG) inventories (IPCC, 2003). The six categories are Forestland, Cropland, Grassland, Wetland, Settlements and Other lands. These classes have been described as flexible and easy to break down into sub categories, robust for carbon estimation in the LULUCF sector, reasonably map able by remote sensing methods and allow a wall to wall mapping of a country or area. For this study those that were most applicable were the forestland, grassland, cropland and settlement. Based on the legal forest boundaries (KIFCON, 1994), the area of interest was obtained which lies on the path (170) and row (60) on the globe. Land use categories were then clipped based on the forest boundary.

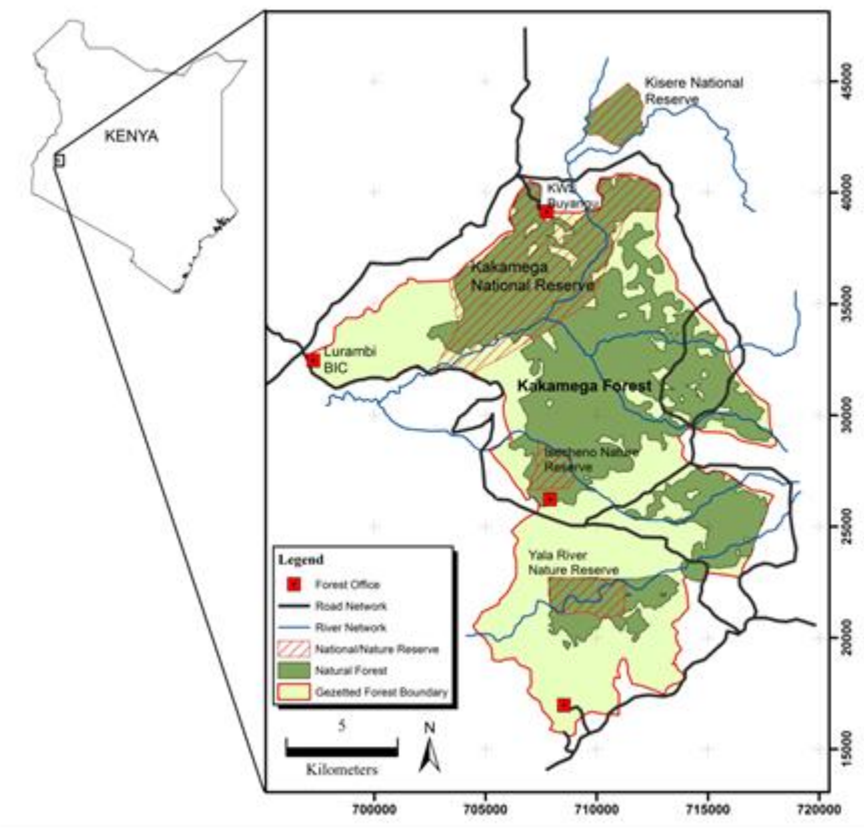

Figure1: Map of the Study Area

In order to cover the intended area of study, different type of images originating from different types of sensors were used. That is Landsat Thematic Mapper(TM) for 1995 and OLI the recent sensor of Landsat 8 for 2015. Image processing was done using ERDAS software for Landsat 7 images bands 4-

red, 3-green, 2-blue and for Landsat 8 bands 5-red, 4-green and 3-blue respectively. After layer stacking, all the scenes were re-projected to UTM Zone 37 South using WGS 84 as a datum. Raster images were brought out by Arc map. Using the Landsat images, on screen digitizing was done to come up with the four land use and cover classes' forestland, grassland, cropland and settlements. Different land uses were digitised for each of the epochs resulting to new shape files. The shape files were used to generate change maps from forestland to any of the other land use categories. The specific statistics of areas of change and their percentages were then generated.

2.2 Data Analysis

2.2.1 Secondary data analysis

Data was analyzed using several softwares which included ArcGIS 10.2, image processing software ERDAS 2010, Garmin software for hot linking photos with GPS points and Microsoft excel. Microsoft excel was used in data management and to analyze primary data which was questionnaires, then summaries of data presented in tables, bar graphs and chart.

2.2.2 Accuracy Assessment

The study focused on relatively small geographic units as compared to basin wise studies. Hence, much variability is not expected within a short distance and some of changes might not be captured due to image resolution. Generally, classification accuracy could be affected by lack of fine details; resolutions of images used, due the need to make generalizations, and errors are always expected accordingly. To assure wise use of land cover maps and accompanying statistics derived from remote sensing analysis, the errors must be quantitatively explained (Sherefa, 2006). The most common and typical method used by researchers to assess classification accuracy is the use of an error matrix (Congalton *et al.*, 1999 in Sherefa, 2006).

3 RESULTS AND DISCUSSIONS

3.1 Land Use and Land Cover within the Forest

Four different land use types were identified within and around the forest for the period 1995 to 2015. Forest land had the highest acreage in terms of cover that showed a positive increase of 12% from 12,675 ha to 16,622 ha in 1995 to 2015 respectively as in table 1. There was a reduction in the area under settlement (.098%) in the period from 144 ha to 49 ha. Grasslands drastically reduced within the forest from 5,169 ha to 921 ha. (21.34%). Cropland showed a slight increase of 3% from 1,769 to 2,174 ha. There is evidence from the land cover maps of 1995 to 2015 that forest land greatly increased as in figure 2.

Percentage of change detection in land use and land cover from 1995 to 2015 was as shown in table 2. Forestland had the highest positive change with 31.14% then followed by cropland at 23.12%. Grassland recorded the highest negative change at -82.18% followed by settlement at 65.97%.

Table 1: Land use land cover for 1995 and 2015

Land Cover Type	1995 Area (Ha)	1995 %	2015 Area (Ha)	2015 %
Forestland	12,675	64.00	16,622	84.13
Grassland	5,169	26.00	921	4.66
Cropland	1,769	9.00	2,174	11.00
Settlement	144	1.00	49	0.02

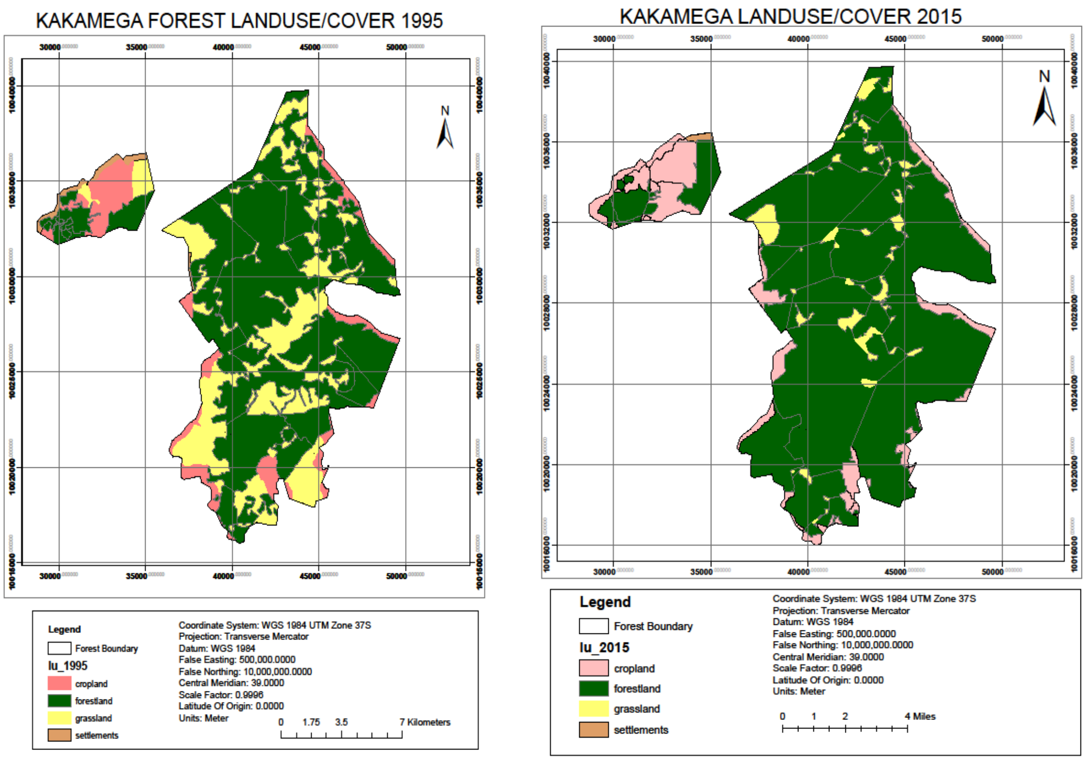

Figure 2: Land cover maps of Kakamega for 1995 and 2015

Table 2: Percentage Change detection in land use land cover from 1995 and 2015

Land Cover Type	Area in 1995 (ha)	(%) Land Cover in 1995	Area in 2015 (ha)	(%) Land Cover in 2015	%Changes between 1995 and 2015
Forestland	12675	64	16622	84.13	31.14
Grassland	5169	26	921	4.66	-82.18
cropland	1769	9	2174	11.00	23.12
Settlement	144	1	49	0.02	-65.97

Accuracy summary

As in table 3 the overall accuracy of the data is 80.90% as shown below.

Table 3: Accuracy summary

Accuracy Summary					
Class Name	Reference	Classified	Number	Producers	Users
Forestland	71	70	55	84.0%	86.3%
Grassland	21	19	17	90.96%	92.29%
Cropland	16	19	15	96.4%	95.37%
Settlement	2	2	2	100%	100%
Totals	110	110	89		
Overall Classification Accuracy = 80.90 %					

Error Matrix

Table 4: Error Matrix

	Reference Data				
Classified	Forestland	Grassland	Cropland	Settlement	Total
Forestland	55	14	1	0	70
Grassland	12	7	0	0	19
Cropland	4	0	15	0	19
Settlement	0	0	0	2	2
Total	71	21	16	2	110

3.2 Land Use Classes around the Forest Block

From the data collected using questionnaires the dominant land use class was cropland (with 40%) and a number of subsistence activities which the forest adjacent communities (FAC) practice for their livelihood as in figure 3. This is followed by agroforestry (26.67 %) then livestock production the least at (13.33%)

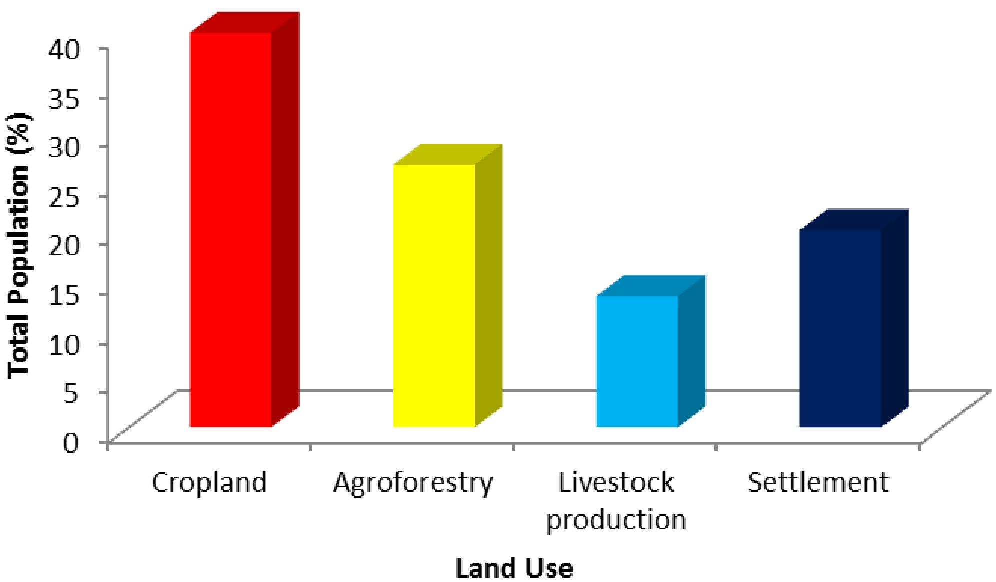

Figure 3: A graph showing land use types around Kakamega forest

3.3 Change maps for 1995 -2015

3.3.1 Forest loss and Recovery maps

These maps show vegetation change dynamics to different forms of vegetation types. This change could have been caused by natural ecological process (forest succession) or even human disturbance (agriculture, livestock keeping etc.).As shown in figure 4 the grassland was which dominated in the year 1995 was greatly reduced and replaced by other land cover types forestland taking the greatest percentage something which as contributed to increase in forest cover of Kakamega forest. Figure four generally gives the overall changes of land cover types from the year 1995 to 2015 which depicts forest cover increase.

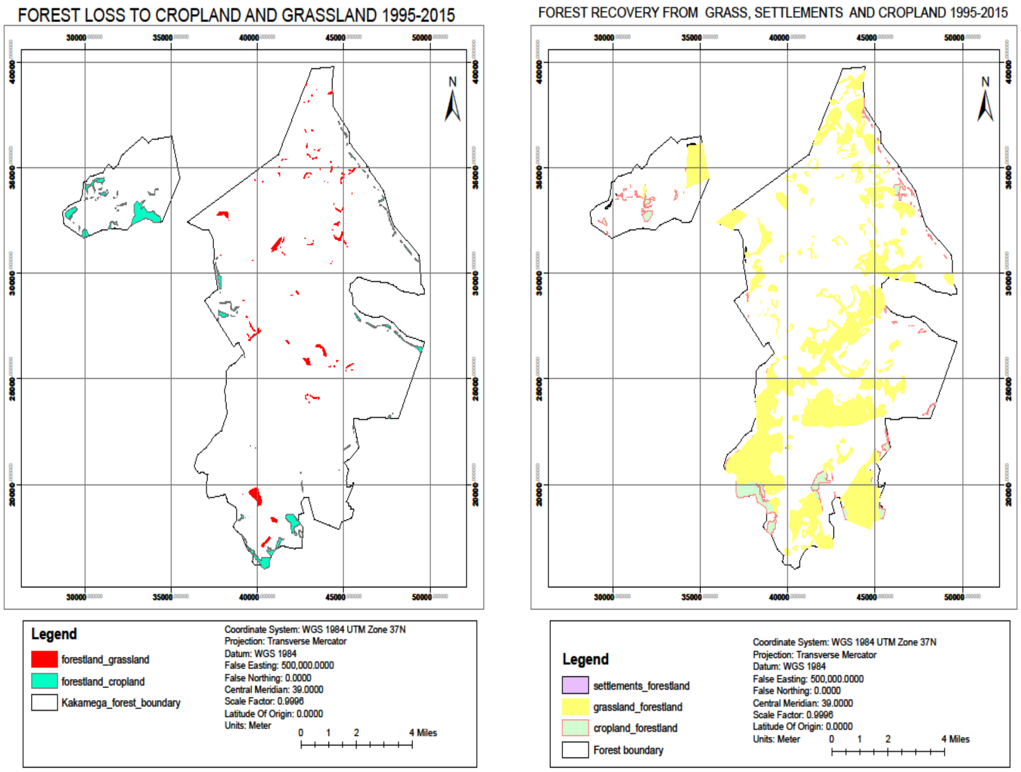

Figure 4: Maps of forest loss and recovery from 1995-2015

3.4 *Condition of Encroachment*

From the questionnaire data level the forest encroachment was significantly decreasing something which has really contributed to forest cover increase. 86.67% of the population interviewed did agree that forest encroachment has been decreasing as evidenced in figure 5.

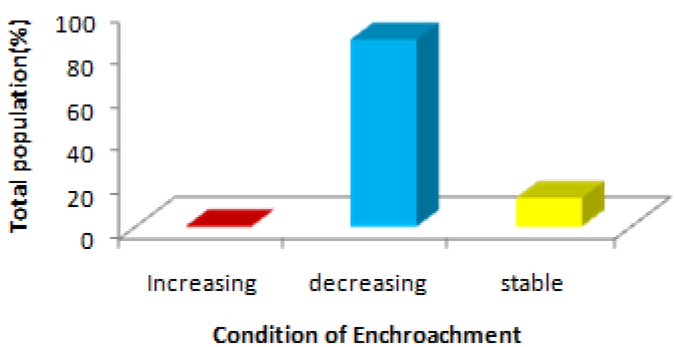

Figure 5: A graph showing the condition of encroachment in the forest

3.4.1 *Restoration responsibility*

Respondents gave varied responses on their perception towards restoration responsibility represented in figure 6. Majority (40%) did agree that it is the responsibility of the community to initiate restoration activities. 26.67 % did observe that the national government through KFS should help in the same.

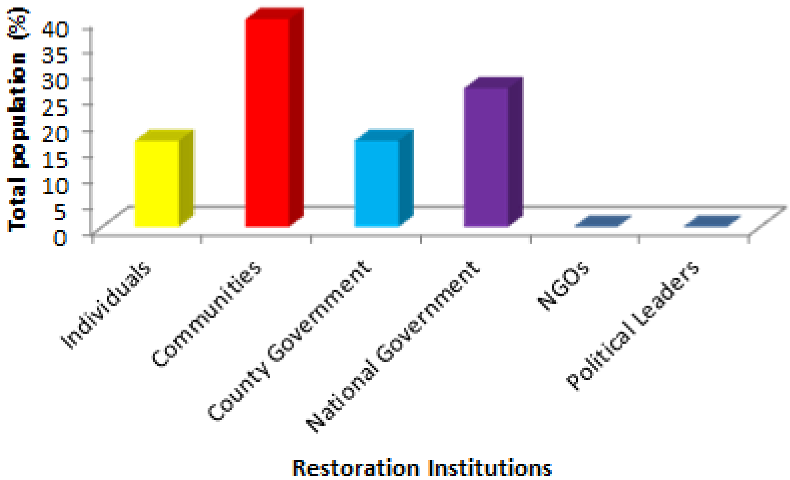

Figure 6: A graph of responsible restoration institutions

4 DISCUSSION

Two satellite images for the years 1995 and 2015 were used to detect change analysis because the satellite images for 2005 which could have increased change detection and the forest trends was a poor quality image composed of back lines which could which could have be attributed by default of the sensor .

4.1 Land Use and Land Cover Dynamics in Kakamega Forest in the year 1995

Based on information from the satellites, Forestland, grassland, cropland and settlements were the major land use and land cover classes during the study periods. A rapidly growing population places pressure upon Kakamega Forest (KIFCON, 1994) as the forest becomes an ever more important resource for satisfying the daily needs of the local people. Charcoal burning, illegal pit sawing, hunting, collection of medicinal plants, grazing, and collection of fuel wood are some of the threats to which the forest is currently exposed (Mitchell, 2004). Additionally, the forest has been commercially exploited for gold, mainly in the 1930s, and in subsequent decades it was commercially logged, involving both selective and clear-felling. These factors have contributed to the current appearance of the forest as a mosaic of dense forest, clearings, forest plantations, regenerating forest areas, and natural grasslands (Kamugisha *et al*., 1997). From the respondents comments and elders who have stayed around the forest for some time including the chairman of Muileshi CFA, it was during the era of second president of the republic of Kenya that the forest faced massive destruction era most of the forest were faced with mass deforestation due to the introduction of multi parties in his government. Politicians could now allow people to go into forests and exploit natural resources in favor of getting back votes from his people. Corruption was very high and transparency lacked among these people. During those days those people in power exercised their power in a bad way, they could grab land tracts of lands and keep them for themselves and even allocate some lands to their people.

In Kenya, 1995 the human population was relatively low with low pressure on the land and associated resources in general. But the level of awareness on natural resource conservation was low because of may be ignorance, lack of sensitization on environmental matters etc. thus a lot of people around Kakamega forest settled within the forest or else they were engaging in livestock keeping which resulted in most of the grass land within the forest.

An image of April 1995 was acquired, when crop harvesting had already started, and farmlands appear bare. Regarding vegetation, there were also relatively undisturbed areas that had been serving as a home for some wild animals with varying levels of density, ground cover and disturbance, according to respondents. Some of these areas were accessed and served as a source of wood and other products used for house construction, fuel wood, farm implements and fencing. Hence, for this particular study, such areas were broadly categorized as forestland depending on their level of ground cover. Analysis of the 1995 Image revealed that forest land constituted the largest proportion of land in Kakamega forest with a value of 64% followed by grassland which accounts for 26 %, cropland (agroforestry under PELIS program) with 9% and finally settlement with 1% .

4.2 Land cover 2015

In 2002 former president Mwai Kibaki introduced the issues of family planning which somehow contributed to forest cover increase because now overdependence and the number of people went down. Former minister of Lurambi Constituency Kakamega County Newton Kulundu in charge of forest and natural resource in the year 2005 evicted people who tried to encroach Kakamega forest without permission. Forest Act 2005 goal of attaining 6%forest cover by 2015, The wildlife Conservation and Management Act 2013 which became operational 10th January 2014.The new law has one of its guiding principles the devolution of conservation and management to landowners and managers in areas where wildlife occur, through in particular there recognition of wildlife conservation as a form of land use, better access to benefit from wildlife conservation, and adherence to the principles of sustainable utilization has really contributed to forest conservation through Community Forest Associations(CFAs) for instance Muleshi Forest Association Kakamega Forest.

Few studies have been conducted to understand land use and land cover change and other related issues in the proposed study areas. Yitaferu (2007) has done satellite image analysis of the Lake Tana basin between 1985/86 and 2001/03. He found that croplands increased by about 4.2%, which largely occurred at the expense of grasslands and shrub lands. Furthermore, forest cover in the basin was found to have increased by about 0.23% in the same time frame. Analysis of satellite images and aerial photos of 40 years provide evidence of changing land cover and flood levels for Hara Swamp (Mc Hugh *et al.*, 2006). It was found that the vegetation of the wetland catchment was almost gone by 2000, although it was covered by dense woody vegetation in the time between 1964 and 1986. The wetland showed continuous increment and was completely flooded around 2000, whereas it was almost dry around 1964. Furthermore, the numbers of houses in Hara town, near the wetland have greatly increased in this period of analysis.

5 CONCLUSION

The trend line for the forest change in Kakamega has a positive gradient. The increase of 3,947 ha of forestland over a 20 year period is equivalent to a recovery of 197.35ha of forest cover per year. This trend is an important tool to monitor the effect of future rehabilitation activities in this forest. There is need to change from focussing on short term benefits, to medium and long term benefits and introducing resource management planning, as well as forest conservation and sustainable utilisation practices by the communities living adjacent to Kakamega in order to safeguard the needs of the future generations.

6 RECOMMENDATION

Long term goals which advocates for conservation of Kakamega for sustained environmental, ecological, hydrological and socio economic benefits for all through implementation of Policies and laws regarding conservation streamlined and fully enforced.

Intermediate goal which includes strategies and plans for the conservation of Kakamega forest enforced achieved through development of management plans to show user zones, propose a forest and water rehabilitation program and finally enforce the proposed management strategies.

These goals can be achieved by

Mapping out the forest to show conservation and priority zones by putting clearly delineate forest boundaries and creating detailed maps and Updating information about the forests. Periodic monitoring of the forest to showing trends towards conservation is important because Information towards recovery of the forest is availed, which will help enhance the working relationship among government institutions like KWS and KFS and also how they relate with non-governmental institutions

Assigning roles among stakeholders, awareness creation on policies regarding forest conservation and stakeholder involvement, promotes formation of community conservation groups like CFAs and WRUAs which would in turn improve tree cover within the forest boundary.

Planting indigenous trees in the deforested areas to retain the original forest cover, promoting use of energy saving jikos and enhancing the productivity of the forest user zones through Nature Based enterprises motivates forest conservation by the immediate forest community.

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Paper No: 06
Page 69 - 74
Sub-theme: GIS in sustainable development

Use of GIS in investigation of land use change in Kakamega county

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Abstract:

Although humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of land use /cover change are far greater than ever in human history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales (DeFries, Foley & Asner, 2004). The main objective was to investigate land use change in Kakamega County. The specific objectives were to: 1. Determine the spatial-temporal land use change, 2. to investigate trend analysis of land use change using GIS as our main tool. ENVI 4.7 and ArcGIS 10.1 enhanced analysis of Landsat images of land use from 1990-2010 with a ten year interval. Excel was utilized in computation to get change in the area covered by various land use categories. Desktop review, actual data and information from relevant forestry offices was applied as a method of data collection. Descriptive method was used in data analysis and data was presented in tables and maps. The research found that expansions of cropping activities have lead into reclamation of previously fallow, bushy, vegetated and other lands. Furthermore, there is continued change in land use activities. Hence there is need to formulate stringent policies and statutes that will govern land use, transmission, conservation and rehabilitation measures in the county. Also mainstreaming environmental issues in the county development planning is also important.

1 INTRODUCTION

Land use involves the management and modification of natural environment or wilderness into built environment such as settlement and semi-natural habitats such as arable fields, pastures, and managed woods (Haberl *et al.*, 2012).

Land use is the process of arranging the activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO/UNEP, 2006). Land resources are used for a variety of purposes which include: agriculture, reforestation, settlement, near-surface water and eco-tourism. Humans have interfered with land use and its impacts have been noted for a long time. Globally, concerns about the changes in land use / cover emerged due to realization that land surface processes influence climate and that change in these processes impact on ecosystem goods and services (Lambin & Meyfroidt, 2011).

Greek philosophers like Plato or Aristotle and Roman Emperors such as Hadrian reported earlier about degradation of natural vegetation and fertile land. George Perkins Marsh's book "Man & Nature" written in 1864 was the 1st manuscripts to identify mankind harmful effect on nature. In addition, many authors such as Henry David Thoreau, John Muir, Aldo Leopold and Rachel Carson have contributed to the increase of consciousness about environmental issues. Publications such as "The Earth as Transformed by Human Action" by Turner et al,. And many reports by Intergovernmental Panel on

Climate Change (IPCC), United Nations Environmental Programme & World Resources Institute (WRI) have identified increase in land use change over the last decades (Foley, *et al.*, 2005)

Land use changes in East Africa have transformed land cover to farmlands, grazing lands, human settlements & urban centres at the expense of natural vegetation. These changes are associated with deforestation, biodiversity loss and land degradation (Maitima *et al.*, 2009). Lack of a proper land use plan in western Kenya has resulted to the various symptom which include low rural incomes, lack of employment opportunity, inadequate subsistence production, shortage of timber and fuel, shortage of grazing land, low, unreliable crop yields, encroachment on forests and wildlife reserve, conflict among farming, livestock and non-agricultural uses and visible land degradation, e.g. eroded cropland, silted bottom-lands and floods in the region (Sayo, 2013).

2 METHODOLOGY

ENVI 4.7 and ArcGIS 10.1 enhanced analysis of Landsat images of land use from 1990-2010 with a ten year interval. The study used Actual data and information from relevant Biodiversity Information Centre (BIC) office. County government office helped in retrieving land use change information and also in understanding the population around the forest and causes of forest fragmentation over time. Desktop research guided in analyzing information already available about land use change. This provided relevant information on spatial temporal land use and its trend for the last 20 years (1990-2010).The data was analyzed using descriptive method. This provided a quick method to make comparisons between different data sets and also enhance spotting of the largest values and trends or changes over a period of time. The research findings were presented using tables and maps.

2.1 Study Area

Kakamega County is one of the four counties in the western region. It boarders Vihiga County to the south, Siaya County to the West, Bungoma County to the north and Nandi County to the east. The county covers an area of approximately 3,050.3 Km^2.

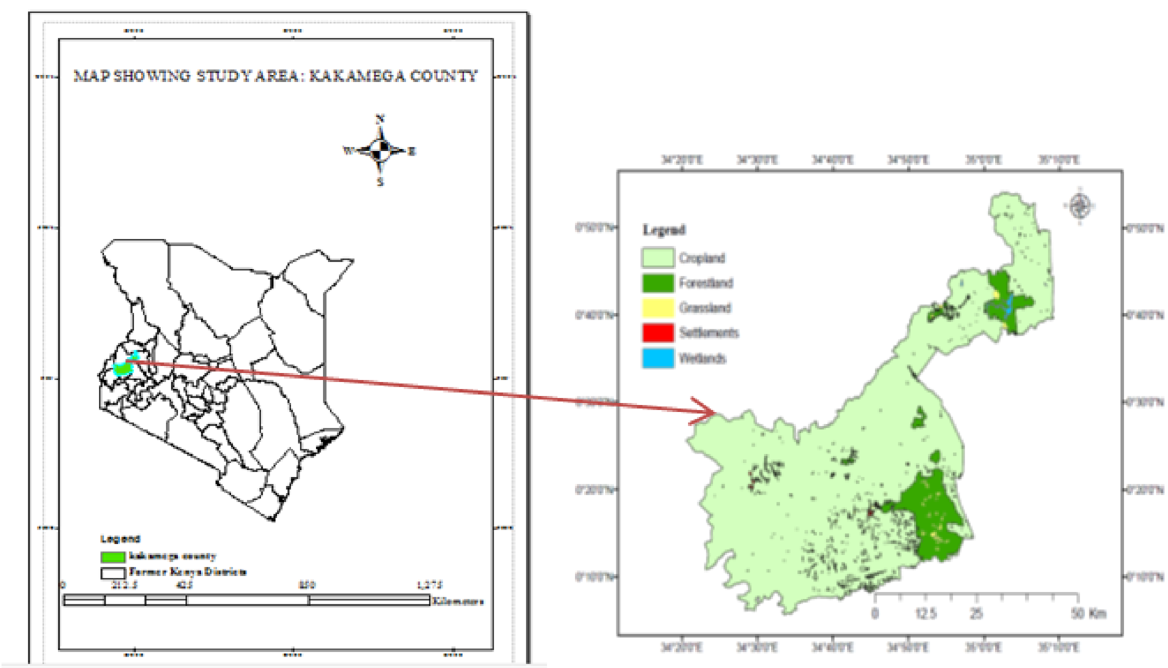

Figure 1: Location of Kakamega County

3 RESULTS AND DISCUSSIONS

This chapter presents the results and findings based on the analyzed data. Results and findings are presented in the form of tables (e.g. Table 1) and figures (e.g. Figures 2 – 4) to quickly convey the essential points or trends in the data. The area covered by cropland has the highest land coverage occupying more than half of the land.

From Figure 2, area covered by cropland is 88.8150%, Forestland 9.3298%, grassland 1.7862%, Wetland 0.03683% and Settlement 0.03215%.

Table 1: Land use changing

Land coverage/use category	1990		2000		2010	
	Area (km^2)	% area	Area (km^2)	% area	Area (km^2)	% area
Cropland	2667.2720	88.8150	2703.3175	90.0152	2684.726	89.3962
Forestland	280.1910	9.3298	249.5496	8.3195	299.6824	9.9788
Grassland	53.6428	1.7862	42.6964	1.4217	6.9649	0.2319
Wetland	1.1062	0.0368	2.7200	0.0906	6.8388	0.2277
Settlement	0.9656	0.0322	4.8939	0.1629	4.9655	0.1653

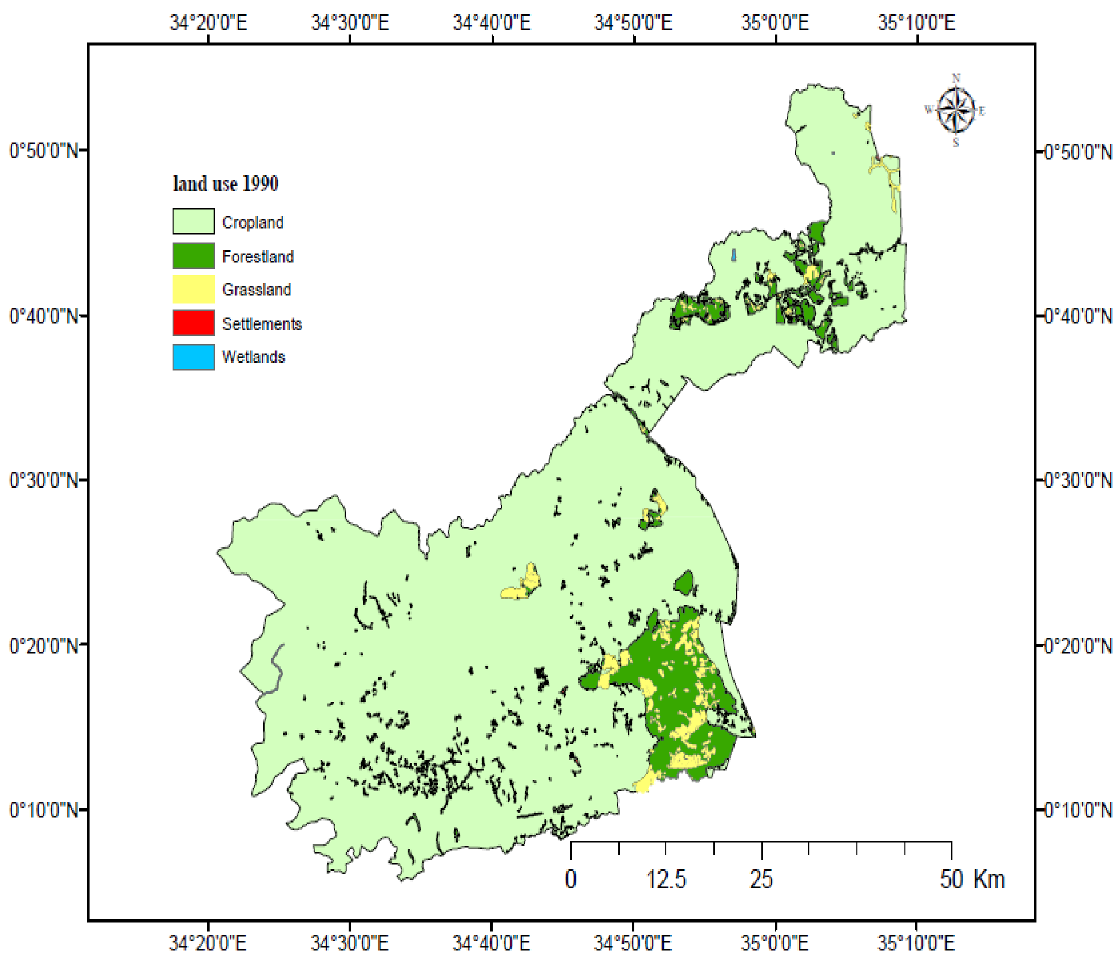

Figure 2: Land use as per 1990

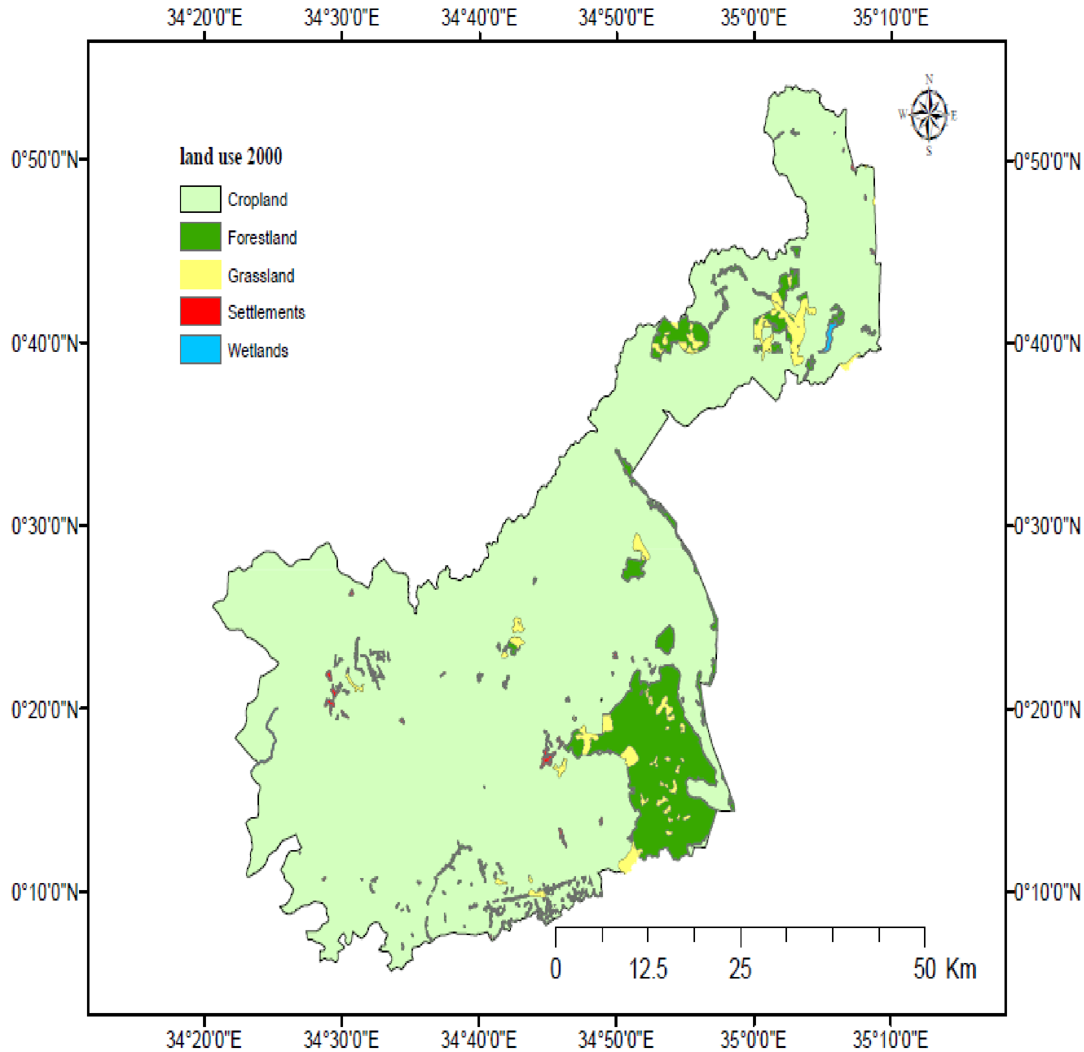

Figure 3: Land use as per 2000

From Figure 3, area covered by cropland increased from 88.8150% in 1990 to 90.0152% Forestland reduced from 9.3298% to 8.3195%, and grassland reduced from 1.7862% to 1.4217%. Moreover, Wetland decreased from 0.03683% to 0.09057% and Settlement increased from 0.03215% to 0.1629%.

Human population has been increasing over the years and people have changed land use systems to cropland to cater for the growing population. Historically, humans have increased agricultural outputs mainly by bringing more land into production (Lambin *et al*., 2003). Forest degradation takes different forms, particularly in open forest formations, deriving mainly from human activities such as overgrazing, over-exploitation (for firewood or timber), repeated fires, or due to attack by insects, diseases, plant parasites or other natural causes (Hermosilla, 2000).

From Figure 4, the area covered by cropland is 89.3962%, Forestland is 9.9788%, grassland is 0.2319%, Wetland is 0.2277% and Settlement is 0.1653%.

There has been continuous decrease in grassland area from figure 3.1, 3.2 and 3.3. Grassland degradation is principally attributed to overgrazing. This unfortunate occurs when animals consume grass at a faster rate than it can grow back. Overgrazing has become more apparent partially because of the increase in population and urbanization which makes less room available for grassland. Due to high population, farmers try to maximise their space and profits by densely packing their land with animals. As a result, grass is given less of a chance to grow back due to either the rapid consumption of grass or the continual stomping of the feet by these animals (Milchunas & Lauenroth, 1993).

In 1990 there was more area covered by wetlands compared to year 2000-2010. This has reduced the fundamental role wetlands plays in the region. Wetlands play very significant role in the environment and their loss or destruction is directly linked to environmental degradation. For instance, wetlands are known to protect water quality by removing and breaking down sediments, nutrients, and toxins, they also provide floral diversity and wildlife habitat protection in the ecosystem, and wetlands also form an important hotspot for care and protection of biodiversity. Wetlands nourish the land during the dry periods, and they also form important habitats for biological diversity in the environment (Wanyonyi, 2012).

There has been increase in settlement in 1990-2010.More people require more food and space which requires more land for agriculture and habitation. This in turn results in more clearing of forests and overexploitation of the land resources. According to the 2009 Population and Housing Census County population is projected to be 1,927,087 and 2,025,081 by 2015 and 2018 respectively. The population growth rate for the County is estimated at 2.12 percent.

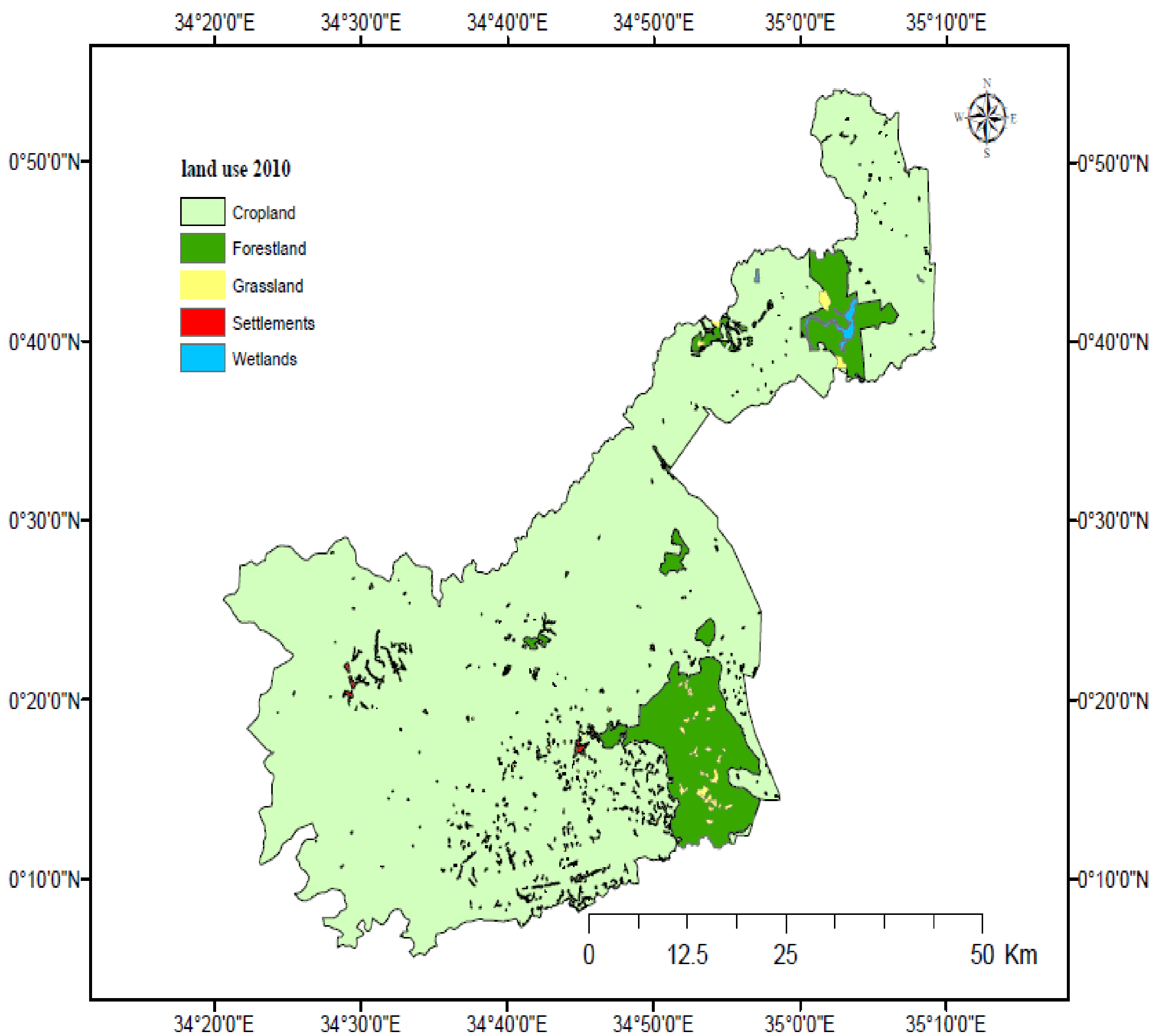

Figure 4: Land use as per 2010

4 CONCLUSION AND RECOMMENDATIONS

Land is currently the most important resource from which the country generates goods and services for the people. The national economy is primarily agro-based. Ninety per cent of the population living in rural areas derives its livelihood directly from land.

4.1 Conclusion

Expansions of cropping activities have lead into reclamation of previously fallow, bushy, vegetated and other lands. Such lands would traditional be used as grazing lands for livestock, in sourcing wood and non-wood products such as herbal medicines or in species diversity conservation.

The trend and extent of land use is likely to continue with the rapid development of infrastructure, agriculture and increasing of population. Ensuring that the natural resources and the environment sustain the supply of benefits without compromising their ability to replenish themselves constitutes the key basis for working towards sustainable natural resource management.

4.2 Recommendation

There is a need to formulate stringent policies and statutes that will govern land use, transmission, conservation and rehabilitation measures in the county. This will necessitate in land conservation thus enhancing sustainable development

Mainstreaming environmental issues in the county development planning is important because it enables the county planning and management unit to guide development programs towards ensuring sound management of natural resources and environmental services in recognition of latest planning framework.

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Paper No: 07
Page 75 - 79
Sub-theme: GIS in sustainable development

Multi-temporal analysis of Nairobi county land use land cover

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Abstract:

Land use land cover classification was run for Nairobi County between 1986 and 2014 with an aim of establishing the trend. The data used was landsat and supervised classification performed to generate six classes. These LULC classes were forest, baresoil, cropland, water bodies, built area and grassland. The LULC changes between the two years under study depicted changes of different magnitude and directions. The results generated showed that the application of geographical information system is critical in the urban land sustainable management.

KEY WORDS: Land Use Land Cover (LULC), supervised classification, multi-temporal, Nairobi

1 INTRODUCTION

Land use and land cover (LULC) describes the economic use of land and surface features, respectively (Campbell, 2007). Humans play a major role as forces of change in the environment, inflicting environmental change at all levels ranging from the local to the global scale (Gamble *et al.*, 2003). The various uses of land for economic purposes have greatly transformed land cover at a global scale (Turner *et al.*, 1994). Over the last 10,000 years, almost half of the ice-free earth surface has changed and most of the result was due to the use of land by humans (Lambin *et al.*, 2003; Turner *et al.*, 2007). The production of agricultural and forest goods have caused agriculture and forestry to become the most transformative events globally; with agricultural land rivaling forest cover and occupying 35% of the ice free land surface in 2000 (Foley *et al.*, 2007). The application of geographical information system in monitoring the changes in LULC is invaluable as it leads to sustainable development.

Nairobi County has experienced varied changes in LULC with residential areas expanding at a high rate. Other LULC changes in this area have encouraged the transformation of land cover to farmlands, grazing areas, urban centers and human settlements with population increase linked to Nairobi expansion (Mundia and Aniya 2006). Sustainable management is the goal of all managers and its achievement in Nairobi city is tied to proper application of spatial planning in the GIS platform.

This study carried land use land cover of Nairobi County from 1986 – 2014 using landsat images with aims of providing the LULC changes and recommendation on the management of Nairobi County. The information obtained is important and will be used to aid decision making thus promoting sustainable management of Nairobi city through spatial planning.

2 MATERIALS AND METHODS

2.1 Study Area

Nairobi County is under, Latitudes 1^0 17.518’and 1^0 18.170’ S, Longitudes 36º 49.588' and 36º 59.017' E and covers approximately an area of 695100 Ha. It has, a population of 3,138,369 and 985,016 households and a mean population density of 4515 People per Km^2 (KNBS). The area receives minimum and maximum rainfall amount of 500mm and 1500mm respectively and with temperatures ranging between 10ºC and 24ºC. Nairobi County being the capital city of Kenya has experienced a high rate of building with a reduction of natural vegetation such as grassland and forest. Many industries, office blocks, residential areas and road networks have been put up replacing the natural vegetation.

2.2 Methodology

Data sources, processing and analysis

The Thematic Mapper (TM) of Land sat 5 and 8 was downloaded from the United States Geological Survey website (http://landsat.usgs.gov/Landsat) for generation of LULC information. The downloaded land sat images are of the year 1986 and 2014 for Nairobi County. The generalized methodology is presented in Figure 2.

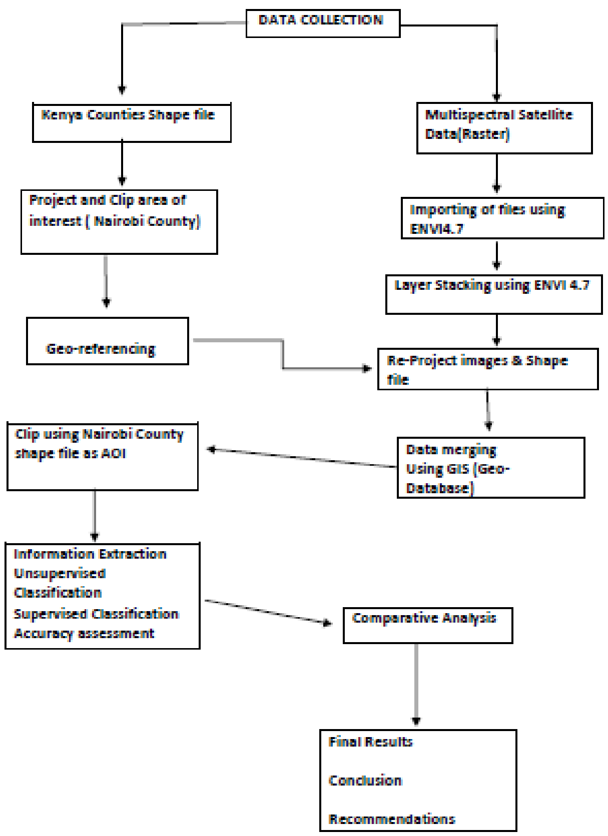

Figure 2: Generalized methodology used in the study

Data processing was done using ENVI 4.7 where the raster bands were stacked to produce images (Figure 3). The clipping process was then applied using Nairobi County vector file to extract Nairobi County (Figure 4) from the satellite images.

Supervised classification was carried out to produce thematic LULC maps for the year 1986 and 2014 using the maximum likelihood classifier. Six major land cover classes were identified and mapped as forest, bare-soil, built-up areas, water-bodies, grassland and cropland. The change trajectory of post classification comparison was used to map the patterns and extents of land-use and land-cover in the study area as well as determine the magnitude of changes between the years of interest, 1986 and 2014.

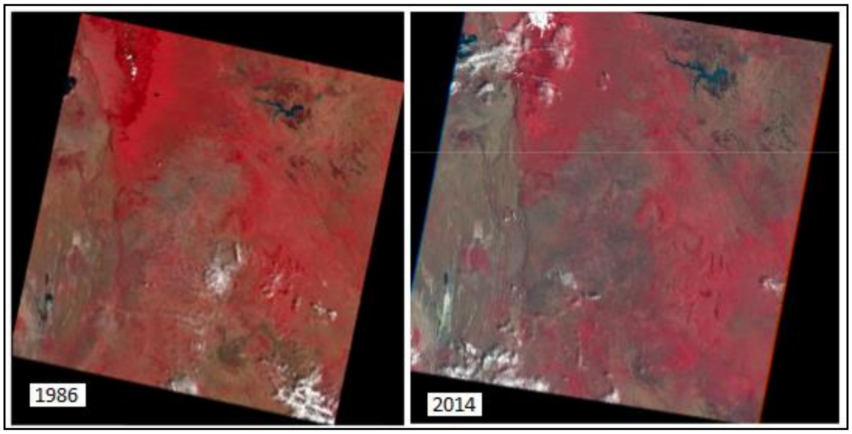

Figure 3: Layer stacked landsat images of 1986 and 2014 (Source: USGS website)

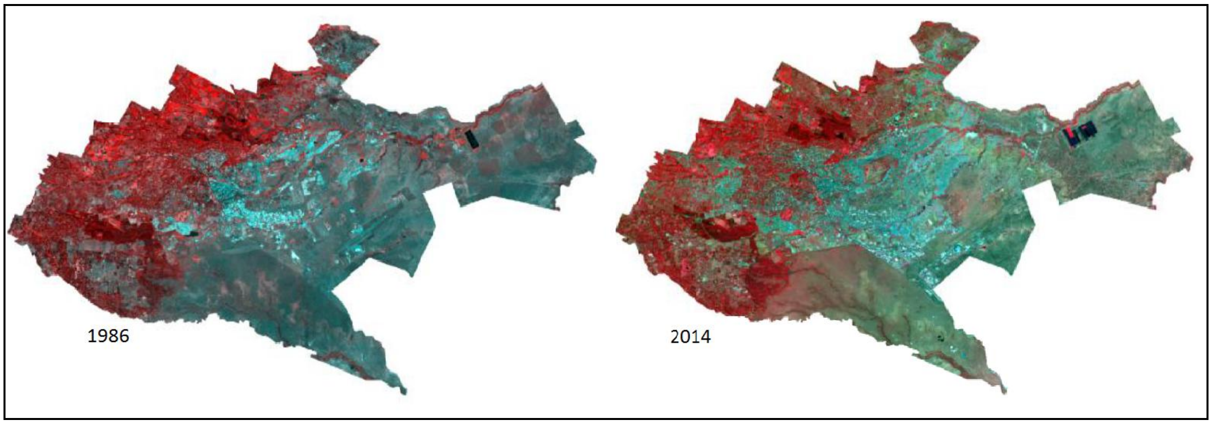

Figure 4: clipped images of Nairobi County (Source: USGS website)

The images were analyzed using change detection techniques along with the Google Earth screen to screen images to come up with the extent of the changes that have occurred. Image differencing of each image's bands (Landsat bands 1, 2, 3, 4, 5, and 7) was done so as to analyze and compare the different images pixel by pixel in order to identify and establish the changes per pixel. In this case, the classified digital layers' statistics were analyzed facilitating comparative analysis of the image along with statistical comparison of the pixel-to-pixel figures. This brought about the direction of change, nature, and magnitude of change detected in the two images of Nairobi County.

3 RESULTS AND DISCUSSION

Land use Land cover mapping

The outcome of the data processing and analysis were presented in form of digital maps (Figure 5) and graphs Figure 6. Nairobi County covers a total of 71048 hectares with LULC in different ratios. The land use land cover classes were six comprising forest, grassland, baresoil, cropland, built area and water bodies.

The land use land cover changes were computed between the two periods under study table 1. In 1986, the grassland covered the largest area of 56.86% (40396.72 ha), followed by built area 23.80% (16913.34 ha), the forest covered 9.34% (6566.31 ha) and cropland was 7.07% (5022.05 ha). The baresoil and water bodies covered 2.36% (1675.8 ha) and 0.33% (232.2 ha) respectively. Some notable changes in LULC by 2014 were both positive and negative for the specific LULC classes with the greatest increase of 271.1% in baresoil and the least change was -29.6% in grassland Figure 6.

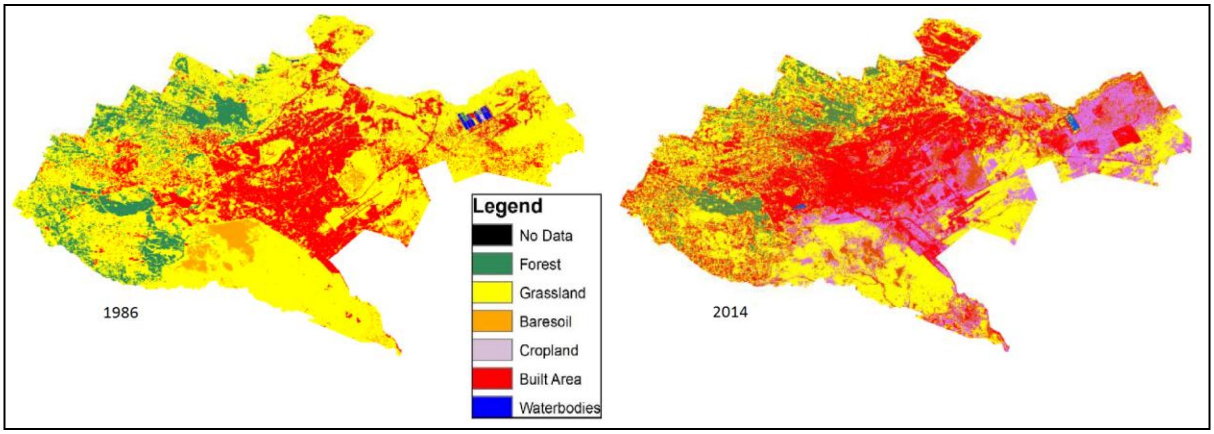

Figure 5: The LULC of Nairobi County of 1986 and 2014

Table 1: The trend of LULC between 1986 and 2014

Class/LULC Type	Area Covered in Ha-1986	Area Covered in Ha-2014	Area covered in %1986	Area covered in %2014	Percent Change% (1986-2014)
No Data	241.74	241.2	0.34	0.33	-0.22
Forest	6566.31	4060.17	9.24	5.71	-38.17
Grassland	40396.72	28481.20	56.86	40.09	-29.50
Bare soil	1675.80	6234.93	2.36	8.78	272.10
Farmland	5022.05	9775.13	7.07	13.76	94.64
Water bodies	232.20	148.23	0.33	0.21	-36.16
Built-Up Area	16913.34	22107.30	23.80	30.71	30.71
Total	71048.16	71048.16	100	100	0

The application of GIS/RS is mostly in image analysis, mapping and monitoring of urban land use. It was applied to estimate various surface features and provide LULC information for planning. The result of LULC Change of Nairobi County was analyzed using object oriented approach which was based on supervised maximum likelihood classification method.

The study shows that there were both negative and positive changes as depicted that Built-Up areas have increased from 23.8% cover in 1986 to 30.71% in 2014. The study further found that conversion of other land cover types to built-up areas was high with a percent increase of 30.71%. Bare surface proportion increased from 2.36% in 1986 to 8.78% in 2014. The bare land cover greatly increased with 272% increase during the 20 year period

The proportion covered by grassland also greatly decreased from 56.86% in 1986 to 40.09% in 2014 with percent decline of -29.50%. The result also shows 0.33% cover of water bodies in 1986 while in 2014 it was 0.21% with -36.16% decline. The proportions covered by cropland have increased from 7.07% in 1986 to 13.76% in 2014 with 94.64% increase during the 20 years period. Lastly, the area covered by forest drastically reduced from 9.24% in 1986 to 5.71% in 2014. The result also shows that forestlands have undergone a negative change with -38.17% changes, which is relatively high.

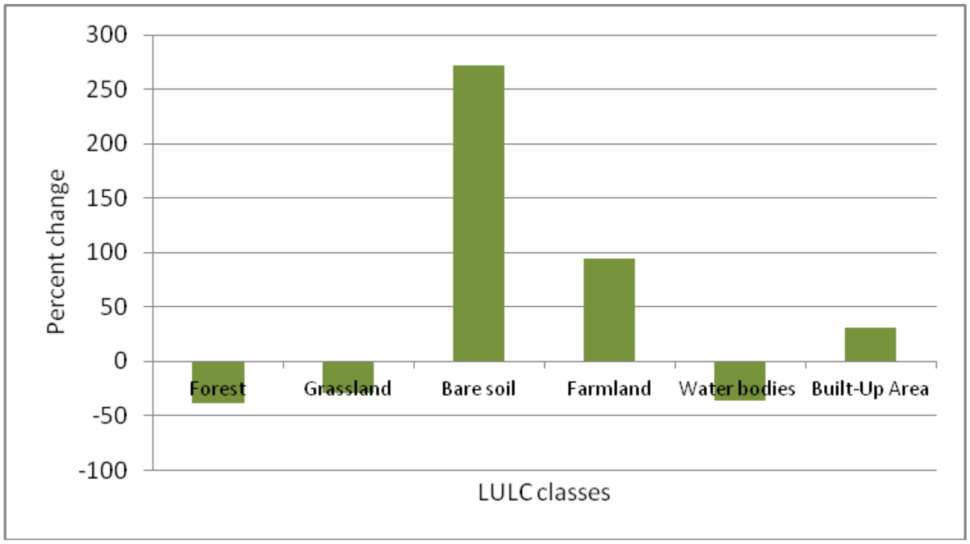

Figure 6: The percent changes in LULC between 1986 and 2014

4 CONCLUSION AND RECOMMENDATIONS

LULC change detection analysis derived from Landsat imagery has provided an accurate account of the situation of the study area during the period 1986-2014. The changes in LULC classes were clearly quantified. The study recommends that comprehensive assessment of human activities and adaptation of sustainable resource management practices such as close supervision of forest and the government should provide funding for environmental monitoring so that changes in LULC in the county are assessed at regular interval enabling sustainable management.

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Paper No: 08
Page 81 - 90
Sub-theme: GIS in resource planning and management

GIS-based mineral resource management system for Taita-Taveta County: Information needs and data requirements analysis

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Abstract:

Taita-Taveta County, situated in the coastal area of Kenya, is endowed with many minerals, including gemstones, industrial minerals and agro-minerals. However, the potential of this wealth has not been fully exploited and its impacts have not been felt by the community. This is mainly due poor information on the location, quantity and quality of mineral resources available in the area. Secondly, there is no accurate information on who is exploiting what, where and how much is being exploited, and hence not all due taxes from the mineral resources are collected. This paper proposes a GIS-based mineral resource management system as a means of increasing information about mining industry in the county with a view of expanding the industry and distributing its benefits equitably. The paper outlines the information requirements for an integrated mineral resource management system, describes the data analyses required to generate the required information. The paper also proposes a two-level system including; a Web-GIS based general information public interface and more detailed government interface for processing confidential information. The paper concludes that the proposed system can enhance the decision making process of the four main stakeholders in the industry i.e. the local community, the government, investors and potential customers and hence enhance their benefits. While implantation of such a system may appear costly, the potential benefits that will accrue outweigh the costs.

KEY WORDS: GIS, Web-GIS, minerals, management, Taita-Taveta

1 INTRODUCTION

Kenya's economy has for many years been supported by tourism and exports from the agricultural sector mainly tea, coffee and horticultural products. However, in the recent past, it has become apparent that the country is endowed with natural resources including oil, industrial minerals such as titanium, iron ore and coal as well as gemstones. The government is in the process of developing mechanisms and infrastructure to encourage investors to explore and exploit mineral resources, which are currently under exploited (EPZA, 2005, GoK, 2007). Establishment of appropriate policies and infrastructure require understanding of the distribution, quality and quantity of commercially viable mineral resources (Stanley and Harris, 2006). This implies that the government should, among other things, develop a comprehensive mineral information system showing the distribution of mineral resources in the country.

Taita-Taveta County, in the coastal region of Kenya is one of the counties in the country believed to have large unexploited mineral potential. The county is situated between longitudes 37° 36' and 30°14'

East and latitudes 2° 46’ and 4° 10’ South (Figure 1). The county borders the Republic of Tanzania and Kwale County to the south, Kajiado County to the west, Makueni, Kitui and Tana_River counties to the north and Kilifi County to the east.

Taita-Taveta County is endowed with vast mineral resources including tsavorite, garnets, rubies, sapphires, tourmalines, rhodolites and kyanites. It is reported that the county is home to over 40 high value gemstones. According to geological experts, the tsavorite and ruby are highly sought after globally and Taita-Taveta is one of the main sources of the minerals worldwide (CBK, 2008). Agro-minerals such as limestone and phosphate rocks are also found in Taita-Taveta (Anyona and Rop, 2015). Recently, large deposits of iron ore have also been discovered in the county and are already being commercially mined (Mazingira, 2014). Currently, there are on-going exploration activities to determine the quantity and quality of coal in the county (Anon, 2015). Unfortunately the potential benefits of these resources have neither been fully exploited nor determined. Consequently, the potential benefits from these minerals are neither known nor have they been felt by the community (Mghanga, 2011). The government revenue generated by this industry is also uncoordinated and below expectations. Among the critical challenges that impede the exploitation of the County’s natural resources that would propel economic development include; inadequate funding from the national revenue and development partners, low private sector investments and participation, and, inadequate local tax revenues base despite the County’s rich minerals base and tourist facilities.

There are several stakeholders in the minerals industry. These include the local community on whose land the minerals are found, the government, which by law owns the minerals (GoK, 1987), miners and traders (buyers and sellers). Each of these stakeholders requires different information in order to effectively participate and benefit from the mineral industry. Unfortunately, such information is not readily available or if it is, it is disjointed and in formats that do not make the information useful in decision making. The purpose of this paper is to describe a GIS-based mineral management information system for the county which will enhance information access to all stakeholders.

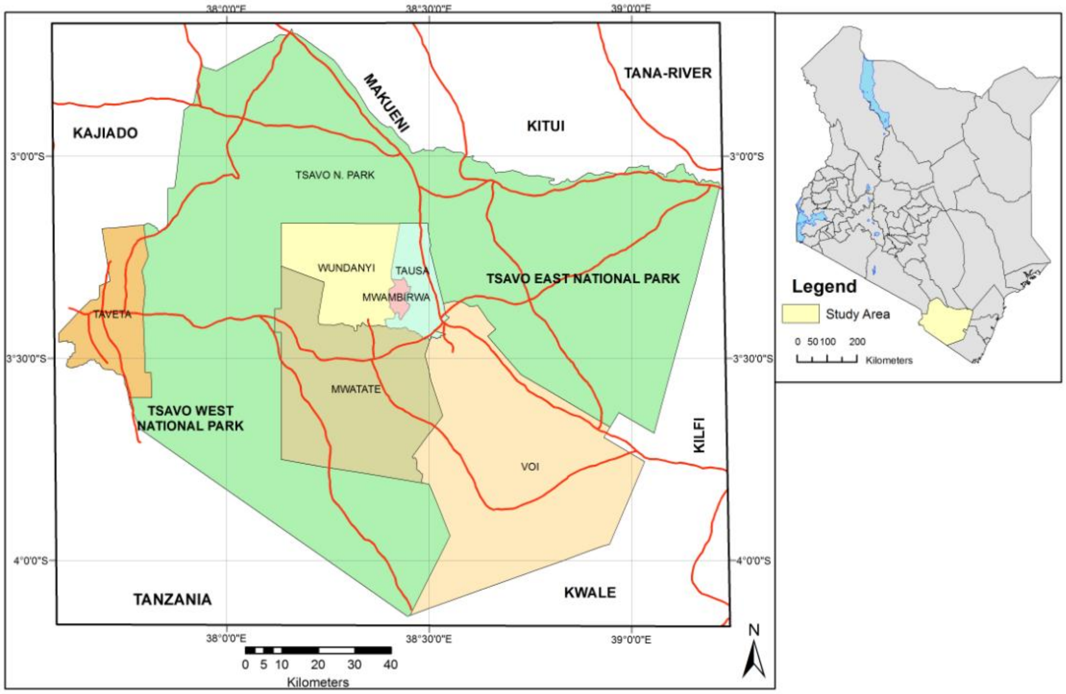

Figure 1: Location of the study area

GIS has been used widely in natural resources management, including mineral exploration and exploitation. One of the strongest application in this context is identification of probability of finding specific minerals on the basis of geo-physical properties, a process referred to as potential mapping (Boham-Carter, 1994; Cassard *et al*., 2004; Otair, 2013). GIS has been used widely in business and marketing from real estate (Wyatt and Ralphs, 2003) to retail, for example identification and monitoring of market areas and competition (Trubint, 2006, Mishra, 2009). GIS can also help in the determination of sustainable rates of exploitation of natural resources, e.g. forest inventory (Kohl *et al*., 2006), water resources mapping, exploitation and management (Johnson, 2008). GIS-based networks has also seen been widely used in navigation and transportation industry for locating sites with some resource or determining the best route to a known resource point. Such applications can boost mineral resource, exploitation, marketing and trading. This paper, therefore, addresses four key components of developing a GIS-based Integrated Mineral Management Information System (IMMRIS), namely: Analysis of the information needs for the various stakeholders (Section 3.1); Determination of the data required to produce the needed information (Section 3.2); Description of the spatial analytical tools that can transform these data into information (Section 3.3); and Proposes system architecture for the mineral information management system (Section 3.4).

Before the development of the proposed system is discussed, a description of the study area's potential is presented in the next section.

2 DESCRIPTION OF THE STUDY AREA'S POTENTIAL

Taita-Taveta County covers an area of 17,128.3 km^2 of which 10,680.7 km^2 is occupied by Tsavo National Park (62%). Of the remaining 6,447.6 km^2, more than 60% of the land is classified as semi-arid and thus unsuitable for arable agriculture. The arable portion, mostly within the scenic Taita Hills and Taveta, is densely populated and is dominated by subsistence agriculture and sub-urban settlements. The main land uses activities in the semi-arid lowlands is ranching, large scale sisal plantations and mining.

2.1 Land Use Characteristics

For a long time the semi-arid lowlands have been considered as low productivity areas. However, it has been realized in the recent past that this area, is rich with a wide variety of high-value minerals. Geologically, the area lies within the mineral-rich Mozambique Belt that stretches 5,000km northward along the Indian Ocean coast line from Mozambique, with average widths of 250-325km inland (Keller, 1992).

As was noted earlier, most of the mineral resources are found in the semi-arid lowlands dominated by group ranches (Figure 2) and the Tsavo National Park as the major land uses. Mineral potential/availability data from multiple sources, including historical, geo-scientific research and government documents, show a rich and widely distributed mineral presence in the county (Figure 2). This data is summarized in Table 1.

2.2 Transport and Communication

The Trans-African Highway (A104) that joins Mombasa to Cairo cuts across the County in a North-west direction (Figure 1). Consequently, most of the mineral rich lowlands are within 200km from Mombasa Port and within twenty minutes to the Moi International Airport in Mombasa from the Voi Airstrip. Another international highway (A23) runs southwards from Voi to Taveta where it crosses to Tanzania (Figure 1). This road links the county to Moshi International Airport and Dar es Salaam in Tanzania. The Kenya-Uganda Railway line, which will soon be extended to Rwanda with the standard gauge line under construction, passes through the county with a major station in Voi. There are 17 airstrips within the county, 6 in Taveta, 5 in Voi and 6 in Mwatate. This strong communication network greatly facilitates the mining industry.

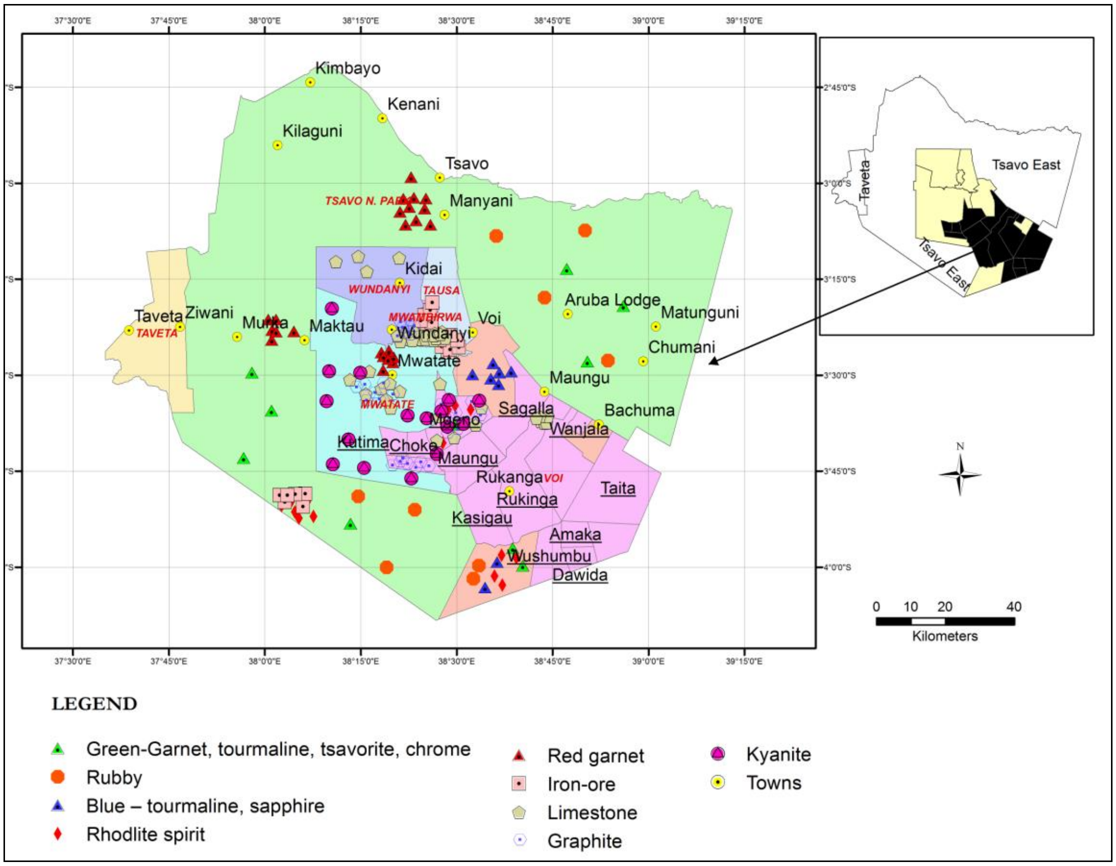

Figure 2: Location of major mining areas

Table 1: Mineral resources in Taita-Taveta

Name	Areas Found
Green - garnet, tourmaline, tsavorite, chrome	Kishushe, Mkuki, Ngongoni, Mgeno, Dari, Kuranze, Tsavo West, Lwalenyi, Tsavo East, Kamtonga, Mwakitau (Fumba hill)
Rubby	Kishushe, Ngongoni, Mangare, Kuranze, Tsavo West, Tsavo East, Kamtonga (Misasanyi), Lwalenyi
Blue – tourmaline, sapphire	Kishushe, Kuranze, Kajire Saghala, Mkuki, Kamtonga, Kilili
Rhodlite spirit	Kisoli (Kuranze), Mgongoni,Mgeno Ranch, Kishushe, Bungule (Kasighau)
Red garnet	Ngulu – Werugha, Sangenyi, Bura, Mwatate, Kamtonga
Tanzanite	Mwairimba, Snake Hill, Buguta
Iron-ore	Kishushe, Mwandongo, Shelemba, Mwambirwa, Kasighau, Kamtonga, Daku, Oza.
Limestone	Rong'e Nyika, Wundanyi, Mugeno, Mgama, Lwaklenyi
Graphite	Nyache, Wanganga, Choke, Mgeno, Lwalenyi, Mgama, Mindi Hill
Kyanite	Mogho, Nyache, Mwatate, Mgeno
Asbestos	Sangenyi
Chrome	Kamtonga, Chungaunga
Potassium feldspar	Kamtonga

3 INFORMATION SYSTEM DEVELOPMENT

The overall goal of a geographic information system is to provide support for decision making through one or some combination of the following activities on data; organization, integration, interrogation, analysis and visualization (Bonham-Carter, 1994). This paper proposes the development of an Integrated Mineral Management Information System (IMMRIS). The development process begins with the anticipation of the information needs of the four main stakeholders in the mining industry. Information is derived by processing data, consequently the development process will also identify the data needed to produce the required information as well as the analytical tools for transforming these data into information. Finally, to be useful, the information has to reach all the stakeholders in an appropriate format, timely and securely. This paper will therefore also describe the system architecture that will store all data, process it into a wide range of information and enable selective and secure access by different stakeholders. This section describes these processes.

3.1 Stakeholder Information Needs

As indicated earlier, the mineral industry at the County level has four main stakeholders, i.e. the government, the community, investors and buyers. The information needs of these stakeholders vary. Investors require information on locations of prospective commercially viable resources and estimates of investment costs and returns. On the other hand, buyers and sellers would want to know where tradable mineral products can be found, varieties available together with their grades/quality, volumes and prices; and the closest transport nodes for transporting the same. Traders will also be interested in information of availability of supporting infrastructure and services such as available modes of transport, optimal routes, as well as location and categories of financial and hospitality services available. Lastly, traders will also be interested in knowing the locations of mineral cutting/polishing and trading centers. Thus the application of GIS as a decision-making tool for administering mineral wealth (Otair, 2013) can be extended to the management of mineral resource trading. The local community is interested in knowing where different mining industry activities are taking place. This information can assist them in improving their livelihoods by identifying employment opportunities, knowing current land leasing rates as well as prices and potential buyers or tenants.

The government, which is both the custodian and regulator, requires a wide range of information on mining industry. Mineral exploitation raises revenue for the government, and by extension the local community. Consequently, the government needs to know what, where, how much, what quality, ownership, type of tenure held for unexploited resources. Second, the government will also be interested in determining who has extracted how much of what on timely basis. This will facilitate calculations of revenue expected so as to plan for its efficient and equitable appropriation. Studies have shown that one of the shortcomings of mineral exploitation world-wide in general, and specifically Taita-Taveta County, is that benefits from mineral exploitation do not trickle down to the community (Mghanga, 2011). The miners and land owners (community) remain in the same state of hopelessness mainly due to exploitation by the middlemen because of lack of adequate information. With accurate and timely information on accruing revenue, the government and the community can plan and budget for the livelihood improvement programs to be funded by the mineral exploitation income. Further, documentation of CSR programs by various agencies in the system will avail information to others for competition, hence societal benefits.

Sustainable mineral exploitation requires that necessary impact and risk assessments are carried out on existing and new mining sites (Cassard *et al*., 2004). By environment law, environmental enforcement agency, i.e. National Environment Management Authority (NEMA), can seek orders to restraint the mining activity in an area that is environmentally strained (EMCA, 1999). NEMA would require information to commence such a proceeding. Further, procedure for restoration of the mined sites and control measures for impacts of mining, such as air pollution and contamination of water mineral remnants, should be documented in a system that is available to all interested organs. The IMMRIS would be a one stop destination for such information.

Lastly, it is also necessary to continuously update the balance sheet showing available mineral resources and document the new discoveries for profitable exploitation. Table 2 presents a summary of the stakeholder information needs that is described in this section.

Table 2: Stakeholder information needs

Module	User Group	Information Description
Investor	a) Prospective Miners	What is available, where found, amounts and quality available Cost of exploitation Potential profit Possible problems Accessibility
Government	a) Mines and geology b) Lands c) Finance d) Agriculture e) Environment f) Infrastructure	Sites with minerals, potentials for different sites Land sizes, ownership details Chargeable/due rates, rents and taxes for different land units Potential productivity Impacts and mitigation measures, management plans Prioritization of infrastructure development
Commercial	a) Buyers/ Sellers d) Brokers	Mineral types available and the costs, buying/selling points, cutting/polishing centres, optimal routes, hotels, banks
Community	a) Job seekers b) Service providers c) Land owners d) Leaders	Active mining areas Customer and characteristics (categories and numbers, Market rates for selling or leasing Estimates of income and funding available for CSR

3.2 System Data Requirements

Cartographic modeling, defined as "the process of sequentially linking the answers to be derived from a GIS analysis with the appropriate commands and datasets" is an objective way for identifying data requirements. One of the advantages of this approach is that it ensures that required results determine the data rather than the available data controlling the outputs. Guided by the range of information needs by different stakeholders (Table 1), it is possible to identify data types and the relevant attributes as well as the analytical processes (Section 3.3) required to produce information from these data. Table 3 summarizes the data requirements for the Integrated Mineral Management Information System (IMMRIS) derived from cartographic models.

3.3 Analytical Operations

All stakeholders are interested in knowing where different minerals can be found and their economic values. This information can be obtained through mineral potential mapping, defined as the process of determining areas that are most likely to contain economically viable concentrations of minerals. This mapping can be done through determining and evaluating spatial associations between mineral occurrences and a variety of biophysical characteristics such as, geology, soils, topography, hydrology and vegetation. When done manually, mineral prospecting can be expensive and time consuming exercise. Use of GIS technology in mineral prospecting will not only reduce time and cost, but also considerable increase prediction accuracy.

The availability of different minerals is largely determined by geology, which is practically invisible from the earth's surface. However, there are some terrain characteristics that can be used as indicators of presence of specific minerals. These include topographic, soils, hydrology and vegetation. These indicators combined with geo-scientific field measurements such as magnetism, seismic and atomic radiations, can predict mineral presence. Mineral prospecting, therefore, involves measuring and analyzing geological and terrain characteristics in mineral-potential areas to determine commercial viability of mineral resources. Such analyses can be done efficiently and effectively using geo-statistical based predictive models. These models determine and evaluate spatial correlation between mineral occurrence (dependent) and predictor variables (soils, vegetation and geological measurements). Such predictions will identify areas with unique overlaps between important predictor variables. Spatial interpolation techniques will be used for creating surface maps for different predictors from point filed measurements. Determination of volumes will require 3-D analytical tools such as watershed delineation and volume computation. Figure 3 shows a typical data analysis process.

Table 3: IMMRIS data requirements

Description	Data layer	Attributes
Potential location of different minerals	Geology Soil Vegetation Terrain	Type, depth, etc. Type, depth, conductivity, pH, age, Form/structure, species, Altitude, slope, aspect, etc.
Potential amounts and quality available	3-D model X-sections	Type, amount, grade, price Vertical profiles
Infrastructure planning	Road network Energy network Water distribution	Class, surface type, condition Lines, voltage, transformers, substations,
Land ownership details	Cadastral	Sizes, land lords, chargeable/due rates, rents and taxes
Location of different minerals	Mineral availability	Site type (buying/selling/cutting/polishing), amounts, unit cost
Available transportation	Transport infrastructure	Road types, conditions, Modes, costs, optimal routes
Facilities/service	Centres	Service types (markets, hotels, banks) classification, pricing, etc.
Dealers characteristics Mining impact on environment CSR projects	Dealers' database Rehabilitation requirements CSR Projects	Buyers/sellers/cleaners location, contacts Impacts, mitigation measures and management plans Location, type, cost, status

The government requires to keep and maintain real-time information on payable, due, paid and outstanding taxes for both miners and mineral traders. Effective management of such a dynamic activity will be greatly enhanced if licensed miners and mineral traders can, at any point and location, enquire and make payments due via the Internet. This can be done via secured database access using personal identification numbers (PIN) and password systems. Further, accessibility and hence utility of basic information on mineral availability locations (mining, cleaning/cutting or auctioning) can be improved if such information was developed and published using Web-GIS.

Mineral exploration, exploitation and trading require different forms of transportation, ranging from bulky, not necessarily fast transportation of industrial minerals, to light and fast transportation requirements of gemstones. Decision on what to use vary within and across stakeholders, depending on unique circumstances. Decision on which mode to use and when, is usually done on ad-hoc basis. GIS-based network analyses provide an effective mechanism for objectively making decisions on the most optimal transportation choice.

Table 3 provides a summary of the major analytical tools required for the wide range of information requirements.

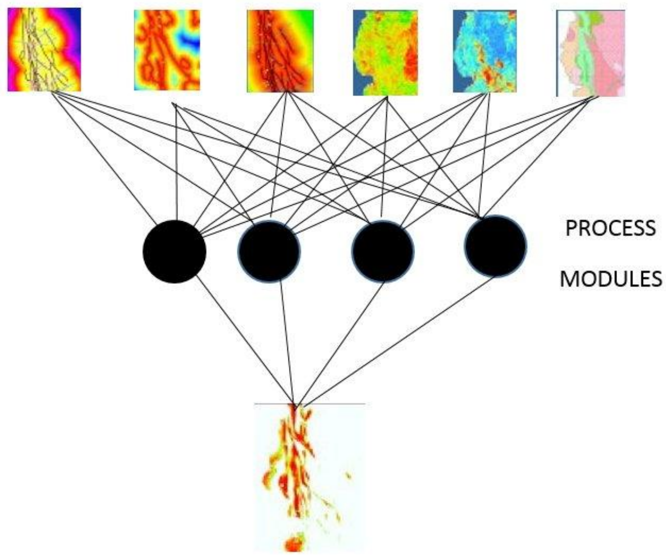

Figure 3: Analytical process (Adapted from Arkhipova *et al*., 2013)

Table 3 Required analytical tools

Information	Analytical tools
Prospecting	Spatial interpolation, 3-D
Trading	Open Web-based database query
Revenue management	Secured Web-based database query and payment system
Transportation optimization	Open Web-based network analysis

3.4 System Architecture

The proposed system will be operated at two levels, i.e. government and public levels. The public level, which will be Web-GIS based will have two sub-components, i.e. open/general and secure/restricted (Figure 4).

The open subcomponents will provide information on location of different minerals, optimum routes to mines, mineral trading centers, and hospitality facilities within the vicinities of different mines. The secure sub-component will provide secure information such as taxes due, paid or pending to registered miners and dealers. The government component, which will serve different government agencies, will be designed to; a) show the location, quantity and quality of different minerals, b) determine relationships between mineral occurrences and biophysical environmental components, c) give ownership details, and d) provide information on taxes and rent/rates due/payable plus all information available in the public level.

4 CONCLUSIONS

From the foregoing discussion, the advantages of automating mineral resource planning and management using Web-based GIS are compelling. It is also clear from the data requirements (Section 3.2), required analytical capabilities (Section 3.3) and system architecture (Section 3.4) that implementing the proposed Integrated Mineral Management Information System (IMMRIS) is relatively costly. However, almost 90% of the total implementation cost is likely to be one-off initial payment, which can be considered as capital investment. Most of this cost will go to database development and hardware and software acquisition. System implementation recurrent costs are minimal and may not require major changes in staffing and organizational structures. Further, weighing the total system costs against the potential benefits discussed in this paper, it can be concluded that the benefits overwhelmingly outweigh the costs.

It is important to note that the design, development and implementation of the proposed IMMRIS requires collaborative inputs from a multi-disciplinary team consisting of, among others, geologists, environmental experts, planners, surveyors, database developers, engineers, economists and information systems specialists.

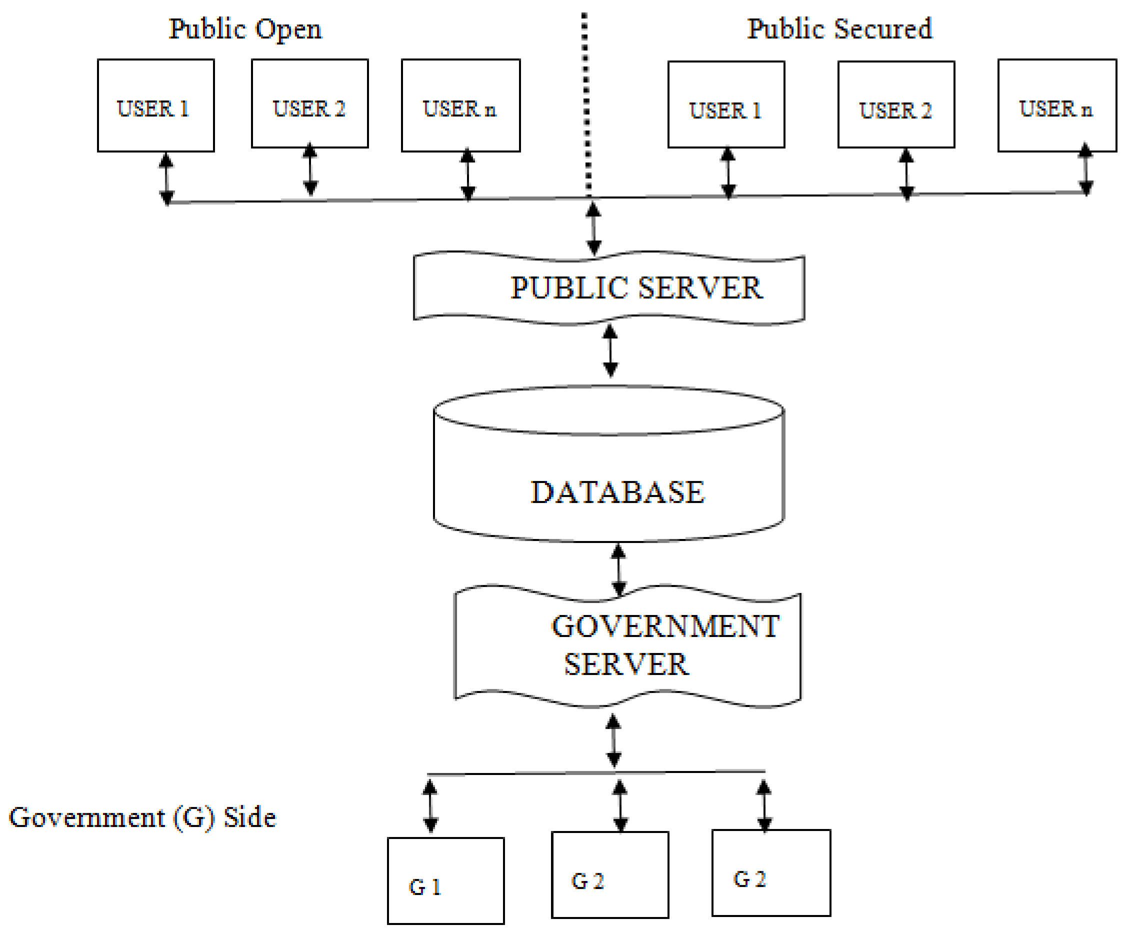

Figure 4: System Architecture

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Paper No: 09
Page 91 - 99
Sub-theme: GIS in resource planning and management

Modeling the determinants of Avifauna distribution in an agro-urban landscape

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Abstract:

Habitat transformation, building constructions, agricultural activities and acceleration of infrastructural developments are critical exogenous drivers behind rapid decline in avifauna populations throughout most landscapes in Kenya. This study investigated the determinants of avifauna distribution in University of Eldoret (UoE). UoE is surrounded by large-scale farms and is undergoing massive building constructions. A hand-held Global Positioning System was used to collect data on avian locations, habitat types and geophysical features. Geophysical variables were extracted by calculating distance buffers of geophysical features using ILWIS Academic software in a Geographic Information System. Data was analyzed using multiple linear regression to determine the relationship between 9 Geophysical variables (distances to dumpsites, power lines, wooded grasslands, open grasslands, wetland, roads, pavements, agricultural farms and buildings) and the spatial distribution of 9 avian foraging guilds (Fruigivores, Granivores, Nectarivores, Omnivores, Insectivores, Carnivores, Piscivores, Insect-granivores and Insect-fruigivores). Multiple regression showed that all the 9 variables were significant determinants of distribution of different avian foraging guilds in UoE but the distribution of most guilds was influenced by 5 variables: wetland, open grasslands, roads, dumpsites, and wooded grasslands. The wetland influenced the distribution of 7 foraging guilds, open grasslands accounted for 5 guilds, roads for 4 guilds whereas wooded grasslands and dumpsites accounted for 3 guilds each. The other 4 factors influenced the distribution of fewer foraging guilds (buildings, agricultural farms and pavements accounted for 2 guilds each whereas power lines accounted for only 1 guild). Understanding of the key determinants of avian distribution is an important pre-requisite for landscape and urban planning to ensure sustainable conservation of birds in agro-urban landscapes. Appropriate planning should conserve existing wetlands and grasslands in areas undergoing urban development. Existing urban areas should establish constructed wetlands and artificial grassland fields between the buildings. Also organic farming should be promoted as it is birds' friendly.

KEY WORDS: Agro-urban landscapes, Avian foraging guilds, Determinants of avian distribution, University of Eldoret

1 INTRODUCTION

Aves are among the sumptuous indicators of ecological integrity of any given ecosystem (Bilgrami, 1995), notably pollination and seed dispersal services to plants, as well as controlling populations of invertebrate and vertebrate pests (Sekercioglu, 2006). They have been widely used to evaluate environmental changes throughout history. Birds have received particular attention in terms of research and conservation activities (Ormerod and Watkinson, 2000). This is largely due to their suitability as important health indicators of the ecological conditions and productivity of an ecosystem (Newton, 1995;

Desai and Shanbhag, 2007). For their known firm reputation of being beautiful creatures, birds play important roles in vegetation and wetland systems. Their reproductive ability, ranging patterns, distribution and behavioural patterns such as migration have most often been used to analyze the long term effects of habitat modifications and degradations.

Current calamitous disappearance of global forests is a massive blow and setback to biodiversity and thus is of grave concern to research scientists, nascent wildlife managers, ecologists and conservationists. Human induced deforestation in many parts of the world has led to the transformation of native vegetation into impoverished forest fragments (Laurence and Bierregaard, 1997), secondary forests, pastures, croplands and other human-dominated habitats. Land use changes often have torrid impacts on tropical biodiversity, because land-use intensity affects vegetation structure, which in turn affects diversity, abundance and distribution of animal populations. Nearly, half of the bird species worldwide show decimating populations, 132 (about 1.3%) species have become extinct since 1600, 44% are stable and 7% are increasing (Butchart *et al*., 2010). Habitat change due to human activities is the most significant cause of avian declines, followed by unfettered hunting and an upsurge in invasive alien species. The risk of predation has been identified as a critical organizing driver for farmland bird communities (Suhonen *et al*., 1994) and nest predation is undoubtedly a significant cause in bird mortality irrespective of nest-site location with respect to edge (Perrins, 1979). Populations of birds have also plummeted in North America, especially in grassland and arid land habitats and have been attributed mainly to habitat loss due to agriculture and urbanization (Butchart *et al.*, 2010). Plunging trends in habitats have also been reported in Australia (Olsen, 2008).

Habitats with adequate resources for food, breeding, water, nesting and cover for predators act as a magnet to large avifaunal populations. For aquatic birds such as the Egyptian goose, grebes and cormorants, wetlands are of central pivots in their lifecycle because these areas serve as sites for breeding, nesting, source of drinking water, feeding, resting, shelter and for social interaction. Wetlands provide food for birds in form of plants, vertebrates and invertebrates. Some birds forage for food in wetland soils with worms and other forms of wetland soil related species which are targeted as the source of diet. Birds have daily and seasonal dependence on wetlands for food and other life supporting systems (Stewart, 2001). Those that are associated with vegetation, the existence of trees are pivotal components to their lifecycle.

The distribution of birds is driven by several factors encompassing abiotic processes, processes dominated by biotic interactions and biologically mediated processes. Changes in land use, chemical, physical and biological properties pose a big threat on avifauna specific localities. Many of these factors operate at different spatial and temporal scales imposing threats to species distribution ranging from local to global scales. Altitude being one of the critical drivers of species distribution patterns, abiotic variables such as relief can change dramatically. These factors exert a turbulent impact on wetlands and vegetation as habitats for avifauna communities. These in turn affects the wetland and vegetation dependent communities as well as the ecosystem attributes such as distribution, density and species richness (Burket *et al*., 2004).

While altitude accounts for much of the variability in bird communities, human activities have also had a torrid influence in determining the distribution of an ecosystem's avifauna. Agricultural activities, effluents disposal in wetlands and logging have significantly altered breeding sites, food reserves and important areas for birds' activities. Ultimately, these changes alter the corresponding feeding relationships (food webs and chains) at primary and secondary production levels (Wrona *et al*., 2006). The main aim of this study focused primarily on examining the critical determinants of avifauna distribution by looking at a range of cleared, disturbed and undisturbed sites in University of Eldoret which lie in the same altitudinal range.

2 METHODS

2.1 Study Area

The study was conducted in University of Eldoret, Kenya, which is centered on 35^o 18'E and 0^o 30'N (Jaetzold and Schmidt, 1983). The climate of the area is semi-humid with precipitation ranging from 900 to 1300mm with an average annual rainfall of 1124mm being recorded and the average temperature stands at 18^{o}C (Jaetzold and Schmidt, 1983).

The bulk of the soils in the study area are volcanic with deep and friable clays dominating them. A few soils with red and brown clays, yellow and red clays stand out in some parts of the study area. Towards Marula swamp, the soils are grayish and alluvial in nature. The soils are fine textured. The area is generally flat and slightly undulating with an overall gentle slope of 1% (Jaetzold and Schmidt, 1983).

The flora of the area is related to the soils and climate of the area. The vegetation is composed of scattered stands of both indigenous and exotic trees, herbaceous and shrub cover that stand out in different parts of the area. At the swamp neighbouring the University, the papyrus reed is a typical indicator of this zone. The fauna of the area comprises of a large variety of bird species, herpertofauna, insects, small mammals and fish. The most notable birds in the study area are the weaver birds, crows, cattle egrets, pigeons, swifts and swallows, bulbuls, Eurasian bee-eaters and wetland birds. Amphibians such as the clawed frog and tree frogs are found in the study area.

The economic livelihoods include activities such as small and large scale maize and wheat farming, livestock keeping, and making of mats from papyrus reeds harvested from the Marula swamp.

2.2 Collection of Bird Distribution Data

Data on birds' distribution were collection for 3 months between December 2014 and March 2015. The study area was divided into five habitats which encompassed; the open grasslands, wooded grasslands, buildings, agricultural farms and the wetland. Other areas in which birds were found included; dumpsites, power lines, pavements and roads. All the birds in the study area were classified into 9 groups based on their food preference. These 9 foraging guilds included the insectivores, piscivores, fruigivores, carnivores, granivores, nectarivores, omnivores, insect-granivores and the insect-fruigivores. Five 500m long transects were established per habitat for counting of birds, making a total of twenty five transects in the study area. Two surveys were conducted on transects in different habitats in the morning (0630hrs to 0830hrs) and in the afternoon (1630hrs to 1830hrs) when most birds were active. In total six survey sessions were conducted per habitat which amounted to a total of thirty survey sessions. Direct counting was carried out severally and at every encounter, the X and Y coordinates for locations of birds using GPS, habitat type, numbers and date were recorded in the field data sheets.

The observer moved through the different habitats unobtrusively at a speed of 1km to 2km per hour, moving carefully and very slowly approaching the birds to avoid disturbance, listening for vocalizations, searching visually and with binoculars in the habitat types. Terrific scanning of birds was supplemented by stopping and observing carefully including kneeling and taking closer looks at almost the ground level and maintaining of the hearing and sighting surveillance. At each sampling point the observer moved unobtrusively through the habitats using 8 × 42 binoculars, Global Positioning System (GPS) and field guide to birds of Kenya and Northern Tanzania (Zimmerman *et al*., 1990) and number of birds observed were recorded. A camera was used to take photographs of some bird species that were not identified during the bird surveys so that they could be identified later on.

2.3 Mapping of Habitats, Geophysical Features and Birds' Distribution

Using the GPS, the coordinates of each and every building, different habitats, roads, power lines and dumpsites in the University of Eldoret were captured. Coordinates were recorded for every corner of each a building, habitat type and the other geophysical features. The recorded data were typed in Microsoft Excel sheet and then saved in command delimited (csv) file format. A separate file was prepared for each variable. The files were then imported into the ILWIS Academic 3.3 GIS software for preparation of maps for habitats, buildings, roads, power lines and dumpsites. The coordinates of birds' distribution recorded in section 2.2 were also typed in Microsoft Excel and saved in CSV file format. Separate files were prepared for the 9 bird guilds. The files were then imported into ILWIS as tables and then converted into point maps. Figure 1 shows different habitats, geophysical features and distribution of birds in the study area.

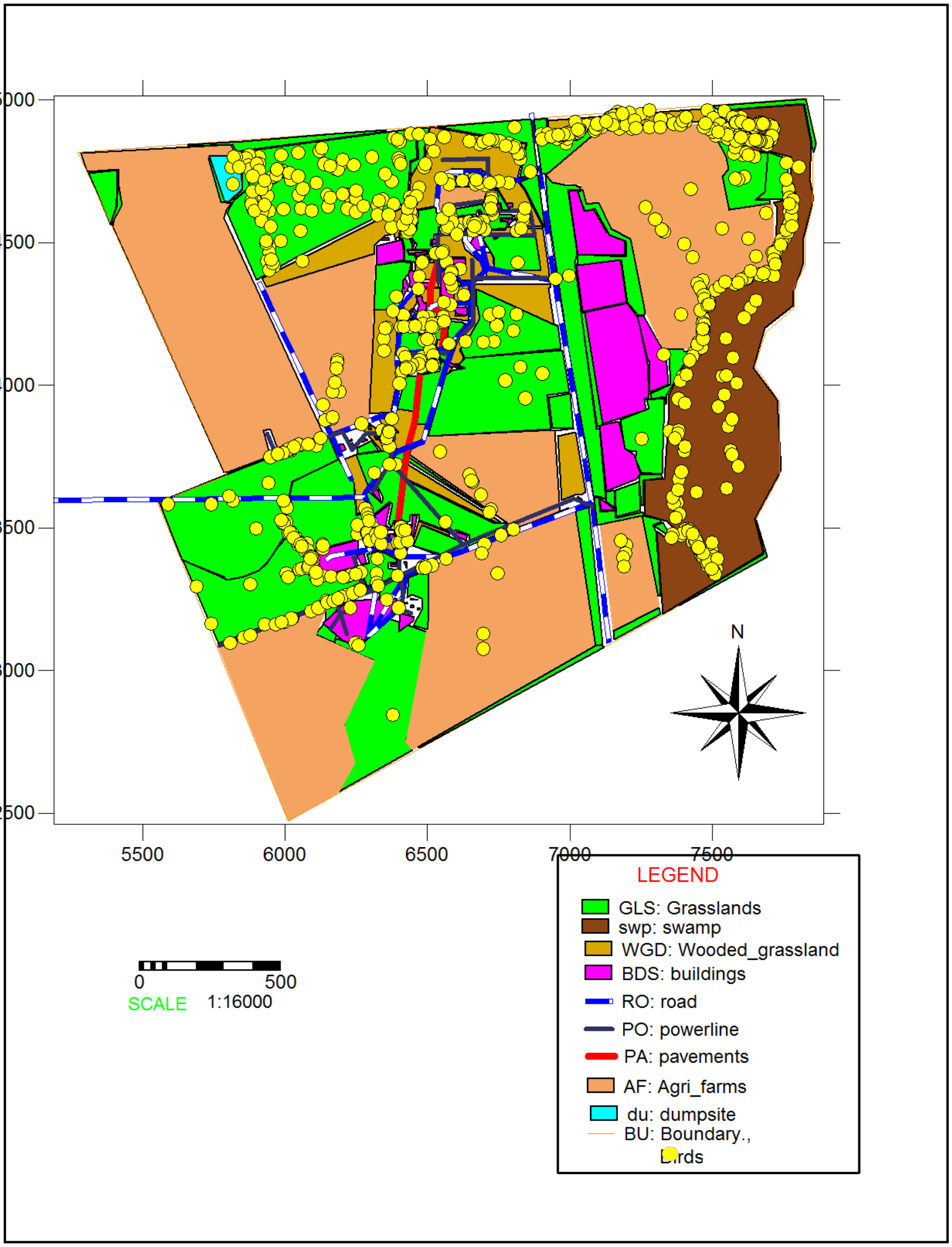

Figure 1: Different habitats, geophysical features and distribution of birds in the University of Eldoret

2.4 Spatial and Statistical Data analysis

To enable spatial data analysis in ILWIS all the maps (habitat, geophysical and birds) were converted into raster maps using the rasterization operation. Distance calculations were performed for the habitat and geophysical maps to enable extraction of distance variables. Distance of the birds to various habitats and geophysical features was obtained by crossing each of the 9 bird guild maps with the various maps of habitats and geophysical features. The generated distance data were saved in tables in dbase file format and exported to Statistical Package for Social Sciences (SPSS) for statistical analysis. Data were analyzed using multiple linear regression to determine the variables that significantly influenced the distribution of different avian foraging guilds. The analysis involved 1 dependent variable (the number of birds) and 9 independent variables (that is, distances to dumpsites, power lines, wooded grasslands, open grasslands, wetland, roads, pavements, agricultural farms and buildings).

3 RESULTS

A total of 84 bird species belonging to 9 foraging guilds were recorded in the study area. The birds' species comprised of 1 frugivore, 25 granivores, 4 nectarivores, 13 omnivores, 11 insectivores, 17 carnivores, 3 piscivores, 6 insect-granivores and 4 insect-fruigivores. Results of multiple linear regression showed that all the 9 factors significantly influenced distribution of different avian foraging guilds. However, the distribution of each foraging guild was determined by different set of factors.

Wetland determined distribution of 7 avian foraging guilds: piscivores, insectivores, carnivores, fruigivores, granivores, nectarivores and insect-fruigivores (Table 1). As the distance from the wetland increased, there was a significant increase in the number of piscivores (β=0.001, p=0.001), carnivores (β=0.001, p=0.023), fruigivores (β=0.010, p=0.009) and insect-frugivores (β=0.002, p=0.018). Conversely, as the distance from wetland increased, there was a significant decrease in the number of insectivores (β=-0.009, p=0.001), granivores (β=-0.019, p=0.013) and nectarivores (β=-0.005, p=0.001).

The open grassland was a determinant factor for the distribution of 5 avian foraging guilds: insectivores, fruigivores, nectarivores, omnivores and insect-fruigivores (Table 1). As the distance from open grasslands decreased, there was a significant increase in the number of omnivores (β=-0.015, p=0.011), insectivores (β=-0.008, p=0.004), fruigivores (β=-0.009, p=0.029), nectarivores (β=-0.005, p=0.015) and insect-fruigivores (β=-0.002, p=0.050).

The roads were critical determinants for the distribution of 4 avian foraging guilds: omnivores, piscivores, granivores and nectarivores (Table 1). There was a significant increase in the number of omnivores (β=-0.049, p=0.001), granivores (β=-0.078, p=0.048) and nectarivores (β=-0.024, p=0.003) and a significant decrease in the number of piscivores (β=0.002, p=0.001) as the distance from roads decreased.

Wooded grasslands and dumpsites accounted for the distribution of 3 guilds each. Wooded grasslands had a significant effect on insectivores, nectarivores and insect-fruigivores whereas dumpsites influenced the distribution of carnivores, fruigivores and insect-granivores (Table 1). As distance from the wooded grasslands increased, there was a significant increased in the number of insectivores (β=0.038, p=0.003) and nectarivores (β=0.011, p=0.002) and a decrease in the number of insect-fruigivores (β=-0.006, p=0.003). Similarly, as the distance from dumpsites increased, there was a significant increased in the number of carnivores (β=0.003, p=0.001) and fruigivores (β=0.012, p=0.004) and decrease in the numbers of insect-granivores (β=-0.004, p=0.046).

Buildings, agricultural farms and pavements accounted for the distribution of 2 guilds each whereas power lines accounted for only 1 guild. Buildings determined the distribution of omnivores and granivores; agricultural farms accounted for piscivores and insectivores; pavements accounted for insectivores and insect-fruigivores whereas power lines accounted for the distribution of insect-fruigivores (Table 1). As the distance from the buildings increased, there was a significant increase in the number of omnivores (β=0.028, p=0.014) and granivores (β=0.079, p=0.003). On the other hand, as the distance from agricultural farms increased, there was a significant increase in the number of insectivores (β=0.005, p=0.026) and a decrease in the number of piscivores (β=-0.001, p=0.004). Similarly, as the distance from pavements increased, there was a significant increase in the number of Insect-fruigivores (β=0.005, p=0.026) and a decrease in the number of insectivores (β=-0.024, p=0.006). Lastly, as the distance from power lines increased, there was a significant decrease in the number of Insect-fruigivores (β=-0.006, p=0.033).

Table 1 Regression coefficients and standard errors for factors significantly influencing the distribution of avian foraging guilds

Foraging Guild	Model Variables	Unstandardized Coefficients		Standardized Coefficients	t	P-Value
		B	Standard Error	Beta		
Omnivores	Open grasslands	-0.015	0.006	-0.234	-2.580	0.011
	Buildings	-0.028	0.011	1.176	2.476	0.014
	Roads	-0.049	0.014	-1.717	-3.504	0.001
Piscivores	Wetland	0.001	0.000	0.508	1875.354	0.001
	Agricultural farms	-0.001	0.000	-0.204	-155.917	0.004
	Roads	0.002	0.000	1.229	1393.701	0.001
Insectivores	Agricultural farms	0.016	0.008	0.250	2.055	0.042
	Wooded grasslands	0.038	0.012	0.964	3.029	0.003
	Pavements	-0.024	0.008	-0.875	-2.820	0.006
	Wetland	-0.009	0.003	-0.630	-3.275	0.001
	Open grasslands	-0.008	0.002	-0.340	-2.432	0.004
Carnivores	Dumpsites	0.003	0.001	0.403	3.412	0.001
	Wetland	0.001	0.001	0.279	2.301	0.023
Fruigivores	Open grasslands	-0.009	0.004	-0.353	-2.346	0.029
	Dumpsites	0.012	0.004	1.359	3.274	0.004
	Wetland	0.010	0.003	1.051	2.879	0.009
Granivores	Buildings	0.079	0.027	0.930	2.953	0.003
	Roads	-0.078	0.039	-0.752	-1.984	0.048
	Wetland	-0.019	0.007	-0.305	-2.496	0.013
Insect-fruigivores	Pavements	0.005	0.002	2.914	2.443	0.026
	Power lines	-0.006	0.002	-2.309	-2.326	0.033
	Wetland	0.002	0.001	1.562	2.608	0.018
	Open grasslands	-0.002	0.001	-0.641	-2.043	0.050
Insect-granivores	Dumpsites	-0.004	0.002	-0.278	-2.026	0.046
	Wooded grasslands	-0.006	0.030	-0.368	-3.126	0.003
Nectarivores	Open grasslands	-0.005	0.002	-0.965	-2.590	0.015
	Wooded grasslands	-0.011	0.003	3.142	3.350	0.002
	Roads	-0.024	0.007	-6.784	-3.251	0.003
	Wetland	-0.005	0.001	-2.399	-3.852	0.001

4 DISCUSSION

This study demonstrated that various habitats and other related geophysical features are significant determinants of different avian foraging guilds in the University of Eldoret (UoE). On the basis of the number of guilds affected by a single factor, these determinants can be ranked as follows (from most to least important): wetland, open grasslands, roads, wooded grasslands, dumpsites, buildings, agricultural farms, pavements and power lines.

The wetland accounted for much of the variability of avifauna distribution in UoE. The wetland underlined distribution of 7 foraging guilds. Insectivores, granivores and nectarivores preferred the wetland. Wetlands have a higher abundance of resources for protection from predators and food provision in form of flora, vertebrates and invertebrates which amounts to dietary requirements of these species. Some birds such as the hadada ibises and Egyptian geese among others forage for food in wetland soils with worms and other forms of wetland soil related species which are targeted as the source of diet (Stewart, 2001). Birds have daily and seasonal dependence on wetlands for food and other life supporting systems (Stewart, 2001). Marsh breeding birds such as marsh sand pipers, cranes and egrets have a heavy dependence on wetlands (Culver and Lemly, 2013). On the other hand, piscivores, fruigivores, insect-fruigivores and carnivores did not prefer the wetland. Massive grazing patterns are highly evident at the swamp and this triggers shifting of habitats by birds. A positive correlation between vegetation and birds has been documented in a study by Mulwa (2011) where compressed habitats experienced a dramatic decline in the quality and quantity of resources critical for survival of species. Livestock grazing has an indirect effect on water birds due to removal of vegetation (Richmond *et al*,. 2012). These guilds reduced in numbers as a result of the pollution, disturbance and noise from the periodic papyrus reed harvesting, massive sewage disposal and heavy predation by the free ranging feral carnivores. According to Rathore and Sharma (2000), birds present in or near water bodies are affected by several factors such as pollution, disturbance by human activities and lack of maintenance of water bodies. These guilds preferred the surrounding agricultural farms for perching due to disturbances from ongoing papyrus reed harvesting.

Based on the omnivore, insect-fruigivore, insect-granivore, nectarivore and fruigivore guilds' bird counts, the numbers increased with a decrease in distance from the open grasslands. A study by Cordy (1981) showed that diversity of habitat niches and resources such as water, nest-sites, song posts, cover for protection against predators and weather conditions provided by a particular habitat determine the diversity of bird species. Substantial areas of the open grasslands are brimming with nesting materials for birds, food ranging from insects, nectar from shrubs and fruits of plants such as lantana plants. Invertebrates are also available in abundance in these habitats and therefore all these attracted these feeding guilds.

The roads affected the number of bird movements across the roads but the net impact of the roads varied among the different foraging guilds. Four feeding guilds (piscivores, granivores, omnivores and nectarivores) were affected by the roads. These birds displayed a distinct preference for the proximity of roads. There are several flowering trees by the road sides at UoE such as the flowering gums and yellow bells that attracted large numbers of nectarivores. Granivores were attracted to the roads by grain droppings from nearby farms and sand that act as grit in their digestion. Omnivores preferred areas near the roads due to food and solid droppings on the roads. Omnivore birds such as the cape rooks and pied crow have a firm and known reputation of consuming solid waste and food remnants that drop on roads.

The number of insectivore and nectarivore feeding guilds did not prefer the wooded grasslands. Food reserves for insectivores tend to decrease in wooded grasslands especially at the understory. These species often decline in abundance near forest edges, avoid clearings (Laurance, 2001) and are highly vulnerable to forest fragmentation. There is a strong positive correlation between the vegetation and species richness and therefore habitat modifications are bound to cause deleterious effects. Patterns of disturbance are very high in wooded grasslands due to periodic coppice management and overgrazing. These species have typically dropped out of the vegetation communities along the gradient to completely urban environments to seek microhabitats and other resources and are constrained to breed there (Jaman *et al.,* 2009). Acceleration of urban development may open up areas for abundance and diversity of resources available to birds. However, insect-granivores displayed preference for wooded grasslands. This is due to abundance of resources in terms of food and cover.

Dumpsites triggered distribution of two avian foraging guilds in the study area. The number of insect-granivores increased with a decrease in distance from the dumpsites while the carnivores declined. Insect-granivores preferred the dumpsites due to lots of grains that are disposed to these areas from buildings and insects that inhabit these areas. Carnivores did not prefer these areas due to lack of sufficient prey and the massive waste paper dumping that constraints their digestion. The immediate effects of dumping to avifauna communities range from physical entanglement, ingestion, physical blockage or damage to feeding appendages or the digestive tract, to possible increased exposure to plastic components and persistent inorganic pollutants from ingested plastics (Moore *et al*., 2001; Arthur *et al*., 2009).

Buildings accounted for much of the variability of granivores and omnivores with the numbers decreasing with decreased distance from buildings. Buildings lead to habitat loss which affects species diversity. Both habitat loss and fragmentation have strong, detrimental effects on plant and animal species

(Fahrig, 2003). Habitat fragmentation limits the movement of organisms and materials across landscapes through introduced barriers of a different land cover type between formerly contiguous areas of the same land cover type (Edwards *et al*., 2004). With massive acceleration in construction of buildings and structures in the University, granivores have been relocated to the periphery of buildings for food and habitat resources.

Agriculture affected the insectivore and piscivore communities across the study area. Insectivores decreased with a decrease in distance from the agricultural farms. Agriculture intensification with the use of heavy machinery, pesticides and herbicides are not bird friendly. The existence of birds in farmlands depends, among other factors, on the distance to remnant patches of forests and on the local structural diversity in farmland habitats (Laube *et al.,* 2008). On the other hand, the piscivores preferred proximity of agricultural farms adjacent to the wetland. This is due to massive disturbance at Marula swamp that makes them retreat to these farms and then later on fly back when the disturbance has cooled down.

The prime factor for insectivore distributions was the distinct preference for the proximity of the pavements. Pavements have a higher abundance of synathropic insects (Mckinney, 2002) which attracted a lot of insectivores during the study period. These include ants, termites and cockroaches. On the other hand, number of insect-fruigivores plummeted with a decrease in distance from the pavements. This is because there is little abundance of fruits in the proximity of pavements to supplement their diet. Power lines triggered distribution of insect-fruigivores. They are not electrocuted and therefore preferred these lines for perching.

The torrid disappearance of habitats as a result of logging operations, vegetation colonization and rapid acceleration of infrastructural development in University of Eldoret suggests that the number of clearings and coppicing will increase in the near future. Efforts are required to reverse this rapid downward trend.

5 CONCLUSION

Although all the 9 variables considered in this study were significant determinants of distribution of different avian foraging guilds in UoE, the distribution of most guilds was influenced by 5 variables: wetland, open grasslands, roads, dumpsites and wooded grasslands. The wetland influenced the distribution of 7 foraging guilds, open grasslands accounted for 5 guilds, roads for 4 guilds whereas dumpsites and wooded grasslands accounted for 3 guilds each. The other 4 factors influenced the distribution of fewer foraging guilds (buildings, agricultural farms and pavements accounted for 2 guilds each whereas power lines accounted for only 1 guild). Understanding of the key determinants of avian distribution is an important pre-requisite for efficient landscape and urban planning to ensure sustainable conservation of birds in agro-urban landscapes. Appropriate planning should preserve existing wetlands and grasslands in areas undergoing urban development. Existing urban areas should establish constructed wetlands and artificial grassland fields between the buildings. There is need to initiate training programs for owners of pastures on appropriate use by extensive cattle farming, where better grass produces best cattle and represents best habitat for obligate grassland bird species (Martinez-Guerrero *et al*., 2014). There is also need to develop mechanisms to accelerate organic farming which is bird friendly. Organic farming usually increases species richness, having on average 30% higher species richness than conventional farming systems (Bengtsson *et al.,* 2005). Inorganic farming with the massive channelization of chemical fertilizers, herbicides and pesticides has deleterious effects on birds and therefore should be discouraged.

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Paper No: 10
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Sub-theme: GIS in resource planning and management

Spatial camping ground multi-criteria suitability modelling

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Abstract:

The GIS-based tools and multi criteria procedures were used to evaluate camping ground suitable areas within Kakamega forest. The objective of this paper is to incorporate the concept of land suitability multi criteria evaluation in decision making to enhance sustainable management of natural resources. The GIS spatial analyst function was used as a platform in data handling, processing and generation of new datasets including the suitable camping ground siting areas. The camping ground requirements were described as map layers in GIS such that each map layer represented one criterion of three factors and two restrictions. The Weighted Linear Combination (WLC) Multi-Criteria Evaluation (MCE) procedures were run to produce suitable camping grounds within Kakamega forest. The developed model indicated that a total of 1998.05 ha (8.35%) of Kakamega forest fall under high, moderate and low suitability levels and were more sensitive to the slope criteria. The application of MCE in a GIS platform is invaluable long term management and optimal use of natural resources.

KEY WORDS: GIS, suitability, spatial analysis, WLC

1 INTRODUCTION

Land is a critical but finite resource essential to key competing uses comprising of ecological functioning and human activities. Nowadays, the use of the forest is more diverse and covers wood production, recreation, protection and conservation of wildlife among others. Thus, the decision on how to utilize forest becomes central in its sustainable use and management. A decision is a choice made between alternatives which can be land use, actions, location, objectives and the like (Malczewski, 1999).

Resource allocation decisions are concerned with control over the direct use of resources to achieve a particular goal. The effectiveness of the decision making is clearly dependent not only on the quality of the information available but also the process of its generation and the method of decision analysis. The spatial multi-criteria decision analysis (MCDA) is an important spatial analysis method in the decision making process that allows information from varied sources to be combined (Feizizadeh & Blaschke, 2001). The application of MCDA in the judgement process creates an enabling environment of making an informed decision (Chen *et al.*, 2011) through designing, evaluating and prioritizing possible course of action (Feizizadeh *et al.*, 2012).

GIS applications have been used to produce new information by combining information from different sources and by spatial analysis of existing data. Spatial modelling has been applied when looking for suitable areas for a specific land use (Reisinger and Kennedy, 1990). The aim is usually to locate areas where the given criteria apply. The Boolean overlay operation uses thresholds resulting in accepting or rejecting areas based on the values (Malczewski, 2004). Unlike Boolean logic, the GIS-based multi-criteria method standardize the criterion score and total score for each alternative is calculated by multiplying the criterion score by its weight factor and then adding the results (Malczewski *et al.*, 2003).

The multi-criteria approaches can be generalized within the framework of the Weighted Linear Combination (WLC). This method provides a way to exclude areas which are not suitable for a certain purpose and to rank the remaining areas based on area attributes thus generating different sets of suitability maps.

To maximise on the competing uses of Kakamega forest and enhance the benefits, the stakeholders of Kakamega Forest developed Kakamega Ecosystem Management Plan (KEMP) 2012 – 2022. The plan among other recommendations proposed establishment of more accommodation facilities and camping ground to promote tourism. The existing and proposed accommodation facilities in Kakamega Forest (KFEMP, 2012) are listed in Table 1.

Table 1: Some of the existing and proposed accommodation facilities in Kakamega Forest

Facility type	Current bed capacity	Proposed bed capacity
Cottage – Rondo	30	-
Guest house – Isecheno	8	8
Bandas (KEEP)	16	10
Udo's bandas	14	12
Isukuti guest house	8	8
De-Brazza bandas	6	-
Campsite	-	-
Eco-lodge – Buyangu	-	30
Hostel	-	40
Eco-lodge – Yala River nature reserve	-	25
Eco-lodge – Isecheno nature reserve	-	30
Eco-lodge – Malava forest	-	30
Campsite – Kibiri forest station	-	-
Campsite – Malava forest	-	-

While the Kakamega Ecosystems Management Plan is comprehensive, there is no information on how the siting of the accommodation and camping grounds was done. The siting of camping grounds should take into account sustainable use of the forest both ecologically and utilization by man. The location of camping grounds have to be identified based on criteria developed taking into consideration the sensitive forest ecosystems, the natural functions of the forest, proximity to natural sceneries and away from disturbances. The criteria, criteria range and criteria weights used is hypothetical and is used with the assumption that a credible process was used to arrive at the values. The study also did not make any reference to the camping grounds and sites in Kakamega Forest Ecosystem Management Plan. The term camping ground was defined as a place used for temporary stay in the outdoors where a tent is pitched while other facilities comprising water, toilet and latrines are provided. Thus, to locate good camping grounds in Kakamega Forest requires considerations of the nature of landscape, the proximity to rivers, proximity to roads, conservation areas and the forest edge. The decisions to be made on camping ground will depend on these criteria. This process is termed land suitability and aims at identifying the most appropriate land uses according to specific requirements, preferences and predictors of some activity (Collins *et al.*, 2001). The aim of this study is to improve land use suitability evaluation to aid informed decision making in a GIS-based framework when selecting camping grounds in Kakamega forest.

2 MATERIALS AND METHODS

2.1 Study Area

Kakamega forest (Figure 1) forms one of the important natural resources in Kenya for both ecological and human development apart from being a major tourist attraction in western Kenya. It is located in Kakamega County and lies between longitudes 696983m and 718086m and latitudes 15582m and 40831m measuring about 23923.5 hectares. It has a varied topography with altitude ranging from 1250 – 2000 meters above sea level (Tsingalia, 1988). The forest is composed of natural and plantation forests with over 300 species of birds sighted. Various primates such as the endangered Debrazza and other monkeys and baboons are also found in large numbers in Kakamega Forest. Other animals include; Bush pigs, Duikers, Pottos, Pangolins and snakes some of which are endemic to Kakamega Forest. Also in the forest are insects, mainly butterflies which have made Kakamega Forest a research site (GoK, 2007).

It has a warm and wet climate and experiences two rainy seasons with annual rainfall averages between 1500-2000 mm (Tsingalia, 1988). The vegetation of the forest includes closed indigenous forest, grasslands and open forest. There is widespread dependence on the forest by the local people who obtain their livelihood by mainly harvesting firewood, thatch grass, medicinal plants and as traditional grazing grounds (Nambiro, 2000).

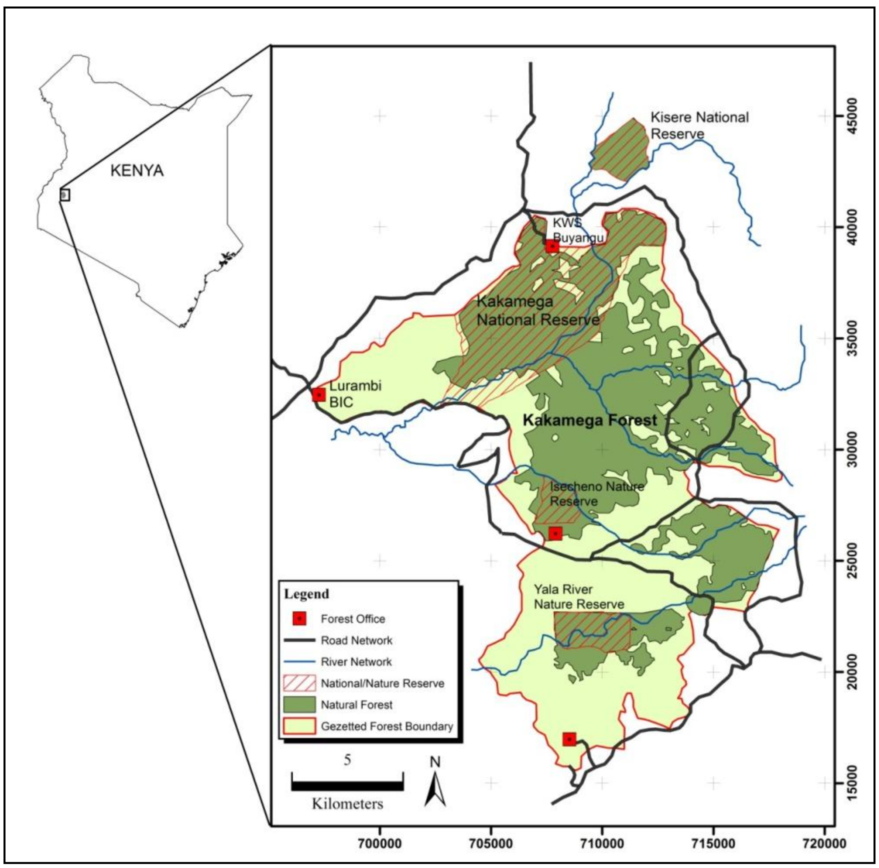

Figure 1: Map of Kakamega Forest (Modified from KEMP, 2012)

2.2 Methods

2.2.1 Data sources, processing and analysis

The generalized methodology is presented in Figure 2 and comprised the MCE procedure.

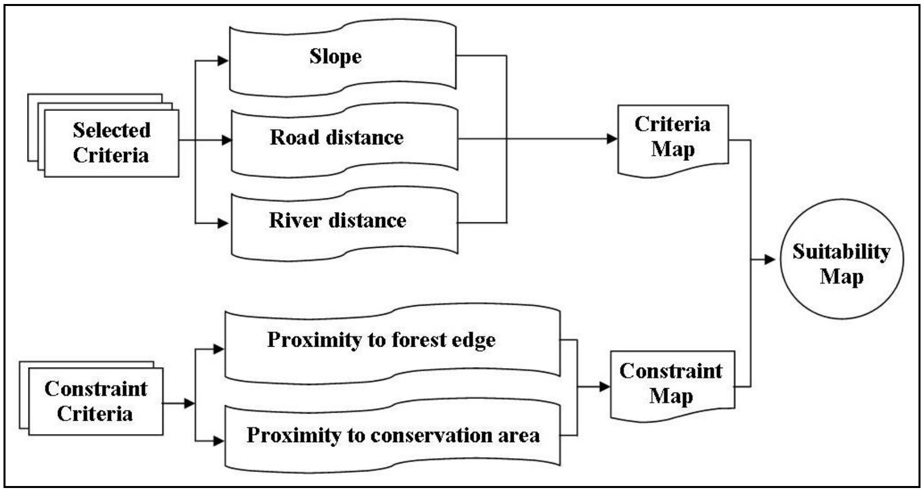

Figure 2: Generalized methodology

The land suitability evaluation for camping ground required gazetted forest edge, conservation areas, roads and rivers network and slope data. The forest boundary, conservation areas, rivers and road network data were sourced from KEMP (2012) while slope data was extracted from digital elevation model of 90m resolution downloaded from World Resources Institute website. Table 2 presents the criteria range and normalization (conversion of criteria into a common index) values applied in the MCE model. The normalization values ranged from 1 – 5 in ascending order of significance while the ranking ranged between 1 and 3 with 3 being the highest representing the most important factor and the distance from the forest edge and away from conservation areas were termed constraints.

Table 2: Criteria normalization/standardization

Criteria	Range	Normalization values								
		1	2	3	4	5	4	3	2	1
Distance from roads (m)	300-1500	300-400	400-500	500-600	600-700	700-1000	1000-1100	1100-1200	1200-1300	1300-1500
Distance from rivers (m)	300-2000	300-400	400-500	500-600	600-700	700-1000	1000-1100	1100-1200	1200-1300	1300-2000
Slope (%)	2-10	0-2	2-3	3-4	4-5	5-7	7-8	8-9	9-10	10+
Distance from forest edge	-1000	Constraint								
Distance away from conservation areas	500	Constraint								

Criteria ranking considered serenity and suitability of the ground for tent pitching in terms of slope. The distance from roads was ranked 3, distance from rivers ranked 2 and the least rank of 1 was awarded to slope. The individual map units of the criteria were meters and percent slope and had to be normalized so as to be used in the MCE process. Malczewski (1999) discussed various methods of data normalization comprising Ranking, Rating, Analytic Hierarchy Process and Trade-off. Criteria weighing was done by ranking and the relative weights generated as described by Malczewski (1999). The Ranking method is in order of preference (i.e., 1= most important, 2 = second most important, etc.). Then the rankings were converted into numerical weights on a scale from 0 to 1, so that they sum up to 1. The criteria, assigned rank and relative weights are presented in Table 3. The relative weights define the degree of influence of the criteria on the camping ground suitability level.

Table 3: The criteria, range and importance of applied factors

Factor	Rank	Relative Weight
Distance from roads	3	0.5000
Distance from rivers	2	0.3333
Slope	1	0.1667
Distance from forest edge to the inside	-	-
Distance away from conservation areas	-	-

Cartographic modelling was used as a means to determine the suitable area, standardization and transformation of raw scores for priority measurement and generation of suitability index as a combination of single habitat factors. Two criteria, the constrained factors were used in the model to screen out the unsuitable areas. The first criterion is that the area has to be 1000m inside Kakamega forest and the area classified as nature conservation and its buffer formed the second criteria. This generated the feasible areas through application of Boolean overly. The model input data layers of 10m resolution are presented in Figure 3 and were used to produce the suitable camping grounds in Kakamega forest.

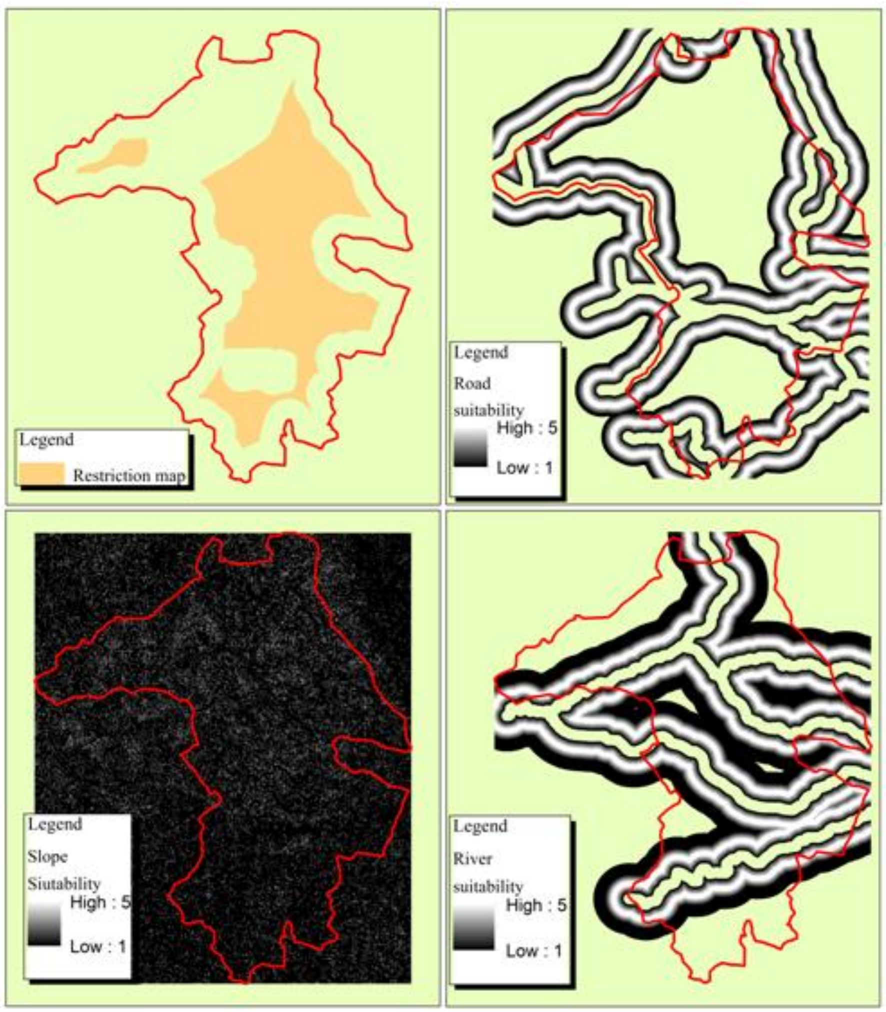

Figure 3: Spatial distribution of the processed criteria input layers

The MCE applies weighted linear combination (WLC) decision rule expressed by Malczewsky *et al.*, (2003) as

$$S = \sum w_i x_i \times \prod c_j$$

Where:

S - The composite suitability score
x - Factor scores (cells)
w - Weights assigned to each factor
c - Constraints (or boolean factors)
Σ - Sum of weighted factors
Π - Product of constraints (1-suitable, 0-unsuitable)

2.2.2 *Sensitivity analysis*

Sensitivity analysis was used to evaluate the degree to which the camping ground suitability areas will change if the criteria weights are varied. The variation made on the criteria weights was to use a uniform weight of 20% (0.2) on all the criteria and the resulting suitability areas compared with the suitability map generated with different weights as specified in Table 3.

3 RESULTS AND DISCUSSION

The five screening factors were the gazetted forest boundary, the conservation areas buffer, slope, road and river network with different ranges and weights as stated in Tables 2 and 3. The final suitability map was divided into five categories between 0 – 100% at intervals of 20% using Equal interval method (Feizizadeh and Blaschke, 2013) Figure 4 for both unequal weights (using the generated relative weights) and equal weights (using the same relative weights for all the criteria).

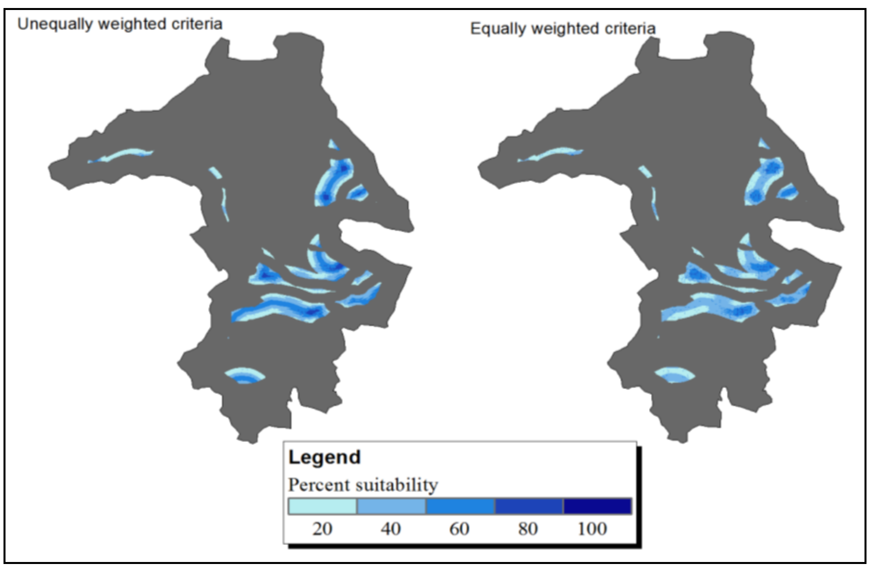

Figure 4: The spatial distribution of camping ground suitability level for unequally weighted criteria (A) and equally weighted criteria (B)

The total suitable area for the unequal weight criteria is 2193.75 hectares equivalent to 9.17% of Kakamega forest while the equal criteria classified 9.181% (2196.41 Ha) as suitable area for camping ground. Under the five suitability levels, the unequal weights criteria scenario showed that high suitability camping ground covers about 0.08ha while that below 20% covers 710ha with the intermediate values in Table 4.

Table 4: The camping ground suitability levels and sensitivity analysis of Kakamega Forest

Suitability level (%)	Area (Ha)		Percent change
	Unequal weights	Equal weights	
0-20	710.08	746.15	-5.08
20-40	807.21	1087.32	-34.70
40-60	602.91	337.13	44.08
60-80	73.51	25.73	65.00
80-100	0.08	0.08	0.00

The sensitivity analysis showed that, in both cases, the total area selected in the different suitability levels were more or less the same with notable differences in the specific suitability levels table 4. Thus weighting has almost a negligible influence on the area with different suitability levels. The percent change in the different suitability classes is more pronounced with an increase of 65% in the areas of 60-80% level while there was no change in areas above 80%.

The potentials of GIS were used in the study to aid in quick and cheap informed decision making to establish camping ground suitability areas in Kakamega forest. The theoretical background in combinations was provided by Weighted Linear Combination (WLC) one of the Multicriteria Evaluation (MCE) procedures. The used criteria were processed by ranking and normalization with a range of 1 (least suitable) to 5 (most suitable). The GIS platform was used and enabled the management of criteria data, processing of layers and calculation of attributes by means of spatial analysis, cartographic modelling and sensitivity analysis. This method has both pros and cons. The major advantages of the method used in the study are the possibilities it offers for producing suitability indices for large areas within a short time and at a very low cost apart from the ability to use different evaluation criteria. However, this method has some short comings including the simplification of dynamic model into a linear model. It is static thus lacks time dimension and it can be subjective leading to controversies.

The method used in the study is based on the analysis of data in raster format whose nature of boundaries and required accuracy depends on the requirements of the application. The camping ground suitability areas were generated in order to demonstrate the application of the method in sustainable land use and thus model validation was not done in the study. The data range applied in the model was hypothetical though it was assumed that camping ground has certain requirements. These conditions include proximity to a road for accessibility, closeness to a water body allowing nature walking and should be inside the forest so as to have a nature atmosphere.

The determination and camping ground criteria and their weights are significant stages in the MCE process. It is likely that even slight modifications in the weights have a noticeable effect on the suitability analysis. Further, criteria ranking can influence the results too. It is impossible to include all the factors affecting the suitability to an MCE model and therefore choices have to be made between the accuracy and costs. Sensitivity analysis was done by investigating the effects of criteria weight in the camping ground suitability areas.

The data used in the study were sourced from published materials in the internet and were assumed to be accurate, thus an error free assumption was made. Sensitivity analysis inspected the influence of criteria weights on the camping ground suitability map by assigning equal weights to the criteria. The output had no effect no effect on the total area under different suitability levels but changes were evident in the individual suitability levels. The changes in the areas under different suitability levels was highest at low level which reduced by 12.71%. The other levels increased by 0.06% and 4.27% for high and moderate suitability levels in that order. These changes are attributed to the increase in the slope criteria weight as it covered the whole of Kakamega while the other criteria were confined as indicated it Table 2.

4 CONCLUSION AND RECOMMENDATIONS

The MCE techniques if applied properly facilitate informed decision making process by making it more open, logical, cheap, fast and competent. The inclusion of MCE with other land use decision making tools aids in evaluating the importance of land use decisions by varying the criteria used. Although several drawbacks of MCE method in a spatial environment were highlighted, its advantages remain very powerful and revolutionary in land use suitability modelling. The study recommends that, other criteria be included and compare the results with the locations identified by the Kakamega Forest Ecosystems Management Plan.

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Paper No: 11
Page 109 - 124
Sub-theme: GIS in disaster management, health and security

GIS proximity analysis of cellphone tower radiation and reported vicinity households health in Kesses region of Eldoret, Kenya

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Abstract:

The mobile phone industry is one of the fastest growing industries in recent times. Location of cellular phone towers especially in residential neighborhoods is a contentious subject in public health debate. Many researcher's have proved that electromagnetic radiation emitted by mobile phone towers could be harmful to the well-being of human health. Effect of electromagnetic radiation emitted by mobile phone towers depends upon the distance of its location; The closer the proximity to the tower the more the health effect. Local resistance by the residents towards putting up of the tower from nearby residents and landowners is often based on fears of adverse health effects despite reassurances from telecommunications service providers that international exposure standards are followed. This study aimed at assessing health effects from cell phone towers radiation on vicinity households in Kesses region of Eldoret. To achieve this objective data on cell phone towers location was collected using GPS receivers and mapped in ArcGIS software while households distribution within Kesses region were mapped from google earth application. Data on assessment of household health effects was collected using questionnaire and processed in SPSS software. Promixity analysis was done using 200meters buffer around cellphone tower location in ArcGIS software. The results indicate that households within 200meters buffer suffer from the following health effects; constant headaches, tiredness, fever and heating of eardrums while making their calls amongst others while those further than 200meters do not experience such health effects. This study concludes that cell phone towers radiation affects the health of households within their vicinity. After this study, it is found that electromagnetic radiation emitted by mobile phone towers are harmful to the people living near the transmission towers, so and therefore people should keep away from the transmission towers. Further, the mobile telecommunication companies should not only focus on the network coverage/ and financial gains for cell phones but work out safety precautions while erecting their cell phone towers within residential areas.

KEY WORDS: Cell phone tower, Electromagnetic radiation, Health effects, mobile telecommunication companies

1 INTRODUCTION

The cell phone industry is the fastest growing industry in modern times. Mobile or cellular phones are integral to modern telecommunications. At the end of 2009, there has been an estimated 4.6 billion subscriptions globally. In most parts of the world today, mobile phones are the most efficient and effective forms of communication available (WHO, 2010). The subscriber base have risen within a short time with millions of people world-wide using mobile phone regularly, and many mobile phone cell towers erected in the midst of densely populated areas, increasing the exposure to high-frequency electromagnetic fields (Hamnerius &Uddmar, 2000).

To reach the signals of mobile phones in every place, the cell phone towers are situated almost everywhere in the country. These towers are essential part of mobile communication network necessary to establish connection between the mobile telephone and the rest of the network (Bhat *et al.*, 2013). The communication companies erecting cellphone towers do not consider their disadvantages. There is a growing body of scientific evidence that the electromagnetic radiation they emit, even at low levels, is dangerous to human health; adverse effects have been noted for cancers in both men and women living near broadcast towers (Henderson & Anderson 1986); childhood leukemia clusters; (Maskarinec *et al.* 1994; Ha *et al.* 2003; Park *et al.* 2004); adult leukemia and lymphoma clusters, elevated rates of mental illness (Michelozzi *et al.* 2002; Ha *et al.* 2007); elevated brain tumor incidence (Dolk *et al.* 1997); sleep disorders, decreased concentration, anxiety, elevated blood pressure, headaches, memory impairment, increased white cell counts, and decreased lung function in children (Altpeter *et al.* 2000); increases in malignant melanoma (Hallberg& Johansson, 2002). Although, the industry has set “safe levels" of radiation exposure within the international commission on Non-Ionizing Radiation Protection (ICNIRP), there is extensive scientific debate amongst doctors, physicists, members of the public and health officials who strongly disagree, and foresee a public health crisis (WHO,2010). The numbers of cell phones and cell towers have increased due to; rapid increase in cellphone ownership globally, service provider market competition, and new technological competition (Valberg, 2007). Although there is considerable public concern about possible effects of mobile telephone base-stations on people’s health and wellbeing no studies on that issue have been published so far (WHO, 1997). Earlier studies have concentrated on the effects of mobile telephones handset usage to human body which have shown that long time high frequency exposure is very harmful to the human body (Altpeter *et al.* 2000). Frequencies used by mobile phones, have most of their energy absorbed by the skin and other superficial tissues, resulting in temperature rise in the brain or any other organs of the body (WHO, 2010). However, there is a fundamental difference between exposure from mobile phones and their base stations that has not been considered. Given the large number of mobile phone users, it is important to investigate, understand, and monitor any potential public health impact of base stations (UNPD, 2001).

1.1 Electro Magnetic Field Radiation

The radio frequency field given off by cell phones and cell phone towers is a type of non-ionizing radiation. It is similar to the type of energy used in AM/FM radio and TV broadcast signals. Unlike ionizing radiation (as emitted by X-ray machines), RF energy from cell phones, and other wireless devices cannot break chemical bonds in your body. Cell phones emit low-levels of radiofrequency (RF) energy, some of which is absorbed into your body. Cell phones are designed to operate at the minimum power necessary to connect and maintain a quality call. They send and receive radio signals from a network of fixed, low-power, cell phone towers. These towers are usually located on rooftops and utility poles. The transmitting power of a cell phone varies, depending on the type of network and its distance from the cell phone tower. The power generally increases the further you move away from the nearest cell phone tower (Health Report Canada, 2010). The most common sources of exposure includes the FM/AM radio, TV transmission, Cellular networks using GSM, CDMA, WLAN, Bluetooth, Zigbee1, WiFi and WiMax technologies, which occupy the VHF, UHF, L, and S band of frequencies (Figure 1). The effects due to FM, AM and TV transmissions are localized to the areas around the location of towers while Bluetooth, Zigbee applications operate at low power levels.

1.2 Cell phone and EMF Radiation

The two main sources of mobile cellphone radiations are Cellphone towers and mobile handsets both of which are at the relatively low end of electromagnetic spectrum. The energy carried by them is unable to break chemical bonds in molecules. Thus, they fall under the non-ionizing radiation category. In order to provide mobile services, cellphone companies establish cell phone towers, at suitable locations, as per their Radio Frequency (RF) Network Planning for proper network coverage and capacity requirements is necessary (Figure 2).

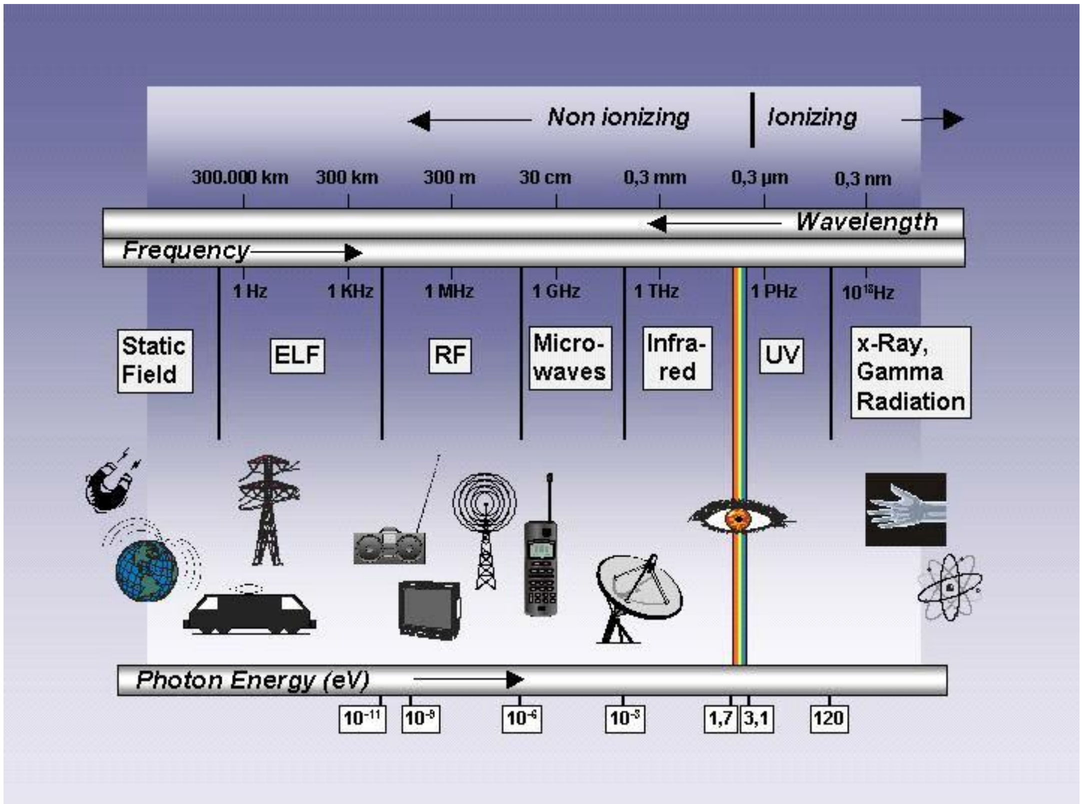

Figure 1: Electromagnetic Spectrum

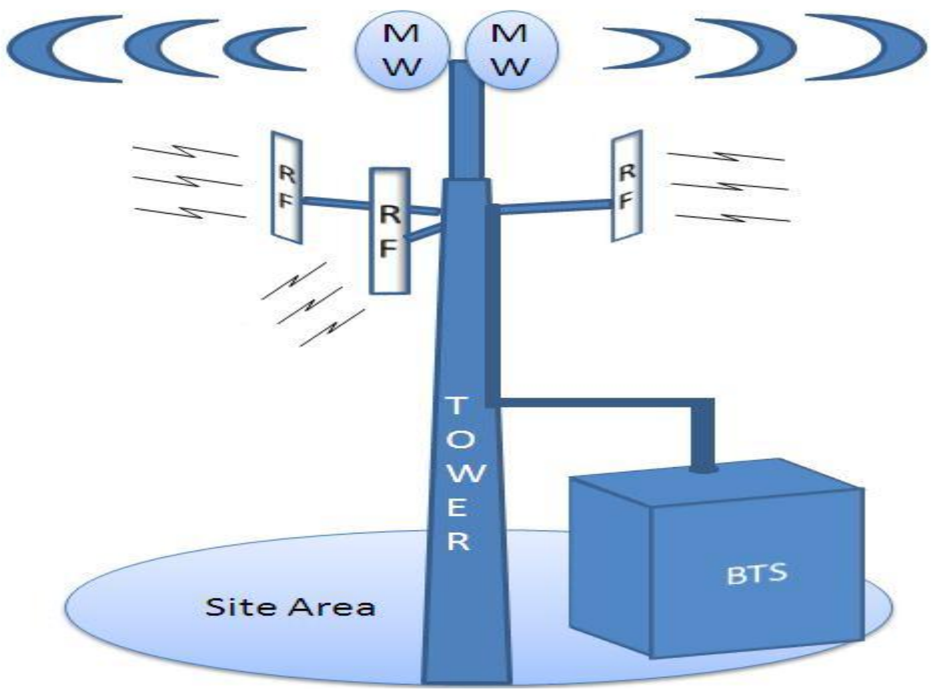

Figure 2: Cellphone Tower

Every antenna on a cell phone tower radiates electro-magnetic in the frequency range of: 935 - 960 MHz (GSM900), 869 - 890 MHz (CDMA), 1805 – 1880 MHz (GSM1800), and 2110 – 2170 MHz (3G) (Kumar, 2011).

The GSM900 frequency band of 25 MHz is divided into twenty sub-bands of 1.2 MHz, which are allocated to various mobile phone operators. There can be several carrier frequencies (1 to 5) allotted to one operator with upper limit of 6.2 MHz bandwidth. Each carrier frequency may transmit 10 to 20W of power. So, one operator may transmit 50 to 100W of power and there may be 3-4 operators on the same roof top or tower, thereby total transmitted power may be 200 to 400W. In addition, directional antennas are used, which typically may have a gain of around 17 dB (numeric value is 50), so effectively, several KW of power may be transmitted in the main beam direction (Kumar, 2010). The density of cell towers is directly connected to the density of population in both directions.

The cellphone tower transmission power levels and the antenna gain used for transmission are critical when dealing with exposure levels. Although the high gain antennas increase the efficiency and coverage, the risk of exposure for buildings in the close proximity of line of sight of the main beam of the antennas increases multifold. The source of EM radiation is the transmitting antenna that determines electromagnetic field distribution in the vicinity of a transmitting station. Radiation will be highest from the primary lobes in the horizontal direction. There is also radiation from secondary lobes which ranges from medium to very low when transmitting horizontally (Figure 3) below. Hence, the direct exposure to the primary lobes along the line of antenna is the most severe of the exposed radiation.

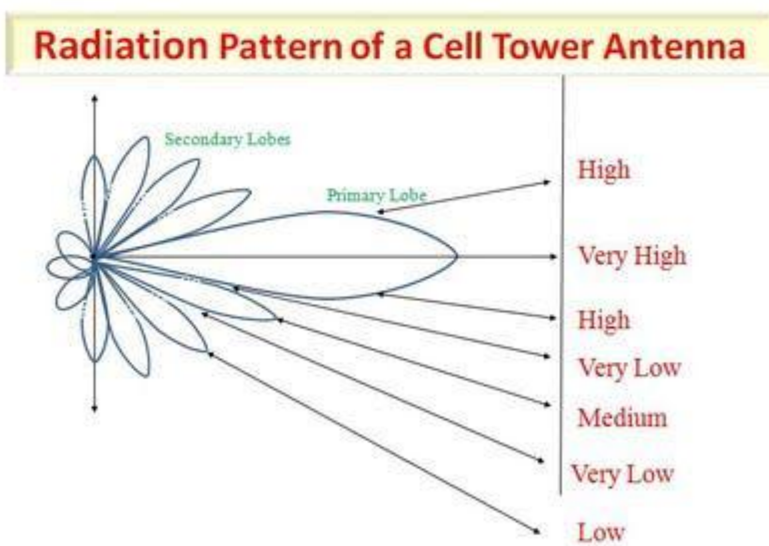

Figure 3: EMR Radiation pattern

Exposure levels to EMR also depend on the distance from the source of radiation. The power density varies by (1/R2), where R is the distance. As one moves away from the antenna, the radiation is less. This is guided by radiation norms given by ICNIRP guidelines of 1998 for safe power density of f/200, where frequency (f) is in MHz. Hence, for GSM900 transmitting band (935-960 MHz), power density is 4.7W/m2 and for GSM1800 transmitting band (1810-1880 MHz), it is 9.2W/m2. The ICNIRP guidelines clearly state that for simultaneous exposure to multiple frequency fields, the sum of all the radiation must be taken into consideration. However, in Kenya the limit is applied to individual carrier, so the radiation levels have exceeded by several times those prescribed by ICNIRP guidelines (Table1), depending upon the total number of transmitters in that area (WHO, 2010).

Table1: ICNIRP EMR Exposure Guidelines

ICNIRP Reference levels				
	Frequency (MHZ)	Power Density (W/m2)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)
General Public Exposure	900	4.5	41	0.11
	1800	9.0	58	0.15
	1900	9.5	60	0.16
	2100	10.0	61	0.16
Occupational Exposure	900	22.5	90	0.24
	1800	45.0	127	0.34
	1900	47.5	131	0.35
	2100	50.0	137	0.36

1.3 Mobile Telephone Industry in Kenya

Historically, mobile telephones were first introduced in the Kenyan market in 1992, but the real diffusion of this technology and affordability of the services started in 1999 when the Communications Commission of Kenya (CCK) was established and the newly privatized company Safaricom, Yumobile, Orange and Celtel Kenya (previously known as KenCell Communications) were licensed by CCK to provide mobile services (CCK, 2012, and CCK, 2006 &2007). These operators are currently providing mobile telephone connectivity in Kenya and have covered majority of the populated areas, and they are still continuing in this trend of growth (Manica and Vescovi, 2008).

Review of mobile telephone situation in Africa indicates that the number of mobile users have doubled over the years than the number of fixed-lines (Momo, 2005, UN, 2007). This trend regards Kenya as well, where the number of mobile subscriber has grown in five years from 2 million to more than 9 million at the end of 2006 (CCK, 2006&2007).This impressive growth of mobile telephone in Africa, and Kenya in particular has posed many challenges and economic opportunities as well (Momo,2007). At the end of 2007, Kenyan mobile operators; Safaricon, airtel, Yumobile and Orange offer services to more than ten million people (Kiberen et al,2013) and currently one in three adults carry a cell-phone in Kenya and about the 80% of Kenyan parts are covered by mobile network signals (CCK,2012). The network is still growing and mobile operators are extending their coverage reaching even more remote areas of the country by erecting mobile telephone towers in residential areas (plate1) without understanding the dangers they pose to residents.

In one year, from 2006 to 2007, the cellular mobile services recorded an increase in the number of channels installed in GSM base station transmitters, from about 15,000 to about 20,000. This increase could be attributed to the increased subscriber base, requiring mobile operators to increase investment in network expansion (Paul, 2007).

1.4 Mobile Telephone Operators in Kenya

The use of mobile telephones has become the most important mode of telecommunications in the world and Kenya in particular. Large part of the population find mobile telephone most affordable and friendly technology, while Internet access is a reality for many businesses and public institutions, but it is still an expensive technology restricted to individuals with higher levels of education and incomes in Kenya (CCK, 2012) quarterly report.

1.4.1 YuMobile

This is Kenya's fourth mobile cellular network under the brand name Yu mobile launched in December, 2008. YuMobile grew its network coverage in Kenya fast and boasts of this achievement within 10 months from the date of its launch., the network had a subscriber base of over 2.8 million by March,2014(CCK,2012) quarterly report. YuMobile offers several innovative product and service offerings all target easier and more convenient. The services include; Yu cash, internet services, SMS services, and voice call services among others.

Plate 1: Celllphone tower location in residential area of Kesses region.

1.4.2 Safaricom Ltd

This is a leading mobile network operator in Kenya. It was formed in 1997 as a fully owned subsidiary of Telkom Kenya. In May 2000, Vodafone group of the United Kingdom acquired 40% share and management responsibility for the company. Safaricom employs over 1500 people mainly stationed in Nairobi and other big cities like Mombasa, Kisumu,Nakuru, Eldoret in which it manages retail outlets. Currently, it has nationwide dealerships to ensure customers across the country have access to its products and services. As of December 2013, Safaricom subscriber base was approximately 20.8 million, most of who are in the major cities; Nairobi, Mombasa, Kisumu and Nakuru. Its headquarters are in Safaricom house on Waiyaki Way in Westlands, Nairobi. Its main services and products include; Short message services, mobile banking services, internet services, M-pesa, Sambaza among others. Its main rival is Airtel Kenya. Other rivals include YU and Orange wireless (CCK,2012).

1.4.3 Airtel Kenya Ltd

Was launched in Kenya in 2000 as Kencell and rebranded to Zain in 2008 and finally Airtel in 2010.The company boasts of being Kenya's most innovative mobile phone operator. The company offers a host of services which includes Airtel money; post paid and prepaid plans, network connectivity, international roaming, and SMS internet access. Airtel Kenya has seen itself grow tremendously from network connectivity and quality of services despite continuous rebranding. Airtel Kenya had a subscriber base of over 5million and several base stations across the country (CCK, 2012). Celtel won a GSM-900 licence in January 2000 and launched services in August of the same year. The company launched under the KenCell brand and took on the Celtel banner in November, 2004. Also Celtel now provides services through the GPRS and EDGE technologies

1.4.4 Orange

This was established as Telecommunication operator under the companies Act in April, 1999. The company provides integrated communications solutions in Kenya with the widest range of voice and data services, fixed lines, and mobile technology and internet facilities for residential and business customers. Telecom Kenya's partnership with France Telecom group saw the launch of orange brand in Kenya in 2008.Orange Telkom has a subscriber base of over 3million by 2013 November.(CCK,2012) quarterly reports.Telkom Kenya, the fixed-line operator in Kenya, launched fixed wireless services based on CDMA-2000 technology in the 800MHz frequency band in July 2007.

Telkom Kenya offers these services using a licence, which allows it to offer wireless telephone services within a restricted area. However, because the CDMA 2000 devices are small in comparison to mobile handsets, users have actually been using the service as a mobile substitute.

2 METHODS AND MATERIALS

2.1 Study Area

Kesses is a sub-county within Uasin Gishu County in the north rift region of Kenya (Figure 4). It's bounded by Latitude and Longitude of 0.277955, 35.3342801 respectively. Kesses is a densely populated region with a total population of about 135,979 within an area of approximately 299.00 Sq. Km (GOK, 2009).

2.2 Study Design

This study used the mixed research design of both qualitative and quantitative. To collect data on household health effects the study population consisted of household within Kesses region from whom information was gathered. It was estimated according to the 2009 national population census that the region had a population of 135 979 (GOK, 2009) inhabitants.

The target population consisted of all households within 200m distance of cellphone tower location and those far away from 200m. This population target was chosen because they were relevant to the research study undertaken. The Mugenda (2003) formula was used in determining the research sample size.

The formula is stated as follows:

$$n = \frac{N}{1 + N(e)^2}$$

where, *n* is sample size, *N* is study population, and *e* is coefficient (0.05).

Using the above formula
N= 135979
n= 135979/1+135979(0.05)2=399 sample size.

2.3 Study Population and Field Data Collection

Sample size of 399 was used; with 200 households sampled within 200meters of cellphone tower location and 199 far away 200meters of cellphone tower location. The sampling technique used was probability sampling. One of the key reasons why probability sampling was used is because there was no documented list of household, particularly those within 200m vicinity of cellphone tower location, and those far away within Kesses region. Simple random sampling was used. This method helped in obtaining information from households who were available within the 200m and those far away from cellphone tower location. It was economical since there was not a high budget allocated to this research. This method was also used because there were a large number of questionnaires to be completed in this case.

Cellphone tower location was marked using Garmin GPS receiver purposively. Within the study area there were seven cellphone towers. Their locations were marked and later downloaded, Microsoft Excel database was created for the locational attributes of the cell phone towers and exported to the ArcMap of Arc GIS (Version 10.0) software for further analysis. The obtained data were integrated into GIS environment. Finally the thematic map was created showing the existing cell phone tower location.

The household distributions were mapped using google earth application. They were then exported to ArcGIS as point features in kml format. Data was analyzed and then presented in the form of graphs, charts, tables.

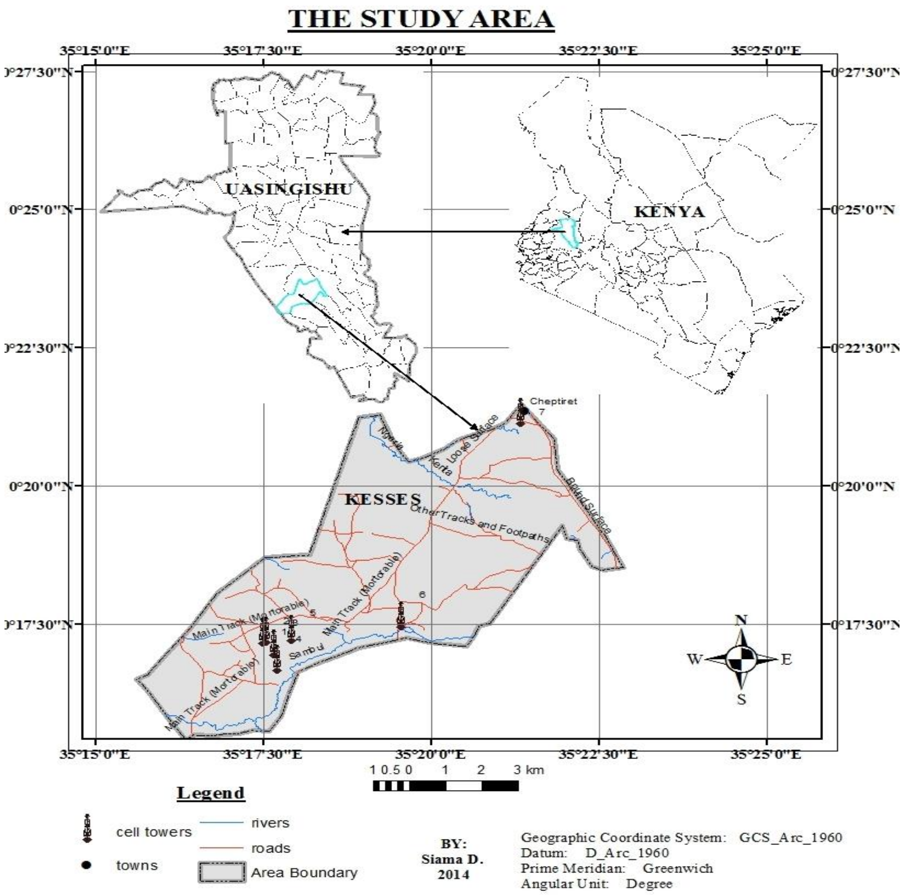

Figure 4: Location of study area

3 RESULTS AND DISCUSSION

The purpose of the study was to map cell phone tower location and assess their associated household health effects in Kesses region Eldoret Kenya. There were two specific objectives to achieve; mapping location of cell phone towers and household distribution within 200meters and further than 200meters from cell phone location and assessment of household health effects. In Kesses region there 7 GSM900 cellphone towers of band width 25MHz erected. They are divided into twenty sub-bands of 1.2 MHz, which are allocated to various mobile phone operators; Two for Yumombile, Seven for Safaricom Kenya ltd, Six for Zain/Airtel Kenya ltd and Five for Orange mobile companies. They were mapped using Garmin GPS receiver (Table 2) and later downloaded in ArcGIS 10 software to generated cell phone tower location map (Figure 5). Among these 7 cell phone towers, one is on top of a building, while others are erected closer to each other making the concentration of radiations to be very high. These towers have many radiation dishes ranging from 2 to 13 pointing to different directions. This facilitates the transmission of radiations to all directions hence increasing the exposure of the residents to radiations.

Table 2: Cellphone tower location

ID	No. operators	Operators	X coordinate	Y coordinate
1	4	Zain, Safaricom, Yumobile and Orange	35.29144	0.28931
2	2	Safaricom and Orange	35.29213	0.28955
3	3	Safaricom , Orange and Zain	35.29422	0.28585
4	4	Safaricom, Zain, Yumobile and Orange	35.29509	0.28101
5	2	Safaricom and Zain	35.29853	0.29005
6	3	Safaricom, Zain and Orange	35.32586	0.29424
7	2	Safaricom and Zain	35.35562	0.3554

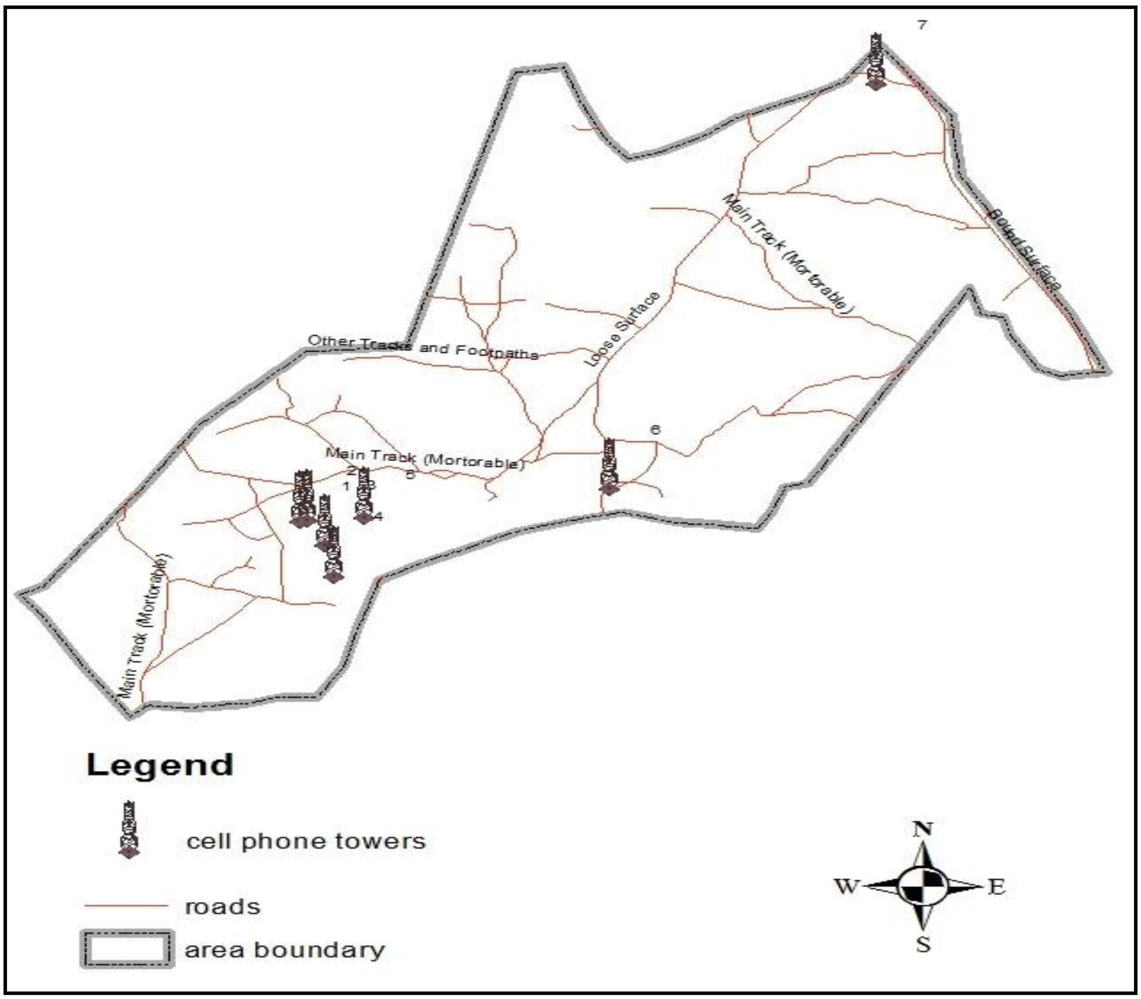

Figure 5: Map of cell phone location in Kesse region

The human height is much greater than the wavelength of the cellphone tower transmitting frequencies, so there are multiple resonances in the body, which creates localized heating inside the body. That results in boils, drying up the fluids around eyes, brain, joints, heart, and abdomen. Individuals differ in their response to similar levels of EMF radiation. For some people, short term effects from cell tower radiation exposure may include headaches, sleep disorders, poor memory, mental excitation, confusion, anxiety, depression, appetite disturbance, and listlessness. Radiation from cell phone towers has been associated with greater increase in brain tumor. This is due to the damage in the blood brain barrier and the cells in the brain which are concerned with learning, memory and movement. For instance, in one of the health surveys among self-declared Electromagnetic hypersensitivity (EHS) individuals, 90% of subjects reported occurrence of health symptoms when present in the exposure area and disappearance of the same after leaving the exposure area (Roosil *et al.* 2004).

Most of the cell phone towers in Kesses are in south western part of the map (Figure 6). The region that is densely populated hence exposing majority of the population to EMR. Figure 4 shows household distribution within Kesses region with 200 m of cell phone tower location having majority of the population. The regions further than 200 m from cell phone location is sparsely populated. This means that cell phone companies have tended to erect cell phone towers in densely populated regions hence making those regions to be highly vulnerable to EMR.

Figure 6 shows households within less and high vulnerable regions within proximity analysis of 200 m. Two hundred metres (200 m) (arbitrary value) buffer was set around communication towers to determine those households that are at high risks of EMR exposure. One of the communication towers was found to affect a lot of households in the region. This tower was erected at a place with many residential houses without considering the health effect that it will pause to the residents around it. Buffered zone and household distribution were intersected to come up with only households that are affected by the cell phone towers radiation that exist in the region (Figure 7).

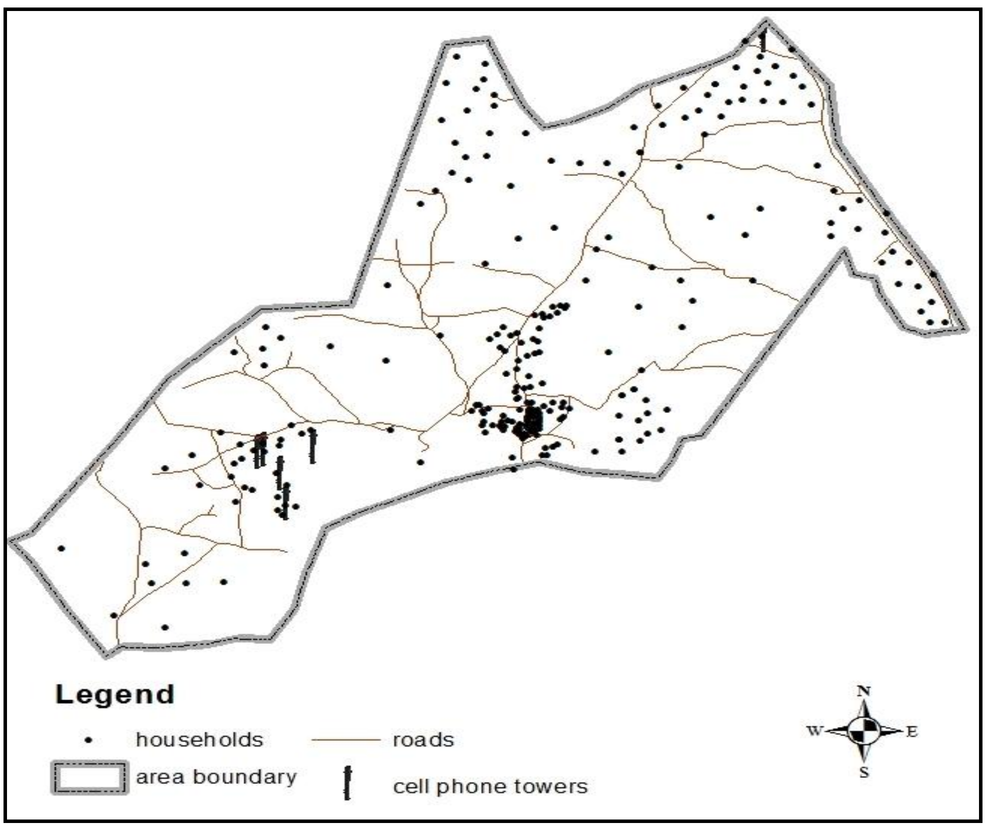

Figure 6: Map of households' distribution in Kesses region

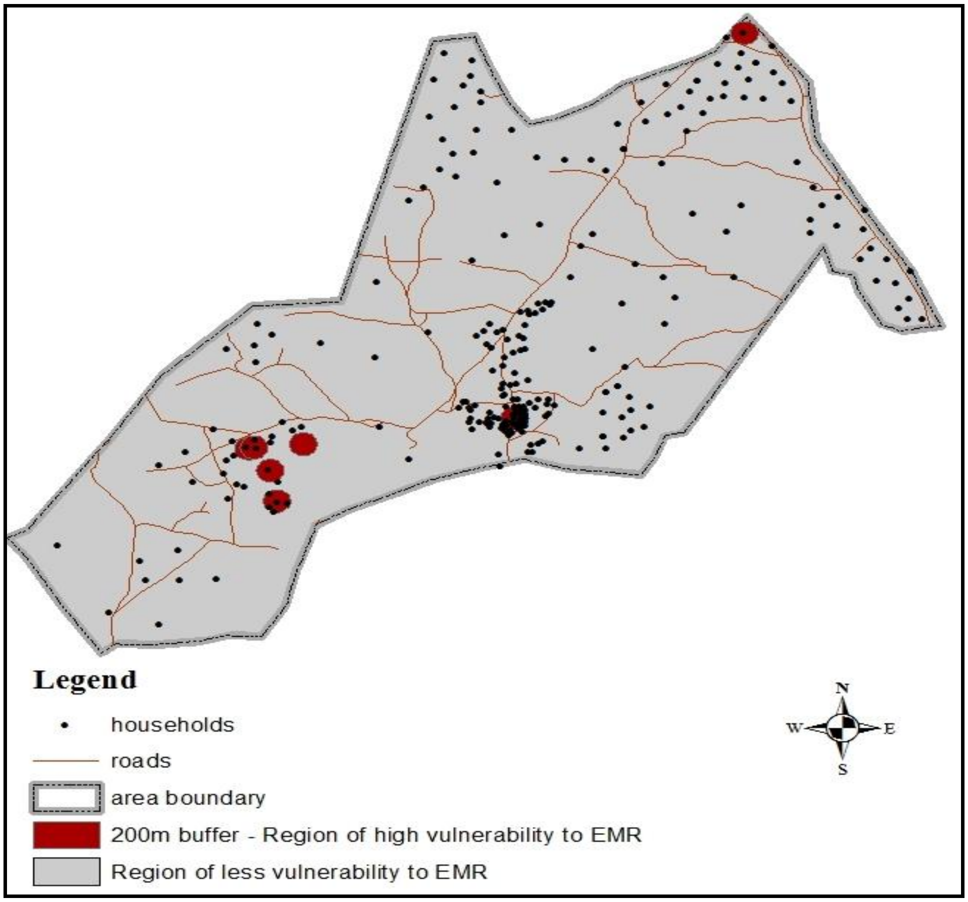

Figure 7: Map showing households within highly and less vulnerable regions to EMR.

3.1 Household Health Effects

The submitted questionnaires were 399 and returned 367 representing response rate of 92%, the completed questionnaires were analyzed in SPSS statistical software to generate information represented below. The results indicate the extent to which RF and EMR can cause more harm to an individual. Figure 7 shows respondents within areas of high vulnerability to EMR experience health effects.

Sixty percent (60%) of the respondents leaving within a radius of 200m from the tower suggested that they were experiencing constant headaches, tiredness, fever and heating of eardrums while making their calls. Thirty percent (30%) of these respondents suggested that they had no effect while 10% had no idea. Figure 9 shows percentages of health effects from the respondents. Among them 60% suggested that they were experiencing health effects, 40% were suffering from headaches, 30% tiredness, 25% eardrum heating, and 5% fever.

The results compares with the findings of a health survey carried out in La Ñora, Murcia, Spain in 2004 around two GSM mobile phone towers which showed "statistically significant positive exposure-response associations between the E-field and fatigue, irritability, headaches, nausea, loss of appetite, sleeping disorder, depressive tendency, feeling of discomfort, difficulty in concentration, loss of memory, visual disorder, dizziness and cardiovascular problems (WHO, 2010). As regards RFR-EMF, Navarro *et al.* 2003, carried out a health survey in Spain within the vicinity of a cellular phone base station, working in DCS-1800MHz frequency range with exposition time greater than 6 hours/day, 7 days/week, in 95% of the subjects. Exposure assessment was done by measuring microwave power densities at residence of respondents. Statistical analysis revealed a significant correlation between the declared severity of symptoms and measured power density.

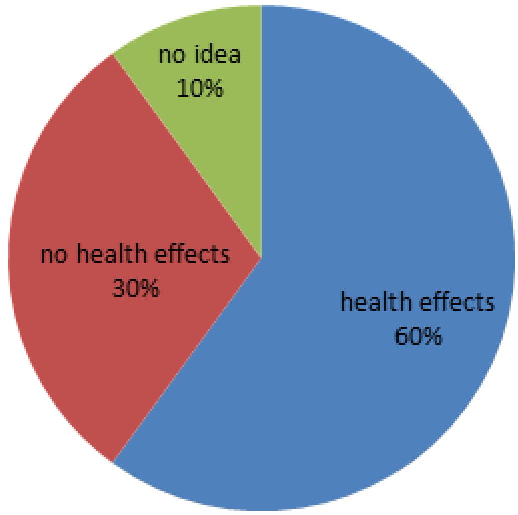

Figure 8: Respondents within areas of high vulnerability to EMR.

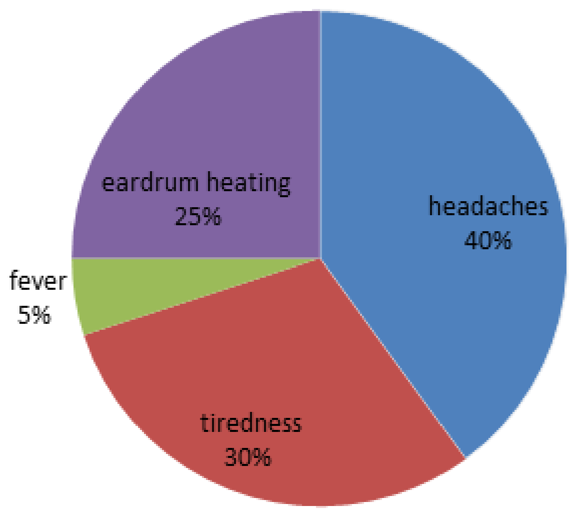

Figure 9: Percentage of health effects from the respondents

The study also showed an increase in the declared severity in groups with higher exposures. Comparable studies have also been performed reporting significant relation of some symptoms to the measured exposures (Hutter *et al.,* 2006). Epidemiological studies also suggest that frequency and severity of symptoms tend to increase with duration of exposure and are reversible if exposure is discontinued temporarily or permanently with symptomatic and general supportive treatment and also severity weakens for those residing far away from exposure source. For instance, in one of the health surveys among self-declared Electromagnetic hypersensitivity (EHS) individuals, 90% of subjects reported occurrence of health symptoms when present in the exposure area and disappearance of the same after leaving the exposure area (Roosil *et al*,. 2004). Figure 10 shows that 80% of the respondents residing beyond 200 m from the cell phone tower location suggested that they have never experienced any problem with the EMR from cell phone towers location rather than heating of the cell phone while in the pocket and heating of eardrums while making prolonged phone calls. Five percent (5%) of these respondents suggested to be experiencing the health effect the same to those experienced by the residents within a radius of 200 m from the tower. Fifteen percent (15%) of the respondents had no idea. Majority of them were experiencing complexions related to fever.

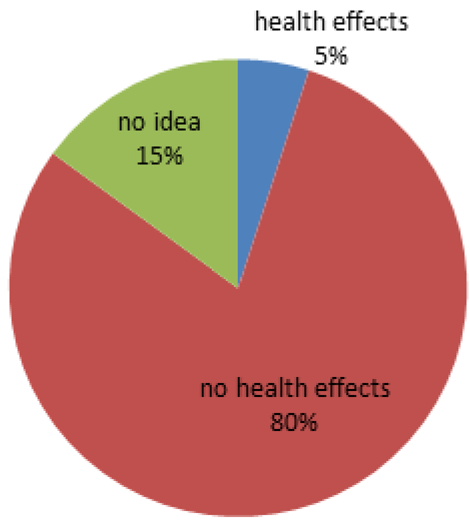

Figure 10: Respondents within areas of less vulnerability to EMR.

3.2 *Health Effects Recorded at Kessess Dispensary Health Centre*

Table3 shows health related cases recorded at Kesses health centre. Sleeping disorders, constant headaches, appetite disturbance are most common and the least experienced health case is poor memory. This could be associated period of exposure to EMR with the location of radiation. The health cases reported in Kesses are similar to those recorded during health effects assessments interview (Figure 8 & 9).

Table 3: Recorded Health Effects at Kesses Dispensary

Disease Type	Patient's Age group	Reported Per Month
Boils	28 - 40	6
Constant headaches	15 - 35	20
Sleep disorders	45 - 55	25
Poor Memory	25 - 55	5
Mental excitation	35 - 40	17
Appetite disturbance	18 - 25	20
Ear drum heating	18 - 40	12
Tiredness	40 - 55	10
Frequent Fever	35 - 55	13

Source: Kesses Dispensary, August, 2015

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Cell phone towers are associated with health effects to households within their vicinity such as; constant headaches, tiredness, fever and heating of eardrums when making calls that posses high vulnerability to them. The reported health cases at the local health centre and health assessment interview are related. This is contrary to the claims of the telecommunication industry that cell phone towers generally donot attribute exceptionally high risks to exposures from their cell phone towers.The common man has not realized the seriousness of the health effects due to radiation from cell phone towers. Cell phone operators have continued to claim that there are no health issues from cell phone towers. Even World Head Organization has not recommended stricter safe radiation guidelines to cell phone companies on the location of cell phone towers. The industry is becoming another cigarette industry, which has kept claiming that smoking is not harmful and yet there are millions of people around the world who have suffered from smoking. In fact, cell phone/tower radiation is worse than smoking; as one cannot see it or smell it, and its effect on health is noted after a long period of exposure.

Therefore, majority of people tend to have casualness towards personal protection. Unfortunately, ignorance and non-awareness adds to this misery and all of us are absorbing this slow poison unknowingly. Even if people are aware of the radiation effects, they may not have the choice to move away from it if the cell phone tower is installed in their residential building.

4.2 Recommendations

The study recommends that, first the mobile telecommunication companies should not only focus on the network coverage for cell phones but work out safety precautions while erecting their cell phone towers within residential areas. This is because, most people from the study (60%) were found to be suffering from health effects related to cell phone tower EMR. This included health effects such as; constant headaches, tiredness, fever, and heating of eardrum while making calls amongst others are also related to cases reported at local health clinic, hence, it is imperative that stricter radiation norms must be enforced by Communication commission of Kenya when licensing mobile phone operators in Kenya.

The intervention to take to minimize exposure to EMR includes;

i). Avoidance or minimizing exposure through contact with EMR as much as possible. In case of a cell phone tower close to your home, use specially formulated RF shield paint, shielding fabric, shielding glass or film for windows, etc. Although they may sound extreme, these measures are a life-saver for someone who suffers from electro sensitivity, a condition in which a person experiences physical symptoms aggravated by electromagnetic fields.

ii).The other means of intervention is to minimize the effects of exposure. Such as use of bioenergetic devices that help reduce the effects of EMR like pendants, chips or other devices designed to strengthen the biofield of the individual.

iii). The last intervention is to help reverse damage caused by exposure. This includes nutritional support like as anti-oxidant supplementation, particularly helpful in countering the effects of free radicals. Supplementing with anti-oxidants SOD, catalase, glutathione, and Coq10 are especially recommended. Microwave radiation has been shown to decrease levels of these anti-oxidants that the body normally produces to protect itself. These levels are sensitive indicators in stress, aging, infections and various other disease states.

The study recommends that World Head Organization should recommend stricter safe radiation guidelines to cell phone companies on the location of cell phone towers. If mobile phone companies accept that cell phone towers radiation causes serious health problems, will people stop living near cell phone towers. Not really, because the cell phone technology has its several advantages. Just like automobiles create air pollution, people have not stopped using them. Instead, solutions have been found such as unleaded petrol to reduce emission. However, then researchers should come up with possible solutions, which may be expensive but cannot be greater than the health risk faced by humans.

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Sub-theme: GIS in disaster management, health and security

Modeling the alteration of malaria vector ecological niches in Kenya by Bioclimatic Envelope Model

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Abstract:

Climate change could accelerate the rise in temperature and rainfall hence the spread of malaria in high altitude areas. However, there has been no attempt to correlate the vectors' habitat with the underlying environmental factors, and further investigate the impact of climate change on their ecologies. Therefore, this study seeks to address the existing gap in spatial-temporal modeling of malaria vectors by correlating the spatial distribution of main malaria vectors in Kenya with the underlying ecological conditions with respect to climate change. The main objective of the study was to investigate spatial-temporal effect of climate change on the distribution of main malaria vectors in Kenya. The specific objectives were to model the spatial-temporal distribution of the main malaria vectors in and project the future ecological niches for malaria vector occurrence in Kenya. This study explored the use of Ecological Niche Modeling (ENM) with DIVA-GIS to correlate climate change and the emerging hotspots of malaria vector in Kenya. Presence geo-location data for the main malaria vectors was used to characterize the vectors' habitat into suitability criteria derived from their present ecological niches. Spatial integration of timely environmental data, biological data and the IPCC projected climate change scenarios was done to quantify the prevalence and distribution of malaria vectors. Climate envelope models were selected, trained and tested under current climate (1950-2000) and prediction was done with future IPCC projected climate. Predictive modeling under current climate and different future climate projections under A2a scenario showed that the future ecological niches for malaria vector occurrence in Kenya will extend from the current niches in most endemic areas, creating new hotspots and some suitable ecology will become unsuitable, resulting in varying areas from current climate predictions to projections by the year 2020, 2050 and 2080 under IPCC A2a scenario.

KEY WORDS: Climate Envelope Models (CEMs), Ecological Niche Modeling (ENM), IPCC A2a Scenario, Projected Climate.

1 INTRODUCTION

Climate change has the potential to significantly impact on the distribution of malaria vectors. A number of species have been affected by recent climate change, with ranges expanding towards higher latitudes and longitudes (Parmesan and Yohe, 2003; Root *et al.*, 2003). Further, recent studies have shown that it is challenging to attribute health outcomes to climate change or variability *per se* (WHO, 2003). Consideration of the relationships between climate change and vector-borne diseases suggests that warmer temperature is likely to have two major kinds of closely related, potentially detectable, outcomes: changes in vectors *per se*, and changes in vector-borne disease outcomes (Kovats *et al.*, 2001).

The ecology of some disease vectors in Africa are likely to be altered by climate change, hence consequently affecting the spatial and temporal transmission of such diseases. In the highland areas of Kenya, malaria prevalence has been associated with rainfall and unusually high maximum temperatures (Githeko and Ndegwa, 2001). The influence of temperature on malaria development appears to be non-linear, and is vector-specific (Alonso *et al.*, 2011). The strongly non-linear response to temperature means that even modest warming may drive large increases in transmission of malaria, if conditions are otherwise suitable (Alonso *et al.*, 2011; Pascual *et al.*, 2006). In Kenya, analysis of environmental factors associated with the malaria vectors Anopheles *gambiae* and Anopheles *funestus* found that abundance, distribution, and disease transmission are affected in different ways by precipitation and temperature (Kelly-Hope *et al.*, 2009). Although the incidence of malaria has reduced over much of East Africa (Stern *et al.*, 2011), increased variability in disease rates has been observed in some high altitude areas (Chaves *et al.*, 2012).

In order to predict the change in malaria vector distribution in Kenya, there should be clear evidence of change in climate in the region likely to affect the ecology. During the twentieth century, world average surface temperature was reported to have increased by approximately 0.6ºC, and approximately two-thirds of that warming has occurred since 1975 (IPCC 2007). Climatologists forecast further warming, along with changes in precipitation and climatic variability, during the coming century and beyond. Their forecasts are based on increasingly sophisticated global climate models, applied to plausible future scenarios of global greenhouse gas emissions that take into account alternative trajectories for demographic, economic and technological changes and evolving patterns of governance. There is *likely* to be an increase in annual mean rainfall in East Africa (IPCC 2007).

Different scenarios (IPCC, 2007) were used to project the future global climate. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends. The four storylines can be described as follows:

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Climatic factors have been reported to greatly influence the pattern and level of malaria transmission globally. Temperature, rainfall and humidity are the most important climatic factors that directly affect malaria transmission. The ranges of minimum and maximum temperature greatly affect the development of the malaria parasite and its mosquito vector, which determines malaria transmission. Temperatures are higher around the equator and are known to vary minimally throughout the year. Temperatures decrease progressively as distance increases north or south of the equator. The warm and relatively constant temperature in tropical Africa is one of the reasons for high levels of malaria transmission near the equator. The right amount of rainfall is often an important factor in providing water collections that support vector breeding, which appears mainly after the rains. Therefore, the period following the rainy season is most conducive and malaria transmission rate is highest.

Temperature affects the malaria parasite life cycle. The time required for the parasite to complete its development in the mosquito can be shorter or longer than usual depending on the temperature. A decrease in temperature results in increase in the number of days necessary to complete the development for a given *Plasmodium* species. The time needed for the parasite to complete its development in the mosquito, decreases to less than 10 days as temperature increases from 21°C to 27°C, with 27°C being the optimum. The maximum temperature for parasite development is 40°C. Below 18°C, the life cycle of *Plasmodium falciparum* in the mosquito body is limited. The minimum temperatures are between 14–19°C, with *Plasmodium vivax* surviving at lower temperatures than *Plasmodium falciparum*. Malaria transmission in areas colder than 18°C can sometimes occur because the *Anopheles* often live in houses, which tend to be warmer than the outside temperature.

Further, temperature is also a determinant factor for the development of the mosquito larva as it matures more quickly at higher temperatures. The number of blood meals taken and eggs laid by the mosquitoes are increased by higher temperatures, thus amplifying the number of mosquitoes in a given area. The minimum temperature for mosquito development is between 8–10°C; the optimum temperature is 25–27°C, and the maximum temperature for it is 40°C. Altitude influences the distribution and transmission of malaria indirectly, through its effect on temperature. Increase in altitude leads to temperature decreases, making the highlands colder as compared to the warmer lowlands. With increase in altitude to beyond 2,400 metres, the temperature does not go high enough to support malaria transmission and these areas are free of malaria.

2 METHODS

2.1 Study Design

In order to model the spatial-temporal distribution of malaria vectors in Kenya, the model-building process entailed model selection, model fitting, and model validation. These three basic steps are applied iteratively until an appropriate model for the data to be analyzed has been developed. In the model selection step, plots of the data, process knowledge and assumptions about the process are used to determine the form of the model that can be fitted to the data. Further to model selection, using the selected model and possibly information about the data, an appropriate model-fitting method is used to estimate the unknown parameters in the model. When the parameter estimates have been made, the model is then carefully assessed. The underlying assumptions of the analysis are qualitatively quantified for plausibility. Validity of the assumptions renders the model useful so as to answer the scientific or engineering questions that prompted the modeling effort. In case the model validation identifies problems with the current model, then the modeling process is repeated using information from the model validation step to select and/or fit an improved model. Figure 1 shows the model-building process.

There exist varieties of environmental modeling approaches that are capable of being applied to generate species distribution in current and future ecologies under climate change scenarios. The selection of appropriate modeling methodology largely depends on the type of data available. This study selected BIOCLIM model as its useful in modeling presence only malaria vector distribution data and prediction is made without any reference to other samples in the study area.

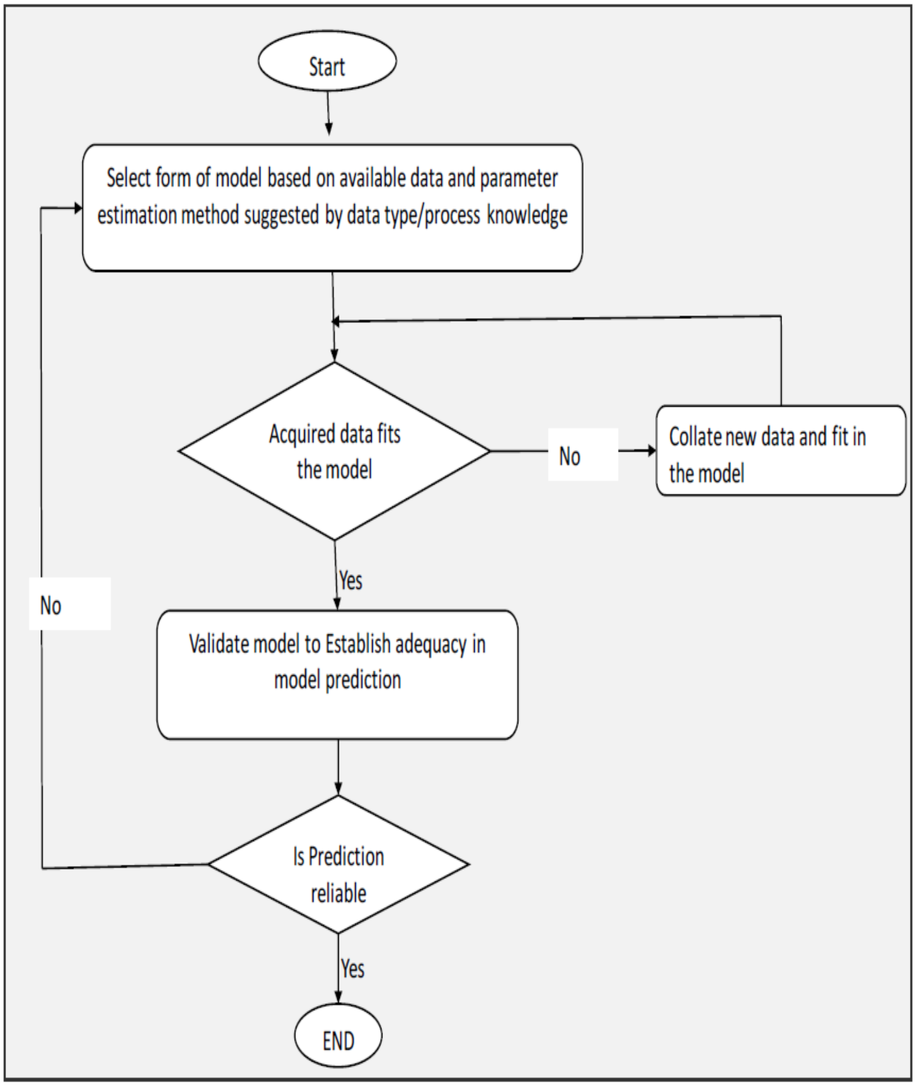

Figure 1: Flow diagram for the steps required in building a species distribution model.

Model validation entails assessing the accuracy of models' predictions. Test data (evaluation data) and calibration data (training data) are used. Training data is that which is used to build the model. In order to test predictive performance, it is necessary to have test data against which the model predictions can be compared. The confusion matrix is used to summarize the predictive performance if a model is used to predict a set of test data. Binary model predictions (i.e. predictions of suitable and unsuitable rather than probabilities) are required in order to complete the confusion matrix. The confusion matrix records the frequencies of each of the four types of predictions from analysis of test data:

(a) True positive - model predicts presence of an event and test data confirms;
(b) False positive - model predicts presence of an event but test data show absence;
(c) False negative - model predicts absence of an event and test data show presence;
(d) True negative - model predicts and test data show absence of an event.

2.2 *Data identification and collection*

The adopted correlative species distribution models require two types of data input: *Biological data* – describing the known species distribution and *Environmental data* – describing the landscape in which the species is found. For the biological data, the malaria vector data acquired, as amassed by Okara *et al.*, 2010 was primary empirical data from published and unpublished sources. This geo-located data was identified for the period from 1990 to 2009. A total of 498 spatially unique descriptions of Anopheles vector species across Kenya were identified. More than half (54%) of the sites surveyed were investigated since 2005. MARA ARMA project (1998) had geo-referenced so as to determine the latitude and longitude to be applied in geospatial analysis. This dataset was also acquired and tested alongside the dataset from Okara *et al.*, 2010.

Environmental data was acquired from the IPCC Third Assessment Report data for future climate projections calibrated and statistically downscaled using the WorldClim data for 'current' conditions was acquired for use in modeling the distribution of malaria vectors in Kenya. It covered the duration from 1950 – 2000 giving scenarios for future climate change for the globe and reconstructed palaeoclimates. The acquired data was adopted as developed by Hijmans, *et al.*, 2005 and comprised the interpolated climate surfaces for global land areas, at a spatial resolution of 30 arc seconds (often referred to as 1-km spatial resolution).

The ESRI grid data format was extracted for geostatistical modeling. Further processing of the data was done to generate the 19 bioclimatic variables that were used for ecological niche modeling. These bioclimatic variables represent:

- annual trends (e.g., mean annual temperature, annual precipitation);
- seasonality (e.g., annual range in temperature and precipitation); and
- Extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters).

Bioclimatic variables were generated in DIVA-GIS eventually to be used in ecological niche modeling. The default coding for the bioclimatic variables was as shown in Table 1.

Table 1: Coding of bioclimatic variables

BIO1	Annual Mean Temperature.
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp)).
BIO3	Isothermality (BIO2/BIO7) (* 100).
BIO4	Temperature Seasonality (standard deviation *100).
BIO5	Max Temperature of Warmest Month.
BIO6	Min Temperature of Coldest Month.
BIO7	Temperature Annual Range (BIO5-BIO6).
BIO8	Mean Temperature of Wettest Quarter.
BIO9	Mean Temperature of Driest Quarter.
BIO10	Mean Temperature of Warmest Quarter.
BIO11	Mean Temperature of Coldest Quarter.
BIO12	Annual Precipitation.
BIO13	Precipitation of Wettest Month.
BIO14	Precipitation of Driest Month.
BIO15	Precipitation Seasonality (Coefficient of Variation).
BIO16	Precipitation of Wettest Quarter.
BIO17	Precipitation of Driest Quarter.
BIO18	Precipitation of Warmest Quarter.
BIO19	Precipitation of Coldest Quarter.

2.3 *Testing Spatial Autocorrelation of malaria vector point data*

The biological data used is for malaria vector distribution in Kenya. It has the spatial component in latitude and longitude derived from Global Positioning System (GPS), as well as the attribute data for each point. The point data represents locations where any species of malaria vector was observed to be present. The point data sets were from MARA ARMA project, 1998 (vectors1 in red) and that from KEMRI published by Okara *et al.*, 2010 (vectors2 in blue). Figure 2 shows the spatial distribution of the acquire malaria vectors distribution from the two data sets.

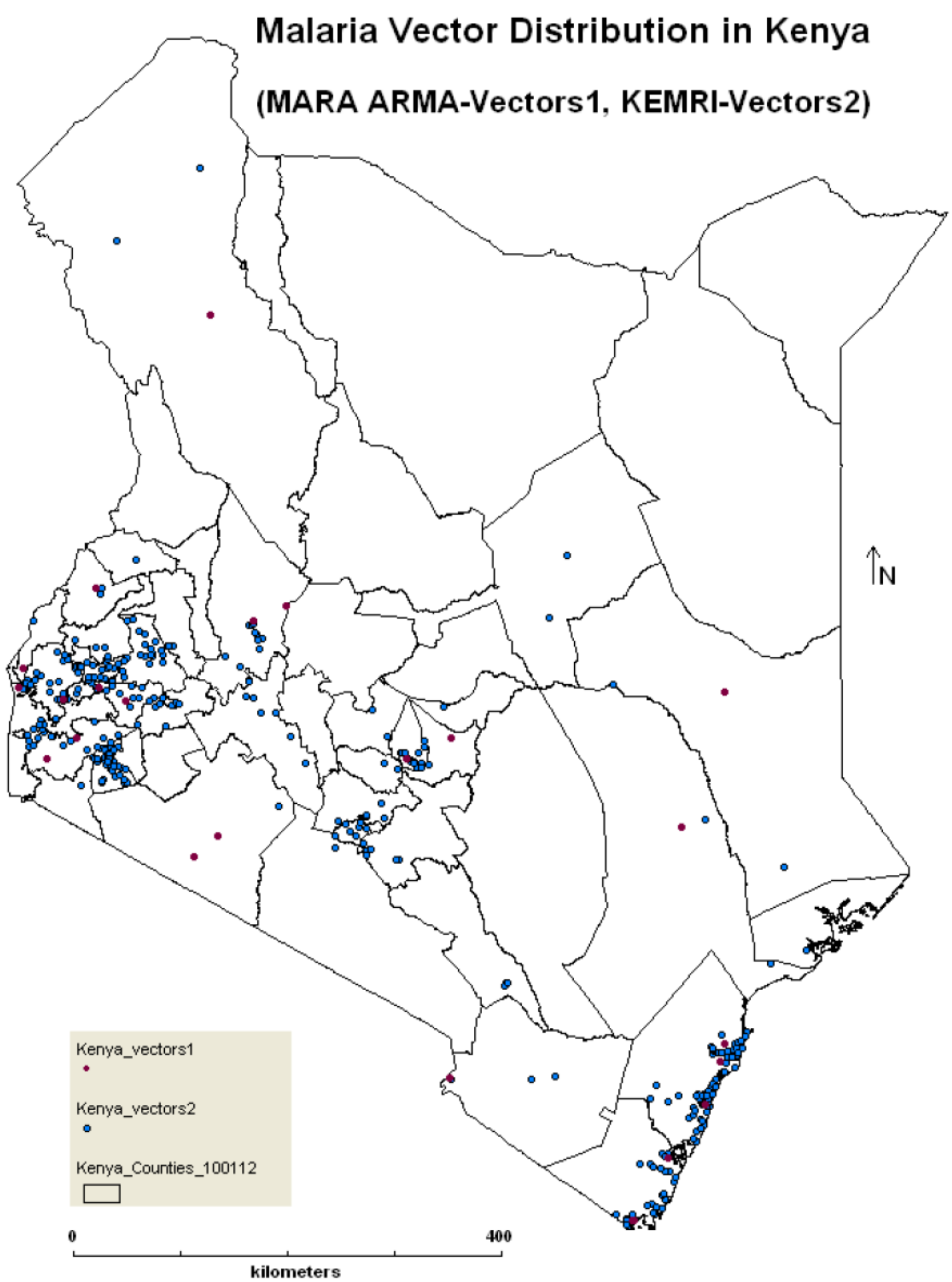

Figure 2: Malaria Vector distribution in Kenya (MARA ARMA, Vectors1 (red); KEMRI, Vectors2 (blue)).

Point autocorrelation in vectors1 was analyzed (Geary, 1954 and Moran, 1948) with a lag distance of 0.05km between neighboring points in the data sample. With the lag distance of 0.05km only 24 pairs could be generated from a total of 166 vector points. The Geary's index value obtained was c = 5.9948 falling under c > 1 in Geary's index and Moran's index value was i = 0.26726 falling under i < 0 in Moran's index. This shows that autocorrelation exists and the data are clustered. A negative autocorrelation exists in vector1 data, explaining the sparse distribution within the spatial space. Therefore, Vectors1 were not used in the correlative modeling.

In order to calculate the autocorrelation for malaria vector geo-located points in Vectors2, it was imperative to define which neighboring points to consider. This was done by specifying the separation distance between vector points referred to as lag (or neighborhood) distance, which was also set as 0.05km. Only pairs of points within the lag distance were considered for calculation. From a total number of 408 vector point observations, 607 pairs were obtained. These statistics include the number of observations (points) and statistics describing the distances among all pairs of points (min, max, mean, median and first and third quartile).

The autocorrelation in vector2 points was calculated and the results are as shown in Figure 4 - 5 below. The value obtained for c is 0.52751, falling under 0 < c < 1 in Geary's index and i = 0.41394, falling under i > 0 in Moran's index. This shows that autocorrelation exists and the data are clustered. Thus, for further predictive modeling in this study using BIOCLIM correlative model, Vectors2 biological dataset was adopted.

2.4 Adoption of Appropriate Future Climate SRES for Kenya

WorldClim future trend analysis makes reference to Intergovernmental Panel on Climate Change third assessment (IPCC, 2001) Special Report on Emissions Scenarios storylines (SRES). Both A2a and B2a storylines describe a 'regionalization' meaning a heterogeneous world development opposed to a 'globalization' of a homogeneous world development as described in the A1 and B1 storyline family. A2a describes a highly heterogeneous future world with regionally oriented economies. The main driving forces are a high rate of population growth, increased energy use, land-use changes and slow technological change.

Conversely, the B2a storyline is also regionally oriented but with a general evolution towards environmental protection and social equity. In Comparison to A2a, B2a has a lower rate of population growth, a smaller increase in GDP but more diverse technological changes and slower land-use changes. This study adopted the A2a storylines to describe the projected climate change in Kenya. The A2a storyline seemed more appropriate since demographic data in Kenya has portrayed an upward trend for population growth rate, hence adoption of the A2a storyline to model the future climate change impact on the malaria vector ecologies.

3 RESULTS

3.1 Climate Envelope for Selected Bioclimatic Variables

Climate envelope generation is done for any desired combination of bioclimatic variables to quantify the number of observations within the selected envelope. For instance, Figure 3 shows the climate envelope for BIO1 and BIO12 while Figure 4 shows the climate envelope for BIO5 and BIO18 when the vector points were climate coverage. All the points inside the two-dimensional envelope shown on the graph are selected and highlighted in yellow on the map. The points that fall outside one or more envelopes are shown in red on the graph. The points that fall within the envelopes for all the climate variables are colored green on the graph. A box is drawn on the graph to indicate, for the two climate variables selected, the points that are within, and those points that are outside the climatic "envelope" defined by the specified percentiles. These points vary for each pair of bioclimatic variables selected. The percentile value was 0.025 to find out which observations were extreme in terms of climate. The percentile is used to exclude the extreme values of all climate variables. The results of BIOCLIM climate envelope prediction with HADCM3 30 arc second future climate under A2a scenario were generated and spatially displayed for visualization.

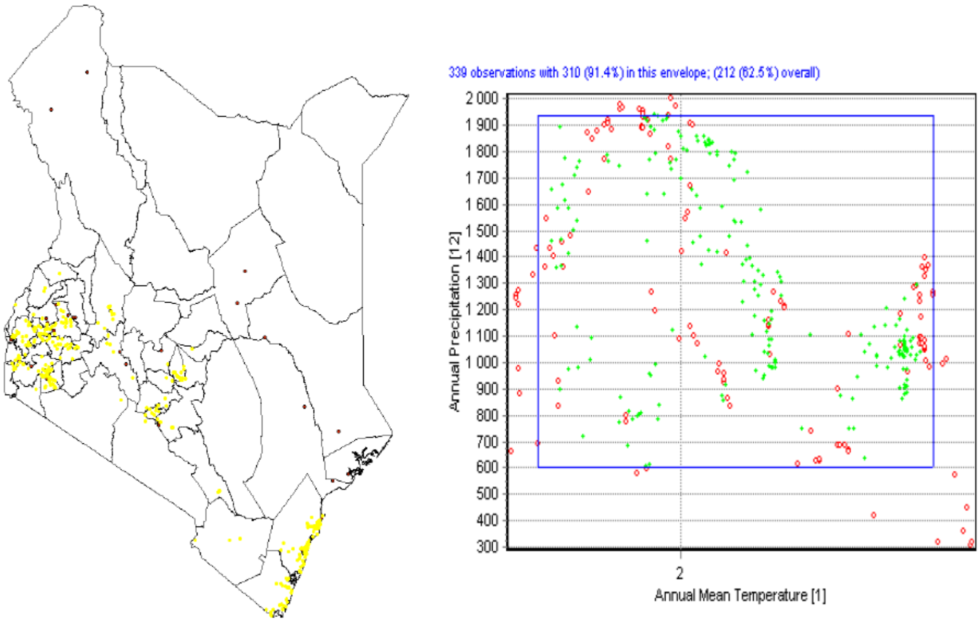

Figure 3: Climate Envelope for BIO1 and BIO12

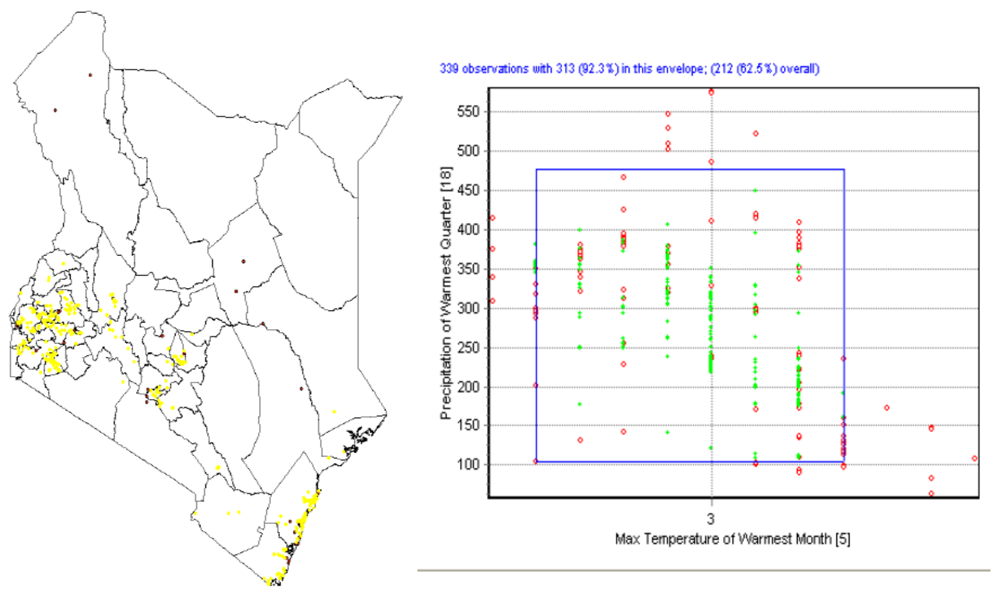

Figure 4: Climate Envelope for BIO5 and BIO18

3.2 Ecological Niche Prediction Outcomes Using Climate Envelope Models

Ecological suitability prediction was based on the assumptions that: malaria vector presence is restricted to locations equally or more suitable than those at which the species has been observed; and most environmental variables are continuous. Discriminant Function Analysis (DFA) was applied to map different classes of suitable areas for malaria vectors to thrive. Areas completely outside the 0-100 percentile envelope for one or more climate variables get a code "0". The cells within the 5-95 percentile get a code "3", those outside this range but within the 2.5-97.5 percentile get a code "2", and the ones outside this but within the 0 -100 percentile for all climate variables get a code "1". Different color shades were used to denote the suitability classes. The approach therefore identifies the minimum areas in which malaria vectors occurs whilst ensuring that no localities at which the vectors have been observed are omitted (i.e. omission rate=0 and sensitivity = 1). BIOCLIM prediction results are shown in Figure 5.

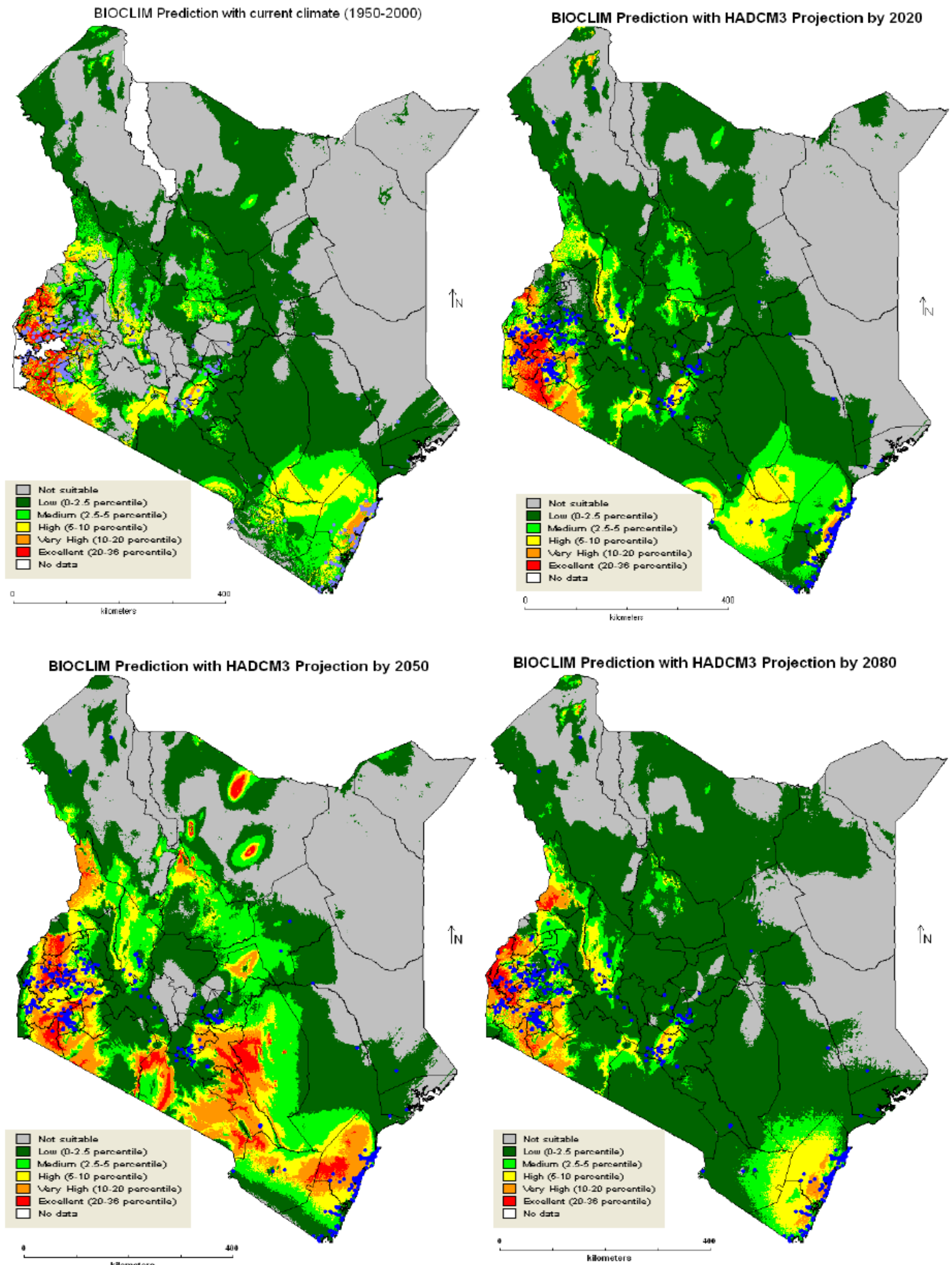

Figure 5: BIOCLIM predictions with current climate and HADCM3 projection for malaria vector distribution in Kenya

BIOCLIM prediction with current climate (1950-2000) resulted in to areas of different suitability as habitats for malaria vectors in Kenya. These ecological niches were analyzed and the total area of non-suitability was found to be 285, 830 km^2. The total area found to be low in suitability was 273, 055 km^2. The ecological niche found to harbor medium potential occupied a total area of 63, 917 km^2 across Kenya. The area of high potential was 38, 939 km2 while area of very high suitability was found to be 11, 861 km^2. The total area that was found to be of excellent suitability was 6, 044 km^2.

When BIOCLIM prediction was done with climate data from HADCM3 projection by the year 2020, analysis of the ecological niches showed that the total area found to non-suitable as malaria vector habitat will be 237, 492 km^2. The total area found to be low in suitability was 325, 411km^2. The ecological niche found to harbor medium potential occupied a total area of 66, 891km^2 across Kenya. The area of high suitability will be 43, 215 km^2 while area of very high suitability was predicted to be 13, 167 km^2. Excellent ecological niche will be 6, 545 km^2; slightly more than that in the current climate condition.

By the year 2050, the predicted ecological niches will emerge with different areas as follows: not suitable area (250, 867 km^2), area of low suitability (210, 485 km^2), medium suitability area (97, 990 km^2), area of high (58, 728 km^2) and area of very high suitability (56, 033 km^2). The ecological niche that will be of excellent suitability for malaria vectors was predicted to be 18, 618 km^2. This area has increased from the previous prediction for by the year 2020.

HADCM3 Future climate by the year 2080 was also used to spatially quantify the effect of climate on malaria vector distribution in Kenya. Different ecologies will emerge and the areas were analyzed as shown in Figure 4.19 below. Area of 195, 802 km^2 will be unsuitable, area of low suitability will be 387, 293 km^2, area of medium suitability will be 46, 046 km^2, area of high suitability will be 39, 846 km2 and area of very high suitability will be 18, 582 km^2. The area of excellent suitability will drop significantly to 5, 152 km^2, being the lowest excellent ecological niche predicted using BIOCLIM model with HADCM3 projection. Figure 6 shows graphical visualization of the predicted ecological areas starting with current climate in top left, prediction results by the year 2020 in top right, by 2050 in bottom left and by 2080 in bottom right.

3.3 *Model Validation Outcomes*

Data was randomly divided into training and testing subsets, with 75% of the records used in model training while 25% of the records were used to test the model. Random absence data was included from the mask since the validation requires an input of presence-absence records. Point values were extracted from the generated bioclimatic grids and Receiver Operating Characteristic (ROC) files from presence – absence distribution of malaria vectors generated for the entire mask. Area under curve (AUC) and Kappa statistic values were computed using the ROC file for each grid. These were the values used to validate the accuracy performance and significance of the ecological niche models.

The malaria vector ecological niche prediction results generated with IPCC model data from the HADCM3 future climate projections were validated to assess the model performance of BIOCLIM climate envelope model. Analysis of the kappa and AUC statistical graphs for model validation outcomes for the current climate and future climate scenarios A2a_2020, A2a_2050 and A2a_2080 showed that BIOCLIM model predictions were acceptable as shown in Figure 7.

4 DISCUSSIONS

Correlative modeling requires input of biological and environmental data in order to predict suitable ecologies for species. When malaria vectors were used with current climate (1950-2000), the observations that fall within BIO1 and BIO12 climate envelope were found to be 91.4 percentages. When the climate envelope was changed to BIO5 and BIO18 climate variables, the observations found within the climate envelope were 92.3 percentage. The results for future projections using BIOCLIM and DOMAIN models showed that climate suitability for malaria vectors will shift and leading to emergence of malaria new hotpots. Climate envelope modeling delineates the suitability zones under future climate change. The red color denotes the zones which will be most suitable for malaria vectors to thrive. Zones denoted by orange color follow in suitability hierarchy. Yellow color is less suitable as compared to orange but more suitable as compared to green. By 2050, the suitable areas will have increased but by 2080, the unsuitable areas will be regained.

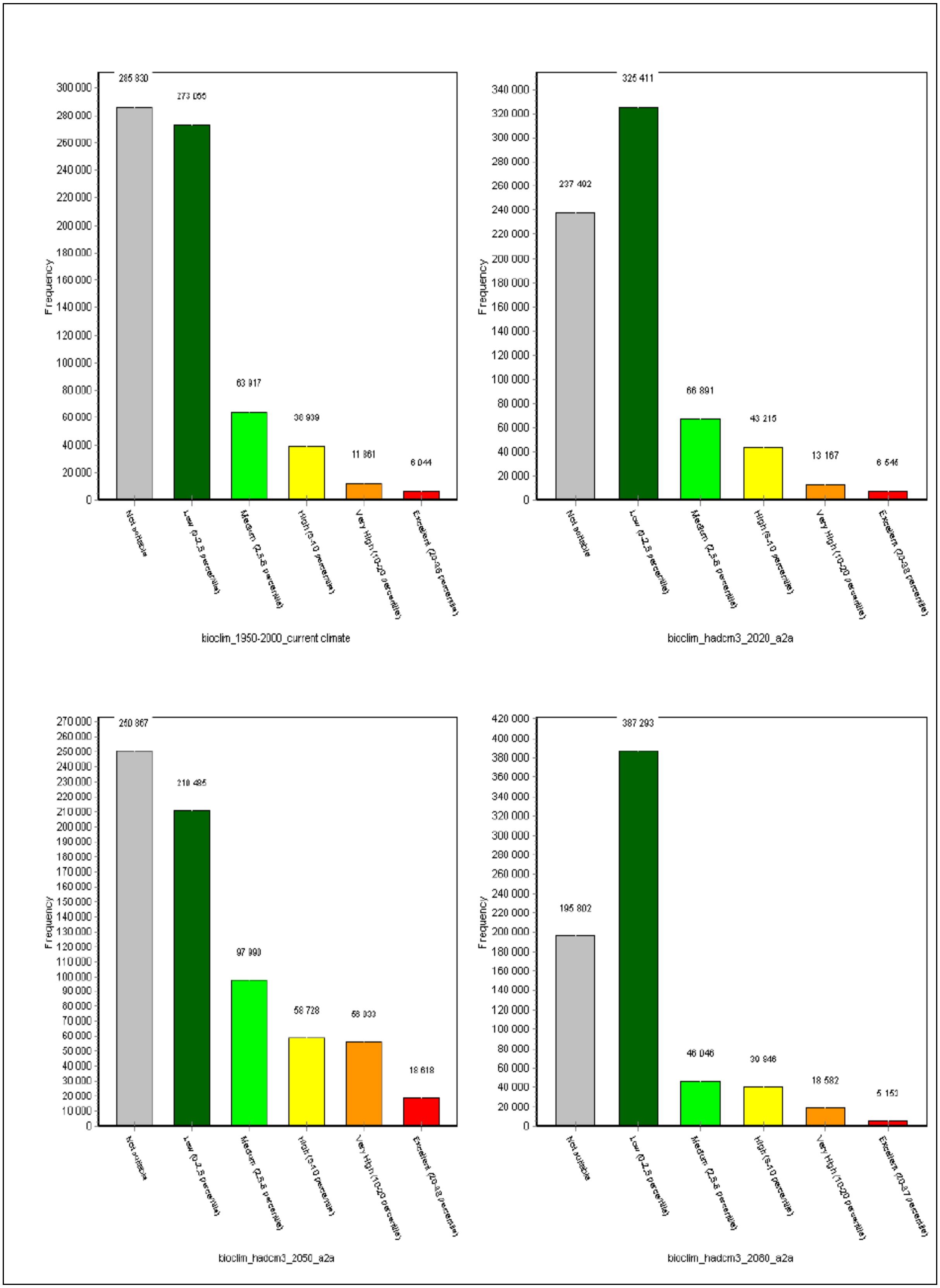

Figure 6: Graphical display of predicted ecological niches

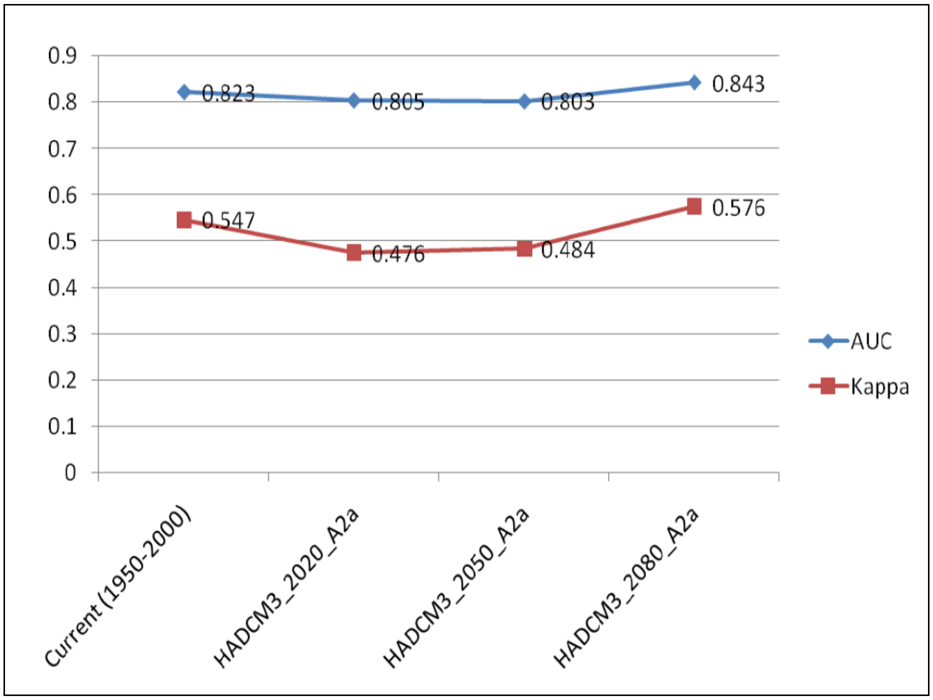

Figure 7: Comparison of Kappa and AUC Values for BIOCLIM prediction with HADCM3.

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HADCM3 Future climate by the year 2080 was also used to spatially quantify the effect of climate on malaria vector distribution in Kenya. Different ecologies will emerge and the areas were analyzed as shown in Figure 4.19 below. Area of 195, 802 km^2 will be unsuitable, area of low suitability will be 387, 293 km^2, area of medium suitability will be 46, 046 km^2, area of high suitability will be 39, 846 km^2 and area of very high suitability will be 18, 582 km^2. The area of excellent suitability will drop significantly to

5, 152 km^2, being the lowest excellent ecological niche predicted using BIOCLIM model with HADCM3 projection.

Validation results for prediction model performance showed that all the models used were very accurate in prediction although not perfectly as none of them achieved maximum kappa =1 or AUC=1. However, the overall prediction performance for all the models was found to be within acceptable range as per the interpretation guidelines provided by Kappa and AUC statistics. Figure 11 shows the obtained AUC and kappa values for BIOCLIM prediction validation with HADCM3 future climate projection.

5 CONCLUSIONS

Bioclimatic envelope modeling for malaria vector distribution in Kenya was done from the climate envelopes and results demonstrated significant relationship between malaria vector distribution and climate change. The spatial-temporal distribution of the main malaria vectors in Kenya were modeled and quantified under multivariate bioclimatic variable. The models predicted that by 2020, there will be expansion of malaria prevalence in new hotspots, by the year 2050, the suitable ecologies will have increased at an alarming rate, but by 2080, the ecologies will start to revert to non-suitable condition. Therefore, climate change in Kenya will occur drastically up to a certain level beyond which there will be stabilization. The following conclusions were drawn from the Ecological Niche Modeling done using BIOCLIM prediction models with HADCM3 future climate projection under A2a scenario: There is correlation between climate change and the distribution of main malaria vectors in Kenya. The spatial-temporal distribution of the main malaria vectors in Kenya varies different under IPCC future climate projections which are HADCM3 by the years 2020, 2050 and 2080. The future ecological niches for malaria vector occurrence in Kenya will extend from the current niches in most endemic areas, new hotspots will emerge and some suitable ecology will become unsuitable. This will result in varying areas of suitable malaria habitats from current climate predictions to projections by the year 2020, 2050 and 2080 under HADCM3 A2a scenario. Intervention strategies such as indoor or outdoor residual spraying, distribution of insecticide-treated mosquito nets (ITNs) and long-lasting insecticide-treated nets (LLINs) should be diversified in new emerging areas for disaster risk reduction and increase adaptive capacity and resilience among local communities.

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Page 139 - 143
Sub-theme: GIS in disaster management, health and security

Use of GIS for identification of expansive soils in civil engineering infrastructure development

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Abstract:

Soil is an essential component in civil engineering infrastructure development. In fact nearly all civil engineering structures are founded on soil. Therefore, collecting appropriate soil geotechnical information is a crucial aspect in infrastructure planning and development. Some soils, such as expansive soils (or black cotton soils) are geo-hazards and require particular attention. These expansive soils typically exhibit a large amount of volumetric swelling and shrinkage, in response to changes in moisture content, due to presence of montimorillonite clay mineral. This property can detrimentally influence construction, performance and lifetime, especially of light weight civil engineering infrastructure.Identifying soils is a crucial concern in geotechnical investigations. However, traditional geotechnical practices of characterizing soils require dense sampling, thus are costly, labor intensive and time consuming. These constraints can force engineers to take as few samples as possible and depend on interpreting the results as representative of the whole project site. In the meantime, presence of expansive soils can be overlooked and their effects underestimated. The objective of the investigation was to establish the extent of expansive soils in Kenya and identify their locations. ArcGIS was used to locate areas in Kenya that are predominantly covered with black cotton soils (Montimorillonitic clays). Clay mineralogy for Kenya was obtained which revealedthat more than 40% of Kenya is covered with expansive soils. The Western region was delineatedand over-laid with road network. Data on geotechnical properties of soils in the sections indicated as having montimorillonite clay was collected. Using Plasticity Chart, it was confirmed that the soils are expansive.

KEY WORDS: Expansive soils, ArcGIS, geo-hazard, civil engineering infrastructure development.

1 INTRODUCTION

Black Cotton soil which is anexpansive type,whose volume changes with variation in moisture content. It expands during the rainy season due to intake of water and shrinks during dry season.

The wetting and drying process of a subgrade layer composed of black cotton (BC) soil result into failure of pavements in form of settlement and cracking. The cracking and eventual collapse of buildings is common in areas with black cotton soils (Ameta *et al.*, 2007). Therefore, prior to construction, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization.According to Jones and Holtza (1973), Nelson *et al.* (1992) and Warren *et al.* (2004), global damage to infrastructure and associated remediation costs are often of far reaching economic consequences. In particular, with increasing number of the global population and related rapid urbanization and demand of new land for expansion of infrastructure, these soils have become significant problems.

The behaviour of expansive soils pose considerable challengesin civil engineeringconstruction activities especially in constructing foundations. In many situations, soils cannot be used directly as road base layers, foundation layers and as a construction material. It needs to be tested for engineering properties to ascertain its capacity to carry or resist loading. Determination of geotechnical characteristics of black cotton clay soils is usually cumbersome, costly and time consuming. For large constructions such as roads, the existing materials along the route varies widely and in such cases, number of tests to be performed becomes very large, extremely time consuming and uneconomical.

Using GIS as a tool can greatly improve the efficiency and effectiveness of these efforts (Singh *et al*, 2015). Soil surveys are now being created in digital format to utilize the power contained in GIS technology. The surveys allow customers to utilize soils information in a variety of ways. Soil maps for areas of interest can be created in a fraction of time that it used to take (Yatagesu, 2012). Maps depicting shrink/swell potential for soils can be published in print and electronic media to enable developers make crucial decisions. In Kenya, soil survey digital maps are now available for use in agriculture and other developments.

In the present study, the objective was to establish the extent of expansive soils in Kenya and specifically their locations on some road sections.

2 MATERIALS AND METHODS

Using ArcGIS, a clay mineralogy map of Kenya was obtained. The study area, Western Kenya part was delineated and road network over-laid. Primary and secondary data on plasticity of soils from various locations identified from the map as having montimorillonitic clay were obtained. Secondary data was obtained for sections on the following roads courtesy of CAS consultants: Kisii-Mukuyu, Ahero-Kisii, Londiani-Muhoroni, and Ainamoi-Muhoroni.

Ainamoi-Fort-TenanPrimary data was obtained throughlaboratory analysis of soils from the following locations: Bunyala in Busia County, Ndhiwa in Homa-Bay County, Dominion in Siaya County, and Ahero in Kisumu County

To confirm the soils expansion potential, a plot of plasticity index against liquid limit of the soils was made on Casagrandesoil plasticity chart.

3 RESULTS AND DISCUSSIONS

Figure 1 shows the distribution of clay minerals in Kenya. It can be seen that over 40% of the country’s area is covered with montimorillonitic clay mineral which is the main composition in black cotton expansive soils.Table 1 and Figure 2 show the quantities of the clays found in Kenya.

Figure 3 is a delineated map for study area from Figure 1 showing road networks. It also shows the areas covered with expansive clay mineral (montimorillonitic) and this is one of the causes of road pavement and light weight building failures.

A plot of Plasticity Index (PI) against Liquid Limit (LL) for the soils in the selected road sections on the plasticity chart revealed that they are expansive clays (Figure 4). The soils fall above the ‘A’ line, which indicates that their composition is dominated by active clay minerals.

4 CONCLUSIONS

Geo-hazards such as expansive soils present a substantial danger to human life, property, infrastructure and environment. It is possible to use clay mineralogy maps to identify areas that have these soils to enable developers make crucial decisions when implementing projects.

From the study it was established that the extent of expansive soils in Kenya is vast. Over 40% of the clays found in the country are expansive type. Using the clay mineral map, it was possible to locate road sections with black cotton expansive soils. This was confirmed using the Casagrande Plasticity Chart.

These soils are a threat to infrastructure development. Hence the need for serious research on expansive soils to offer solutions on how best the soils can be used as opposed to the current practice of discarding it.

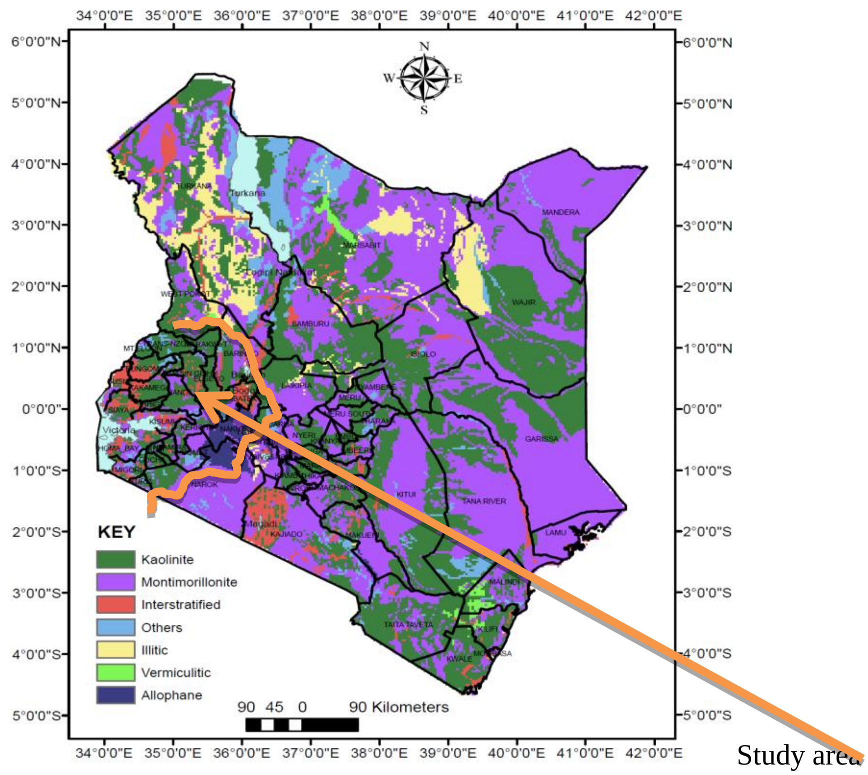

Figure 1: Clay Mineral Distribution in Kenya

Table 1: Percentage of clay mineral cover in Kenya

Clay Type	%
Montmorillonitic	48.1
Kaolinitic	35.6
Illitic	5.8
Interstratified	4.2
Allophane	1.2
Vermiculitic	0.6
Others	4.4

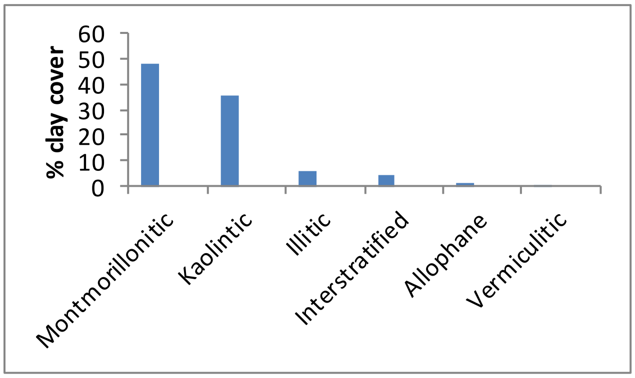

Figure 2: Chart showing Distribution of clays in Kenya

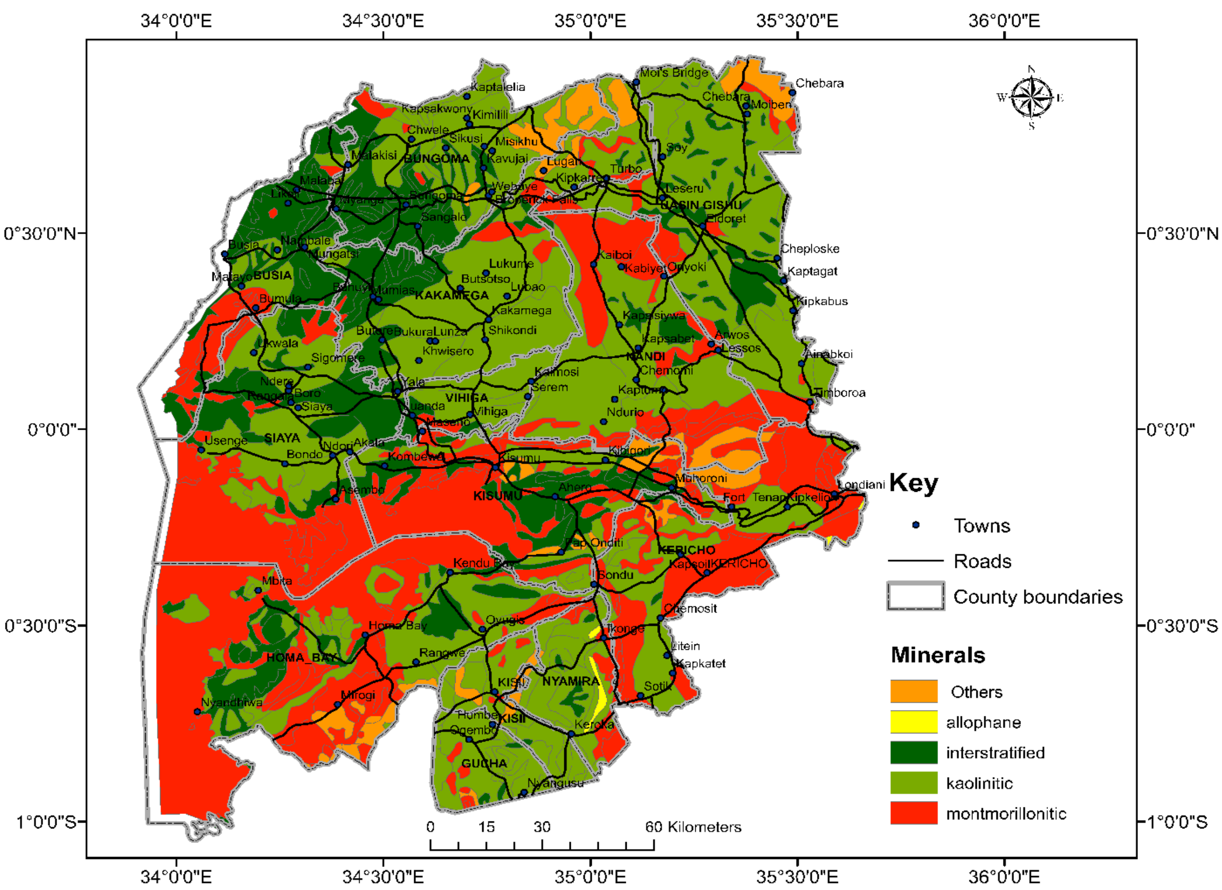

Figure 3: Delineated map showing road network for western part of Kenya as the study area

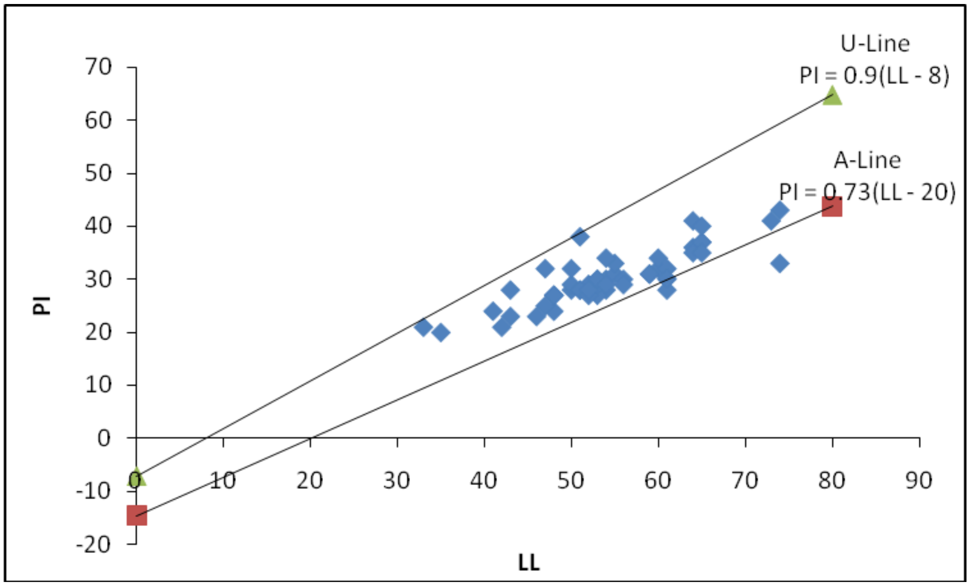

Figure 4: Plasticity chart for the soil samples

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Paper No: 14
Page 145 - 157
Sub-theme: GIS in disaster management, health and security

Using GIS to map and analyze urban flooding challenges in Ruiru subcounty, Kiambu County

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Abstract:

Ruiru experiences floods during seasons of heavy rainfall. Urban floods in Ruiru are aggravated by the inadequacy of planned mitigation measures by the local authorities. This research mapped the locations that are vulnerable to flooding by making use of geo-processing and spatial analysis tools while identifying the extent of floods in specific location in Ruiru. The study aimed at producing functional results for use by the Physical Planning Department of the Ruiru Municipal Council. Urban flooding was simulated using one-dimensional hydrodynamic modelling that incorporated data on soil, geology, elevation, Land cover and the drainage systems in the area. Soil data, land cover data, elevation data and natural drainage pattern was collected, rasterized, reclassified and weighted based on an calculated percentage of influence at 30 % for soil, 25% for slope and 45% for land cover. The southern and south western zones of the sub-county were found to be susceptible to flooding. Slope, soil, land cover and the in adequate storm water drainage facilities are some of the factors contributing to the urban floods in Ruiru. The study found out that about 14.3Km² (27 %) of the total Ruiru Sub-County area of 52.1Km² is likely to experience flooding, ranging from high to moderate possibility of flooding. About 70% of the residents in the study area are directly or indirectly affected by the urban floods. This was based on the overlay of the susceptibility map and the land use map of the area as well as the distribution of the population. Most of the land that is highly to moderately susceptible to flooding is located in the low lying areas where those who have settled there are vulnerable to flooding. This study illustrated the benefit of using GIS technology in physical planning especially in the management of urban flooding disasters.

KEY WORDS: urban planning, urban flood risk assessment, Susceptibility modelling, weighted overlay.

1 INTRODUCTION

Urban drainage analysis and urban floods or inundation prediction modelling involves a thorough evaluation of the urban area structure. Modelling is based on the slope derived from Digital Elevation Model (DEM), the soil and geology structure, drainage system and river discharge in the area and the land cover type and density (Fuchs *et al.* , 2013). In Ruiru Sub-County, the elevation and soil structure play a major role in influencing the occurrence of urban floods in the area. The other factors contributing to urban floods in Ruiru are the inadequacy of storm water drainage facilities, developments in flood-prone areas and the absence of forests or vegetation cover upstream. It is the understanding of these factors and their percentage influence that is used in the analysis of the flooding impact in Ruiru.

1.1 Background Information

GIS as a tool is used in many aspects of planning. The GIS tools make physical planning more efficient, user friendly and cost effective (ESRI, 2006). In Ruiru, planning of infrastructure is carried out by conventional method, which is slow. To speed up the planning process, high resolution satellite data could be used (ESRI, 2006).This study employed GIS techniques in mapping storm water infrastructure and modelling flood inundation to improve drainage and curb urban floods in Ruiru Town.

Flooding from storm water in urban areas is influenced by the topography of an area, the degree of impervious surfaces and the existing storm water management infrastructure (Cunderlik, 2002). In urban areas, water must follow through prescribed pathways set forth by large urban water systems that direct water flow (Cunderlik, 2002). As an area becomes urbanized, there is an increased flood risk due to the restricted flow infrastructure. The main problem with urban flooding is that in highly populated areas the vulnerability and fatality and damage to infrastructure is high. Also high population areas may be at risk of water prone diseases (Pradhan, 2009). Appropriate urban area planning seeks to manage storm water quantity and quality and reduce impacts from flooding. In Ethiopia for instance, inadequate urban storm water drainage represent one of the most common sources of complains from the citizens in many towns and this problem is getting worse with the on-going high rate of urbanization (GTZ, 2006). The pattern of urbanization and the modernization in Ethiopia has meant increased densification of urban infrastructure development. This has led to deforestation and use of corrugated roofs and paved surfaces. Due to inadequate urban storm water drainage infrastructure provision and poor management, significant proportion of the area is exposed to flooding hazards. This has resulted in negative impacts on urban residents (Belete, 2011).

In India, urban flooding is often as a result of inadequate drainage system. The impact is that even moderate levels of rainfall produce high flows of water in urban areas. Parava suggests that localized flooding is as a result of the location of settlements and poor drainage infrastructure. Over the past four decades, Delhi has experienced severe urban floods affecting 70,000 ha of land between 1953 – 1984. This is 50% of its geographical area of 148,300 ha. Although the capital city of India has suffered floods in various periods (1924, 1947, 1967, 1971, 1975, 1976, 1978, 1988, 1993, 1995, 1998), the 1978 flood was the worst ever when the gauged flood water level reached 207.49m from the danger level of 204.83 m. In this flood, 30 villages and 25 urban centres in the flood plains of Delhi were submerged (Parava, 2008).

The need for suitably locating urban centers influences the presence of urban floods. Various kinds of depressions and low lying areas near or around the cities act as cushions and flood absorbers. However, urban developments gradually fill up the low depressions as they seek to flatten the land for development infrastructures to support the urbanization pressure (Ramlala, 2007). This results in inadequate channel capacity causing urban flooding as documented by Ramlala (2007) for Trinidad and Tobago, that are plagued with perennial urban flooding problem. This has led to significant damage to the livestock, agricultural produce, homes and businesses particularly in the Caparo River Basin. Clearly, there is a need for developing flood mitigation and management strategies to manage flooding in the areas most affected (Ramlala, 2007). Ramlala (2007) utilizes geographic information systems to map the extent of flooding, estimate soil loss due to erosion and sediment loading in the rivers in the Caparo River Basin. In addition, he developed a watershed management plan and a flood control plan. The results indicated that flooding was caused by several factors including clear cutting of vegetative cover, poor agricultural practices and uncontrolled development in floodplains.

Storm water management can provide economic benefits to local communities. Proper management can result in reduced costs and /or fees for remediation of adverse impacts to stream channels, water quality, property damage and loss of life created by increased storm water runoff (Douglas, 2008). A successful case of flood management is seen in Denmark where the city planning department adopted a delay and infiltration process for storm water runoff locally in the city rather than discharge it through sewer systems (Douglas, 2008). Addis Ababa, Ethiopia on the other hand adopted integrating the roads network and the urban storm water drainage to reduce the rate and impact of floods (Belete, 2011). According to Meenar (2006) local municipalities in many parts of the United States have adopted storm water management ordinances where GIS based data inventory are created not only to monitor existing storm water management practices but also as a guide to planning and analysing vulnerable areas. Data used in the US case includes digital elevation model, triangulated irregular network, contour or other high quality elevation data as well as watershed boundary, stream bank, natural water body or water reservoir, water distribution network, land use, soil type, tree canopy density, impervious surface forest fragmentation and riparian buffer data (Meenar, 2006).

The current paper illustrates the role GIS technology can play in urban drainage mapping and analysis. It identifies the predisposing factors that lead to urban floods and explains the effect of each factor on urban floods, the trend and relationship to each other. Further, the study integrates the information necessary to form a basis for relevant stakeholders to come up with mitigation measures.

1.2 Study Area Characteristics

Ruiru Sub-County lies between Latitudes 01° 08′ 56″S, Longitudes 036° 57′ 24″E in Kiambu County, Kenya (Figure 1). It is located within 3Km from the Nairobi City Boundary. Ruiru is connected to Nairobi and Thika by both road and rail and by road to Kiambu. Ruiru Municipal boundary covers 292 Km^2. Located on the extreme south-eastern fringes of the Aberdare Range within the Athi River drainage area, the project area is characterized by relatively gentle terrain with a general fall towards Athi River to the east. However, the higher areas to the North West of Thika Road are characterized by deeply dissected topography with numerous streams and ridges, while the south eastern parts are lowlands with fewer streams, shallower and wider valleys. The average altitude is about 1520 m above mean sea level. The highest elevation in the project area is 1550m.a.s.l and is located around the Ruiru Prison area. The geology of Ruiru Municipality comprises of tertiary volcanic rocks, the most important being what is termed as the Nairobi Stone, a volcanic tuff mined for building blocks. Soils resulting from tertiary volcanic rocks are dark reddish brown, well drained, friable and very calcareous. The soils in the study area are derived from volcanic rocks that gradually occur on levels between 1500 to 2000m a.s.l. The general nature of the soil ranges from shallow to red friable clays. In geological terms, these are youthful soils formed after removal of black clays by erosion process. However there are patches of black cotton soils.

Rainfall in Ruiru is bimodal with long rains occurring from March to May, and the short rains from October to December. The mean annual rainfall averages between 600mm-1100mm per annum and falls in two maxims i.e. short rains from October to December and Long rains from March to May. The temperature is generally high, the mean annual temperature averaging between 18°C - 20°C. The mean annual potential for evaporation ranges between 1550 - 2200mm. From the Census of 2009 the Population of Ruiru sub county was 238,858. Currently the estimated population could be much higher as a result of new settlements and urbanization of the rural areas following the expansion of Thika Road to a Super Highway. This therefore predisposes an increasing number of the population to flood-related risks.

2 MATERIALS AND METHODOLOGY

2.1 Introduction

ArcGIS 10.3, spatial analysts tools were used in the study. The spatial analysis tools used were ArcHydro Extension, Model Builder, Reclassify and Weighted Overlay. The Raster Calculator was also used in the determination of the weights assigned to the various variables. Data used for this study was open source data readily available in public domains. The project also made use of Landsat Imagery in classification of land cover for the study area.

2.2 Data Acquisition

The collected data was stored into a storm water features dataset that contained the following feature classes: basins, channels, culverts, inlets, manholes, outfalls and pipes. The points where the streams enter and exit Ruiru's boundaries and accessible sites within the boundary were also recorded to assess the possibility of flooding.

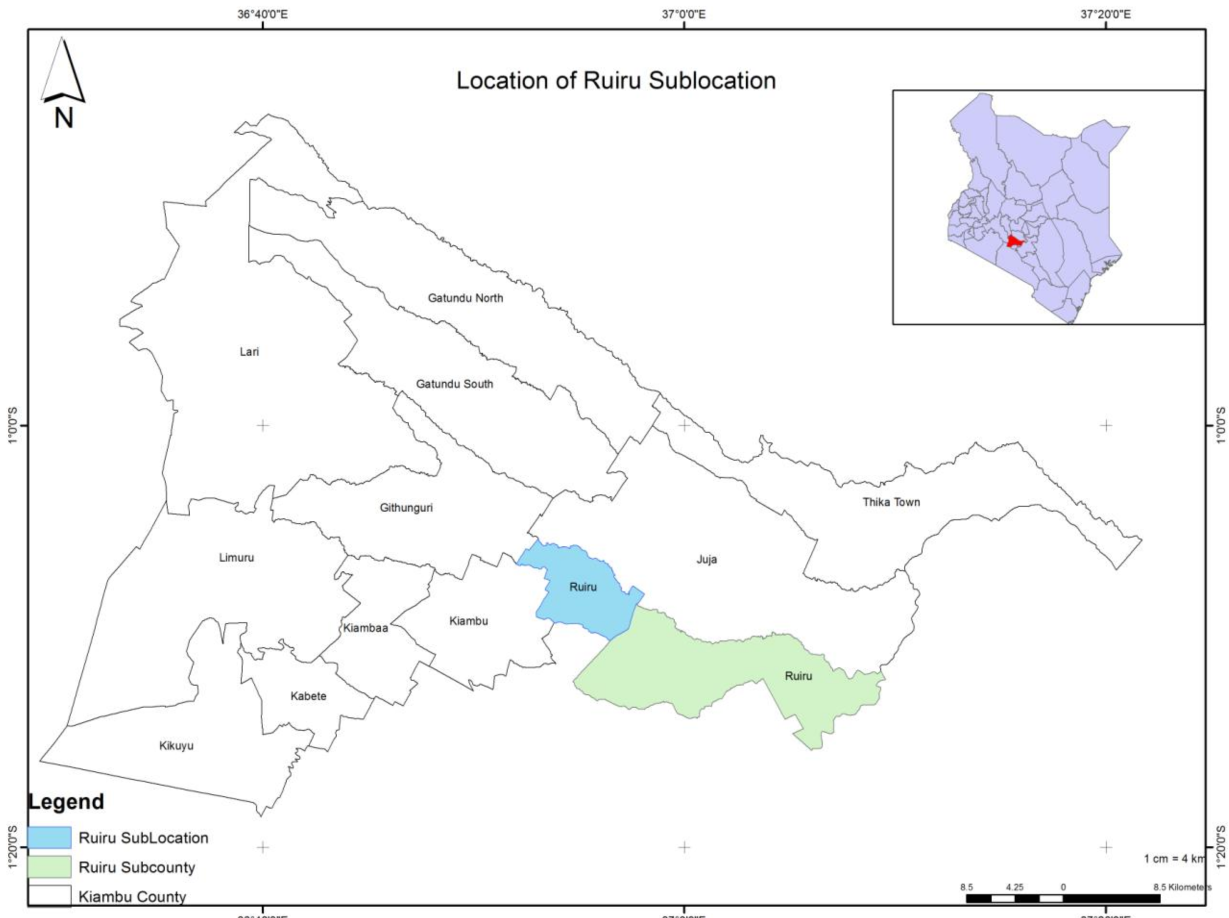

Figure 1: Location of Ruiru SubLocation in Kiambu County

2.2.1 Methods applied

Land cover data was obtained from Landsat imagery that were analysed and classified. Physical collection of geographical data from the field was done using GPS android application Polaris Navigation as well as the ESRI Collector application. These were used in geo-referencing the image used to obtain data layers.

2.3 Data Processing

Since some of the data such as soil, elevation data was obtained from other institutions was gridded in different projections, it was necessary to re-project the individual datasets to the Geographic Coordinate System, WGS 84 datum. This was performed with ArcGIS 10.3 using the projection and transformation tool. In the case of Rivers, Roads and Streets datasets, buffering was done using the geo-processing tool. A project geo-database was created to centralize all project based processes.

2.4 Data Manipulation

Most of the data collected was country wide. This included soil data, DEM, Rivers, Land USE and Land cover. An effective boundary of the study area, Ruiru Sub County, was extracted from the Kenya Administrative Boundaries shape file collected from Esri Eastern Africa and used for the purposes of this study. The project data that includes, Soil, Land cover, DEM, rivers, collected was then clipped to fit into the boundary of the study area. This was carried out using ArcGIS 10.3 analysis tools select and clip. Data collected in Vector format was also converted to raster to ensure uniformity and better analysis.

2.5 Data Reclassification

The ArcGIS 10.3 reclassification tool was used to reclassify the datasets collected in order to use the data for analysis. The process involved taking input cell values and replacing them with new output cell values. This was done to simplify or change the interpretation of raster data by changing a single value to a new value and grouping ranges of values into single values—for the soil data assigning a value of 1 to cells that have values of 1 to 50, 2 to cells that range from 51 to 100. Reclassification operations merely repackage existing information on a single map. This makes it possible to view resulting map details as significant values. Whereby for soil data areas represented by cells that have values between 1 to 50 represent areas likely to flood.

2.6 Weighting

Weighted was done by combining the soil data, DEM, Land cover and river data and applying a common measurement scale of values to each of the raster data, weighting each according to its importance as follows: soil data 30%; DEM 25 %; Rivers 25%; and Land cover 20%. The percentage signifying the importance of the factor as a causative agent in flooding in Ruiru was derived from using the formula below.

$$W = \frac{(\mathrm{cf} \times rank)}{\sum(\mathrm{cf} \times rank)} \times 100 \tag{1}$$

where, *w* is weight and cf is contributing factor.

These layers were added together to create an integrated analysis. The weighted overlay tool output was generated into two categories: 1: floods and 2: does not flood. The categories were based on the results of the overlay of all the four datasets and the percentage of influence placed for all the datasets.

2.7 Flow Direction and Watershed Generation

Watersheds in the study area were computed using ArcHydro extension on ArcGIS 10.3. This was done to establish the terrestrial region of the land that drains water into a common terminus. This was done by first filling sink on the elevation data in order to stabilize DEM data. The results of the fill were used to generate flow direction of the area in order to establish the route followed by rain runoff or groundwater flow. The flow direction output was used to generate a flow accumulation and snap pour points. These were in-turn used in the final tool watershed tool to generate watershed with the different snap pour point.

3 RESULTS AND PRODUCTS

3.1 Flood Prone Areas

As showed from the results of the weighted overlay of the factors assumed to contribute to flooding, the areas susceptible to flooding were found to be concentrated within the Southern and south eastern areas of Ruiru Sub-county above areas below 1550 m asl. A Susceptibility map (Figure 2) was created based on three aspects: Low susceptible areas, moderate susceptible areas and high susceptible areas. The resulting susceptibility map shows a few locations of the total study area are prone to severe flooding along the river beds due to inadequate vegetation cover. Flooding in the study area is considerably high in the flat and low lying areas of the study area which totals to about 14.3 Km^2 due to slope aspect and the presence of poorly drained soils in the regions among other contributing factors such as land use and land cover. The study noted that the flooding in the region has increased with the increase in impervious surfaces in the region and the inadequate provision of storm water management channels. After reclassifying and overlaying soil, rivers, slope and land cover using the spatial analysis weighted overlay tool and raster calculator data a conclusive result was generated dividing the study into three divisions as shown in the resulting map below: high possibility of flooding, moderate possibility of flooding, and low possibility of flooding

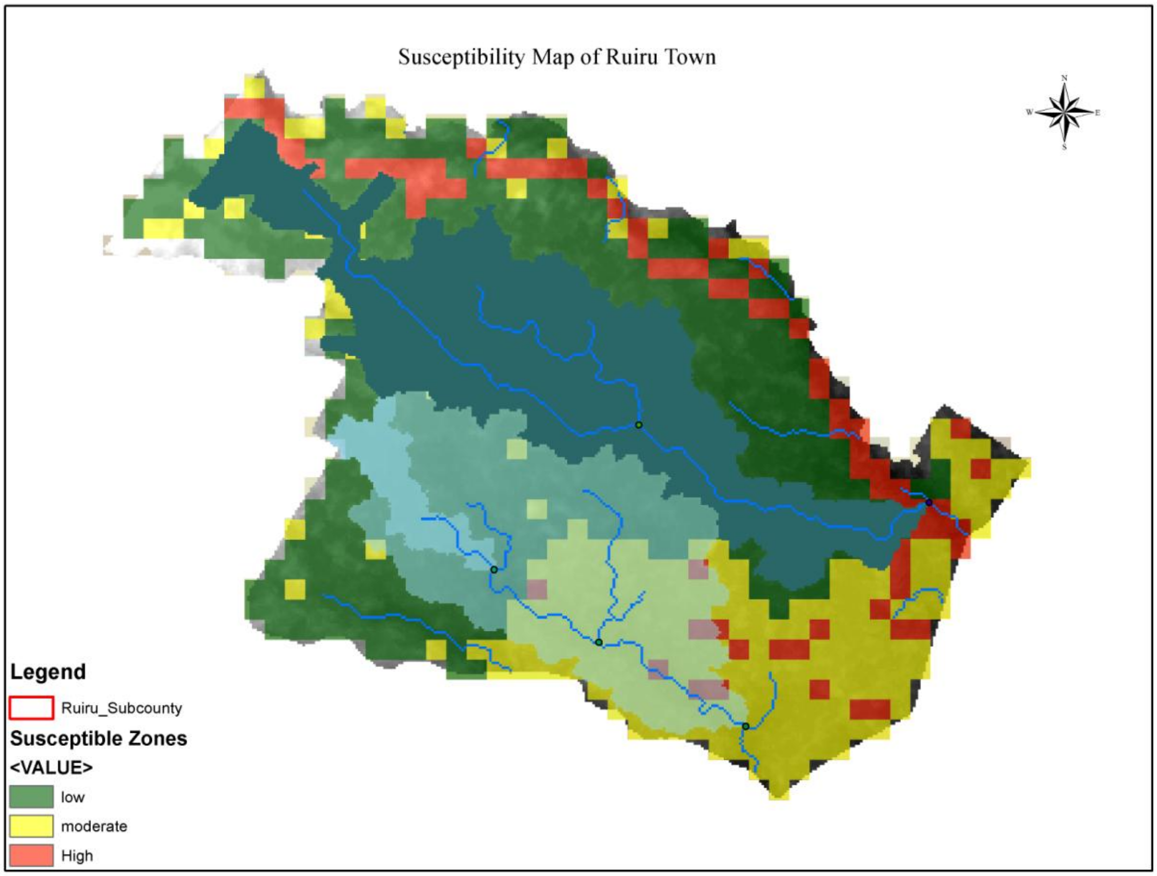

Figure 2: Map showing flood prone areas in Ruiru Sub-County based on overlaying

3.2 Effect of Soil and Geology on Flooding in Ruiru Sub-county

An analysis of the soil and geology in Ruiru was carried out in ArcGIS 10.3 to obtain various characteristics of the soil in the study area. A soil map of the area was created to illustrate the distribution of the soil type and therefore make analysis of the influence of soil on flooding. A comparison of the soil map and the output of the weighting give a clear understanding of the influence of soil type on flooding.

There are two soil types in Ruiru Sub-county. The study broadly categorized the soils into well drained and poorly drained (Figure 3). The poorly drained soils are most common in the low-lying regions of the study area. As indicated in the susceptibility map the low lying area and areas along the rivers are most prone to flooding. This therefore means that soils and the underlying rock play a huge causative role in the occurrence of urban floods in Ruiru.

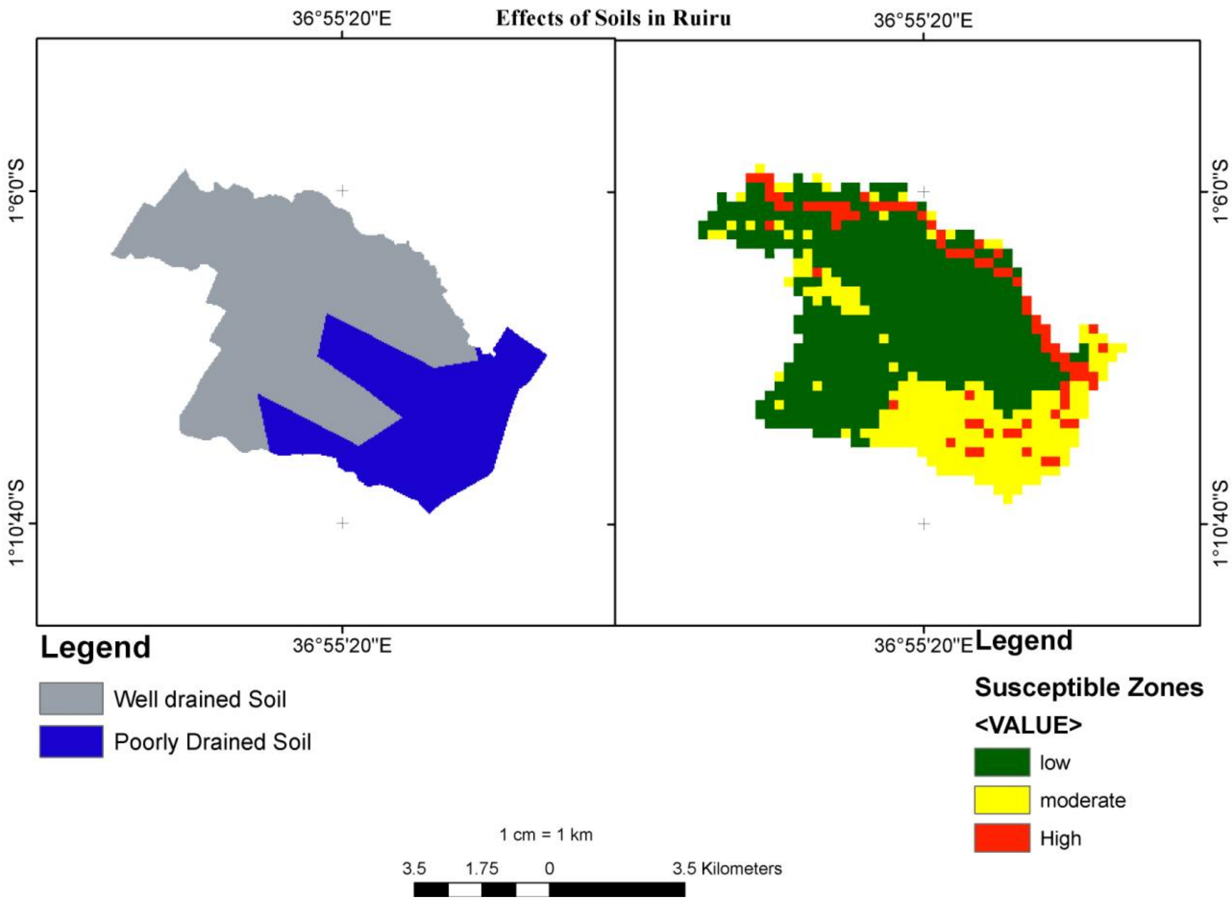

Figure 3: Map showing relationship between Soil and Flooding in Ruiru Sub-county

3.3 Effects of Slope on Flooding

A study carried out by Cunderlink (2002) illustrates that the slope aspect of an area influences the flow direction of rainwater or surface water in an area. The effect of the slope aspect in Ruiru was established by generating a flow direction map through terrain processing and DEM manipulation done on ArcGIS 10.3, spatial analyst's .hydrology tools. A comparison of the flow direction map and the output of the weighting were also done to establish the relationship between slope and flooding. As seen from the slope generated (Figure 4), the flow direction follows the elevation of the area.

3.4 Effects of Land use and Land cover

In order to establish the relationship between effects of land-cover on flooding, a land cover map of the area was created. This was done through manual digitizing of the study area on ArcMap 10.3. The study analysed the percentage of pervious surfaces versus impervious surfaces to establish the relationship between the land cover and urban flooding in Ruiru. Analysis of the effects of land cover was carried out through weight calculation. With a consideration of all the other factors, and the different land use in the area, the value factors were assigned 1 for least likely to cause floods and 3 for most likely to cause floods. Values assigned for Land cover were as follows: The values assigned were based on the regression method where each factor is considered independently and ranked on a scale depending on the number of factors they are.

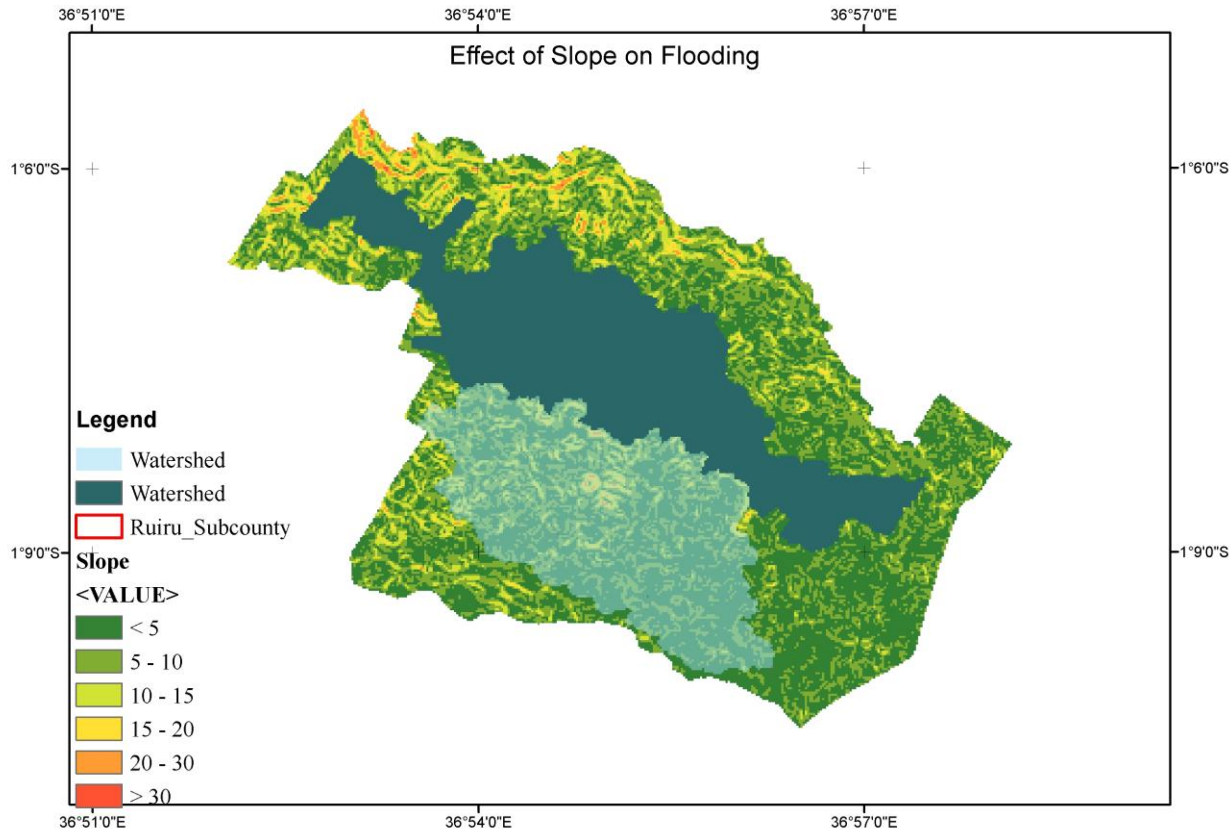

Figure 4: Map showing relationship between the slope and flooding in Ruiru Sub-county

Table 1: Weighted of the different uses of land to establish how much they influence flooding in the region

Land Cover	Value of Contributing index
Urban and associated areas, rural settlements	3
Shrub savannah	2
Scattered (in natural vegetation or other) Rain fed	3
Shrub crop (field density 20-40% of polygon area)	2
Rain fed shrub crop	2
Rain fed herbaceous crop	2
Open trees (65-40% crown cover)	2
Open low shrubs (65-40% crown cover)	2
Closed trees	1
Closed herbaceous vegetation on permanently flooded land	1
∑ contributing index	20
Rank	2
Rank x ∑ contributing index	40
Weight	0.519480519

As seen from the table, Land cover as a factor contributing to flooding scored highest in the weight calculation. The study therefore concluded that Land cover is major contributing factor to urban flooding in Ruiru.

3.5 Effect of Rainfall

Rainfall is bimodal with long rains occurring from March to May, and the short rains from October to December. The mean annual rainfall averages is between 600mm - 1100mm per annum and falls in two maxims i.e. short rains from October to December and long rains from March to May. The North Western side of the study area averagely receives the highest rainfall. Rainfall runoff from the highlands of Ruiru Sub-county and the neighbouring counties in the Northern and North western sides flow downwards through flow direction as illustrated in Figure 5. This water is often held by the watersheds in the low-lying areas of the study area, thus contributing to the flooding in the area. The amount of rainfall received in the period determines the impacts of flooding in the area.

3.6 Utilities Affected

An overlay of the land use map was done on the flood susceptibility map of the study area to find out percentages of the utilities likely to be affected by the floods in the areas highly prone to flooding and the extent of the impact generated. As is evident from the map (Figure 6) the area moderately and highly prone to flooding is mostly urban utilities such as residential buildings, factories, churches and other religious amenities and business premises.

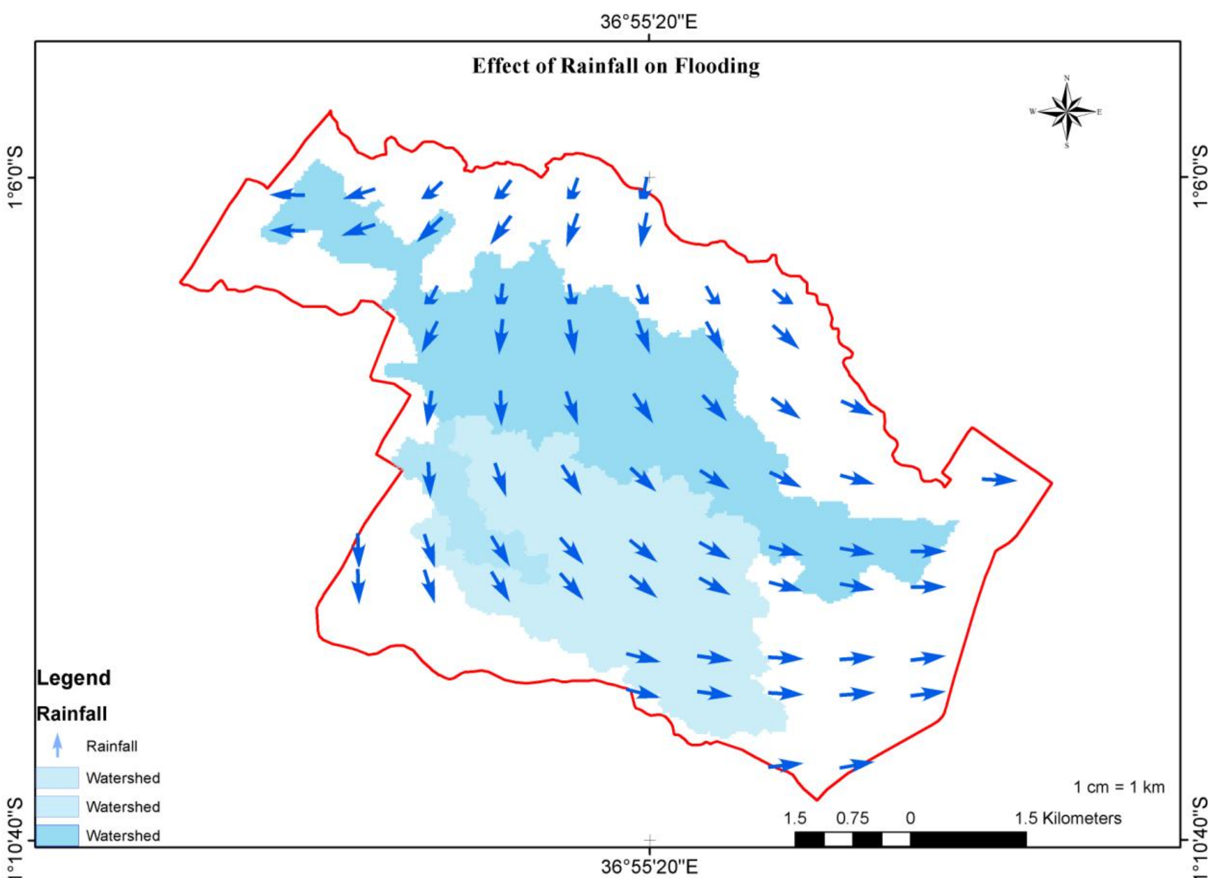

Figure 5: Map of rainfall data in 2014

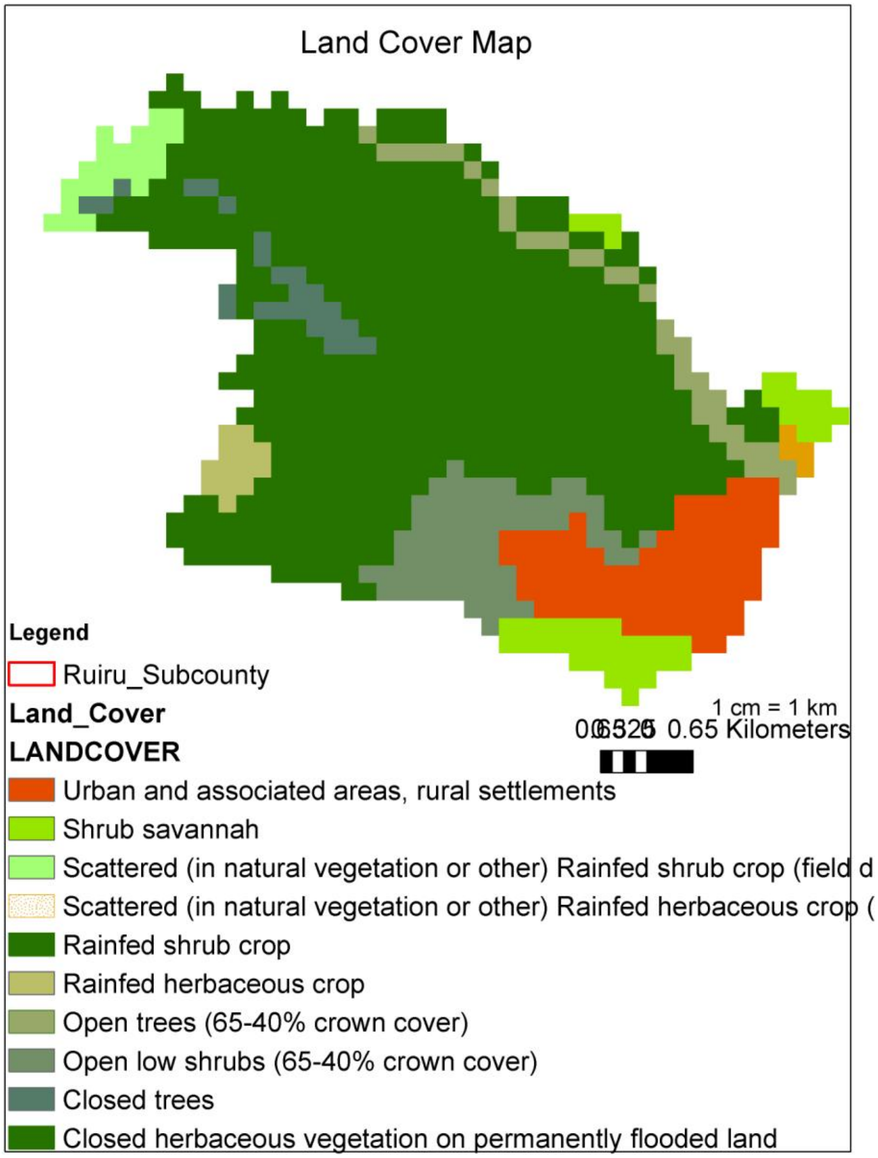

Figure 6: Land cover map of Ruiru Sub-county

4 DISCUSSION

According to (Pradhan, 2009), for validation of flood susceptibility models, two basic assumptions are needed. One is that flooded areas are related to spatial information such as topography, soil, flow direction, flow accumulation and land cover, and the other is that future flooded areas will affected by a specific factor such as rainfall. In this study, the two assumptions are satisfied because the flooded areas were related to the spatial information and the flooded areas were triggered by heavy rainfall in the study area. For instance in highly populated areas such as the Central Business District every rainfall seasons comes with loss or damage of property belonging to residents. This loses can be avoided if storm water management channels and flood appropriate buildings were constructed in the area. Existing channels are either vandalized or clogged in sand and garbage due to low maintenance.

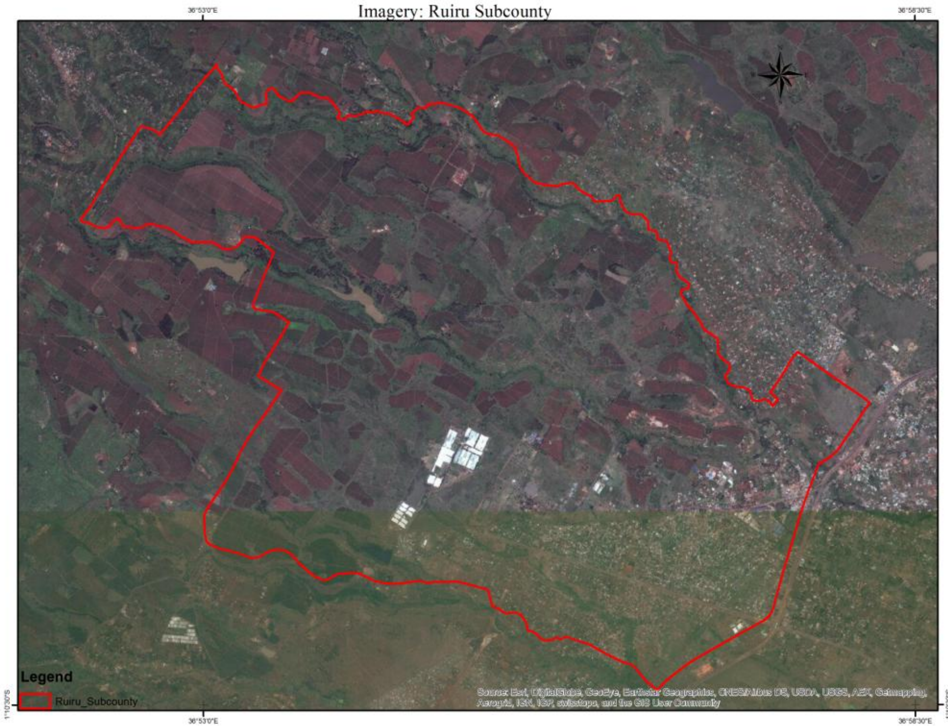

Figure 7: Imagery of land use in Ruiru Sub-county

Figure 8: Photograph of one of the flooded residential flats in Ruiru town

Although the study heavily assumed that the increasing rate of urban development in Ruiru, is the major contributing factor to flooding in Ruiru, This study has proven that the underlying soil and rock is the major contributing factor. This is evidenced by the marking of a huge percentage of unoccupied land as flood prone. We can therefore conclude that the increase in impervious surfaces in the area increases the extent of flooding and does not necessary lead to flooding in the area. This study found out that most of the highly inhabited areas are moderately to highly susceptible. This increases the size of the population predisposed to flood risks. As analysed in the study the risk of flooding Ruiru with the least possible amount of rainfall has a 15% possibility of occurring illustrated in Figure 9. It is therefore important information about the risk of flooding is disseminated to the public to reduce rate of disaster.

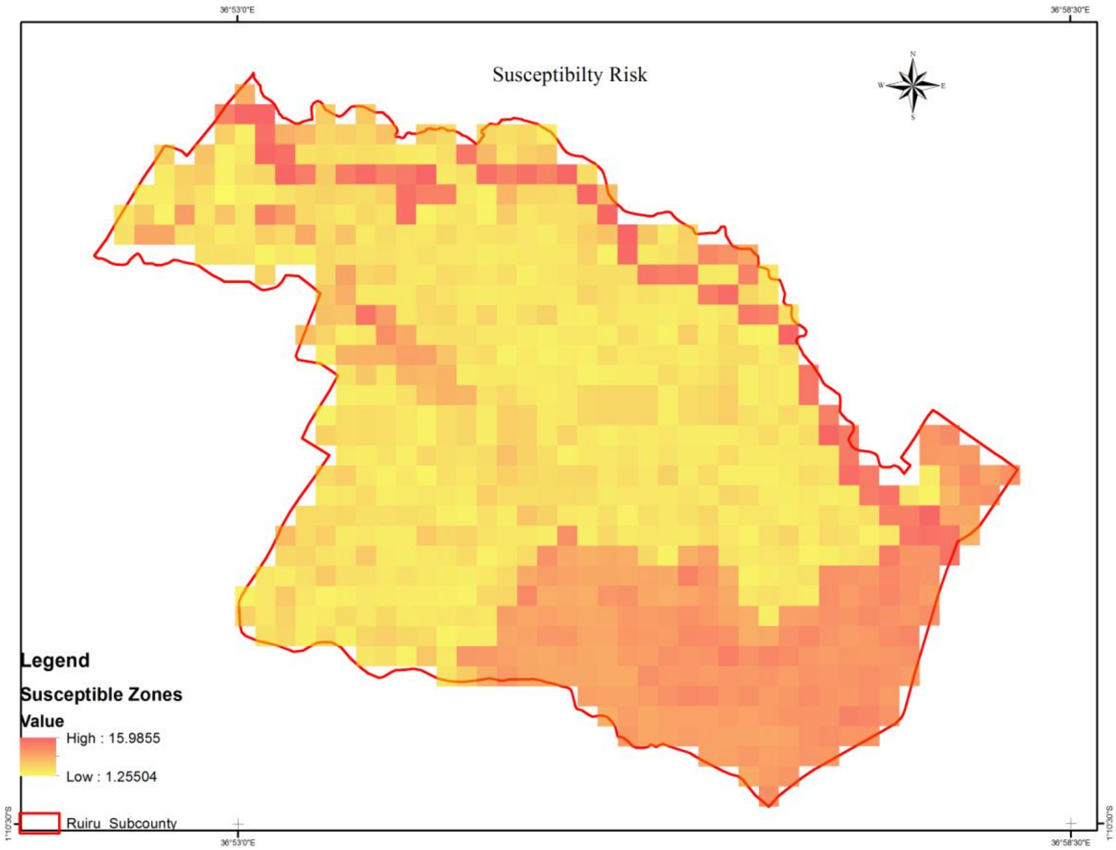

Figure 9: Map showing the risk of flooding Ruiru Sub-county from 1.2 to a highest of 15.95 in period of least rainfall

Among some of the limitation of this study is to understand flooding Threshold. How much rainfall actually causes flooding? As stated by Farrelly, 2008 Flooding in an area occurs when the amount of infiltration or flow of water is lower than the amount of rainfall received. It would therefore be important to understand the rate of infiltration against the amount of rainfall received in order to analyse the extent of flooding.

5 CONCLUSION

Urban flood assessment is an important aspect in the physical planning of a town. For disasters such as this, In order for floods to be avoided stakeholders and decision makers need to understand the areas that flood and the extent of the flooding per season depending in the amount of rainfall received. Impacts of the flooding in the Ruiru sub-county can be felt by closely looking into the overlay of land use –Land cover Map and the Flood Susceptibility map. Utilities such as business and residential buildings, stadiums and football grounds flood after rainy seasons for quite some time. Susceptibility modelling is simple and the process of input calculation and output can be readily understood. The large amount of data can be processed in the GIS environment quickly and easily. Therefore this kind of modelling can be carried out every 5- 10 years as the area continues to undergo land use changes. This mapping and analysis is important so as to inform the stakeholders and decision makers of the locations to expect flooding and influence their decision on the best way to mitigate losses, damages and inconvenience to the public. This study recommends that much more research is carried out in the rainfall and urban infrastructure so as to better understand and come up with complete mitigation measures of the urban floods in Ruiru.

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Paper No: 15
Page 159 - 167
Sub-theme: GIS in disaster management, health and security

Determination of the extent of Yala river flood flows in the Yala basin, Kenya

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Abstract:

In Kenya, hazards caused by river floods are a common phenomenon in most parts of the country. Areas of Kano plains in Kisumu County, Budalang`i in Busia County and Coastal areas are prone to floods. Flooding of the lower reaches of the Yala River has been occurring for a long time causing havoc in the basin. The basin has experienced loss of lives, destruction of property, outbreak of water borne diseases and siltation of arable lands that have followed flood events. In the recent past, the frequency and intensity of the floods has increased, partially attributed to climate change. The extent of Yala river flood flows and the damage they cause in the basin have not been known in order to propose proper mitigation measures. The lack of information on the flood extent has been due to difficult conditions to measure discharge in the lower Yala basin because of channel instability, high silt content and presence of Papyrus Reeds in the swamp. The main objective of the research was to carry out mapping of Yala river flood extent in the lower basin using Satellite imagery data integrated with ArcGIS as a suitable alternative in obtaining information where traditional discharge measurement methods were not possible. The results show a change in the flood extent of about 34.23 km^2 from 1984 to 2010. The mapped area extent results may be used for future flood management planning in the basin. The quantification of the extent of flood waters in the basin is critical for future water resources planning and design of infrastructure such as reservoirs upstream of Yala River. This research forms anew basis for research on the extent and impacts caused by the Yala river flood flows in the basin using satellite imagery analysis technique.

KEY WORDS: flood extent, Satellite imagery, flood early warning, Yala River

1 INTRODUCTION

Flood is a natural phenomenon that occurs when the volume of water flowing in a system exceeds its total water holding capacity. United Nations defined flood as excess flowing or overflowing of water, especially overland which is not normally submerged (ESCAP/UN, 1997). Floods have several sources such as: prolonged rain with considerable intensity, dam or dyke break, river blockages, storm surges, abnormally high tides and tidal waves or *tsunami* (Badilla, 2008).

Floods have occurred in the world throughout recorded history and as a natural phenomenon affect mankind and his/her activities particularly the poor who lack resources to mitigate their effects (BIAB, 2007). There are many different types of floods, namely; coastal floods, giant tidal waves floods, flash floods, river (or fluvial) floods, urban floods, ponding (or pluvial flooding) from tsunamis and earthquakes or volcanic eruptions in the ocean (Xuan, 2006). Floods are natural hazards that regularly occur due to changes in climatic conditions and exacerbated by human activities as a result of environmental degradation. Floods become disasters when they interact with the society, and result in death and destruction of property, thus requiring outside assistance in order to cope.

Although natural factors are the main causes of floods, anthropogenic factors, such as occupation and settlements in the flood plains, extensive urbanization, basin-wide land-use changes, structural measures (flood levees and walls, cutting river meanders, river training) have modified the natural characteristics of extreme floods worldwide. Proper knowledge and information on extent of impact of flood is therefore necessary. When this information is poorly known, communities with a limited capacity to respond experience increased scale of devastation (Masibayi, 2011). Riverine floods are the most dominant floods in Kenya. River floods mostly occur along floodplains as a result of exceeded stream flow capacity leading to over spilling of the natural banks or artificial embankments (Smith & Ward, 1998). River floods affect both the rural and urban areas in form of flash and urban floods. Flash floods have a characteristic short duration and steep rises and rapid falls of flood levels. In Jamaica for instance, flash floods were experienced with insufficient lead time to effect adequate mitigation response in Cave River, Rio Cobre and Rio Grande Valleys (Errol, 2003). To mitigate the effects of these floods, information on the magnitude and extent of impacts was mapped out in order to develop a low cost early warning system. Therefore, national and county planning should have proper information on the magnitude and extent of impacts of floods in order to develop reliable intervention measures whenever floods occur. Floods in Yala river basin are caused by intense storms upstream (Nandi Hills) of the catchments that produce more runoff than the catchment can store or the main Yala river can carry within its normal channel (Kiluva *et al.,* 2010).

1.1 Flood Mapping using Satellite Imagery

Flood mapping using Satellite imagery data is one of the methods of obtaining information on flood risk mapping.

Flood mapping based on satellite imagery data provides useful information for disaster monitoring and assessment (Stancalie *et al.*, 2012). There are different methods used for obtaining useful products for flood risk mapping such as: land cover/land use maps, hydrographic network characteristics and water accumulation, maximum flood extent, flood area classification, flood evolution and flood damage assessment (Stancalie *et al.*, 2012).

Huizinga *et al.*, 2005) proved that methods for deriving the water level directly from combining observed flood maps and digital elevation models (DEM) are very sensitive to small errors in geo-referencing of the maps and local errors in the inundation.

Flood maps derived from satellite imagery data can play an important role for improved flood modeling and forecasting. For example, when no gauging stations are available, gauging stations fail or unforeseen events (such as dyke breaches) happen. Geo-referenced and classified satellite data can provide information on flood extent as well as water levels for large flooded areas (Barneveld *et al.*, 2008). Satellite data may provide near real-time information on the flood event, better flood predictions, a tool to detect flood detention areas and improve management of rivers and their catchments (Barneveld *et al.*, 2008).

In recent years, different remote sensing techniques have been used to detect water bodies and their characteristics (water extent, height, variability, vegetation cover and sediment load) (Leauthaud *et al.*, 2012). Synthetic Aperture Radar imagery is very popular because of its high spatial resolution and its capacity of mapping water under thick vegetation. However, the radar signals change continuously due to wind induced waves, especially in the C-band, limiting the use of this band for water detection (Alsdorf *et al.*, 2007). L-band data are limited by their low orbital repeat cycles, cost and limited archives. Passive microwave data have been used to detect flooded surfaces (Sippel *et al.*, 1998; Ticehurst *et al.*, 2009), but are limited by low spatial resolution.

Thermal satellite data have been used to map inundated areas (Leblanc *et al.*, 2011). An alternative solution is the use of passive optical/infrared sensors on board the Landsat, Moderate-Resolution Imagery Spectroradiometer (MODIS) and SPOT satellites. Differences in the spectral signature of land and water covers are used to distinguish water bodies from other surfaces (Leauthaud *et al.*, 2012).

Many Water Indices have been developed using different spectral bands and deferent satellite data (Gao, 1996; McFeeters, 1996; Xu, 2006). However, they don't always distinguish between flooded and non-flooded vegetation. Oliesak (2008) used the Modified Normalized Difference Water Index (Xu, 2006) to map the open water bodies in the Inner Niger Delta and the Normalized Difference Water Index of Gao (NDWIGao) (Gao, 1996) to include the vegetated water.

The Landsat image was used to examine the impacts of land use activities in Budalangi and Yala Swamp Area in Western Kenya. It focused on the assessment of the land cover/use trend in the study area by collection of data and documentation on the status of encroachment into the wetland areas and therefore the level of their degradation (Onywere *et al.*, 2011).

The Tana Inundation Model (TIM) was used to quantify essential hydrological variables of ecological importance for 2002–2011 such as flood extent and duration, flood timing and frequency, flood peaks and water height in Tana River Delta (TRD), Kenya. The TRD is characterized by scarce hydrological data and a high cloud cover limiting the use of many remote sensing techniques. The methodology therefore combined a conventional water-balance analysis with the extraction of inundation extents from MODIS satellite imagery at a medium spatial and temporal resolution (Leauthaud *et al.*, 2012). Although, there is frequent flooding in Yala basin, there is no information on flood extent from the flood flows. Flood extent in Yala river basin was mapped using satellite imagery technique since there are no stable controls in the lower reaches of the basin due to low gradients in the swamp where water spreads beyond the main channel making gauging or installation of measuring devices like staff gauges and area surveying difficult. During flood periods it is impossible to measure area extent directly because of Papyrus Reeds, excessive widths and silt.

2 MATERIALS AND METHODS

2.1 Study Area

This study focused on the Yala River Basin. Yala basin is located within Lake Victoria North Catchment in Kenya. The catchment is centered about 35^{o} E, 0.1^{o} N (Githui *et al.*, 2005). The basin was divided into three zones; the upper, middle and lower based on regular gauging stations at the outlet of each sub-catchment. The upper catchment falls in Nandi County, middle catchment falls in Kakamega and Vihiga counties of Western region and the lower catchment is found in Siaya County in Nyanza region.

As an alternative to capture the flood area extent, this research study extracted and analysed the flood area extent using satellite images for the years 1984,1990, 2000 and 2010. The Landsat images for 1980 could not be used due to poor resolution; hence 1984 data sets were used. The years were chosen to cover a period of at least 27 years to study change. The lower Yala ground during flooding situation had created a gap in data collection, flow quantification and area surveying hence requiring use of Satellite imagery technique.

This study applied the use of satellite imagery technique integrated with ArcGIS to generate resultsof the flood extent for the years 1984, 1990, 2000 and 2010..Satellite imagery data was obtained from the Regional Centre for Mapping of Resources for Development (RCMRD) for the years 1984, 1990,2000 and 2010.The LANDSAT images of TIFF format were sourced courtesy of U.S. Geological Survey, (http://eros.usgs.gov/products/satellite) with a resolution of 30mx30m.

2.2 Satellite Imagery Analysis

Multi-temporal LANDSAT Thematic Mapper satellite imagery was integrated with ArcGIS to detect, delineate and map land cover change on lower Yala basin and its surrounding. The data was extracted, composed and developed into maximum likelihoods for determination of Yala flood extent. Emphasis was laid on; the extent of water mass on the land surface with time and changes in land area with time. The LANDSAT images obtained were clipped using lower Yala shape file in ArcGIS 10.0.

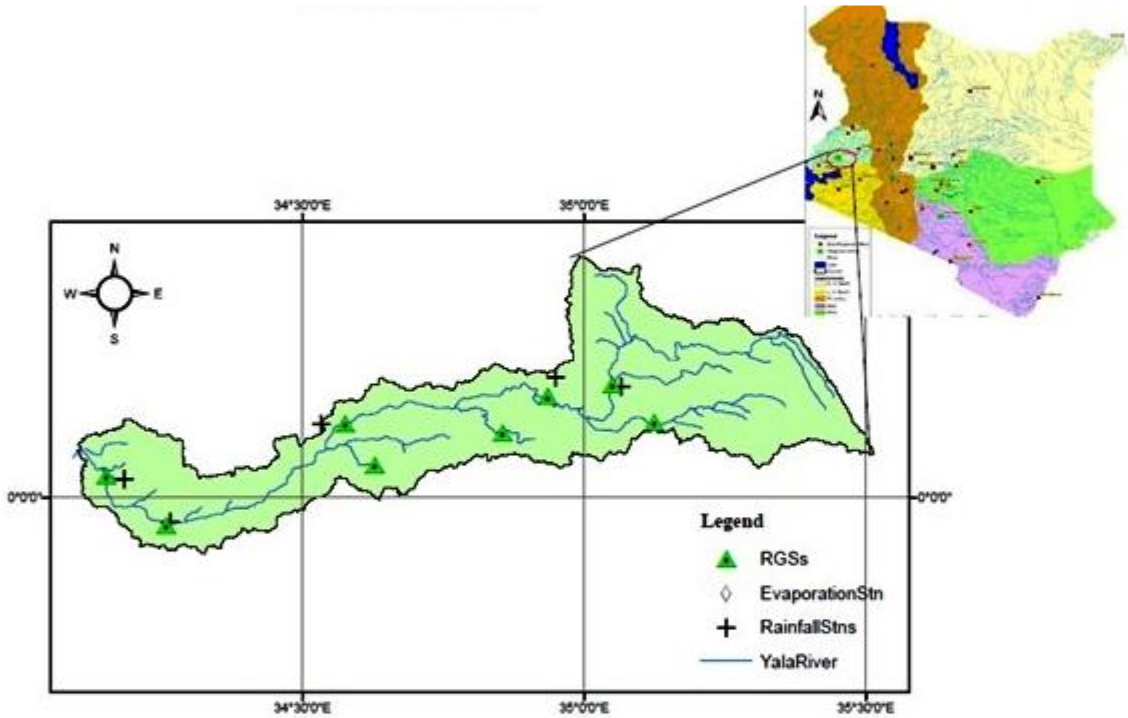


Figure 1: Map of Yala catchment in Western Kenya

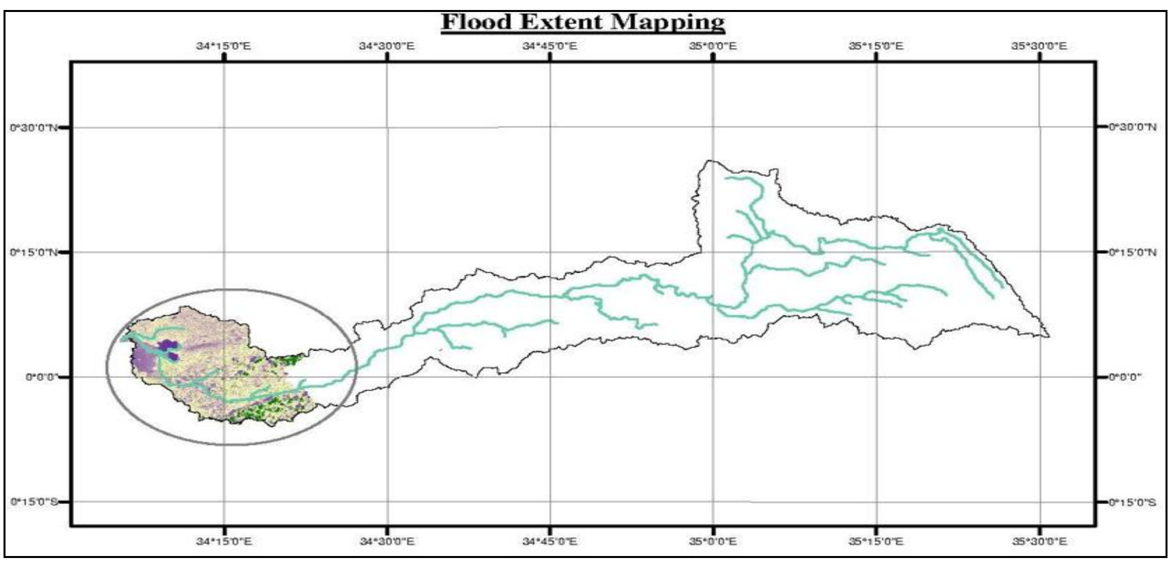


Figure 2: Circled part represents the Lower Yala basin used for Flood Extent Mapping

The resulting clipped images were loaded onto Adobe Photoshop software platform where they were rectified to improve the resolution and to separate colour bands along the river Yala channel. The images were then loaded back to ArcGIS platform where training samples were then created and grouped to either land or water for each of the images and their respective signature files saved.From the satellite imagery, points representing the different inundation were identified for ground truthing. The reference

UTM coordinates were determined and ground conditions determined in the field. The actual points on the ground were visited and information at the time when images were taken was recorded. This was accomplished by interviewing the land owners what the land cover was during the dates when images were taken. Such information included the depth of the flood and areas which were under water.

Maximum likelihood classification Method of Extraction was used according to the analysis procedure. Data on coverage area for each criteria of classification was obtained from the properties of the respective layers that gave the count of the number of cells and areas for each classification criteria (land or water). The methodology that was adopted is as shown below.

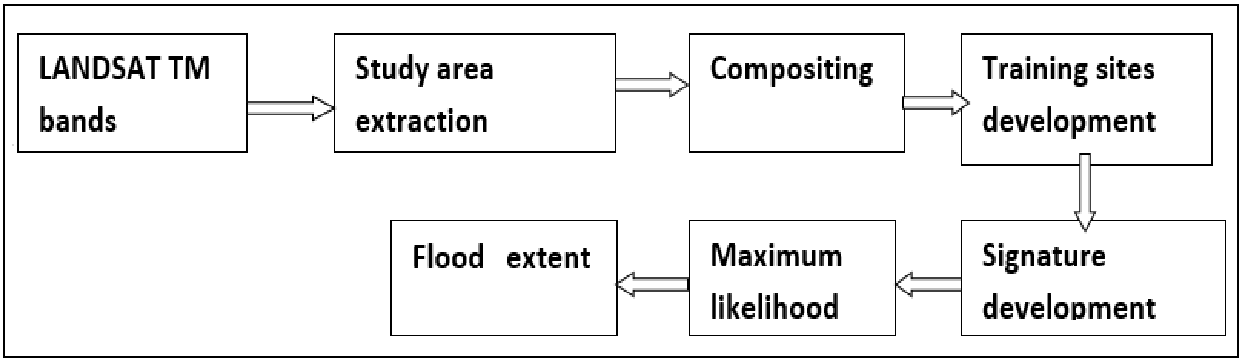


Figure 3: Methodology adopted

3 RESULTS AND DISCUSSIONS

Land cover and water mass classes were mapped around lower Yala basin from the LANDSAT images. The flood extent extracted using the satellite imagery data for the middle and lower sub-catchments covering an area of 1725 km^2 that were considered for flood area extent. An 8-bit false colour composite image (Figure 4) and flood extent maps (Figure 5) of Yala basin were developed.

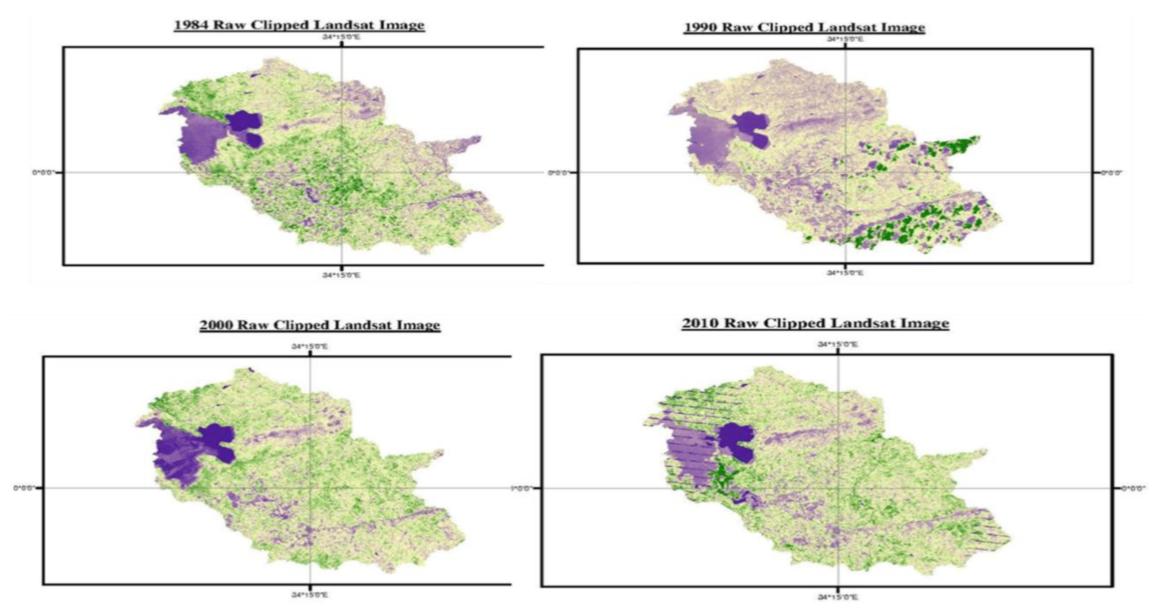
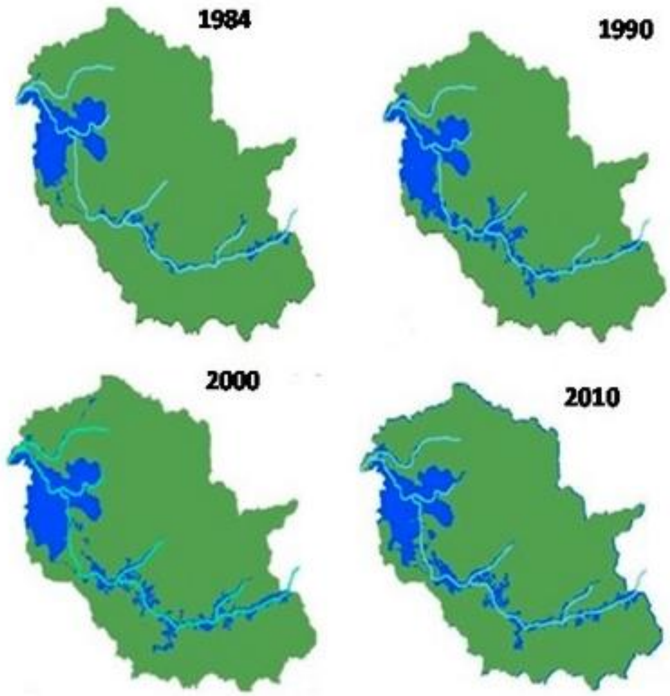


Figure 4: Flood extent mapping for selected years



Legend

	Color	Area(sq Km)				%age			
		1984	1990	2000	2010	1984	1990	2000	2010
Land		**528.85**	507.29	505.09	494.74	91%	87%	87%	85%
Water		52.54	74.13	76.33	86.77	9%	13%	13%	15%

Figure 5: Flood Extent Maps

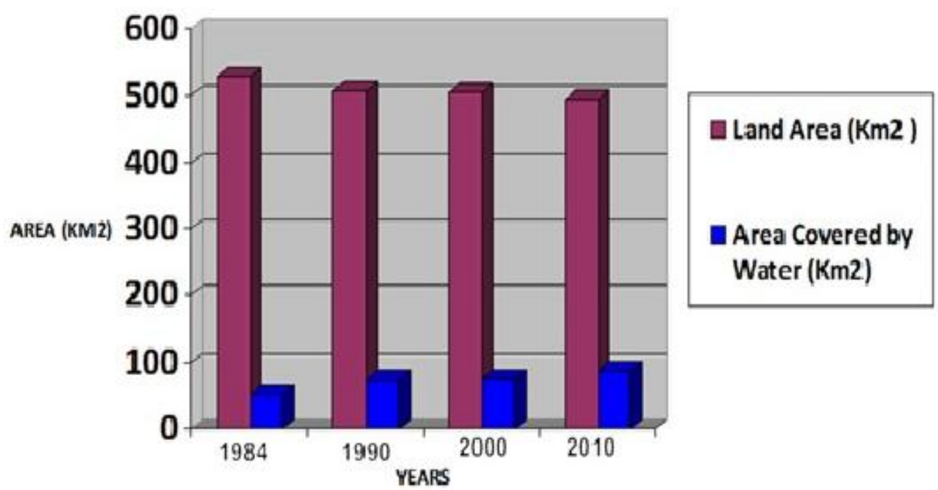


Figure 6: Variation in Flood Extent for the years 1984, 1990, 2000 and 2010

The study addressed land cover changes over 27 year period, 1984 to 2010.Raw clipped Landsat images (Figure 4.) for each year were collected and the study area identified. The resulting clipped images were rectified to improve the resolution and separate colour band (Figure 5) along the lower Yala basin.

The area for each class for 1984 to 2010 images was compiled in a table and represented in (Figure 5.) From the table, the land cover in 1984 was 528.85 km^2 against water mass cover of 52.54 km^2 representing 91% land cover to 9% water mass cover. While in 2010, the land cover was 494.74 km^2 against water mass cover of 86.77 km^2 representing 85% land cover to 15% water mass cover. From 1984 to 2010, the water mass cover has changed by 34.23 km^2 representing 6% change over the study period. This could be attributed to climate change and land use practices within the upper Yala basin that have led to increased flows over the 27 year period.

Flood extent chart for the years, 1984, 1990, 2000 and 2010 (Figure 6) were generated to indicate variation in water mass and land cover changes.

Variation in flood extent in the lower Yala basin has gradually increased in the past 27 years. The land area covered by the floods has increased by 34.23km^2 for the period between 1984 and 2010. The study also noted that there is a strong correlation between water rise at the last gauging station (1FG03) and the extent of the floods as indicated by R2 (85%) as shown in Table 1 and Figure 7.

Table 1: Change in flood extent Vis-a-Vis water levels for base year (1984) at 1FG03

Satellite imagery dates	Water Level at 1FG03	Area cover by water	Change in water level at 1FG03	Change in Flood Extent Area
09/08/84	3.09	52.54	0	0
07/02/90	3.32	74.13	0.23	21.59
06/03/00	3.5	76.33	0.41	23.79
29/01/2010	3.89	86.77	0.8	34.23

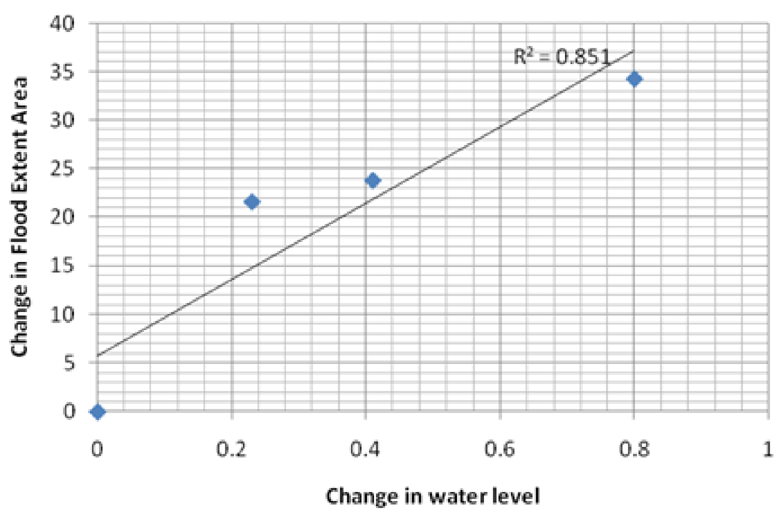


Figure 7: Correlation of flood extent with water level rise at 1 FG03

The water level changes at station 1FG03 could therefore be used to predict future water mass changes in the lower Yala basin where traditional methods like land surveying are not applicable.

The overall inundation extent results from the satellite imagery are similar to remote sensing estimates from Papa *et al.* (2010) showing the seasonal variation of flood extent in Yala basin. This scenario is likely to continue based on the climate change projection in the western parts of Kenya (USGS, 2010) and human activities being carried out in the basin. With a population of 100 persons per square kilometer near the Lake Victoria area (KNBS, 2011), about 3,400 persons have been affected by the change. These people experience loss of lives, destruction of property, and outbreak of water borne diseases.The extent of Yala river flood flows has a significant impact in the basin requiring proper planning by government (National and County) and other agencies to mitigate the vise.

4 CONCLUSION

The extent of Yala river flood flows has a significant impact on the community in lower basin and future urban planning along beaches to develop resorts and tourist attractions. The mapped out flood extent change (34.23 km2) should therefore be planned for through appropriate flood intervention measures upstream of the Yala catchment to mitigate against potential urban development by Siaya county Government that is seeking increased investment in hotel industry to attract tourism. The Yala Basin is important environmentally and economically and acts as a buffer to Lake Victoria in terms of sediment loading into the lake. More attention should therefore be given to the monitoring of water discharges upstream to mitigate against the flood area extent that give indication on the deteriorating health status of the basin in terms of water management.

5 RECOMMENDATIONS

From the foregone discussion, the following recommendations to improve flood extent mapping for management of Yala flood flows are advanced:

i. The performance of the developed flood extent maps to be enhanced through intensified real time data collection to complement Satellite imagery. This will assist to increase the lead time between the initial sensing of flooding and the moment of impact.
ii. The scope of the study was limited to seeking to determine the flood extent in the Yala river basin for more focus. However, to optimize interventions aimed at reducing the risk to flooding including investments to enhance lead agencies interventions, the socio-economic contributions caused by Yala flood flow extent on the affected community should be investigated through similar extensive research.

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Paper No: 16
Page 169 - 175
Sub-theme: GIS in Agriculture

Assessing the impact of climate change on sugarcane productivity in Kibos – Miwani, Kenya

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Abstract:

Enhanced crop productivity is a global concern aimed at ensuring food security, to eradicate extreme hunger and poverty. Climatic characteristics that impact this productivity should therefore be investigated to negate effects that contribute negatively to a stable socio-economic environment. There is however, limited documentation on the impact of climate change on sugarcane productivity in Kenya. This study investigated the impact of rainfall and temperature characteristics on sugarcane productivity using 30 years weather and yield data collected for Kibos-Miwani sugar zone from field data and data archives at Sugar Research Institute. The global positioning system (GPS) was used to collect positions of rain gauges within Kibos-Miwani sugar zone. The weather data was documented from the existing datasets at each weather station and cross tabulated at the year scale to facilitate analysis with yield data that was provided at the same year scale. The data was then analyzed using mean correlation and regression analysis through statistical tools to establish cause effect relationship between rainfall and temperature characteristics on sugarcane yield to inform management recommendations for the study area. These results showed that rainfall distribution was significantly correlated with sugarcane yield ($r = 0.70$; $P = 0.001$).Temperature variations was equally significantly correlated ($r = -0.36$; $P = 0.027$) with sugarcane yield and this was attributed to deficiency in soil moisture during its maximum growth season. The study concluded that rainfall distribution through the growth season of sugarcane impacted its productivity hence; adaptation strategies such as planting season, maturity period and harvesting method would enhance sugarcane productivity in Kibos-Miwani sugar zone. This study recommended the use of irrigation, appropriate management practices that ensure soil moisture conservation, planting of early maturing varieties and timely harvesting as action practices for enhanced food security.

KEY WORDS: GIS, rainfall, temperature, productivity

1 INTRODUCTION

In recent time climate change has become a topical issue because of its largely detrimental impacts on natural and human systems. The most frequently cited activities or operations likely to be affected by climate variability and change are agriculture, forestry, hydrology and fisheries. Agriculture forestry and hydrology usually top the agenda of the most affected areas by the issue of climate change and variability (FAO,2010) because of its implication on livelihood.

Agriculture contributes heavily (over 50%) of the gross domestic product (GDP). Moreover, agriculture is the main source of livelihood in most developing countries yet, it is vulnerable to changes in climatic variables such as rainfall, temperature and radiation (Mendelsohn *et al.*, 2008).This is because despite technological advances made, climate and weather play a vital role in agricultural production (Villanueva and Hiraldo, 2011). Furthermore, production of agricultural product process such as food fibre, beverages energy, fishery and poultry will be greatly affected by climate change based on their response to extreme weather conditions. Suitability of land for different types of crop and pasture will also be affected by the increasing changes in weather variability. Due to increased variability in climate and weather there will be increased drought, aridibility and ground water depletion. This eventually affects agricultural productivity as well as occurrence of pests and diseases (Adamgbe and Ujoh, 2013). In the recent past, the potential of GIS to capture spatial variability in climatic variables and their impact on agriculture has been reported (Longley *et al.*, 2005). Studies have shown that GIS is used to produce suitability maps to inform kind of crops to be grown in designated agro-environmental conditions (Mulianga *et al.*, 2013).

Changes in temperature, rainfall, ultra violet (UV) radiation, and carbon dioxide (CO2) levels also have a major impact on agricultural production. Other climatic effects on agriculture are the shifts in seasonal climatic patterns and increase in frequency and intensity of weather extremes. It has also been noted that crop productivity can significantly be influenced by variability in rainfall and temperatures(Rowhani, Lobell *et al.*, 2011). Therefore, countries in sub-Saharan Africa like Kenya are at a greater risk because of predominantly being on rural economies and low levels of agricultural diversification (IFAD, 2010). Furthermore, most of them depend on rainfed agriculture and lack capacity in terms of political, social, technological and financial base to adapt to effects of climate change (Eriksen *et al.*, 2008). Current climatic trends, predictions and analysis studied using GIS technologies have shown that the most vulnerable groups to increased climate risks are small scale farmers in the tropical and subtropical areas (Change, 2007). This explains the reason why there has been decrease in production of main crops such as maize, sugarcane, wheat and rice while population continues to increase. Because of these we are likely to experience the risk of hunger, food insecurity and reliance on aid from developed counties.

In order to address these challenges there is need to be able to increase agricultural productivity. Sugarcane being the 3rd leading cash crop to tea and horticulture in Kenya requires best management practices to enhance its productivity. It is this economic contribution of sugarcane to Kenya that increases its importance in Africa and in the world (Lindell and Kroon, 2011).

Sugarcane is highly herbaceous, being a source of food for man and also fodder for feeding animals. Other researchers have described sugarcane as an important source of carbohydrate, phosphorous, calcium, iron, magnesium and potassium (Evans, 1959). Despite the many advantages that sugarcane and its bi-products have, its yield has continued to decline over the recent past (KSB, 2009). Low sugarcane yields in western part of Kenya have been attributed to factors such as pressure on land due to population growth and declining size of farm holdings, inability of the peasant farmers to access fertilizers, conservative attitudes towards extension services, and market forces that are disincentives (Board, 2009). Others include field operations, timing of planting, pests and diseases, soil and effects of climatic variables (Onyango, 2012). In their study, Cong and Brady (2012) found that among the climatic factors, rainfall, temperature and potential evaporation are the most critical in agricultural production.

Rainfall plays a major role in determination of crop yields in a tropical environment because it determines the supply of water to plants. Furthermore growth and production of crops can be limited by the same rainfall, as the crop is usually sensitive to moisture deficit. Furthermore, rainfall determines most growing season among the developing countries such as Kenya where agriculture is usually rainfed(Mulianga *et al.*, 2013). Usually every farmer is keen to know the amount of rainfall to expect as it determines the success and failure of their crops.

In Kibos - Miwani sugar cane growing zone there is a high variability in temperature and rainfall. From year to year and place to place the rainfall in this area has been characterized by evident variability (KESREF, 2010). In the recent years there has also been unpredictable delay of onset effective rainy season without delays in cessation. This has made it difficult for farmers who rely on the recommended planting seasons (Amolo *et al.*, 2010), usually causing them to plant with uncertainty any period the receive rainfall. Moreover this uncertain rainfall season is significant variable in its duration, sometimes stretching to two or three months. Based on soil type, delay in planting implies that the crop will be stressed before its root network is fully developed to extract deep soil moisture. The variability of this weather patterns and climate change has got serious consequences to the inhabitants as it seriously diminishes the effort that is being put in place by individuals and the government to ensure food supply and food security in the area. Up to date, no study has been undertaken to show the effect of climate change to sugarcane yield. It is against this backdrop that this study focuses on examining the variability in rainfall and temperature; to investigate their effect on sugarcane yield in Kibos Miwani, with a view to recommending appropriate adaptive management mechanisms to cope with the rainfall and temperature variability. In this study, GIS will be used to collect spatial location of weather stations and record information on rainfall and temperature over the study period.

2 MATERIALS AND METHODS

2.1 Study Area

The study covers Kibos-Miwani sugarcane zone in Kenya (Figure 1) within a space of 104 km2 and located between 34.8° E to 35.08° E and 0.01° S to 0.11° S. An altitude of 1000 m (in lowlands)-1800 m (in the escarpment) characterizes the topography, with rainfall of between 1400 mm and 1550 mm. The main crop in the zone is sugarcane, besides maize and horticultural crops. Different sugarcane varieties are planted in the months of April and September in accordance with the bimodal rainfall in February to June and September to December (Mulianga *et al.*, 2013; Shisanya *et al.*, 2012).It is the low rainfall with prolonged drought between November and April that provide an enabling environment to undertake this study.

The climate is sub-humid tropical with a seasonally bimodal rainfall distribution characteristic of African equatorial latitudes located near the inter-tropical convergence zone (ICRAF, 2003). The rainfall pattern shows no distinct dry season.

Peaks occur during the long rains (March - May) and short rains (October - December). The proximity to the highlands and nearness to the lakeshore causes a considerable spatial variation in rainfall. The annual monthly maximum temperatures

ranges from 29 to 31 ºC, while the annual monthly minimum temperatures range from 12 to 16 ºC (Onyango *et al.* 2005). Farming in this zone is dependent on rainfall and therefore all farming activities are influenced by climate hence crop production usually takes place during the rainy seasons.

2.2 Data and methods

2.2.1 Data

Time series rainfall data from six weather stations was collected from the local offices where rain gauges are installed. Further, time series temperature data was collected from two meteorological weather stations at Kibos and KARI. Yield data was collected from the Sugar Research Institute's data archives. Average annual rainfall was obtained by summing the daily rainfall amounts and dividing by the number of days. Average annual temperature was also obtained by summing the maximum temperature and the minimum temperature and dividing by 2. Yield in tonnes of cane per hectare (tch) data was obtained from 1976 – 2013 which gave a-37 point data points.

2.2.2 Methods

Positions for these weather stations were encoded using the global positioning systems (GPS) with an accuracy of 1 m. These datasets were then normalized through cross tabulation in statistical software at the year because the archived yield data was also provided at the year scale.

Time series plots were used to determine the trend for yield, rainfall and temperature over time. Karl Pearson's correlation analysis was then used to determine the presence and significance of relationship between yield and rainfall; and yield and temperature. Significance level was set at 95% Confidence Level (CL) and so the correlation coefficient was significant if it's associated P-value was equal or less than 0.05.

Significant correlation was further exposed to a linear regression analysis to determine the extent of the effect of rainfall and temperature on yield.

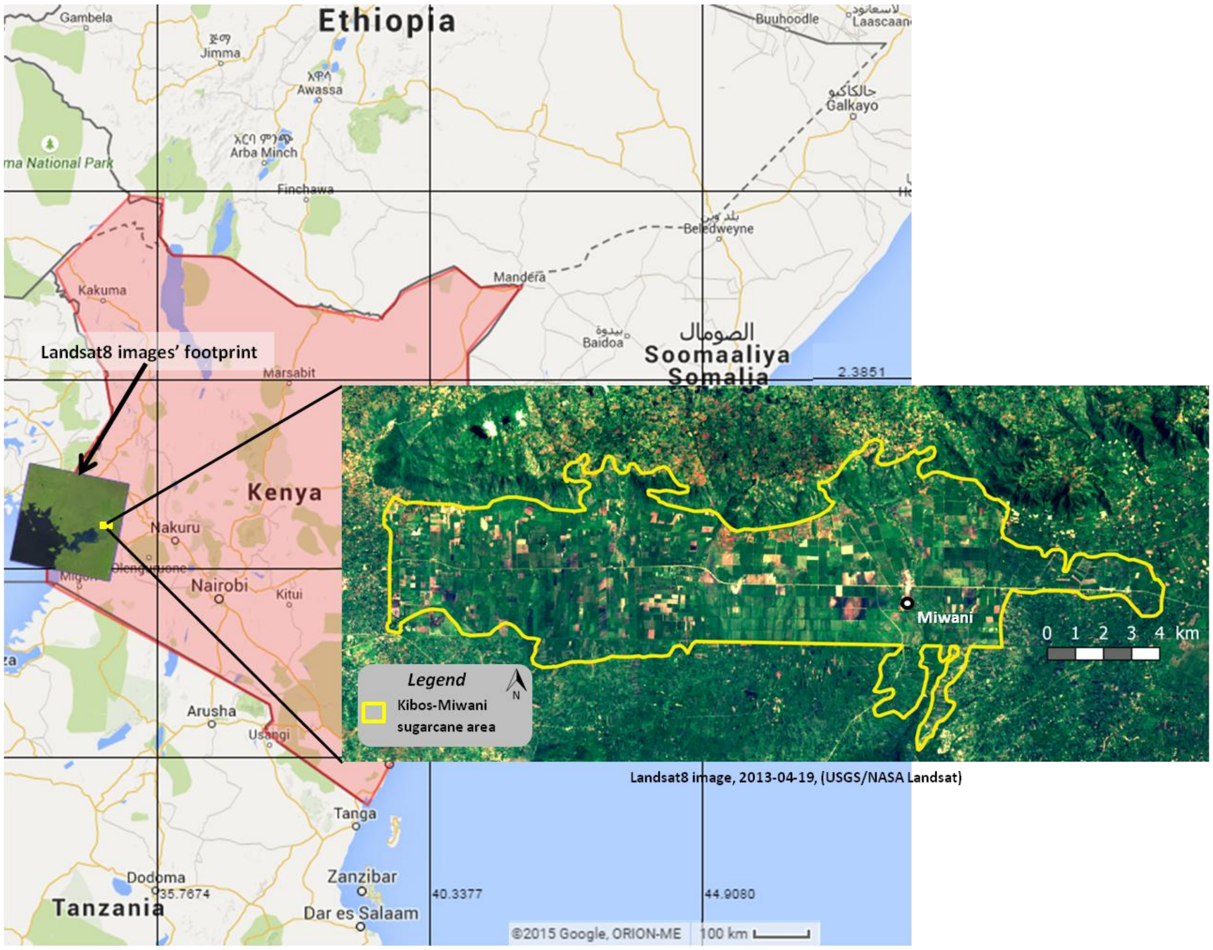

Figure 1: Location of Kibos-Miwani sugar zone (Data source: Kenya-GIS online Data, 2015).

The regression model followed the following shape:

$$Y = \beta 0 + \beta 1X1 + \beta 2X2$$

Where β_0= Intercept

$\beta_1$and β_2 = Regression coefficients estimates

X_1 = Average Annual Temperature

X_2 = Average Annual Rainfall

Y = Average Annual Yield

The significance level was set at 5% and therefore the regression coefficients would be significant when the associated p-values was less than or equal to 0.05.

Yield was regressed with both temperature and rainfall and also regressed with rainfall and temperature independently.

3 RESULTS AND DISCUSSION

The time series plot (Figure 2) illustrates a constant decrease in yield over time. These findings are similar to those of Mutonyi (2013), who attributed this decline to soil degradation and other environmental factors (Mulianga *et al.*, (2013); Shisanya *et al.*, (2010)).

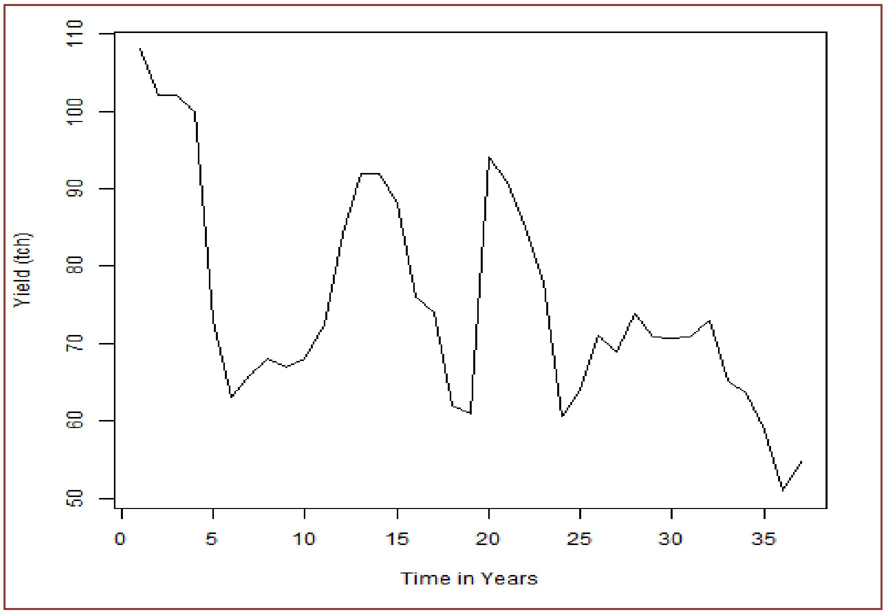

Figure 2: Yield trend from 1976 to 2013

3.1 *Correlation of yield, rainfall and temperature*

Results of Karl Pearson correlation test between rainfall, temperature and yield found that there was a significant negative correlation of r = - 0.36; P = 0.027 between yield and temperature at 95% confidence level. This shows that increase in temperature leads to decrease in yield due to water deficiency in the soil that limits the circulation of micro-organisms into the crop. There was also a significant correlation between yield and rainfall (r = 0.7, P=0.001) at this scale. In their study, Mulianga *et al.*, (2013) found significant correlation between rainfall and yield when yield and rainfall data were aggregated at the zonal scale (r = 0.80). Mulianga *et al.*, (2013) concluded that the significance of this correlation was due to consideration of the agro environmental conditions in the different agro ecological zones. In this study, the coefficient of determination R2 = 0.53 in the relationship between rainfall and yield suggests that there are unexplained factors such as time lag and sunshine hours that affect yield. This argument is supported by a different study which explained that rainfall was significantly correlated with biomass over a one month time lag (Shisanya *et al.*, 2010). Data on sunshine hours for the period under study was however not available to ascertain this effect on yield. Table 1 shows the correlation coefficients and their associated significance.

Table 1: Correlation coefficients for rainfall and temperature with yield at annual scale

	Yield(tch)	*Average Temperature*	*Average Rainfall*
Yield (tch)	1.000		
Average Temperature *Significance*	-0.3642** 0.0267	1.000	
Average Rainfall *Significance*	0.7045 0.0013	-0.2757 0.0987	1.000

An investigation on variations of rainfall and temperature over the period, from 1977 to 2013 showed that there was slight variation (2.1^{0}C) between the average rainfall and temperature (the minimum average annual temperature = 21.8^{0}C and maximum average annual temperature = 24.9^{0}C). The minimum annual average rainfall in the period was 2.7 and maximum annual average rainfall was 2.7mm and maximum annual average rainfall was 5.5mm.

Figures 3(i) and 3(ii) show the time series plots for the years 1977 to 2013.

A linear regression model was then fit to determine the effect of rainfall and temperature on yield over the period. It was found out that annual average temperature had a significant effect on yield at 95% CL, P= 0.04, R^2=0.54 with a regression coefficient of -7.768. The regression model is given below;

*Yield (tch) = 245.75+1.978*Rainfall – 7.768*Temperature*

Rainfall had a significant effect on yield at 95% CL, P=0.03, R^2=0.53 and a regression coefficient of 1.978.

We infer that the long dry months in Kibos (December to April) affect productivity of sugarcane negatively. This study recommends irrigation to supplement the water requirement of the crop at the critical stage of its growth to enhance food security. The over reliance on rainfed agriculture by farmers in the 21st century pose a threat on food security.

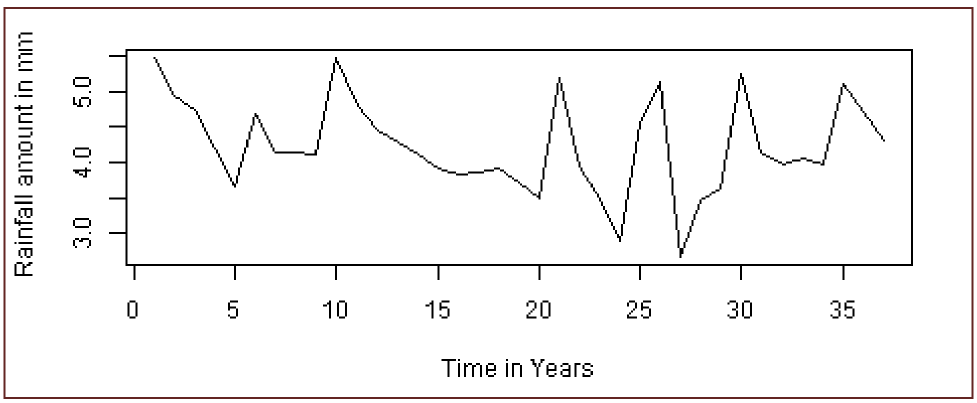

Figure 3 (i): Plots of average annual rainfall from 1977-2013

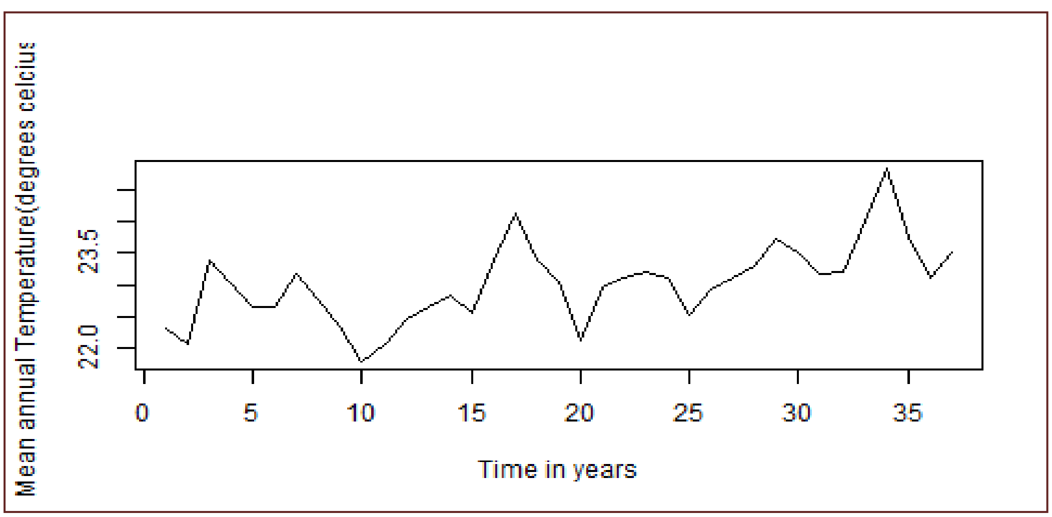

Figure 3 (ii): Time series plots of average annual temperature from 1977-2013

4 CONCLUSION AND RECCOMENDATION

The study has shown that there was a significant correlation between rainfall and yield at the seasonal scale. Moreover, there was great variability in annual average rainfall and yield. We concluded that when rainfall is normalized at the seasonal level, the effect of time lag and its impact on biomass is minimized. Further, temperature has an inverse effect on yield. The long dry months in Kibos (December - April) affect productivity of sugarcane negatively.

This study recommends irrigation to supplement the water requirement of the crop at the critical stage of its growth to enhance food security. Further, improved sugarcane varieties that require less consumptive use of moisture and have shorter growing period should be made available to farmers to counter the impact of temperature for enhanced productivity. A crop calendar should be put in place by the research Institute to guide farmers on when to plant so that the crop is ready for harvesting during the dry season to minimize stress on crop moisture requirement. The high significance in the yield versus rainfall at the zonal scale presents the need to educate farmers on the appropriate techniques that will ensure moisture availability that is crucial for sustainable sugarcane production.

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Sub-theme: GIS in Agriculture

Modelling Climate-based changes of sugarcane growing areas in Western Kenya

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Abstract:

Sugar cane *(Saccharum* spp. hybrids*)* is an important cash crop for Kenya's sugar industry contributing significantly to the country's economy through farming and employment. Its production in Kenya is both irrigation and weather dependent. In Western Kenya, it is a major economic activity heavily dependent by more than 50% of the population. To plan for sustainable development of the counties in western Kenya, it is important to understand how the anticipated climate change will influence this cash crop. This paper modeled the potential sugarcane growing areas of current and the year 2050 climatic periods. The sugarcane location data were extracted using fishnet from published materials while climate data was obtained from world climate database website. Data analysis and modeling was done using Maxent and DIVA-GIS softwares. The model generated an excellent Area Under Curve of 0.996 and more than 0.6 suitability level areas increased by 167.21% in 2050 climatic period. The main variables contributing more than 5% of change in suitability areas are Precipitation of Driest Period (42%), Precipitation of Coldest Quarter (28.8%), Isothermality (13.3%) and Precipitation of Wettest Quarter (8.1%). The generated information will guide the policy makers and stakeholders in making informed decisions with regard to the efforts of promotion of sugarcane production in western Kenya Counties.

KEY WORDS: Sugarcane, Maxent, DIVA-GIS, modeling

1 INTRODUCTION

Sugarcane *(Saccharum* spp. hybrids*)* is the driver of Kenya's sugar industry and is identified by Vision 2030 (GoK, 2007) which is largely confined in the western region. It has been cultivated in Kibos, Siaya County since 1902 and expanded to western Kenya region in the mid 1960s and early 1980s (Luckman, 1959). The Sugar Industry Strategic Plan of 2010-2014 (GoK, 2009) indicated that other factories constructed comprise Muhoroni (1966), Chemelil (1968), Mumias (1973), Nzoia (1978), and South Nyanza (1979), West Kenya (1981), Soin Sugar Factory (2006) and Kibos Sugar and Allied Industries (2007). In 2008, cane variety CO 945 occupied 35.72% of the total area under cane while Varieties CO 421, CO 617 and N14 occupied 28.4%, 13.29%, 10.95% of the total area respectively and Kenya Sugar Research Foundation developed four new cane varieties (KEN 82-062, KEN 82-472, EAK 73-335 and D8484) in 2007 Gok (2009).

Sugarcane growing in Kenya by 2008 covered an area of 1694.21 km^2 producing a total of 5,165,786 tons of sugarcane (Gok, 2009). The sugarcane growing areas are between 1300 – 1700 meters above sea level with a mean annual rainfall of 1200 – 1900 mm and an average temperature of 20^0C

(Jamoza, 2005). These climatic conditions are changing and are anticipated to change more in the future (IPCC, 2014). The predicted climate change in these regions shows an elevated annual average temperature and a decrease in rainfall amounts (KNMI, 2007) and spatial modelling will give insights into the resulting vegetation change.

A number of studies have been done on spatial species distribution modeling, using either one method or a comparison of different methods. Many studies conducted on climate change and its impacts on plant and animal communities have produced varied conclusions. KNMI (2006) used 12 models to investigate changes in precipitation using runs forced with Special Report Emission Scenario (SRES) A1B scenario. The research concluded that Kenya would experience elevated precipitation under global warming. KNMI (2007) indicated that there will be variations in climate observed in Kenya by the year 2100. The report contains different precipitation variations from different models and emission scenarios. In the north-western, northern and coastal regions an improvement in precipitation is projected in the year 2100 short rain events. Similar studies have been undertaken by CIAT (2011) who focused on climate change influence on tea growing areas in Kenya. This study observed that there will be a decrease in suitable tea growing areas in Kericho and Nandi regions and expansion of the same in Central Kenya regions by the years 2020 and 2050. Kigen *et al.* (2013) who studied climate change impact on the Grevy's zebra niche concluded that there will be a significant habitat expansion in the year 2080 climatic period. A study in South East Asia on the impacts of climate change on pine distribution using Maxent and DIVA GIS software concluded that the spatial distribution of pine will change with climate by the year 2050. The pine populations, especially in China, Cambodia and Thailand, are under threat (Zonneveld *et al.*, 2009) with potential new areas covering the Malay Archipelago. The Maxent and DIVA GIS software models the spatial suitability of selected crops, plants and animals based on a given criteria of controlling variables such as climate, soils and altitude. Maxent apart from selecting the suitable areas also allocates the suitability level ranging from 0 (unsuitable) – 1 (maximum suitability) while DIVA GIS functionality is primarily display and area calculation.

Many researchers (Pearson and Dawson, 2003; Chen, 2001; Christensen *et al.*, 2007 and Zonneveld *et al.*, 2009) recommended the use of Climate Envelope Modeling (CEM) in species distribution studies. Climate Envelope Modeling (CEM) and spatial analysis tools were used in estimating the current and 2050 sugarcane growing areas. The outputs of the model are maps showing sugarcane growing areas under different climates therefore providing new information to aid informed decision making. In view of the anticipated climatic variations, this paper modeled potential areas of growing sugarcane currently, and the projection for the year 2050 with an objective of identifying areas to grow this crop. The generated information is useful in determining how climate change will affect the suitability of sugarcane production thus influencing economic development decisions in Kenya's western counties.

2 METHODOLOGY

2.1 Data Sources and Processing

Data were sourced from different published materials. The sugarcane location data were sourced from Survey of Kenya (1985). From these spatial data, 169 geo-referenced points in decimal degrees were generated in the sugarcane growing areas to be used for modeling. The current and the year 2050 climate data with a resolution of 5 km were downloaded from Global Climate data website (www.worldclim.org). The future climate data is under CCM3 A2 carbon dioxide emission scenario and contain annual precipitation, and minimum and maximum temperature. Using DIVA-GIS, climate data was used to generate other sixteen climate variables all grouped as bioclim variables. The bioclim variables are coded as BIO1 = Annual mean temperature, BIO2 = Mean diurnal range (maximum temperature– minimum temperature) (monthly average), BIO3 = Isothermality (BIO1/BIO7) * 100, BIO4 = Temperature seasonality (Coefficient of variation), BIO5 = Max Temperature of warmest period, BIO6 = Min temperature of coldest period, BIO7 = Temperature annual range (BIO5 - BIO6), BIO8 = Mean temperature of wettest quarter, BIO9 = Mean temperature of driest quarter, BIO10 = Mean temperature of warmest quarter, BIO11 = mean temperature of coldest quarter, BIO12 = Annual precipitation, BIO13 =

Precipitation of wettest period, BIO14 = Precipitation of driest period, BIO15 = Precipitation seasonality(Coefficient of variation), BIO16 = Precipitation of wettest quarter, BIO17 = Precipitation of driest quarter, BIO18 = Precipitation of warmest quarter and BIO19 = Precipitation of coldest quarter.

2.2 Modeling the Current and Future Sugarcane Potential Growing Areas

Data required for modeling potential growing areas was prepared in excel and DIVA-GIS and model built in Maxent. The climate envelopes were then mapped and categorized as 0-0.2, 0.2-0.3, 0.3-0.5 and 0.5-0.7 and 0.7-1 suitability areas. The robustness of the developed model was validated using cross tabulation a method available in the Maxent software. The changes in suitability growing areas were sought and mapped using DIVA – GIS for the two climatic periods.

3 RESULTS AND DISCUSSION

All the 19 bioclim variables were used in the model with 67 of the location data used for training and 10061 used to determine the Maxent distribution (background points and presence points). Figure 1A is the omission rate and predicted area as a function of the cumulative threshold which is calculated on the training presence records and the test records. The closer the Omission on training samples line is to the Predicted omission, the more accurate the generated model. In work done by (Zonneveld *et al.*, 2009) the location data used for *Pinus kesiya* and *P. merkusii* were 46 and 50 respectively. Scheldeman *et al.*, (2010) in their research on the influence of presence points in a model concluded that after 50 species presence point, the prediction of potential distribution stabilized. Comparing modeling methods, regions and taxa, (Elith *et al.*, 2006) reported a general progression of performance (least to best performing) from BIOCLIM to DOMAIN and Maxent. Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC) curve (Figure 1B), is used to evaluate the predictive ability of the generated model. It measures the likelihood that a randomly selected presence point is located in a raster cell with a higher probability value for species occurrence than a randomly selected absence point.

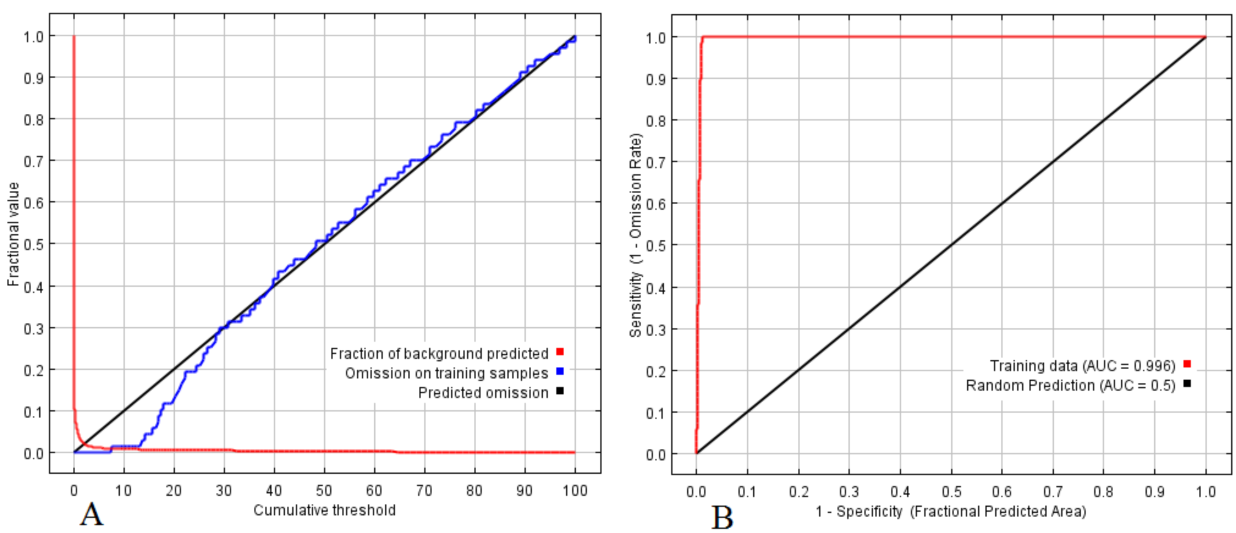

Figure 1: The omission and predicted area (A) and sensitivity vs specificity (B) for sugarcane

The generated model's AUC for training data was 0.996, an excellent model as per (Araújo *et al.*, 2005) guidelines, with a random prediction AUC of 0.5. Apart from Maxent being substantially superior to GARP (Genetic Algorithm for Rule-Set Prediction), (Phillips *et al.*, 2005) concluded that it also has a natural probabilistic interpretation and can be easily understood by non-experts. Their results showed that Maxent and GARP were significantly better than random prediction when tested for omission and ROC analysis. They further concluded that Maxent showed better discrimination of suitable and unsuitable areas of the species in the analysis of AUC.

3.1 Change of Variables with Climate

The bioclim variables were dissimilar in the two climatic periods under study with differing contribution levels. The bioclim variables contributions were highest at 43% with the lowest being four variables at 0.0%. The four variables contributing more than 8% to the model (Table 1) were BIO14 (43%), BIO19 (28.8%), BIO3 (13.3%) and BIO16 (8.1%). The values of the 67 location points used in the model were averaged for each variable and differences sought in each climatic period and presented in per cent change. Three of the variables are predicted to be reducing by between -11.74- -0.64% except BIO16 which increased by 1.58%.

Table 1: Change in the key environmental variables in current sugarcane location points contributing more than 8 % in sugarcane suitability growing areas

Variable code	Variable title	Percent contribution	Current values	2050 values	2050 % change
BIO14	Precipitation of driest period	43.0	50.10	44.22	-11.74
BIO19	Precipitation of coldest quarter	28.8	442.82	414.61	-6.37
BIO3	Isothermality	13.3	86.90	86.34	-0.64
BIO16	Precipitation of wettest quarter	8.1	648.40	658.62	1.58

Figure 2 is the response curves of the four bioclim variables. It shows how the environmental variable affects the Maxent prediction. They demonstrate the logistic prediction change as each environmental variable is varied, keeping all other environmental variables at their average sample value Phillips *et al.*, (2005). The BIO14 ranged from -10 – 100mm with an inverse logistic output of above 0.9 – 0. The variable BIO14 ranged from 37 - 67 mm in the current climatic period and predicted to be 32 – 62 mm in 2050 climate. The BIO19 logistic output peaked at 500 with a value of 0.65 in a range of -100 – 700. This variable in the current climate ranges from 349 – 525 mm and between 310 – 505mm in 2050 climate. BIO3 displayed a sharply increasing trend after 80mm and peaking at 90mm with a logistic output of 0.65. Its values range from 85.66 – 88.11 and 83.79 – 88.17 in the current and future climatic periods respectively. The precipitation of wettest quarter (BIO16) ranged from 0-1200mm with a maximum of 1200mm at a logistic output of about 0.68. The bioclim has values ranging from 561 – 705 in the current climate and 566 – 732 in the 2050 future climate.

3.2 Modeled Sugarcane Growing Suitability Areas

The modeled sugarcane growing areas in square kilometers of more than 0.2 suitability level were mapped (figure 3). In both climatic periods, the areas with more than 0.6 suitability levels are restricted within Kakamega and Bungoma counties. The current modeled areas of between 0.4 – 0.6 are largely found in Kakamega and Bungoma expanding to Busia and Vihiga in 2050 climatic period though the total area reduced. The suitability levels of 0.2-0.4 cover all the counties with a general expansion to new areas on the eastern part side of the western counties in 2050. These current modeled suitability areas are in agreement with information published by (Survey of Kenya 1985; Jamazo 2005; GoK 2009) as Kenya's sugarcane growing areas. The sugarcane suitable growing areas are predicted by the model to change in 2050 climate in different magnitudes with the highest being an expansion by 167.21% in the more than 0.6 suitability level.

Spatial modeling research have been done by (Zonneveld *et al.*, 2009; Kigen *et al.*, 2013) on the impacts of climate on pine and Grevy's zebra niche respectively. Others include CIAT (2011), working on the impacts of climate on tea and Pearson (2003), working on the impacts of climate change on the distribution of species. They all concluded that the climate variables are predicted to influence the species under study. The changes in areas under different suitability levels in the different climatic periods are summarized in table 2.

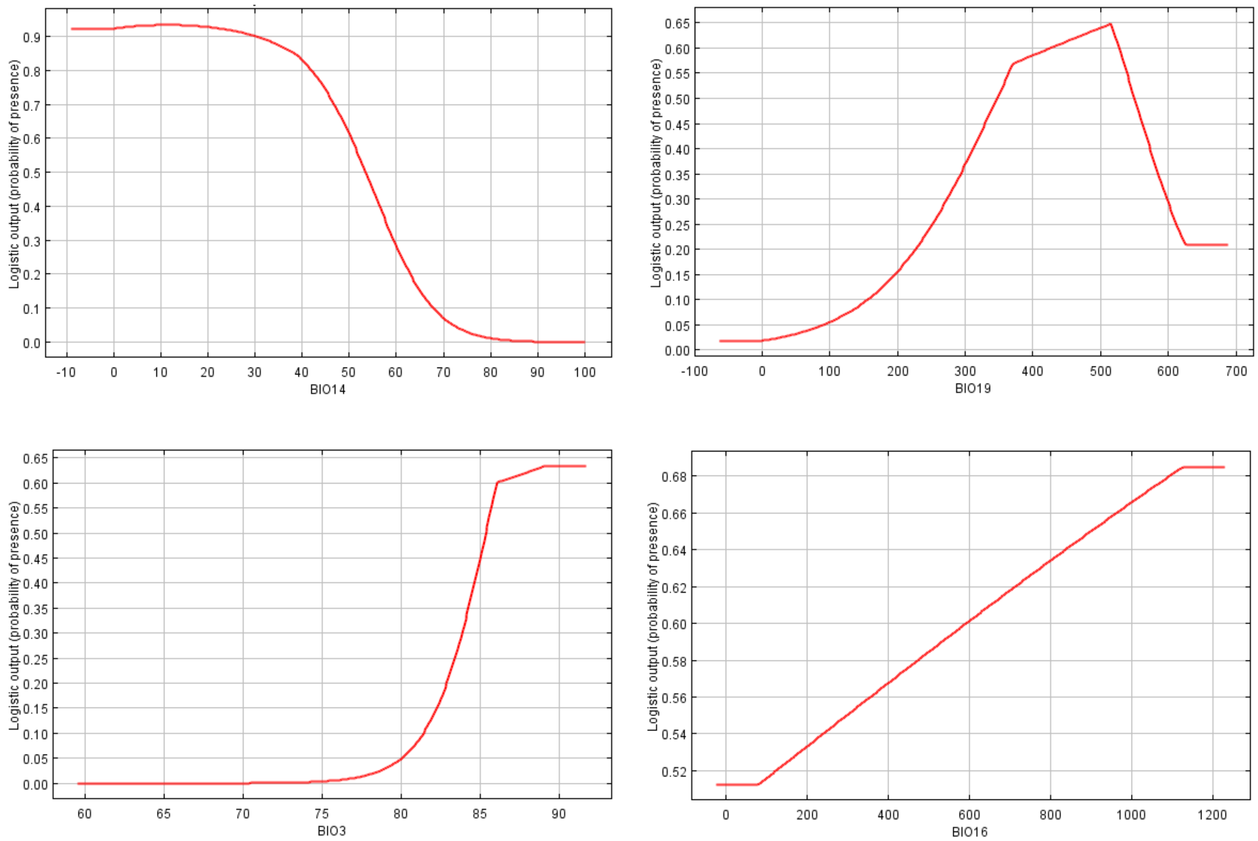

Figure 2: The logistic response curves of the bioclim variables on Maxent prediction

Table 2: Changes in sugarcane suitability growing areas (square kilometers)

Suitability level	2015 area (km^2)	2050 area (km^2)	Area (km) % change
0.2-0.4	2600	4075	56.73
0.4-0.6	2900	1800	-37.93
0.6-1	1525	4075	167.21

The percentage change of sugarcane growing areas for the future climatic period was calculated based on the current growing area. The 2050 climate will have an expansion effect of 56.73 and 167.21% in the 0.2-0.4 and 0.6-1 sugarcane growing suitability levels respectively. The 0.4-0.6 suitability level is predicted to reduce by -37.93% to cover an area of 1800 km^2 from 2900 km^2. Parry *et al.*, (2003) used models to estimate change in world percent cereal changes in different climatic periods. Their results showed that under SRES A2 emission scenario, percent cereal yield changes in Kenya range from 2.5 in 2020, -2.5 in 2050 and -30 in 2080.

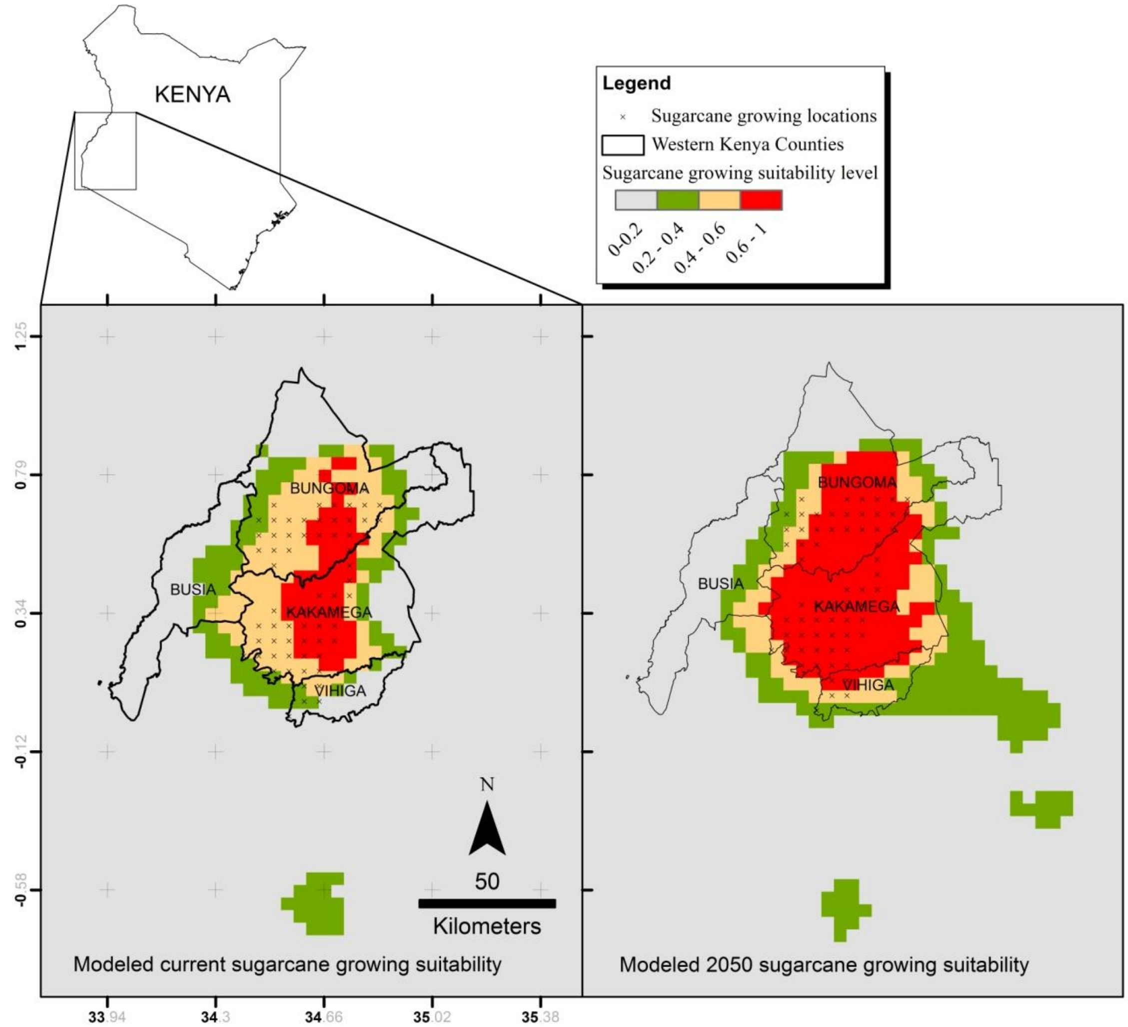

Figure 3: The modeled current and 2050 sugarcane potential growing areas in western Kenya

4 CONCLUSION AND RECOMMENDATIONS

The 2050 predicted climate will have a positive effect in western Kenya sugarcane growing areas. The information from the model is useful in the management of sugar industry in Kenya and the policy makers should take appropriate action. The study recommends inclusion of other factors controlling sugarcane growing and use of more refined bioclim data.

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Sub-theme: GIS in Agriculture

Integrating seasonal climate variability in sustainable agricultural planning of Lake Victoria Basin in Kenya

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Abstract:

Variability in agro-climatic parameters is increasingly a source of concern in the rainfed agricultural regions of the world. To a large extent, Kenya relies on rainfed agriculture for her food requirements. However, the agro-climatic characteristics within the Lake Victoria basin region of Kenya are quite variable. This study evaluated the variability of seasonal agro-climatic parameters in Lake Victoria basin region in order to understand how growing seasons influence sustainable agricultural planning. To evaluate these characteristics, analyses of the dry spells, reference evapotranspiration (ETo), rainfall characteristics (amount, onset, cessation and length) were done using H614 maize variety as the reference crop. Dry spells were analyzed using a daily rainfall threshold (DRT) of 5 mm, and dry spell trends interpolated in GIS. ETo was obtained using the ETo calculator while the rainfall characteristics were analyzed using the RAIN software package combined with descriptive methods. The results reveal that there exist variability in all agro-climatic parameters analyzed. It is shown that proper integration of agro-climatic variability into seasonal agricultural planning is needed for sustainable agricultural production. Re-introduction of indigenous crops will heavily depend on access to climate knowledge and proper dissemination of results, through technical advisory and extension services.

KEY WORDS: Agro-climatic parameters; sustainable agriculture; GIS; maize crop

1 INTRODUCTION

Although farmers continue to adapt their farming systems to both environmental and socio-economic change, yield levels are not increasing in step with population growth (Critchley, 2000; Mortimore and Adams, 2001). In the tropics intra-seasonal and inter-annual variability in climate, caused by prolonged dry spells, reduced rainfall amounts and natural shocks such as floods (Paeth and Hense, 2003; Usman *et al.*, 2005; Mishra *et al.*, 2008) still limit agricultural production. The effects of intra-annual rainfall distribution are well demonstrated (Sultan *et al.*, 2005). Crop suitability in any habitat is primarily determined by the distribution of climatic elements, soil characteristics, moisture availability, farm management, as well as socio-economic and catastrophic factors (Lobell and Burke, 2008).

In Kenya, the agro-climatic characteristics within the Lake Victoria basin region are quite variable. The erratic nature of rainfall distribution and amounts makes analysis of dependable rainfall important (Tesfay and Walker, 2004). Basing agricultural planning on the relationships between rainfall and reference evapotranspiration is more meaningful (Tilahun, 2006; Araya *et al.*, 2010) than using monthly and annual rainfall totals. To minimize risks, decadal data of effective rainfall are needed to study whether crop water requirements are optimally met at various stages of the crop. These concepts have extensively been studied (Dorenbos and Kassam, 1979, Raes *et al.*, 2006, Araya and Stroosnijder, 2011).

Most studies on the soil water availability to crops and analysis of dry spells have focused on dry land areas with little regard to rainfed agriculture regions (Geerts *et al.*, 2006; Rockstrom *et al.*, 2003; Rockstrom *et al.*, 2002). Given that climate change, differently affects crop production in different regions, a major challenge is to produce more food from less water by optimizing crop-water productivity (Kijne *et al.*, 2003). Short or long-term fluctuations in weather patterns, associated with climate change and variability (IPCC, 2001 a, b) reduce crop yields. In Kenya, adoption of agricultural innovations is sub-optimal, with irrigation rarely employed due to the high installation costs. Consequently, farmers elect to utilize available resources and operate within existing conditions to meet their domestic food requirements (Parry *et al.*, 2004; Maracchi *et al.*, 2005; Motha and Baier, 2005).

Theoretical and practical issues of different geostatistical techniques have been discussed in detail (Goovaerts *et al.*, 2000; Price *et al.*, 2000; Vicente-Serrano *et al.*, 2003; Lloyd, 2005; Geerts *et al.*, 2006). Spatial analysis uses statistical and mathematical functions of measured points to generate prediction and error or uncertainty surfaces. Several spatial interpolation techniques exist, although they differ in their assumptions, local or global perspective and deterministic or stochastic nature (Webster and Oliver, 2001; Hossein, *et al*, 2011). This study integrated variability of seasonal agro-climatic parameters in sustainable agricultural planning for Lake Victoria basin region.

2 MATERIALS AND METHODS

2.1 Study Area

The Lake Victoria basin in Kenya is classified into eight homogeneous zones based on seasonal climatic clusters (Figure 1). Daily records of meteorological and agro-meteorological parameters, spatially distributed based on homogeneous zones (Ogallo, 1980), were collected from sampled stations. The sampling design consisted of both simple random sampling (from all existing stations in each zone) and purposive sampling in order to meet the criteria for climatic analyses that required a minimum of 30 years of continuous data records.

2.2 Secondary Data Collection

Historical climatic data were obtained from Kenya Meteorological Department (KMD). For stations that collect most climatic parameters, the ETo calculator (FAO, 2009) was used to determine reference evapotranspiration (Allen *et al.*, 1998). The climatic parameters used included maximum and minimum temperature, sunshine hours, wind and mean temperature. It was observed that most stations lacked solar radiation data.

2.3 Intra-Seasonal Dry Spells

Reference evapotranspiration involved two analyses which included both the sensitive growth stages (germination and flowering) and monthly analyses for the Lake Victoria basin. The analyses targeted the maize growing seasons covering the period March to November using the available data. Analysis for germination and flowering stages was done at decadal (Mugalavai, 2013) time steps based on the region’s rainfall onset, focusing on the months of March and April (germination) and June and July (flowering). The monthly analyses captured all the phenological growth stages of the maize crop. Intraseasonal dry spells were also analyzed using rainfall.

2.4 Onset, Cessation and Length of the Growing Seasons

The actual onset, cessation and length of the growing seasons were generated using RAIN software (Kipkorir, 2005) RAIN is a software package designed to determine the onset, cessation and length of the growing season. It executes a frequency analysis of these three parameters, which are important variables in planning rainfed agriculture. The onset criterion of 40 mm in 4 days for the region (Mugalavai *et al.*, 2008) was employed to determine seasonal rainfall onset. Cessation was quantified by considering the date on which the water stress in the root zone of a maize crop exceeds a threshold value. The length of the growing season (days) for a particular season or year was taken as the difference between the Julian day numbers of the determined cessation date and the determined onset date for that season or year (Hulme, 1987).

2.5 Monthly Analysis of Reference Evapotranspiration

The reference evapotranspiration (ETo) was calculated using the ETo Calculator (FAO, 2009) and dekadal and monthly values were derived (Barron *et al*., 2003). The monthly rainfall was converted into the monthly effective rainfall-M_{eff} (Barron *et al*., 2003) and used together with the monthly reference evapotranspiration to generate monthly crop evapotranspirative demand statistics.

2.6 GIS Mapping

In this study, dry spell severity zones were mapped using ordinary kriging (OK) function in ArcGIS 10.0. OK uses a linear combination of weights at known points to estimate values at unknown points (Price *et al*., 2000). OK measures the spatial autocorrelation between points, such that weights change based on the spatial arrangement of samples (García-León, *et al.*, 2004; Ishida and Kawashima, 1992). OK was preferred for interpolating dry spells since it gave a lower standardized root mean square errors and was suitable for sparsely distributed sample points (Lloyd, 2005; Haberlandt, 2007).

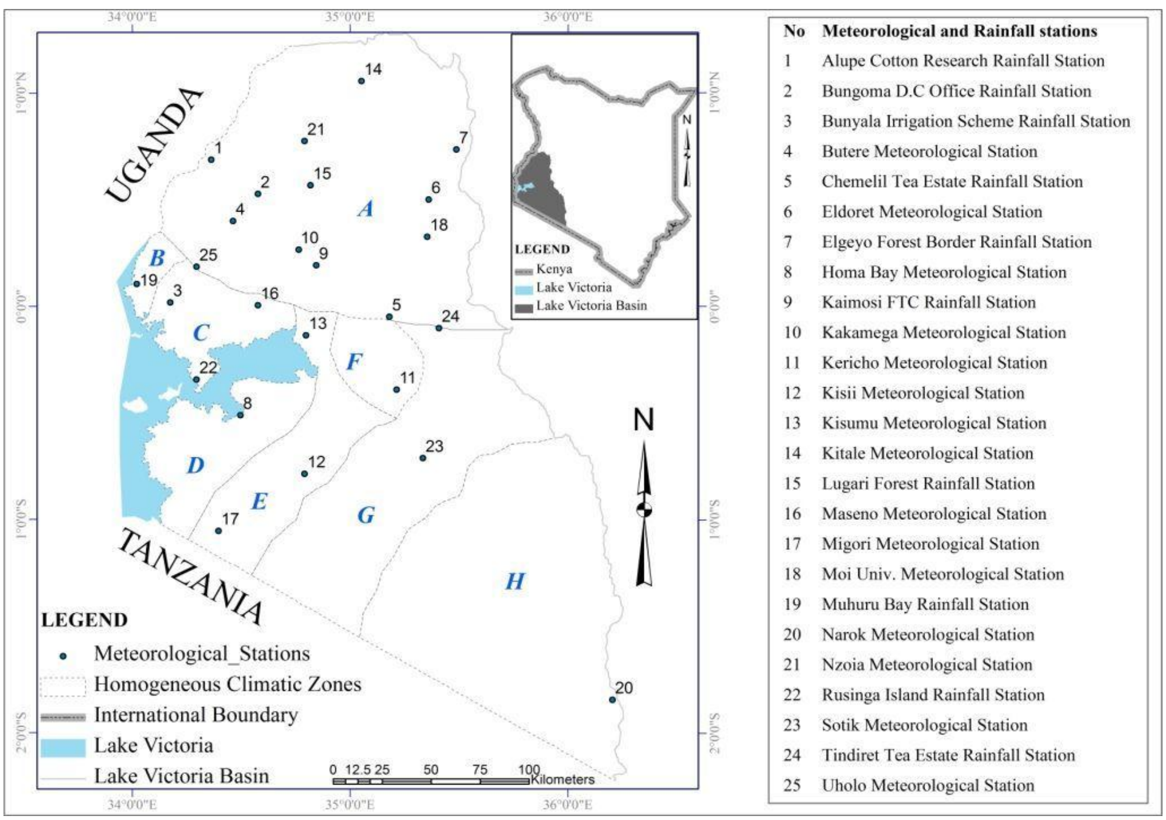


Figure 1: Location of study area showing homogeneous zones (Ogallo, 1980)

2.7 Integrating Climate Variability in Agricultural Planning

Integration entails understanding the characteristics of the agroclimatic parameters and their relationship(s) with the growing seasons, and tries to fit agricultural planning into the existing climatic conditions without much modification. It involved comparing the obtained agro-climatic parameters with the WMO established regional trends with the aim of incorporating these parameters into the agricultural practices. If adopted, this can reduce production costs and thus promote sustainability while increasing crop yield (Mugalavai and kipkorir, 2015). Integration also calls for enhanced research into high yielding varieties of crops that flourish under natural conditions.

3 RESULTS AND DISCUSSION

3.1 Monthly Analysis of Reference Evapotranspiration

The monthly reference evapotranspiration analyses for the western Kenya zone (Kakamega, Kisumu and Kisii) show lower variability during the flowering stage (June) compared to the dekadal analysis during the germination stage (Mugalavai, 2013). Uncertainties in the onset of the rainy season (March) require continuous monitoring of the dekads to establish the true onset (Mugalavai, 2008). Results reveal that the crop at the germination stage is more vulnerable to dry spells. Monthly analyses of reference evapotranspiration (Table 1 and Table 2) were vital in establishing the evapotranspirative demands for all the phenological stages (germination through grain filling).

Kakamega station is free from severe water stress between April and September (active maize growing season). Water stress occurs during the short rains season in October and November. Kisumu station is free from severe water stress in April. However, water stress occurs in March and from May through November. Kisii station is free from water stress for most of the year except during the months of June and July (Table 1 and Figure 2).

The monthly analysis of ETo indicates that during the germination period (March) dry spells occur in Kakamega and Kisumu, while Kisii was free from dry spells. Stations in western Kenya zones could employ different strategies to mitigate water shortages. During the flowering stage (June), Kakamega and Kisii stations were free from dry spells while Kisumu registered higher evapotranspirative demand levels compared to the effective rainfall (Figure 3).

These findings strengthen the need for supplemental irrigation requirement for Kisumu station and its environments. On the other hand, field management practices involving runoff water harvesting and conservation agriculture could be applied to mitigate dry spells in Kakamega and Kisii stations.

The monthly analysis for stations in the Rift Valley zone show that Kitale experiences water stress in March and from June to November (Table 2 and Figure 4). Kericho station is free from water stress for most of the year with dry spells occurring towards the end of the season in November. Eldoret and Moi University stations experience water stress between March and June (germination and vegetative stages) and from September to November (grain filling stage). The months of July and August (flowering stage) show low evapotranspirative demands. Narok station indicates high evapotranspirative demands throughout the period (March to November) considered (Table 2).

The germination stage for the Rift Valley zone indicates that Eldoret, Moi University and Narok have a higher evapotranspirative demand during the month of April (germination stage). The analysis however, shows that only Kericho station is free from water shortages (Figure 4). Kitale and Narok stations show a higher evapotranspirative demand during the flowering stage (July) while Kericho, Eldoret, and Moi University are free from water stress (Figure 5).

Table 1: Mean monthly rainfall and ETo statistics (Western Kenya zone)

Station	Month	M_{rain} (mm)	Mean monthly rainfall and ETo statistics				
			M_{eff} (mm)	ETo (mm/day)	M_{eff}/ETo	SD (mm)	CV (%)
Kakamega	March	172.0	129.0	145.6	0.9	88.1	0.7
	April	259.0	194.3	119.3	1.6	93.5	0.5
	May	255.5	191.6	108.8	1.8	75.0	0.4
	June	156.0	117.0	103.8	1.1	62.9	0.5
	July	157.8	118.4	107.3	1.1	72.3	0.6
	August	212.5	159.4	115.7	1.4	91.4	0.6
	September	177.8	133.4	122.4	1.1	71.4	0.5
	October	160.1	120.1	127.6	0.9	58.3	0.5
	November	152.7	114.5	117.7	1.0	76.4	0.7
Kisumu	March	138.5	103.9	157.1	0.7	61.7	0.6
	April	204.1	153.1	134.0	1.1	73.1	0.6
	May	157.9	118.4	125.3	0.9	54.3	0.6
	June	86.8	65.1	118.8	0.5	41.8	0.6
	July	72.9	54.7	125.9	0.4	49.5	0.6
	August	79.8	59.8	137.0	0.4	48.8	0.6
	September	84.6	63.5	141.9	0.4	46.8	0.6
	October	113.5	85.1	149.0	0.6	57.7	0.6
	November	148.0	111.0	134.0	0.8	88.5	0.6
Kisii	March	243.8	182.8	134.2	1.4	83.4	0.5
	April	276.6	207.4	111.1	1.9	79.0	0.4
	May	221.7	166.3	113.6	1.5	76.4	0.5
	June	141.6	106.2	109.5	1.0	63.6	0.6
	July	118.5	88.9	112.6	0.8	42.7	0.5
	August	175.1	131.3	114.3	1.1	45.0	0.3
	September	170.6	128.0	126.8	1.0	71.7	0.6
	October	193.7	145.3	123.5	1.2	53.0	0.4
	November	172.5	129.4	109.5	1.2	69.8	0.5

M_{eff} (mm): Monthly effective rainfall; ETo (mm/day): Monthly ETo; M_{eff}/ETo: Ratio of M_{eff} to ETo; SD (mm) Standard deviation; CV (%): Coefficient of variation

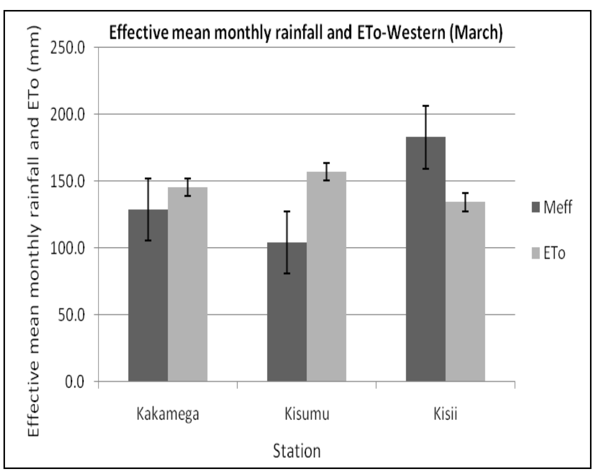


Figure 2: Effective mean monthly rainfall and ETo-Western March); error bars show standard deviation with standard error.

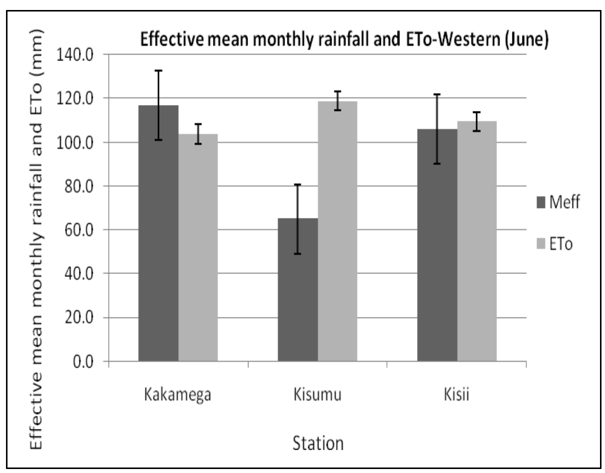


Figure 3: Effective mean monthly rainfall and ETo-Western (June); error bars show standard deviation with standard error.

Table 2: Mean monthly rainfall and ETo statistics (Rift Valley zone)

Station	Month	M_{rain}	Mean monthly rainfall and ETo statistics				
			M_{eff} (mm)	ETo (mm/day)	M_{eff}/ETo	SD (mm)	CV (%)
Kitale	March	76.3	57.2	137.1	0.4	51.2	0.9
	April	170.0	127.5	113.3	1.1	66.1	0.5
	May	148.7	111.5	111.0	1.0	81.5	0.7
	June	88.8	66.6	99.6	0.7	46.8	0.7
	July	110.0	82.5	101.3	0.8	58.7	0.7
	August	133.9	100.4	111.1	0.9	57.1	0.6
	September	96.5	72.3	115.3	0.6	66.0	0.9
	October	111.0	83.3	120.7	0.7	66.9	0.8
	November	87.8	65.8	112.7	0.6	58.2	0.9
Kericho	March	215.6	161.7	131.2	1.2	125.2	0.8
	April	282.2	211.6	104.4	2.0	86.2	0.4
	May	227.3	170.5	100.2	1.7	97.5	0.6
	June	166.0	124.5	96.0	1.3	64.4	0.5
	July	182.2	136.6	97.0	1.4	59.6	0.4
	August	204.5	153.4	103.1	1.5	84.6	0.6
	September	162.6	121.9	111.7	1.1	62.8	0.5
	October	158.5	118.9	113.7	1.0	70.9	0.6
	November	133.0	99.8	105.4	0.9	107.9	1.1
Eldoret	March	94.0	70.5	145.3	0.5	65.2	0.9
	April	159.6	119.7	121.2	1.0	76.8	0.6
	May	124.3	93.2	119.3	0.8	69.8	0.7
	June	114.0	85.5	107.0	0.8	57.6	0.7
	July	171.4	128.6	109.7	1.2	71.4	0.6
	August	170.1	127.6	112.0	1.1	78.3	0.6
	September	76.8	57.6	123.0	0.5	44.4	0.8
	October	83.4	62.5	129.0	0.5	74.2	1.2
	November	71.6	53.7	124.3	0.4	58.6	1.1
Moi Univ.	March	88.1	66.1	151.4	0.4	62.4	0.9
	April	159.0	119.3	128.5	0.9	74.8	0.6
	May	136.2	102.1	125.6	0.8	64.7	0.6
	June	122.9	92.2	112.8	0.8	52.0	0.6
	July	170.9	128.1	116.0	1.1	71.5	0.6
	August	177.3	133.0	121.8	1.1	69.0	0.5
	September	87.7	65.8	130.7	0.5	58.2	0.9
	October	84.8	63.6	135.6	0.5	60.6	1.0
	November	65.5	49.2	124.0	0.4	57.9	1.2
Narok	March	97.5	73.2	151.7	0.5	69.2	0.9
	April	149.5	112.2	123.4	0.9	87.1	0.8
	May	65.7	49.3	110.8	0.4	49.5	1.0
	June	21.8	16.3	99.0	0.2	24.4	1.5
	July	21.6	16.2	108.0	0.1	22.7	1.4
	August	26.8	20.1	119.0	0.2	24.4	1.2
	September	23.0	17.3	135.8	0.1	17.3	1.0
	October	27.5	20.6	148.4	0.1	22.0	1.1
	November	87.4	65.5	135.6	0.5	71.5	1.1

M_{eff} (mm): Monthly effective rainfall; ETo (mm/day): Monthly ETo; M_{eff}/ETo: Ratio of M_{eff} to ETo; SD (mm) Standard deviation; CV (%): Coefficient of variation

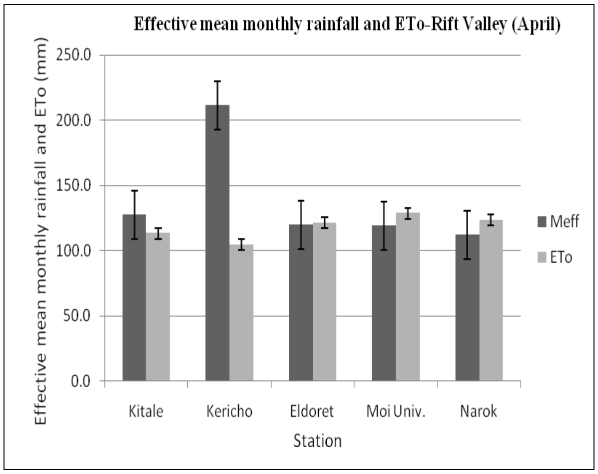


Figure 4: Effective mean monthly rainfall and ETo-Rift Valley (April); error bars show standard deviation with standard error.

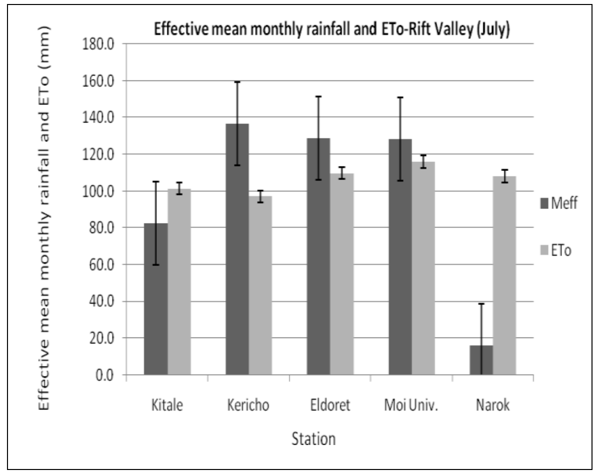


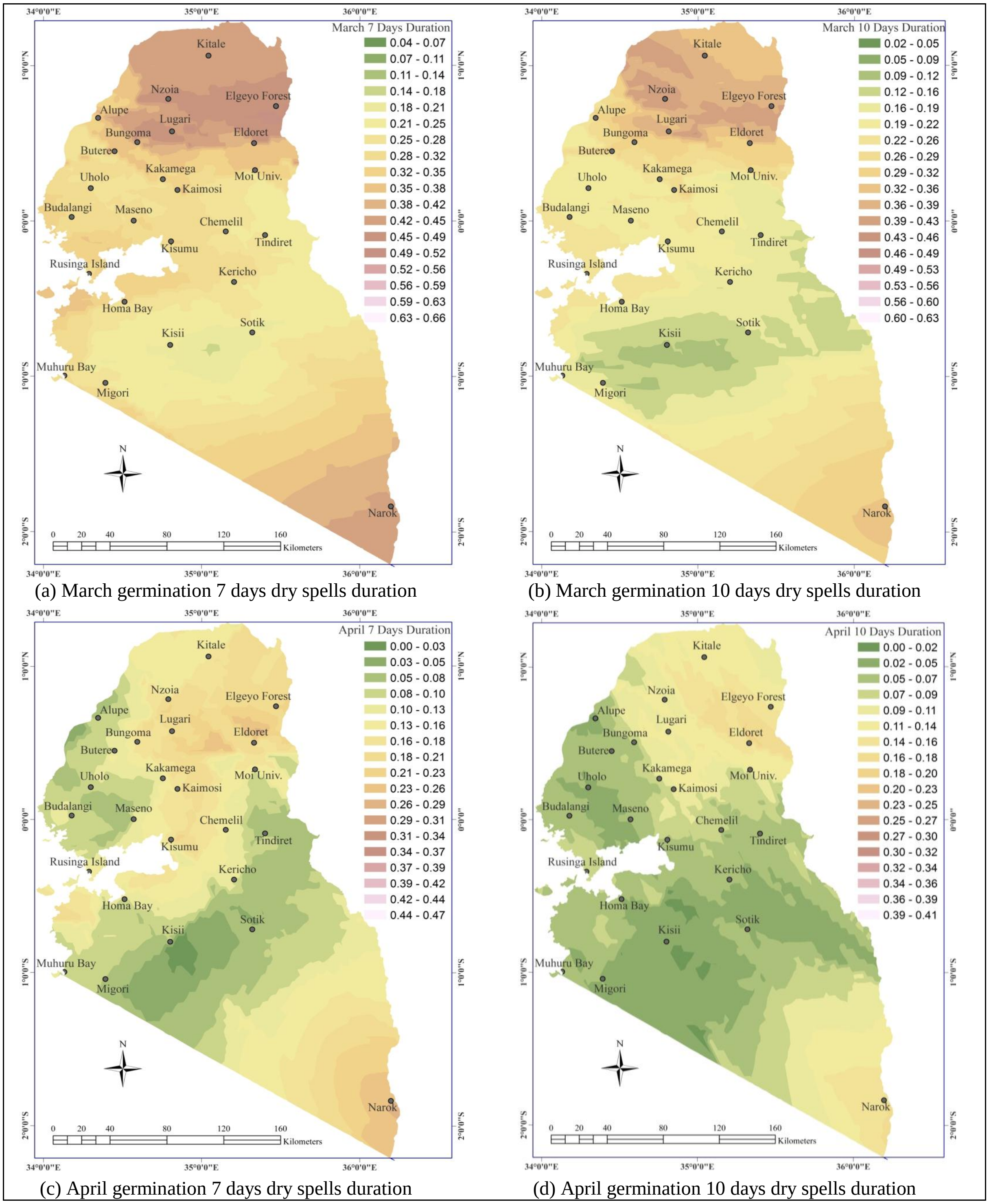
Figure 5: Effective mean monthly rainfall and ETo-Rift Valley (July); error bars show standard deviation with standard error.

3.2 Monthly Dry Spell Mapping

The monthly analysis results of dry spells were mapped to establish whether patterns exist for the region. Similar patterns (Figure 6*a* to 6*d*-germination and Figure 6*h* through 6*j*-flowering) to those of the dekadal analysis (Mugalavai, 2013) were observed at monthly intervals but with slightly lower probabilities of dry spells for the Rift Valley zone (March to July). The monthly analysis of dry spells confirms that the vegetative, flowering and grain filling stages in June, July and August, for Western Kenya zone, and in July, August, September and October for the Rift Valley zones, experience water stress requiring adaptation strategies or supplemental irrigation. Studies that have been done reveal that crop yield is severely affected by intra-seasonal dry spells (Araya and Stroosnijder, 2011; Barron *et al*., 2003; Segele and Lamb, 2005; Meze-Hausken, 2004). Understanding both temporal and spatial characteristics of dry spells is therefore important in agricultural planning. Spatial patterns (Figures 6*e*, 6*f*, 6*k*, 6*l*, 6*m*, 6*n* through *6r*) for the severity of dry spells are similar to those of the dekadal analysis. A similar approach of agro-climatic suitability mapping has been employed to identify zones with high vulnerability to dry spell conditions for use in both supplemental irrigation and other field management strategies (Geerts *et al.,* 2006).

3.3 Integrating Climate Variability in Agricultural Planning

The analyses of agro-climatic parameters in western Kenya zone depict seasonal variability in their characteristics. It is necessary to link crop characteristics with the agro-climatic conditions in different zones. Considering the most commonly grown crops such as maize, stations in western Kenya zone (Kisumu, Kakamega and Kisii) need to exploit short season varieties that mature in 105 days (Table 3). The amount of rainfall received within the season varies from 530 mm to 730 mm (Table 4), which approximates to the seasonal rainfall threshold of 750 mm (Allan, 1972) for maize crop.



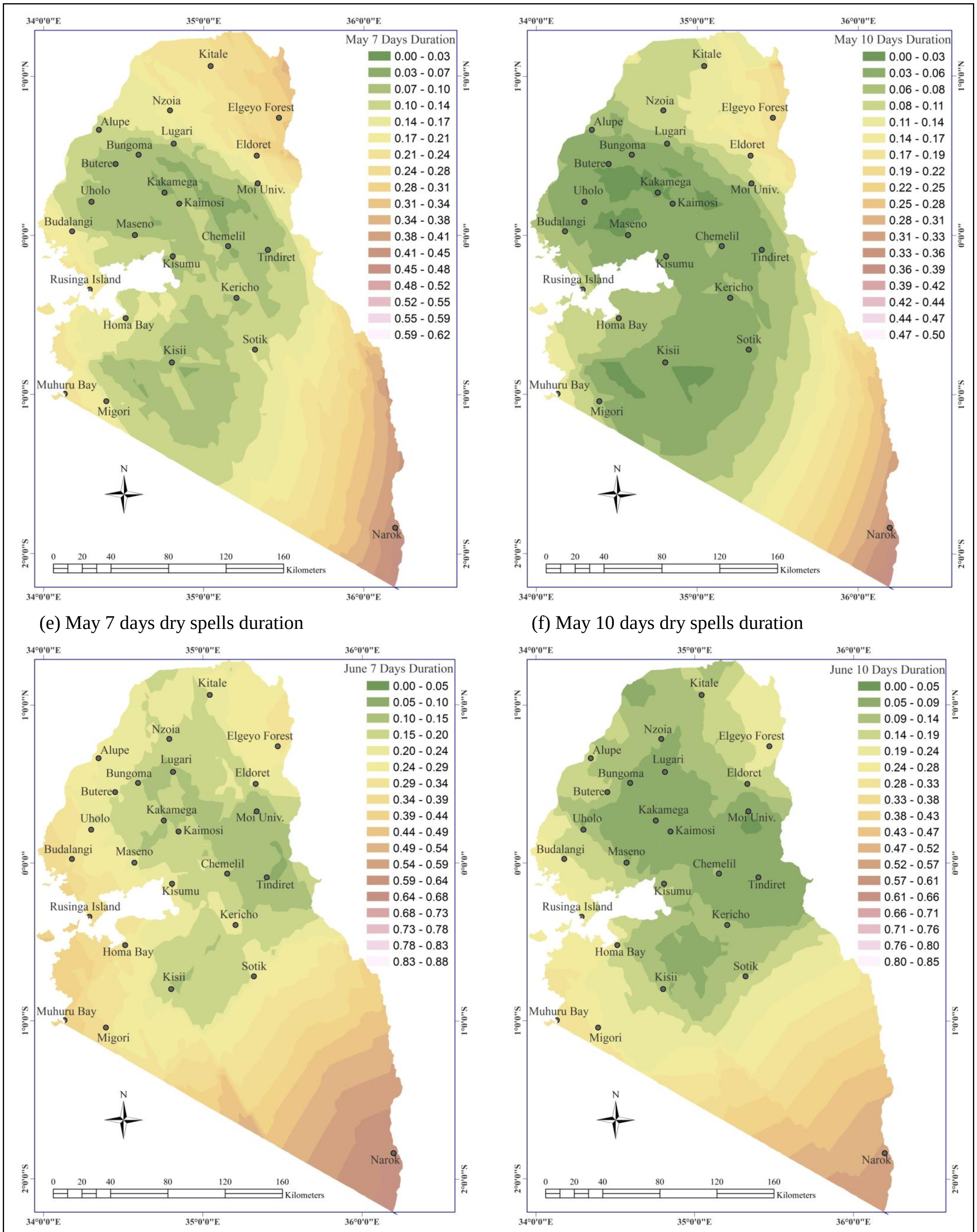
(a) March germination 7 days dry spells duration

(b) March germination 10 days dry spells duration

(c) April germination 7 days dry spells duration

(d) April germination 10 days dry spells duration

Figure 6:



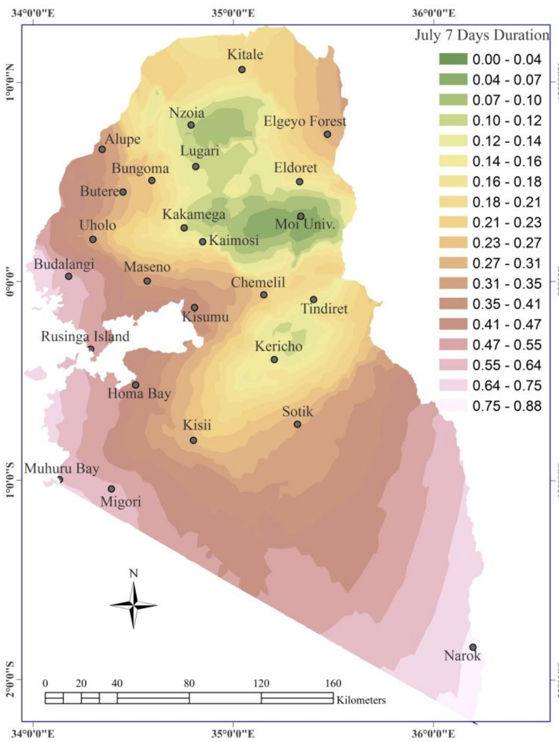
(e) May 7 days dry spells duration

(f) May 10 days dry spells duration

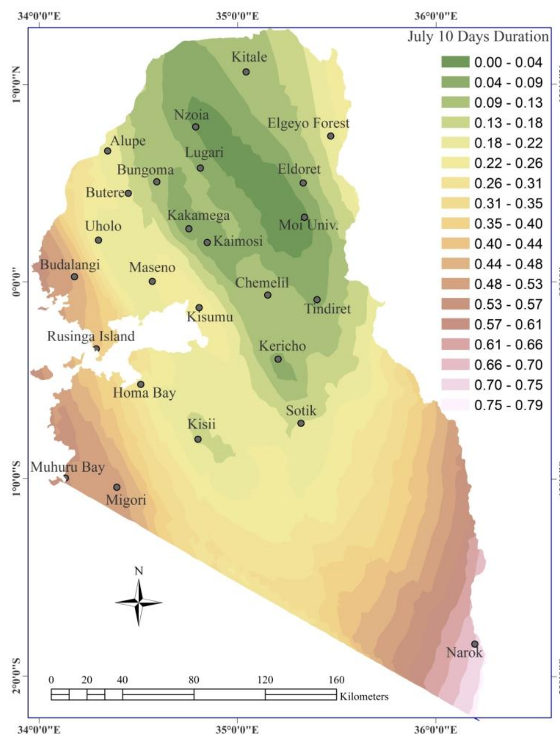
(g) Flowering stage June 7days dry spells duration

(h) Flowering stage June 10 days dry spells duration.

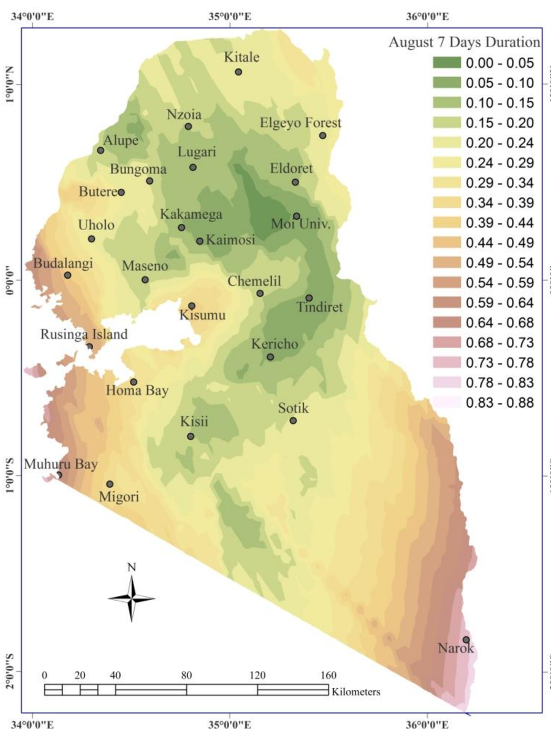
Figure 6: (Continued)



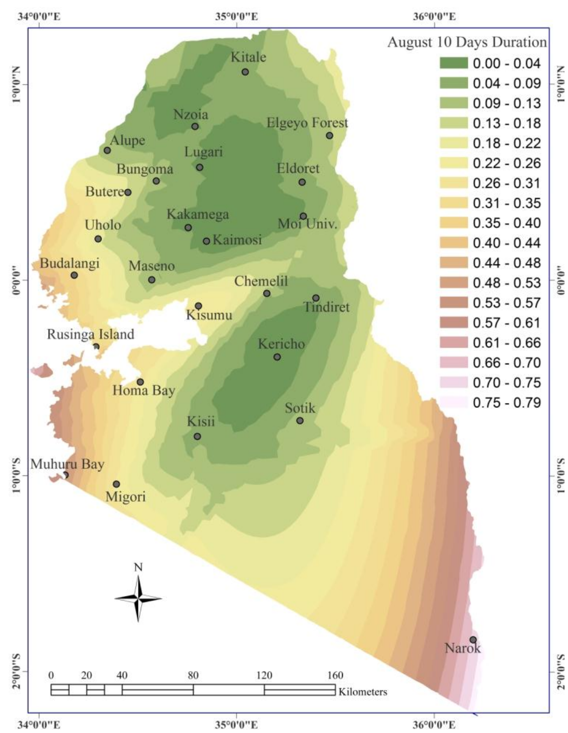
(i) Flowering stage July 7days dry spells duration



(j) Flowering stage July 10days dry spells duration

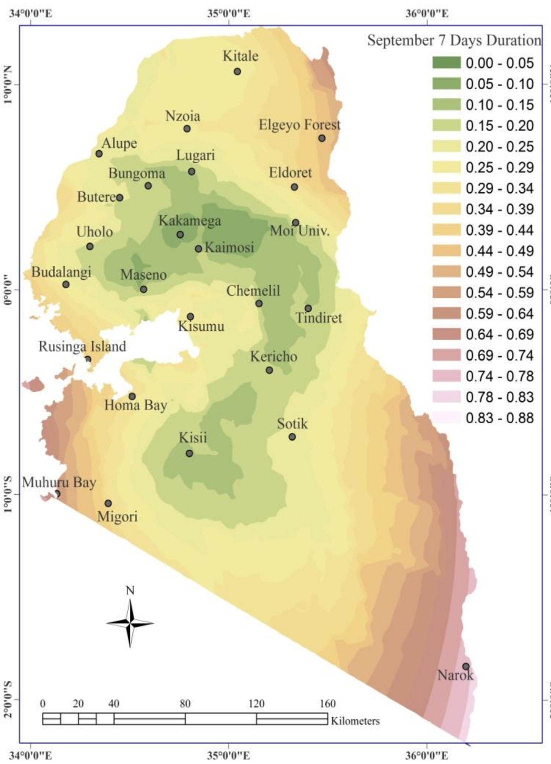


(k) August 7 days dry spells duration

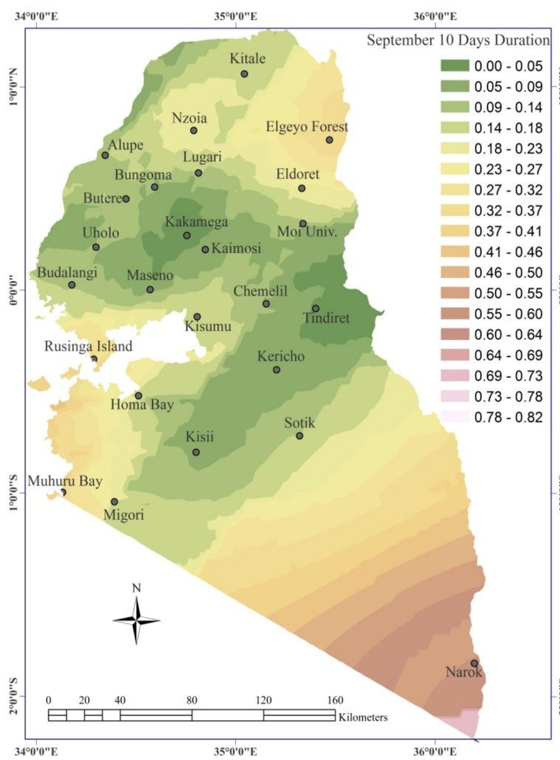


(l) August 10 days dry spells duration

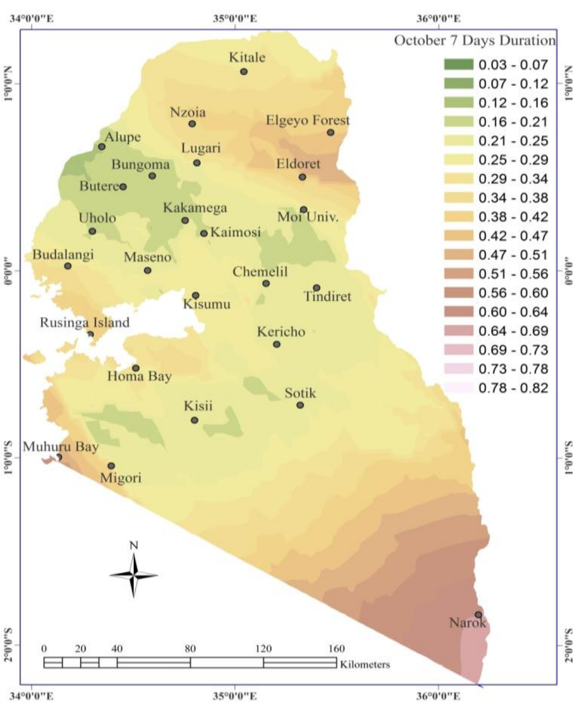
Figure 6: (Continued)



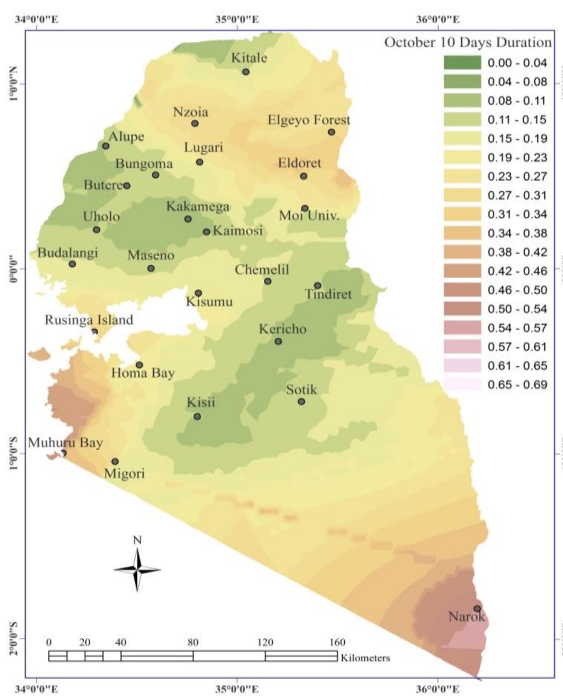
(m) September 7 days dry spells duration



(n) September 10 days dry spells duration.

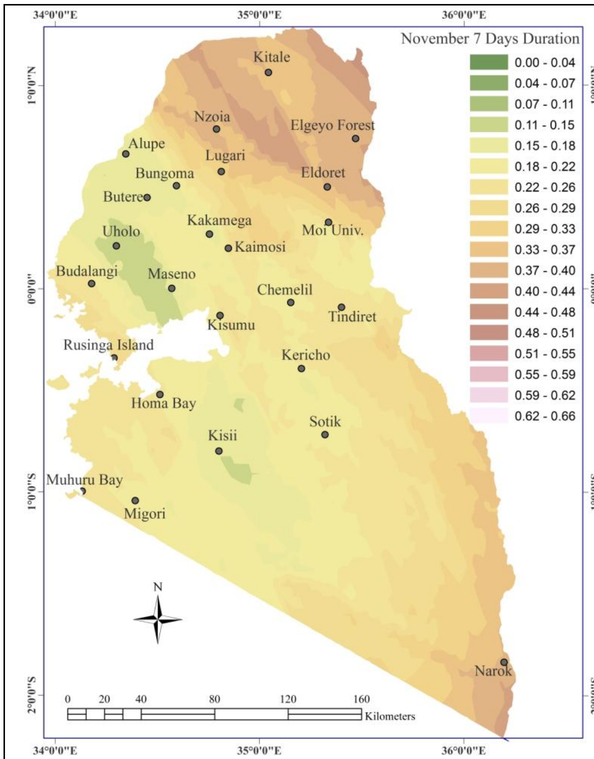


(o) October 7 days dry spells duration

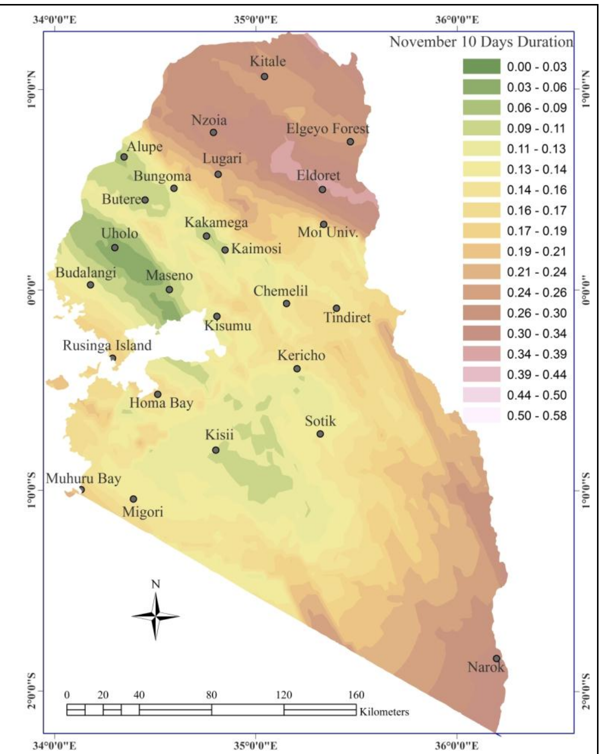


(p) October 10 days dry spells duration

Figure 6: (Continued)



(q) November 7 days dry spells duration



(r) November 10 days dry spells duration

Figure 6: (Continued)

Table 3: Lengths of crop development stages for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Cassava	20	40	90	60	210	Rainy season	Tropics
Sweet potato	15	30	50	30	125	Rainy season	Tropics
Soybeans	15	15	40	15	85	Dec	Tropics
Wheat	15	30	65	40	150	July	East Africa
Maize (grain)-Short season	20	25	40	20	105	March/July	East Africa
Maize (grain)-Long season	30	50	60	40	180	April	East Africa
Millet	20	30	55	35	140	April	East Africa
Soghum	20	35	45	30	140	Mar/April	Arid region

Source: FAO 56, Allen *et al.*, 1978 (Eds)

Stations in kakamega and Kisii can also exploit the short rains by planting indigenous crops such as millet and sorghum whose growing length averages 140 days. Stations found in the Rift Valley zone (Narok, Moi University, Eldoret, Kitale and Kericho) could make use of one long growing season due to the high altitude that promotes low temperatures and hence lowers the growth rate of the crops. The length of the growing season for these stations varies from 146 days to 191 days, thus these stations could grow long season maize crop varieties that take 180 days to mature. All these stations have the required threshold for the long season maize crop.

Table 4: Characteristics of agro-climatic parameters

Station	Season	Onset (Date)	Cessation (Date)	Season length (Days)	Rainfall amount (mm)
Kakamega	Short Rains	(26/7)	(23/11)	(117)	JJA (535.4)
	Long rains	21/3	26/6	103	MAM (676.4)
Kisii	Short Rains	(24/8)	(13/12)	(112)	JJA (465.1)
	Long rains	17/3	5/7	155	MAM (730.7)
Kisumu	Short Rains	(9/11)	(30/11)	(20)	JJA (215.1)
	Long rains	30/3	31/5	62	MAM (531.2)
Kitale	Short Rains	(19/10)	(28/11)	(45)	MAM (382.8)
	Long rains	5/4	30/9	162	Season (799.8)
Kericho	Short Rains	(11/8)	(2/12)	(116)	MAM (570.1)
	Long rains	19/3	12/6	191	Season (1296.2)
Eldoret	Short Rains	(15/10)	(21/11)	(41)	MAM (420.3)
	Long rains	13/4	1/6	161	Season (766.2)
Moi Univ.	Short Rains	(17/10)	(18/11)	(31)	MAM (471.1)
	Long rains	1/4	14/6	161	Season (854.4)
Narok	Short Rains	(-)	(-)	(-)	(-)
	Long rains	12/1	29/5	146	Season (394.1)

Kericho station exceeds the optimum length of the growing season. The rest require field management strategies to counter intra-seasonal dry spells and sustain the crop through the 20 to 40 days water deficits (Table 3 and Table 4). However, it is clear that with suitable crop varieties there is potential for growing other crops that can be accommodated within the length of the growing seasons in both zones such as sweet potatoes (125 days); soybeans (85 days); wheat (150 days) and cassava (210 days). The importance of understanding the agro-climatic conditions is paramount to agricultural planning in Kenya.

4 CONCLUSION AND RECOMMENDATIONS

The results for agro-climatic parameters analyzed reveal that there is variability in all the parameters including rainfall amount, onset, cessation, length and dry spells for the growing seasons. The results further indicate that despite the observed variability, agricultural production can be improved by integrating agro-climatic variability in agricultural planning. Enhancing crop production requires the choice of high yielding crop varieties that can thrive within the prevailing conditions. This may involve changing the types of crops grown in order to accommodate unpredictable climatic conditions.

Re-introduction of indigenous crops such as millet and sorghum that mature faster and easily adapt to the changing climate is a feasible option. Multiple cropping could also be employed as a strategy to ensure that at least some crops survive the harsh conditions. Research into high yielding varieties that mature faster is recommended for the region since the lengths of the growing season continues to shrink with time. Farmers need regular trainings through extension services to enlighten them on the changing climate and appropriate mitigation measures.

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