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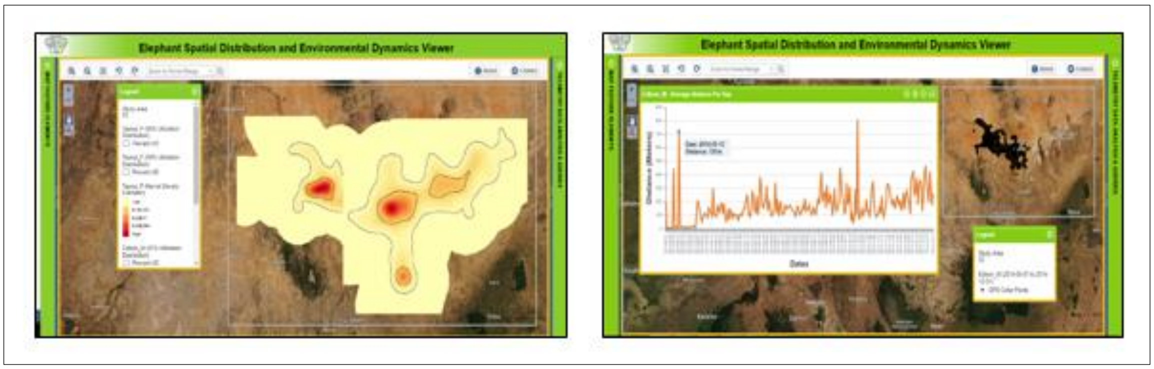
An open source web GIS tool for analysis and visualization of elephant GPS telemetry data, alongside environmental and anthropogenic variables



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Master Thesis, 30 credits, in Geographic Information Science

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Abstract

Elephants are among the most intriguing land-dwelling mammals, with the complex abilities to adapt and survive in different ecosystems and dynamic environment. Despite, their heavy food and water intakes, elephants poses an inherent capacity to cope through shifting their movement patterns to reduce competition with their conspecifics and other species including humans.

The movement and distribution of ecologically important herbivores such as elephants are of great significance to conservation biologist seeking to understand the fundamental triggers that influence their mobility and the extent to which these parameters affect how they utilize their immediate and surrounding resources. The recent advancement in animal tracking technology coupled with the availability of moderate to high-resolution satellite data, permits scientists to develop elephant cognitive maps of their adjacent environment, thus offering novel opportunities for research in the fields of wildlife movement ecology and the wider conservation biology.

This research study explored the use of an interactive web GIS application in mapping and visualization of elephant GPS telemetry data alongside other critical variables such a weather, environmental and anthropogenic factors - that are known to have a direct impact in determining presence/absence of elephants in a particular location. The web GIS approach allows for the automated processing, analysis, and visualization of Earth Observation data and the integration of the Elephant GPS Telemetry data, thus, permitting the end user to access, query, and visualize the time series datasets in a simple and intuitive graphical user interface.

This web GIS tool leveraged on the existing applications and modules such as: MODIS Reprojection Toolkit, ArcPy, and Python for automated preprocessing of the Earth Observation data; ArcGIS desktop and Movement Ecology Tool for developing customized elephant movement ecology products; PostgreSQL-PostGIS as the database server; Geoserver as the web GIS server and a host of other open source libraries such as HTML, ExtJS, GeoExt, OpenLayers and Python-CGI in the development of the web GIS application.

From the web GIS tool, we deduced that NDVI was the main biophysical factor that influenced the immediate movement and distribution of elephant, in comparison to other factors such as temperature and rainfall. The fragmented nature of ecosystem compounded with a high level of encroachment to protected areas also limited free movement of elephant within their home ranges. Female elephant spent more time in protected areas compared to their male counterpart in spite of their periodically visits' to high risk zones at some point in time, most likely in search of vital elements such as salt or clay licks. All the three elephants had their home ranges extending through low elevated areas. There was also evidence of close association between these elephants as a result of their overlapping home ranges and close proximities at various stages such as during the male perennial hyperactivity (musth) episodes which coincided with the wet period. All the three elephants also had their core ranges closely overlapping with the existing riparian zones.

Keywords: geography, GIS, wildlife, elephant, ecology, time-series, telemetry-data, web-GIS

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Lastly, I dedicate this work to my son Blessing Kabatha, "your charming smile and liveliness kept me going even when the tides were not on my side".

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Glossary

API – Application Programming Interface

CHIRPS – Climate Hazards group Infrared Precipitation with Station data

CRS – Coordinate Reference System

CSS – Cascading Style Sheet

CSV – Comma Separated Values

DBF – Data Base File format

DBMS – Database Management System

DEM – Digital Elevation Model

EO – Earth Observation

ESRI – Environmental System Research Institute

ETD – Elliptical Time Density Raster Grid

EXTJS - Extended JavaScript

FOSS – Free and Open Source Software's

FTP – File Transfer protocol

GCS – Geographic Coordinate System

GEO – Geography

GeoJSON – Geographic data format used for describing spatial features and their non-spatial attributes

GIS – Geographic Information System

GPS – Global Positioning System

GSM – Global System for Mobile Communications

GUI – Graphic User Interface

HEC – Human Wildlife Conflict

HDF – Hierarchical Data Format

HTML – Hypertext Markup Language

ICT – Information Communication and Technology

ID – Identifier

IT – Information Technology

Java – A general purpose programming language that is procedural, class-based and object-oriented

JPEG – Joint Photographic Experts Group

JSON – JavaScript Object Notation

JS – JavaScript; a programming language for the web

KDE – Kernel Density Estimator Raster Grid

KWS – Kenya Wildlife Services

LST – Land Surface Temperature

MET – Movement Ecology Tool

MM – Millimeters

MODIS - Moderate Resolution Imaging Spectrometer

MRT – MODIS Reprojection Tool

MVC – Model View Controller

MVVM – Model View View Model

NASA – National Aeronautics and Space Administration

NDVI - Normalized Difference Vegetation Index

OGC – Open Geospatial Consortium

OL – OpenLayers

OSGEO – Open Source Geospatial Foundation

PDF – Portable Document Format

PHP – Hypertext Preprocessor

PL – Procedural Programming

QGIS – Free and open source system GIS desktop application

RAM – Random Access Memory

RDBMS – Relational Database Management System

SASS – Syntactically Awesome Stylesheets

SD – Standard Deviation

SDK – Software Development Kit

SLD – Styled Layer Descriptor

Source Code – A specialized language used for the development of computer programs and applications

SRID – Spatial Reference Identifier

SRTM – Shuttle Radar Topography Mission

ST – Spatial Type

STE – Save the Elephants

SQL – Structured Query Language

Terra – A multi-national NASA scientific research satellite in a sun-synchronous orbit around the Earth

TIFF – Tagged Image File Format

URL – Uniform Resource Locator

USGS – United States Geological Survey

UTM – Universal Transverse Mercator

WCS – Web Catalog Service

WFS – Web Feature Service

WGS – World Geodetic System

WMS – Web Map Service

XML – Extensible Markup Language

1.0 Introduction

Understanding the movement and distribution of animals is key to the formulation of sound ecological plans and conservation policies (Pinand, 2008). Studying animal mobility and how the existing environmental factors - influence - animal behavioral responses are not only important to theoretical and applied animal movement ecology (Boettiger et al. 2011) but also applicable in predicting the eventual spatial population distribution of animals within their defined ecosystem (Turchin 1991, Lima & Zollner 1996).

The distribution of most ungulates and elephants, in particular, is influenced by both biotic and abiotic factors (Ngene et al. 2009). Biophysical factors such as rainfall variabilities, vegetation quality and quantity, salt licks, and landscape terrain have a significant influence in determining elephant's movement in space and time (Tchamba et al. 1995; Blom et al. 2005; Wall et al. 2006) while anthropogenic factors such as settlements, road network, fence lines, croplands among others limit elephant's ranges or restricts their known migratory corridors (Newmark, 1996).

Biophysical aspects such as the presence of water resources and quality forage patches are directly influenced by weather patterns such as precipitation and temperatures (Scholes et al. 2003). For instance, in Africa Savannah ecosystems, seasonal variations in rainfall determines forage availability (Owen-Smith et al. 2010) and consequently, animals alter their movement patterns with respect to these dynamic environmental conditions (Fryxell et al. 2008).

These shifts in movement patterns pose a challenge to conservationist seeking to understand the complex association between environmental factors and elephant's mobility (Douglas-Hamilton et al. 2005). It's important to understand why animals move to a certain place at and for a given period of time (Wittemyer et al. 2008; Beyer et al. 2010; Morales et al. 2010). This allows scientists to develop models that can estimate their home ranges (Moorcroft et al. 2006; Smouse et al. 2010), understand their cognitive abilities with respect to mobility (Gautestad & Mysterud 2006; Wolf et al. 2009) and assess the relationship between animal movement and ideal habitats (Rhodes et al. 2005; Johnson et al. 2008). Decision-makers may, therefore, be informed by defining the time periods when these animal species are most likely to change their movement patterns (Birkett et al. 2012), thus enabling them to develop and implement the most appropriate conservation strategies and plans (Douglas-Hamilton et al. 2005).

The recent advancement of animal mounted, satellite-linked GPS collars have enhanced our knowledge and understanding of elephant's movement behaviors as a factor of both biotic and abiotic components (Galanti et al. 2000, Nathan et al. 2008, Hebblewhite et al. 2010). The GPS collars are used to accurately locate the definite positions of elephants at any given time and location (Wall et al. 2014). However, GPS based data lacks information on the surrounding resources or the probable activities being undertaken by the animal at a particular time and place (Cagnacci et al. 2009).

Therefore, it’s important to integrate the GPS fixes with data on environmental resources and behaviors either obtained from bio-sensors (Cooke et al. 2004; Rutz & Hays 2009) or from accurate remote sensing datasets of weather and environmental variables (Hebblewhite & Haydon 2010; Urbano et al. 2010)

Using GIS technologies, the high spatial-temporal resolution GPS collaring data of individual elephant are overlaid/mashed up with the existing environmental data and further analyzed to determine the main aspects influencing elephant’s movement and distribution in a given ecosystem (Douglas-Hamilton et al 2005, Ngene et al. 2009).

This research explores the possibilities of using innovative web GIS in enhancing the management and conservation of elephants through the development of a spatial web application tool that compares and relate key weather, environmental and anthropogenic data with the elephant’s collaring GPS telemetry data. This system will not only enable the visualization of elephant’s movements with respect to environmental and weather patterns but also incorporate anthropogenic data, whose eventual impact on elephant’s movement and migratory patterns are of great significance (Blanc et al. 2008).

Emphasis will be placed on the mapping and visualization of the ingested time series datasets, making visual analysis between the time series datasets and the existing physical features while taking advantage of latest advancements in open source web GIS technologies to design and develop a simple and efficient web client application interface.

1.2 Objectives

The main objectives of this study was to assess individual elephant movement and distribution with respect to weather, environmental and anthropogenic factors using the open source web GIS tool/application.

To achieve this, the following specific objectives were undertaken:

- Developed an open source web GIS tool/application with features necessary for mapping and visualization of feature layers, elephant GPS telemetry data, and Earth Observation data.
- To run basic analysis and comparison on elephant movement and distribution using the open source web GIS tool/application.

2.0 Background

2.1 Factors that Affect Elephant Movement and Distribution

The key factors that influence the distribution and movement of elephants are landscape type, rainfall-related changes in food quality and water availability, elephant's density and social structures, and the presence of human settlements (Graham et al. 2009).

These factors can broadly be classified as either biophysical or anthropogenic factor (Kyale et al. 2011). Biophysical factors comprises of naturally occurring factors such as rain-fed vegetation (Cordon et al. 2006; Kinahan et al. 2007), natural water points and water sources (De Boer et al. 2000; Harris et al. 2008) and the landscape topography (Wall et al. 2006; Ngene et al. 2009; Ngene et al. 2010).

On the other hand, anthropogenic factors consist of human direct and indirect influences (Harris et al. 2008) such as settlement and infrastructural development, large and small-scale farming, charcoal burning, fuelwood collection, mining, overgrazing, construction of artificial fence lines, poaching, habitat destruction etc. (Harris et al. 2008, Ngene et al. 2010).

It's well proven that in Savannah ecosystems, elephant's movement is predominantly influenced by seasonal changes in rainfall (Cushman et al. 2005; Van Aarde & Jackson, 2008; Young et al. 2009) and temperature (Scholes et al. 2003). These abiotic factors affect the net primary productivity of savannah biomes (Prins & Loth, 1988) and herbivores respond to these dynamic weather conditions by altering and shifting their movement patterns over time (Fryxell et al. 2008).

Both male and female elephants seem to exhibit different behavioral responses to seasonal rainfall variations with prime changes occurring at two transitional periods: at the end of the dry season and at the end of the wet season (Birkett et al. 2012). During dry periods lactating females reduce their movements in order to save energy and to safeguard their calves from malnutrition due to decreased forage quality and quantity (Birkett et al. 2012). In semi-arid savannah's, dry season rainfall variations have a significant impact on elephant's population (Ogutu & Owen-Smith, 2003) with high dry seasonal rainfall closely correlating with high elephant densities in a particular area (Valeix et al. 2007).

In Northern Kenya and Namibia, elephants range increases when water sources are more abundant than during dry spells when most herds restrict themselves to near water points (De Leeuw et al. 2001, Leggett et al. 2006). Elephants make use of different habitats within their ranges during the wet season (Western & Lindsay, 1984; Verlinden & Gavorv, 1998).

However, during dry periods, elephants limit their foraging ranges within key water points (Osborn & Parker, 2003; De Beer et al. 2006), thus they tend to seek nutritious vegetation's growing in close proximity to the available water sources (Harris et al. 2008). This phenomenon has been clearly demonstrated in Hwange National Park in Zimbabwe during the dry seasons, where elephant's densities escalate near water holes with profound exceptions to areas with low vegetation productivity and water quantities. These densities seem to be well distributed across active waterholes within the Hwange National Park (Chamaille-James et al. 2007).

Therefore, environments such as riparian and wetland ecosystems support larger elephant herds (Harris et al. 2008) in comparison to others, while steep slopes and rugged terrains are avoided due to high energy requirements for elephant's mobility due to their higher body weights (Wall et al. 2006).

In savannah environment, rainfall is a key driver of primary productivity (Coe et al. 1976) and the NDVI is considered as an important measure of primary productivity (Pettorelli et al. 2005). Duffy and Pettorelli (2012) research on savannah elephants' revealed a linear relationship between long-term NDVI and elephant's densities among most of the considered populations. A close correlation exists between NDVI and primary productivity (Running, 1990; Turner et al. 2003) as previously demonstrated by Pettorelli (2011); where NDVI has been used as a predictive index of analyzing the impacts of climate change on the population's densities and distribution of large herbivores within Savannah ecosystems.

Furthermore, female elephants seemed to synchronize their conception with seasonal variations in weather so as to coincide their parturition with probable episodes of high primary productivities (Wittemyer et al. 2007b). These unique inherent abilities to match their reproductive patterns with periods of increased environmental productivity enhances their breeding success and in general improves the overall juvenile survivorship rates (Pianka, 1976; Kennish, 1997), as also observed in other vertebrate species such as some specific groups of fish and reptiles (Madsen & Shine 2000; Rubenstein & Wikelski 2003).

Elephant conservation and management are most challenging in regions where they co-exist with human populations (Van Aarde & Jackson, 2007; Kumar et al. 2011). For instance, in Kenya, a large number of elephant populations occurs outside protected areas (Douglas-Hamilton et al. 2005) and for these reasons cases of human-wildlife conflict are quite rampant especially where competition for resources subsists between the two (Hoare & Du Toit, 1999).

However, elephants in general, try to limit contact with humans (Van Aarde & Jackson, 2007). For example, this is achieved by restricting their visits to common water points/sources at night instead of daytime when they are most likely to encounter human presence (Jackson et al. 2008). In situations where elephants suitable habitats overlap one or more human settlements; elephants are known to make fast and swift nocturnal movements to limit time spend on unsafe grounds (Douglas-Hamilton et al. 2005).

Elephants are also known to vacate an area that has an increased human population density (Hoare & Du Toit, 1999). Parker and Graham (1989) suggested a negative linear relationship between human and elephant density. Thus, anthropogenic factors such as habitat destruction and hunting/poaching have a significant effect in determining elephant's geographic distribution and numbers in Kenya and Africa at large (Litoroh et al. 2012).

Subsequently, gradual habitat loss have been observed in Africa over the last couple of decades (Litoroh et al. 2012), resulting in fragmented landscapes, that have led to increased spatial interaction between elephants and the adjacent communities especially those living closer to protected areas (Kumar et al. 2004; Abdulkadir et al. 2013).

This phenomenon is most likely to escalate due to impacts of climate change and land use land cover change as observed in northern Kenya games reserves and national parks - where higher concentrations of free-ranging elephants populations are in existence (Sitati, 2005; Graham et al. 2009).

The use of innovative GIS technology is highly encouraged in assessing the gradual changes in the ecosystems that support elephant populations (CITES, 2008). Therefore, this research explores the possibilities of using Web GIS technology in monitoring elephant movement and distribution with respect to both biotic and abiotic factors. Thus, pointing to the most important factors that influence elephant densities within their natural habitats.

2.2 Web GIS and it's advancements in animal movement ecology

Moretz (2008) defines web GIS as a network-based geospatial system that utilizes either wired or wireless connectivity to access and distribute geographic information, spatial analytical tools, and geospatial web services.

The terms web GIS and web mapping are most often used synonymously (Neumann, 2008), but web GIS focuses more on the data exploratory through analytical and computation procedures (Yang et al. 2005), whereas, web mapping places emphasis on designing, implementing, producing and distributing map services on the web (Neumann, 2008).

Recent advancements in computing power and web information technologies have enabled adopting some basic and fundamental GIS functionalities from the traditional desktop programs to internet and intranet web applications (Lupp, 2008). These IT infrastructural related improvements, in conjunction with the current pace of web technologies have substantially harnessed the use of Internet GIS in delivering solutions (Haklay et al. 2008; Harrower, 2008) where most needed.

The effective and affordable sharing of geospatial information across the internet, permits the integrated use of distributed data sources, thus minimizing data redundancy and duplication among specific stakeholders and partners (Cammack, 2005; MacEachren et al. 2008).

At the moment, web GIS allows automatic streaming and updating of data into the database and simultaneous display and visualization of the dynamically created web maps (Neumann, 2008;

Li et al. 2011). Most of these web maps are generated using statistical approaches (AvRuskin et al. 2004), spatial analytic processes (Anselin et al. 2006) and computer simulation methods (Koua & Kraak, 2004).

Web applications can be customized to support the integration of multimedia files and elements such as videos, audio and animations in a standard browser environment (Neumann, 2008). This enables the development of animated map services, which can be used to display the dynamic variables such as weather patterns and natural ecosystems, in addition to mashups of different map services from various sources (Li et al. 2011).

The OGC standards and specifications have also enriched web GIS applications and technologies (Harrison & Reichardt, 2001) by developing and promoting the use of open standards and techniques that support geospatial interoperability at an international level (Reed, 2011).

These standards have been incorporated in most web GIS API's such as google maps, Open Street Map, ESRI, Bing Maps, OpenLayers etc. to ensure smooth compatibility of maps and data across the main browsers and operating systems (Neumann, 2008; Li et al. 2011).

Conservation biologist and ecologist have taken advantage of these advancements in computer science and IT (Klomp et al. 1997) by adopting them into several disciplines of ecology such as molecular biology and genetic engineering, evolutionary biology, environmental physiology and behavioral ecology (Krebs, 1985).

Research techniques in biotechnology, satellite tracking and GPS systems, GIS and remote sensing etc. heavily rely on IT in delivering the expected results (Klomp et al. 1997). Currently, GIS is widely used by ecologist for the management of spatial data (Klomp et al. 1997). GIS tools and software's allows for the collection, processing, analysis, interpretation, storing, sharing/dissemination and visualization of spatial ecological variables (Walker, 1996). The field of conservation ecology, which bridges the gap between pure ecology and its application to species and habitat conservation (Soulé & Willox, 1980), has experienced a magnificent transformation as a result of improvements in GIS (Goodfellow, 2014).

GIS has been used for modelling wildlife corridors, development of species distribution models for plants/animals of economic importance, assessing changes in biodiversity due to impacts of climate change and other factors, identifying biodiversity hotspots for priority conservation measures, land cover and habitat diversity, temporal analysis and trends, predictive distribution maps etc. (Klomp et al. 1997; Joshi et al. 2004; Goodfellow, 2014).

Recent technological improvements in the accuracy & reliability of GPS telemetry devices (Cagnacci et al. 2009; Dyo et al. 2010; Urbano et al. 2010; Dwyer et al. 2015) has led to the availability of highly precise and regularly updated movement based data for large terrestrial animals (Douglas-Hamilton, 1998; Tomkiewicz et al. 2010) for a significantly longer time periods (Eckert & Stewart, 2001; Fedak et al. 2010).

These GPS telemetry types of equipment are lately reduced in terms of size, weight and their eventual costs (Cohn, 1999; Ropert-Coudert & Wilson, 2005) thus becoming applicable to a wide range of animal species and at various stages of their growth and development (Cagnacci et al. 2009; Dwyer et al. 2015).

These essential synergies between animal ecology and ICT marks a remarkable milestone in the field of movement ecology (Cagnacci et al. 2009) by giving credible insights into when, how and why animals use a given resource, associate with other species (including conspecifics), migrate to/from a specific location and moreover how anthropogenic pressure affects their general behaviors (Blake et al. 2001; Cagnacci et al. 2009; Wall et al. 2014).

The GPS fixes from animal tags are usually time series data representing movement patterns (Nathan et al. 2008) and they are highly autocorrelated in terms of space and time (Boyce et al. 2010; Fieberg et al. 2010), thus the higher the frequency rates of point data, the stronger the likelihood of an individual collared animal having spent more time in the specified location (Cagnacci et al. 2009).

The reduced cost in conjunction with efficiency in telemetry data collection has resulted in large volumes of datasets (Dwyer et al. 2015) thus creating a need for specialized tools and applications for handling and managing the periodically updated GPS fixes (Urbano et al. 2010).

An efficient system for the management of GPS telemetry data should put these factors, among others into considerations: cost-effectiveness, data scalability, data formats, periodic and automatic data updates, multi-user support, development of new algorithms and functions, data sharing and dissemination - using web GIS applications and other tools to allow data accessibility to other important stakeholders and targeted users (Urbano et al. 2010; Wall et al. 2014; Dwyer et al. 2015).

However, some wildlife researchers have underscored the need to have free online platforms that can support basic analysis, visualization and sharing of animal telemetry data (Coyne & Godley, 2005; Hartog et al. 2009), while some have expressed their discontent over fears of data misuse and/or improper citation and acknowledgments by their purported users' (Davidson, 2014).

This research explores an open source approach into the management of big data within a web GIS interface, where comparisons may be conducted between the elephant GPS telemetry datasets, weather and environmental layers and other existing features. This web GIS approach would also allow periodic updates, automated processing, analysis, and sharing in a multi-user environment. The web GIS application would also be flexible enough to cater for improved algorithms and functions deemed necessary in the near future.

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3.0 Methodology

The web GIS approach was mainly favored for use due to the fact that the key datasets (elephant GPS telemetry and earth observation data) were bulky and dynamic in nature and therefore, for efficient ingestion, processing, storage, access and visualization, an automated system with a simple graphical user interface was deemed fit for use.

The use of panels, forms, drop down menus, combo boxes, checkboxes etc. in the Web GIS application, allowed for easy searching, querying and visualization of a huge volumes of datasets in the databases and web map server, without the need for the user to peruse and scan volume of datasets like in the traditional desktop GIS applications.

The web GIS also leveraged on specific Python and JavaScipt libraries, in addition to OGC standards and specifications to develop a standard graphical user interface with features necessary for providing basic GIS functionalities such as zoom in, zoom out, panning, zoom to default, legend, etc. This also enhanced the look and feel of the application making it fun and intuitive to use.

This web GIS technology also allowed concurrent multiple users to access and use within the internet or intranet environment without the altering the underlying datasets. Thus, this platform may as well be used as a reporting platform for standardized map products.

The PostgreSQL-PostGIS Relational Database Management System and Geoserver raster mosaic tool were put to task in the management of these time series datasets, most of which had a high temporal scale and resolution. This also ensured high data integrity and performance in a multi-user environment.

3.1 Study Area

The study area enclosed the extent of the three elephant home ranges derived from their GPS collaring points.

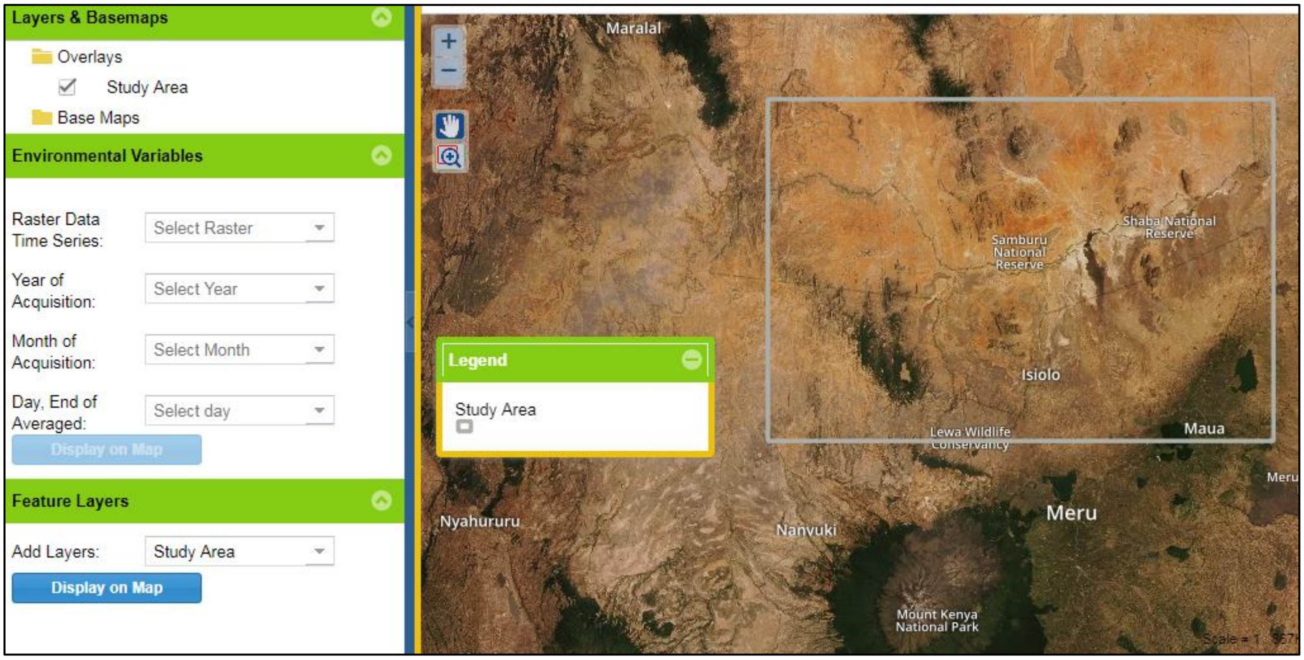

Fig 1. The study area in the web GIS viewer

The study area is approximately 1000 square kilometer extending through four counties in the central part of Kenya. On the Northern side is Samburu Country, on the Southern flank is Meru Country, and on the Central and Eastern peripheral is Isiolo Country while Laikipia Country lies on its South-Western end.

These four counties fall within the arid and semi-arid lands (ASAL) of Kenya, where, Samburu and Isiolo are considered as arid counties while Meru (north) and Laikipia are classified as semi-arid (Njoka et al. 2016).

ASAL regions in Kenya are well enriched with a variety of natural resources such as distinct wildlife and biodiversity species, extensive savannah, forest, and wetlands ecosystems, numerous minerals coupled with unique and diverse cultural practices (Njoka et al. 2016).

These regions are of high economic importance to the country as they support about 70% of the national livestock grid and are a host to over 90% of wildlife population which constitutes the backbone of Kenya's tourism industry (Republic of Kenya, 2004).

The study area lies within latitudes 0.000 and 1.000 north of the equator and longitudes 37.000 and 38.000 east of the prime meridian and is situated about 40 kilometers north of Mount Kenya, the country's highest mountain and Africa second highest towering over 5000 meters above sea level (KFS, 2010).

The South-eastern sections of the study area are influenced by the greater Mt. Kenya ecosystem as they are well positioned on the leeward side of the mountain and therefore receive a relatively higher rainfall (900 mm/annum) in comparison to the other regions of the study area.

However, the windward side of the mountain is much wetter with an annual precipitation of over 2000 mm. Generally, the entire Mt. Kenya ecosystem receives rainfall in the month of March to June and October to November, while January and February are the driest (KFS, 2010; KWS, 2010).

The northern section of the study area mostly comprises of savannah ecosystem, with prolonged hot and dry weather conditions and a fairly variable and erratic rainfall patterns (Ngene et al. 2013) most of which falls in the months of April and November (Barkham & Rainy, 1976) while January and February are the driest (Samburu County Report, 2017).

The Mt. Kenya ecosystem comprises of Mt. Kenya National Park, Mt. Kenya Forest Reserve, Meru National Park with adjacent bio-network of Ngare Ndare Forest and Lewa Wildlife Conservancy both situated on its northern frontiers (KWS, 2010).

These ecosystems play host to numerous mammalian species of high ecological interest such as the African elephant, Black rhinoceros, White rhinoceros, Grey's Zebra, Mountain Bongo and several primates such as the White colobus, Sykes Monkey, Olive baboon, the lesser and the greater bush babies (KFS, 2010).

The Mt. Kenya ecosystem sustains Kenya's largest existing forest population of elephants evaluated at 2000-3000 individuals. Previous research has shown the movement of elephants from the Mt. Kenya forest reserve to the savannah grasslands of Laikipia-Samburu ecosystem via an established wildlife corridor connecting the forest reserve to Lewa Wildlife Conservancy (KWS, 2010).

The Laikipia and Samburu counties constitute the ecologically renowned Laikipia-Samburu ecosystem, which boasts of the second richest terrestrial biodiversity in Kenya (Frank 1998; Frank et al. 2005), after the world famous Masai Mara National Reserve (Georgiadis et al. 2007).

This ecosystem supports a high diversity of ungulate species such as the endangered grevy's zebra, baisa oryx, gerenuk, reticulated giraffe, and klipspringer among others (Spira, 2014) and acts as vital wildlife corridor, essential for the connectivity of wildlife populations in Kenya and Eastern Africa at large (Riggio, 2011).

The Laikipia-Samburu ecosystem has the largest population of elephants existing outside the protected area (Omondi et al. 2002) and also harbors the second largest population of elephants in Kenya, after Tsavo national park (Litoroh et al. 2009).

This ecosystem is also a home to three protected areas: the Shaba NR, Buffalo Spring NR and the IUCN category II protected area, the Samburu NR; three indigenous forest reserves: Kirisia, Leroghi and Mathews range; a host of community conservation areas such as Kalama, Meibae, Namunya and Il Ngwesi among others (Ngene et al. 2013; Spira, 2014) and the splendid Ewaso Ngiro river, which together with its tributaries provide water for both the wildlife and the pastoralist communities living within the county (Litoroh et al. 2009).

However, this ecosystem has been heavily ravaged by effects of climate change and environmental degradation resulting in shortened rain seasons, frequent droughts and periodic flooding incidents (Samburu County Report, 2017).

Consequently, the vegetation cover and the surface water capacity has been adversely affected beyond its earlier carrying capacities (Harding & Devisscher, 2009) resulting in a multiplicity of challenges to human, livestock and wildlife at large (Koske, 2014; University of Nairobi Report, 2016) in addition to heightening incidents of human-wildlife conflict in the region (Samburu County Report, 2017).

The Human-Elephant conflict (HEC) remains to be the most common form of human-wildlife conflict in the region (King et al. 2011; Graham et al. 2009) with increased incidents being reported during prolonged drought periods where elephant’s encroach into both grazing and croplands and humans also intrude protected areas and conservancies in search of water and pasture (Thoules, 1994; Samburu County Report, 2017).

3.2 Data Acquisition and Processing

Data preparation were conducted mainly using ArcGIS for Desktop and other specific tools such as the Movement Ecology Tools for ArcGIS (ArcMET) developed by STE, and MODIS re-projection tool (MRT) developed by USGS. ArcMET is an ArcGIS extension module consisting of several tools used in processing and analysis of GPS data telemetry and the derivation of intended datasets and products applicable in the field of wildlife movement ecology and conservation biology (Wall, 2014). A number of specific products were derived from this tool and later on ingested into the web GIS application.

ArcGIS Desktop is a high-end desktop GIS application with multiple functionalities for advanced and extensive data management and processing. It allows automation of data processing methods using Python programming language as well as inbuilt tools such as model builder (ESRI, 2016). ArcGIS ArcPy is an ArcGIS python scripting module developed for spatial data analysis, processing and management (ESRI, 2017).

The MRT, on the other hand, is a customized tool built specifically for preprocessing of MODIS data and products. This tool enables users' to read the common MODIS HDF data format files and perform several procedures such as geographic transformation to a different coordinate system, resampling, mosaicking and changing the output files formats to users' specific. This tool also allows batch processing using the window command line interface (USGS, 2011).

3.2.1 Feature Layers

These datasets comprised of basic GIS vector datasets such as Kenya counties, Land use types, Road line, and River line. These layers were mashed up with the elephant points and derived datasets for the purpose of understanding how elephant's utilize space with respect to some of these features. They also allowed for analytic querying of elephant points with regards to their proximities to protected areas, human habitats, river lines among other features of interest.

These datasets were obtained from RCMRD organization in Nairobi, Kenya. Most of these datasets existed as open source data within RCMRD's internal and external data portals in GIS vector formats. The land use data used in this study were collected and created in the year 2013, thus allowed making comparisons with the elephant GPS telemetry data that covered the time period 2010 – 2017.

The above datasets were clipped to the study area extent using ArcGIS Analysis tool. The land use types were vaguely divided into two categories: land use human activities and land use other types. The land use human activities represented the actual features that represent human presence such as Settlements, Campsite, Hotel, Lodges, Schools, Town, Villages, Offices, and Shops etc. while the land use other types represented land cover types such as community conservancies, conservation area, forest reserves, national reserves etc.

All these datasets were then re-projected to WGS 84 UTM Zone 37N to allow for distance related analysis besides also being one of the most favored CRS in Kenya (Mugneir, 2003).

3.2.2 Elephant GPS Telemetry

The datasets consisted of elephant location points and their derived products. These datasets allowed the investigation into time-specific queries, point and time density, percent utilization contours, proximity and association analysis among other interesting exploration.

These datasets were also mashed up with environmental parameters (NDVI, LST, and PPT) to investigate changes in elephant movement with respect to biome and weather dynamics as well as with feature layers such as river lines and land use human activities to examine ecological and anthropogenic influences on elephant mobility respectively.

The distance statistics were also derived from elephant location points. These statistics were used for observing daily distance coverage for individual elephants using the graphical charts. The derived products consisted of points representing elephant locations, raster grids representing kernel and time density maps, polygons representing percent utilization distribution contours and minimum convex polygons, polylines representing proximities between individual elephants, and tables representing daily distance statistics for individual elephants.

Datasets for three individual elephants namely: Edison, Taurus, and Wendy were obtained from Save the Elephants (STE) organization through a formal request and a signed agreement to STE management[1]. These datasets were shared in CSV format and consisted of the combined tracking points of the three elephants and their consequent metadata files.

The three elephant datasets generally covered the time period February 2010 to July 2017, though, there were some existing gaps within individual's elephant files which were clearly indicated in the contained metadata file. The existing data gaps may have resulted due to GPS battery failures or other GPS collar hardware related problems. However, these gaps were short-lived as these GPS collars were replaced with new ones, thus ensuring an almost continuous monitoring of these elephants.

According to STE field ecologists, Edison is a male elephant of about 31 years of age, while Taurus and Wendy are female elephants of around 35 years of age. Taurus belongs to Zodiacs family while Wendy is a member of the Poetics1 family (Wittemyer et al. 2005b). The Zodiac group currently consists of about 25 members while the Poetics1 are about 30 members. Edison, like most male elephants, lives on the fringes of several family groups and is thus considered solitary by nature.

The elephant's points tables were first sorted into individual elephant group before being converted to GIS point data (shapefile) format using ArcGIS desktop. The shapefiles files were

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[1] STE data sharing agreement: https://drive.google.com/file/d/0B4sVUFLfABuLVWFuRnBnUGdza0E/view

then cleaned off erroneous point/outliers before being re-projected to WGS 1984 Zone 37N to allow for distance related computations. The outlier points were sorted out using their spatial extents, which were way off the expected home ranges of these elephants and the intervals between consecutive GPS collar points, which varied from the normal elephant tracking pace.

Using ArcMET, several elephant movement related datasets were derived from these points datasets. These included: Kernel Density Estimator (KDE), Elliptical Time-Density (ETD), Utilization Distribution (UD) Percent Contours, Minimum Convex Polygon (MCP), Proximity Analysis and Distance Statistics.

The KDE was used for the computation of the utilization distribution of an animal using the point density approaches (Worton, 1989) while the ETD calculated the amount of time spent per location using a consecutive pair of points (Wall et al. 2014). The derived outputs of both analyses were gridded raster files in TIFF format.

The Utilization Distribution (UD) Percent Contours were a set of polygons that represent percentiles for a specified utilization distribution raster. This tool sorts out pixels and generates polygons that correspond to the desired percentile value (Wall, 2014).

Table 1: Edison UD percent contours showing actual percentages and represented area

CalcID	Input Raster	Desired Percentage	Actual Percentage	Area (sq. km)
edisonKDEGrid	edisonKDEGrid	0.50	0.49	129.50
edisonKDEGrid	edisonKDEGrid	0.90	0.89	525.70
edisonKDEGrid	edisonKDEGrid	0.95	0.94	685.25

The Minimum Convex Polygons (MCP) is used for the estimation of home ranges in animal ecology (Harries et al. 1990). The output polygon basically represented the outermost points enclosing all geometries within the input GPS location datasets (Wall, 2014). These MCP could also be computed from PostGIS using the Convex Hull function (OSGeo, 2017).

The Proximity Analysis was used for testing associations and interaction between individual elephants. This tool calculated distances between individual animals with an overlapping home range (Wall, 2014). This tool required data-time fields in the input GPS points datasets to compute the distance between animal A to animal B, the bearing of animal B from animal A and the time of the proximity calculation (Wall, 2014). The output polylines contained the names of the relating elephants, the dates, inter-distances in meters, absolute bearing etc.

Two proximity computation polylines features were generated for this study i.e. Edison-Taurus and Edison-Wendy, to investigate the interaction between Male (Edison) and Female (Taurus and Wendy) elephants.

Table 2: Sample table of conspecific proximity analysis

AnimalA Name	AnimalA Fix Date	AnimalA Xcoordinate	AnimalA Ycoordinate	Proximity (meters)	Absolute Bearing	AnimalB Name	AnimalB Fix Date	AnimalB Xcoordinate	AnimalB Ycoordinate
edison	2/9/2015	325515.60	65450.44	38253.52	161.14	taurus	2/9/2015	337883.22	29251.35
edison	2/9/2015	325193.77	65992.38	26389.96	80.58	taurus	2/9/2015	351227.57	70313.46
edison	2/9/2015	325121.67	66126.22	11546.91	107.04	taurus	2/9/2015	336161.93	62743.36

The final dataset derived from elephant's points were the Daily Distance Statistics. To achieve this, the displacement between consecutive points were computed. These tables were then summarized per day using dates (fixtime) to generate the distance statistics in meters for all the three individual elephants.

Table 3: Edison summarized distance statistics

fixtime	Count fixtime	Min distance (m)	Max Distance (m)	Average distance (m)	Sum distance (m)	STD distance (m)	Variance Distance (m)
4/30/2014	42	0	171.05	39.64	1664.81	34.33	1178.26
5/01/2014	48	0.37	4932.10	202.57	9723.57	918.56	843751.57
5/02/2014	48	0	35.85	7.52	360.89	6.74	45.36

3.2.3 Digital Elevation Model

These datasets consisted of the study area DEM and the derived contour lines. These layers allowed for examination of the study area topographical and relief features and visual comparison of elephant spatial distribution with respect to elevation.

These layers were overlaid with elephant points to investigate aspects of high altitude and eventual elephant movements. These layers were also mashed up with NDVI to observe effects of elevation to vegetation health and density.

The Shuttle Radar Tropical Mission (SRTM) DEM tiles for the study area were downloaded from USGS Earth Explorer online data repository (USGS, 2017). The USGS Earth Explorer provides a reference tile-map for guiding users on which tiles to use for a particular regions of interest.

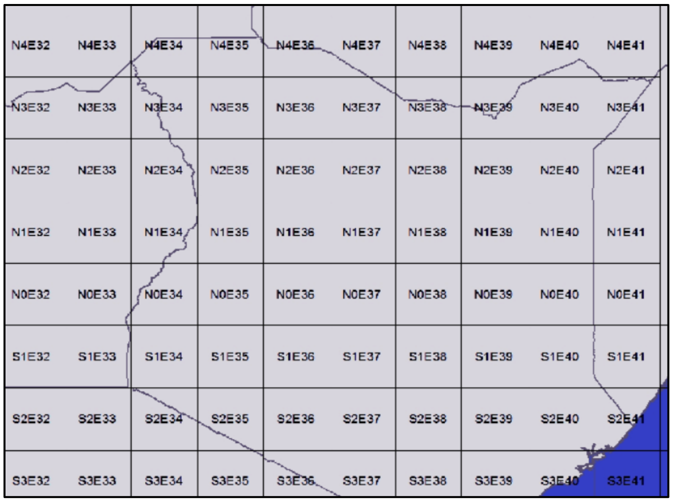


Fig 2: The USGS Earth Explorer tile reference map for SRTM 30 meters datasets for Kenya

In this case, the SRTM 30 meters tiles N1E36, N1E37, N0E36, and N0E37 were acquired for use in the study area. These SRTM tiles were merged into one single raster file using the Raster mosaic tool in ArcGIS.

A contour polyline feature was also generated using ArcGIS at an interval of 200 meters and a base contour of 200 meters. The ArcGIS contour tool under Spatial Analyst tools was used for the creation of the contour polylines.

3.2.4 Normalized Difference Vegetation Index

These datasets consisted of the 16 days interval NDVI time series from Jan 2010 to July 2017 and statistics derived from the same. The NDVI time series were used for investigating vegetation health and density, time-related trends within the study area while comparing them to elephant points to create a simulating effect of how elephants alter movements in relation to ecological changes.

NDVI statistics were derived from the NDVI time series and were used for showing NDVI variations over time using charts in the web GIS application. The NDVI time series were stored in raster TIFF file formats while the derived statistics were stored in DBF file formats.

The MODIS Terra NDVI (MOD13Q1) were downloaded from NASA online tool called Reverb. Reverb is a state of art online repository that provides a simple and efficient interface for searching, accessing and downloading earth observation systems data products and services (NASA Reverb, 2016). The downloaded datasets covered the time period January 2010 to July 2017.

These MODIS products were packaged in tiles of approximately 12,000 square meters, in a sinusoidal grid projection and as HDF files (USGS, 2014b). Each tile consisted of 11 bands (subdatasets), where, NDVI was assigned ID 0.

These tiles also had a specific naming structure consisting of products acronym, Julian date of acquisition, tile ID, version ID etc. while NDVI value range for individual tile was -2000 to 10,000. All MODIS data use the Julian calendar date formats (USGS, 2014c).

Several steps were undertaken in processing and preparation of the raw NDVI data. Firstly, the NDVI (subdataset ID 0) was extracted from the multiband MODIS tiles and then clipped to the study area extent using the MRT windows command line resampling technique as described by the MODIS Reprojection tool user's manual. The MRT tool permits batch processing of the MODIS datasets (USGS, 2011).

During this process, the parameter files were set to nearest neighbor for the resampling method since it's the most suited technique for MODIS NDVI datasets (Perez & Torino, 2006) while the projection was set to GCS WGS 84 to ensure consistency with other raster datasets i.e. DEM, LST and PPT data.

The spatial subset extents were also set to our study area while the output cell resolution was maintained at approximately 250 meters (0.00210 decimal degrees). The derived NDVI files were then scaled down by multiplying them with a coefficient of 0.0001 (NASA, 2006) to derive the actual NDVI value range of -1 to 1.

Each file was then renamed from the original MODIS naming format (e.g. MOD13Q1.A2010001.h21v08.006.2015198101444) to a simplified naming structure (ndvi_2010010) while converting the Julian dates (yyyyddd) to Gregorian dates (yyyymmdd).

The no data values were then assigned to 255 while retaining the default pixel depth to 64bit double precision, since adjusting its value resulted in rounding off of cell values zero decimal places, thus reducing the precision and the quality of the output raster files.

The simple naming structure that suits the geoserver time-series image mosaic specifications (OSGeo, 2016a) and also for allowing easy searching and filtering capabilities in geoserver and in the web GIS application, was adopted for use. All the above processes were automated using a python script available in Appendix A.

The NDVI statistics for the study area were derived from NDVI time series raster files. The ArcGIS spatial analyst tool called zonal statistics to table was used to loop through all the NDVI time series and save the resultant DBF files in a given directory. Two fields were added to the resultant NDVI statistic tables: 'Names' to define the name of the NDVI table i.e. ndvi_20100101 and 'Date' to describe the dates of the NDVI table i.e. 20100101.

Finally, the individual NDVI statistic tables were merged into a single DBF (ndvistats) that contained all the derived statistics plus their respective dates. All the above processes were automated using a python script available in Appendix B.

Table 4: Sample of the final NDVI aggregated table

MIN	MAX	RANGE	MEAN	STD	SUM	Names	Date
-0.30	1.00	1.30	0.41	0.18	75784.22	ndvi_20091219	2009-12-19
-0.30	0.99	1.29	0.44	0.17	80032.89	ndvi_20100101	2010-01-01
0.11	0.91	0.81	0.37	0.16	68038.90	ndvi_20100117	2010-01-17

3.2.5 Land Surface Temperature

These datasets consist of the 8 days interval Land Surface Temperature time series from Jan 2010 to July 2017 and the derived statistics of the same. LST time series were used for investigating the long-term land surface temperature for the study area. These raster files were also mashed up with elephant points to visualize elephant distribution with respect to land surface temperatures. LST statistics were derived from the LST time series and were used for displaying LST disparities over time in a graphical interface within the web GIS application.

The MODIS Terra LST (MOD11A2) datasets covering the period January 2010 to July 2017 were downloaded from NASA online tool called Reverb (NASA Reverb, 2016). The product of choice was MODIS level 3 global land surface temperature and emissivity at 1 km spatial resolution and 8 days temporal resolution stored in sinusoidal map projection grids i.e. MOD11A2. The temperature values were represented in Kelvin units/days and were stored in hierarchical data format (HDF) - Earth observation system file formats (USGS, 2014).

MOD11A2 was an averaged 8 days, clear-sky LST product with accuracy levels of 1 Kelvin at the 1-kilometer resolution and these products could be validated from field samples collected on flat uniform land surfaces (Wan, 2013).

The products' tiles swath were approximately 1100 km by 1100 km, in a sinusoidal grid projection and packaged as HDF files while each tile consisted of 11 bands (subdatasets). These raw tiles had the default MODIS naming structure and their temperature units were in the range of 7500 – 65535 (USGS, 2014b), thus required scaling by a factor of 0.02 to obtain the actual temperature units in Kelvins.

The two important subdatasets were the LST_Day_1km (subdataset 0) and LST_night_1km (subdataset4) since elephants are known to be active both during the day and at night (Loarie et al. 2009). The two bands LST_day_1km and LST_night_1km were extracted from individual MODIS tiles using the MRT resampling technique as described in the MODIS Reprojection tool user's manual, thus, allowing batch processing of the MODIS LST datasets via the windows command prompt (USGS, 2011).

In the resampling parameter file, the spatial subset was set to the extents of the study area. The GCS WGS 84 was the preferred CRS, and the nearest neighbor method was the favored resampling technique (Williamson et al. 2014) while the output cell resolution was maintained at approximately 1 kilometers (0.00830 decimal degrees).

The derived LST outputs were then multiplied by a scaling factor of 0.02 (USGS, 2014d) to attain the actual temperature values in kelvins (K). The day and night LST outputs were then combined to get an averaged (8 day-night) LST value and then converted to degrees Celsius (^{o}C) by subtracting a value of 273.15 from the averaged LST output results.

The resultant LST files contained negative values as their minimum temperatures, with most datasets having -273.15 as their least pixel values. This is due to the fact that zero (0) represents the (fill value) data used for gap filling in original MOD11A2 raw data products (Wan, 2013).

Thus, the LST values below zero were then reclassified to no-data values using the ArcGIS condition tool. This tool utilized an if-else condition statement on input raster cells to control their output values based on the merits described in the conditional statement (ESRI, 2016).

The derived outputs were then renamed from the MODIS naming structure (USGS, 2014c) to a simpler format consisting of the products name and dates in Gregorian formats (lst_20100101) as described by the geoserver time-series image mosaic specifications.

This naming structure allowed for easy indexing, searching and filtering in geoserver (OSGeo, 2016a) and in the subsequent web application graphical user interface. All the above geoprocessing steps were undertaken using a python script available in Appendix C.

The LST statistics for the study area were derived from LST time series raster files. The ArcGIS spatial analyst tool called zonal statistics to table was used to loop through all the LST time series and save the resultant DBF files in a given directory. Two fields were added to the resultant LST statistic tables: ‘Names’ to define the name of the LST table i.e. lst_20100101 and ‘Date’ to describe the dates of the LST table i.e. 20100101.

Finally, the individual statistic tables were merged into a single DBF file (lststats) that contain all the derived statistics plus their respective dates. All the above processes were automated using a python script in Appendix D.

Table 5: Sample of the final LST aggregated table

MIN	MAX	RANGE	MEAN	STD	SUM	Names	Date
14.57	33.90	19.33	25.72	3.28	307147.15	lst_20100101	2010-01-01
14.54	32.14	17.60	26.36	3.36	315571.99	lst_20100109	2010-01-09
15.99	34.58	18.59	28.66	3.61	343045.83	lst_20100117	2010-01-17

3.2.6 Precipitation/Rainfall

These datasets consisted of the 10 days interval (dekadal) rainfall time series from Jan 2010 to July 2017 and the derived statistics of the same. The Precipitation (PPT) time series were used for examining the precipitation trends within the study area. These raster files were also mashed up with elephant points to visualize elephant movement with respect to rainfall distribution. PPT statistics were derived from the PPT time series and were used for visualizing rainfall discrepancies over time using charts in the web GIS application.

The 10 days (dekadal) average precipitation datasets were downloaded from the climate hazards group FTP portal. These datasets consisted of zipped TIFF files at Africa-wide geographic extent and covering the time period January 2010 to July 2017. The datasets were then unzipped to individual files and then clipped to our study area. The output files were then renamed from the original formats (e.g. chirps-v2.0.2010.01.1.tif to ppt_20100110.tif) in order to suit the geoserver time-series image mosaic specifications. All the above geoprocessing procedure was accomplished using a python script Appendix E.

The PPT statistics for the study area were derived from the PPT time series raster files. The ArcGIS spatial analyst tool called zonal statistics to table was used to loop through all the PPT time series and save the resultant DBF files in a particular directory. Two fields were added to the resultant PPT statistic tables: ‘Names’ to define the name of the PPT table i.e. ppt_20100110 and ‘Date’ to describe the dates of the PPT table i.e. 20100110.

Finally, the individual statistic tables were combined into a single database file (pptstats) that contain all the derived statistics plus their respective date fields. All the above processes were automated using a python script in Appendix F.

Table 6: Sample of the final PPT statistics aggregated table

MIN	MAX	RANGE	MEAN	STD	SUM	Names	Date
17.87	76.59	58.72	36.85	8.73	12161.28	ppt_20100110	2010-01-10
1.26	20.79	19.53	4.35	2.49	1435.57	ppt_20100120	2010-01-20
1.05	21.12	20.08	4.72	2.68	1556.73	ppt_20100130	2010-01-30
0.00	15.26	15.26	5.23	3.24	1724.92	ppt_20100210	2010-02-10

3.3 Web GIS System Design and Implementation

This project utilized free and open source software's (FOSS) for Geospatial data management and publishing as well as free libraries for the design and development of the web GIS applications. FOSS are computer application libraries that are legally and technically available for use by any interested party (Fiorenza et al. 2014), without a patent, copyright or any other limitations (Auer et al. 2007).

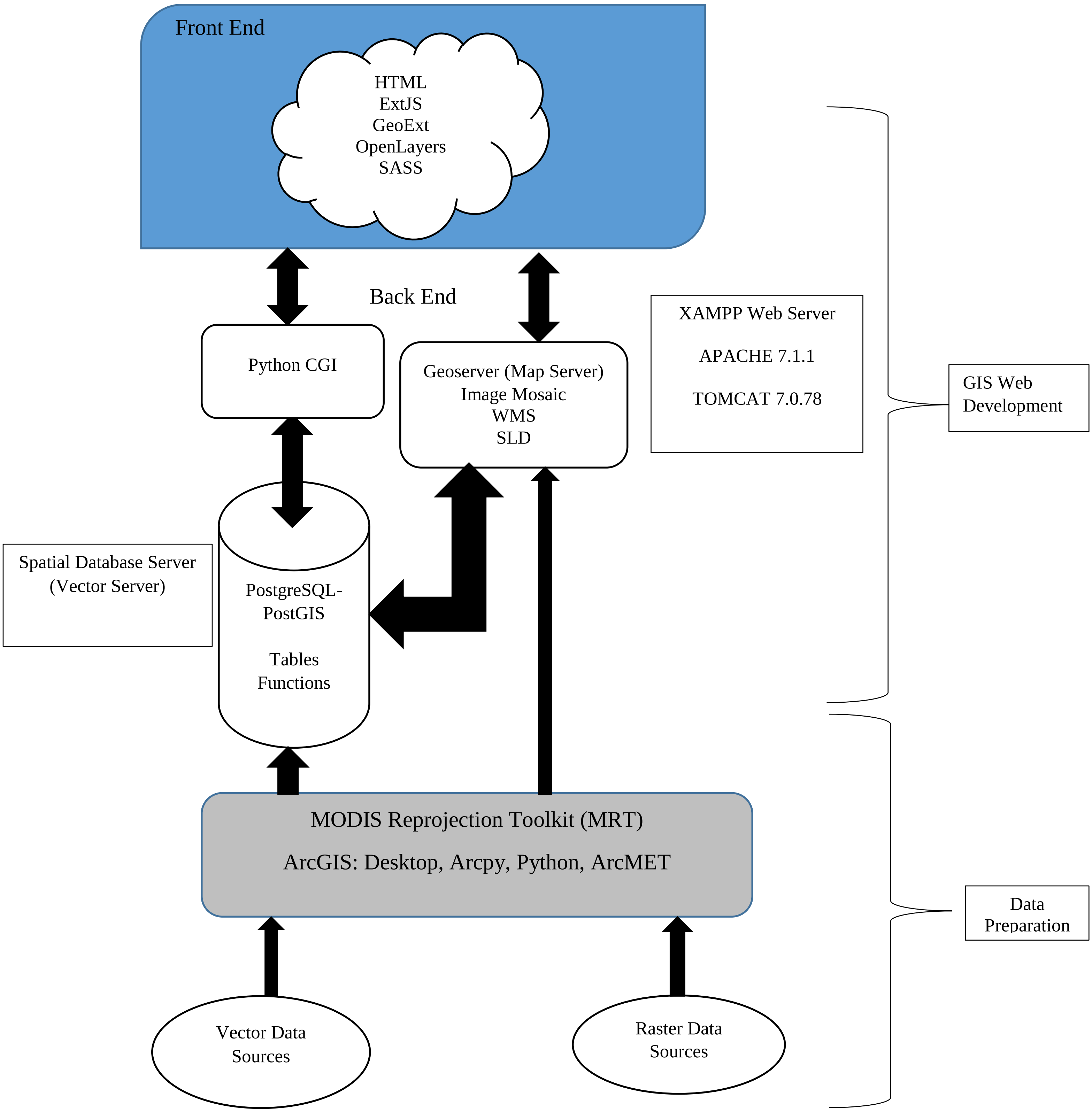
These software's are freely accessible in standardized formats that are compatible with most computer operating systems (Fiorenza et al. 2014). FOSS are released under specific licenses that allow users to access, use, modify and redistribute their source codes without any royalties or costs associated with the software (IDABC Programme, 2010).

In today's GIS world, FOSS has become commonplace (Gerlek, 2007; Steiniger & Bocher, 2008), providing competitive features that have demonstrated the potential alternative to commercial and proprietary software's (Ramsey et al. 2007).

Open Source Geospatial Foundation (OSGeo) has been at the forefront of promoting the development of high-quality open source geospatial software's (OSGeo, 2016b), that are geared towards meeting the Open Geospatial Consortium (OGC) standards and specifications (Gerlek et al. 2009).

This project utilized a number of OSGeo geospatial libraries such a PostGIS, GeoTools, Geoserver, and OpenLayers. Other open source software's used in this project include PostgreSQL, Aptana Studio, QGIS, and QGIS extension called SLD4Raster.

3.3.1 System architectural design



3.3.2 Geospatial Data Management

A database is a collection of related data, constructed and populated with data for a specific goal or purpose (Elmasri & Navathe, 2004) and in a computer environment (Rigaux et al. 2002). A DBMS is then a computer program that interacts with the users, other computer applications and the database itself to capture, store and analyze data (Ramakrishnan & Gehrke, 2000).

A DBMS allows various database processes such as definition, creation, querying, updating, administration and sharing of the database among multiple users and computer applications (Elmasri & Navathe, 2004).

The development of RDBMS come along with the establishment of the structured query language (SQL) developed by IBM in early 70's (Codd, 1970). SQL is a high-level declarative language, where the user only needs to specify what is required and leave the optimization and implementation of the query to the RDBMS (Elmasri & Navathe, 2004). Many RDBMS are currently available in the market i.e. Oracle, SQL Server, PostgreSQL, MySQL etc. and most of them offer support to spatial data types.

All vector data types were stored and managed within a Database Management System (DBMS). This project made use of PostgreSQL object-relational database because of its highly advanced features (Riggs & Krosing, 2010; PostgreSQL, 2016) as well as its robust support for geometric models, functions, and operations (Rigaux et al. 2002) including spatial indexes, which act as query optimizer (Nguyen, 2009).

PostgreSQL is built for extensibility (Obe & Hsu, 2014; Rigaux et al. 2002), hence supports procedural languages such as PL/pgSQL, PL/Perl and PL/python in addition to non-standard procedural languages such as PL/PHP, PL/Ruby, PL/Java etc. (PostgreSQL, 2016).

PostGIS is one such extension that adds extra data types such as geometry, geography, and raster in PostgreSQL databases (Obe & Hsu, 2015) as well as functions and indexes (Nguyen, 2009), thus permitting spatial queries to be executed in using a standard SQL syntax (Obe & Hsu, 2015). It also offers opportunities for scripting and automation of time-consuming processes (Urbano & Cagnacci, 2014). Thus, the PostGIS-PostgreSQL platform has all the key functionalities for maintaining reliability and efficiency in a spatial database (Marquez, 2005, Corti et al. 2014).

The 'elephant' database was created for storing all feature layers and elephant related vector files while the second database, called 'rasters', was created for storing the image mosaic index created by Geoserver while publishing NDVI, LST and PPT time series datasets.

3.3.3 Geospatial Data Publishing

Spatial data publishing entails converting desktop GIS data and products into web GIS services, thus enabling accessibility of GIS data and their derived functionalities over the internet (Li, 2008, Stopper et al. 2012) in a globally accepted standard such as OGC standards (Reed, 2011).

The OGC standards provide a framework for solving various geospatial interoperability challenges such as data structures and formats, software compatibility issues related to different platforms and environments (Reed, 2011, Stopper et al. 2012) among others. This allows a variety of desktop and web applications to access and consume GIS web services and functionalities in a seamless and reliable means through a standardized web GIS protocol (Alesheikh et al. 2002).

A number of software applications such as ArcGIS server (Peggion et al. 2008), MapServer (Singh et al. 2012) and GeoServer (Ivanković & Vučić, 2011) provide web GIS server capabilities, which permit publishing of web GIS services using defined procedures defined by OGC standards.

This project employed the use of Geoserver, an open source OGC compliant web GIS server application with proven reliability and consistency in publishing GIS data using open standards as well as its simplicity in configuration and implementation (Ivanković & Vučić, 2011; OSGeo, 2014). Geoserver allows users to share and edit geospatial data. It supports publishing GIS web services OGC standard specifications such as Web Feature Service (WFS), Web Map Service (WMS) and Web Catalog Service (WCS) (OSGeo, 2015).

The PostGIS vector datasets and existing raster layers were published using Geoserver. All the published layers in Geoserver required appropriate styling following cartographic best principles and practices as defined by OGC SLD specifications (OGC, 2018). This project used SLD files generated from QGIS desktop for vector data and QGIS SLD4raster plugin (Pasotti, 2016) for raster files for styling the published layers.

Publishing Geospatial data involve converting commonly used GIS data formats such as shapefiles, database tables, GeoTIFF etc. to OGC supported web services. All the feature layers and the contour lines were published as PostGIS vector database layers, while the DEM, KDE, and ETD raster grids were published as GeoTIFF stores, whereas the NDVI, LST and PPT time series layers were published as raster’s Image Mosaic.

The remaining tables in the ‘elephant’ database such as the elephant points, elephant proximity layers, LST statistics, NDVI statistics, and PPT statistics, were not published as they were later used in querying and analysis procedure and generation of expected results in GeoJSON formats that would eventually be displayed in the web GIS application.

3.3.4 Web GIS Front End Development

In web application development, the term front-end and client-side are synonymously used to imply what the user sees and interacts with. Thus, front-end development entails the design and the implementation of the graphic user interface whose main purposes is to relate with the targeted users.

Several programming languages with their supporting libraries were used in the development of the web GIS front end application. This included HTML, JavaScript, ExtJS, GeoExt, OpenLayers and CSS/SASS. HTML was used in the development of the main web page and the HTML file comprised of the web page title, web page metadata, and the links to styles and libraries used in the development of the web application as shown in Appendix G. The 'About the Project' and 'Contact Information' pages were also purely developed in HTML.

This project used three JavaScript libraries i.e. OpenLayers, Extended JavaScript (ExtJS), and GeoExt. OpenLayers is an open source, client-side JavaScript API library used for making interactive web maps, viewable in most modern web browsers (elearning OL2, 2016). It makes it easy to place dynamic and interactive map layers (raster and vector) on web pages (OpenLayers 2, 2017). It also allows most basic customization of mapping components such as layers, controls, events, etc. (elearning OL2, 2016).

OpenLayers also supports multiple map servers delivering data to the web application. These data sources are consumed as OGC standard web services such as WMS, WFS, and WCS. OpenLayers also supports tiling and caching of bulky layers thus improving rendering and visualization performance of the web map application (elearning OL2, 2016).

This project utilized OpenLayers 2.13.1, which was the most stable version and was also compatible with GeoExt 2.1.0 and ExtJS 4 (GeoExt, 2016); all of which were used in the development of the web GIS application.

ExtJS is a pure JavaScript application structure used for developing interactive, platform independent web applications that work on most modern web browsers. It's a client-side JavaScript application framework used for building enterprise applications and supports object-oriented programming concepts using JavaScript which makes easy application development and maintenance.

The current version of ExtJS has adopted the MVC and MVVM architectural design. The cross-platform applications are developed using web browsers only and include a suite of a refined graphic user interface, form controls and widgets that perform the following tasks among others (List box and combo boxes, Radio and checkbox controls, Date field with a pop-up date picker, Numeric fields, Toolbars, HTML editor control, Desktop application style menus, vector graphics charts etc.) (Sencha ExtJS, 2017). This project employed the use of ExtJS 4.2.1 version, which supports most of the above-listed widgets and also runs on all commonly used web browsers.

GeoExt is an open source JavaScript library that allows building rich web applications, akin to desktop GIS programs. It integrates the advanced geospatial features of OpenLayers with the classy user interface of ExtJS library to develop the interactive web GIS applications (GitHub, 2016). GeoExt also provides a number of customizable widgets and data controls that allow easy building of geospatial web applications with styling, visualization, querying, editing among other features. This project applied the use of GeoExt 2.1.0 as it was the most stable available version. GeoExt 2.1.0 is built on top of OpenLayers 2.13.1 and ExtJS 4.2.1 (GitHub, 2016).

The cascading style sheet (CSS) is a simple design language used in managing the look and feel of HTML web pages. It comprises of simple and easy codes for styling and making the web pages more presentable. SASS, on the other hand, is an enhanced CSS language, with additional functionalities and capabilities. ExtJS 4 entirely relies on SASS for styling. This allows easy and flexible editing of the look and feel of the web GIS application (Duncan and Ashworth, 2012). This project utilized both CSS and SASS for enhancing the graphic user interface of the web GIS application.

The development of the web GIS application adopted the ExtJS MVC architectural design. This was to ensure that the application is well organized, extensible and maintainable (Sencha Docs, 2013). The application consisted of about 10 main components that were using the above mention libraries and programming languages.

These components were the ButtonOnClickAction, WebMappingViewPort, MapPanel, GeoExtMapPanel, MainToolbar, RasterSearchMapForm, ElephantAnalysisForm, ElephantQueryForm, ElephantDateForm and StatisticalChartForm.

Most of these JavaScript related files and codes were quite lengthy and thus couldn't be included in the appendix section of this report. For instance, the ButtonOnClickAction file which controlled all the clickable actions in the Web GIS application contained over 2500 lines of JavaScript codes.

The WebMappingViewPort held together the entire web application design and structure and thus it constituted of the graphical user interface of the web mapping application. It comprised of the left, center and right panels.

The left panel contained windows for Layers and Basemaps, Environmental Variables and, Feature Layers. Layers & Basemaps was for showing layers added to the map viewer and the default base map, Environmental Variables consisted of a series of combo boxes for allowing a user to search and add raster datasets to the map viewer while Feature Layers contained a drop-down menu for allowing a user to add feature layers to the map viewer.

The center panel consisted of the Toolbar Menu, Legend window, and the Map Viewer section. The Toolbar Menu comprised of map navigation icons such as the Zoom In, Zoom Out, Zoom to Default Extent etc. and the About and Contact icons for giving additional information about the web mapping application.

The legend window was used for describing the contents of the map viewer using their color codes and attribute information while Map Viewer allowed visualization of the maps and other graphical elements.

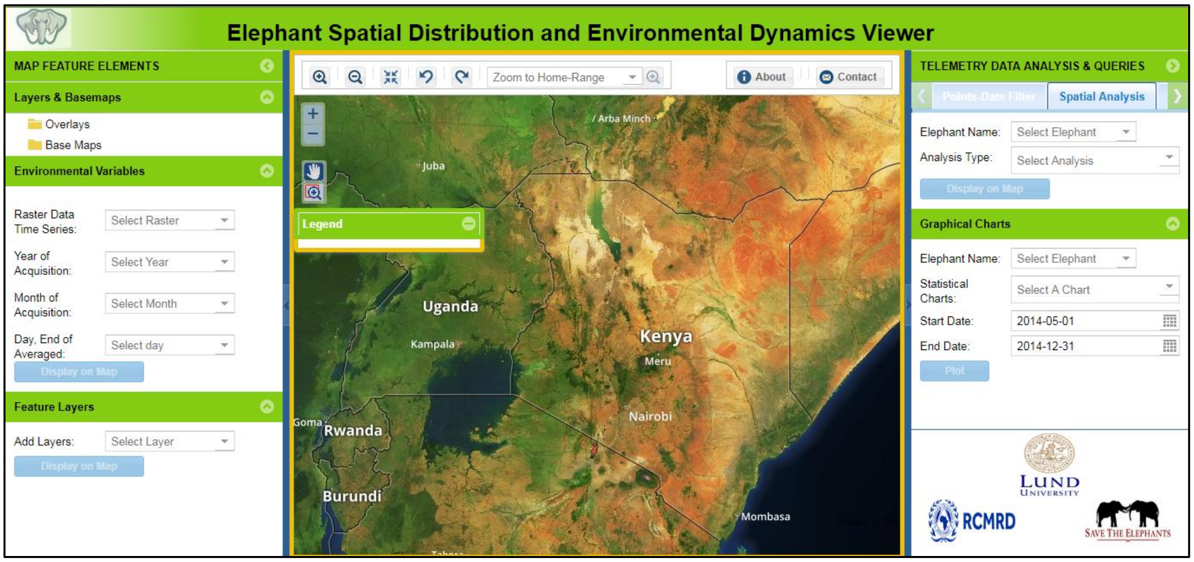


Fig 4: The Graphic User Interface of the web mapping application

The right panel comprised of the Telemetry Data Analysis and Queries window, Graphical Charts, and Logo window. These items performed functions for elephant point's queries and analysis, chart analysis and visualization and displaying logos for the relevant institutions respectively.

The GeoExtMapPanel provided a panel container for the selected map to allow its visualization. It also added the base map from a pre-defined list such the online Google maps services or Kenya Counties Geojson layer, depending on internet availability.

The RasterSearchMapForm was used for providing the user with a list of combo boxes for allowing searching on raster granules from Geoserver database. It offered a drop-down menu with a pre-defined list of stored items.

The MainToolbar contained the Toolbar menu which comprised of buttons necessary for enhancing user's interactivity within the web mapping application graphical user interface.

The ElephantAnalysisForm allowed a user to search, select and display different elephant analytic maps such as the KDE, ETD, Percent UD, Proximity analysis etc.

The ElephantQueryForm allowed a user to query and display map outputs from several computations such as points in/outside the protected area, points closer to human habitats, points closer to river lines etc.

The ElephantDateForm permitted a user to search, retrieve and visualize elephant GPS collaring points for a specific time interval and consequently making comparisons with the existing environmental parameters such as NDVI, LST, and PPT.

The StatisticalChartForm was designed for the purposes of allowing a user to display several graphical charts such as elephant distance/day, mean NDVI, LST or PPT for a given time period.

3.3.5 Web GIS Back-End Development

Back-end or server-side development, on the other hand, entails developing scripts that interact with the web servers and the database, in this case, Apache and Tomcat servers and PostgreSQL-PostGIS databases (Sentence & McNicol, 2016). These scripts were used for performing queries and analysis, facilitating search and populating drop down-menus, loading maps etc.

Python was the preferred back-end programming language for this project and is also one of the many procedural languages (PL) adapted for use as a server-side programming language in PostgreSQL RDBMS.

Python also allows importation of other modules and packages such as Common Gateway Interface (CGI), Geoserver Rest API, Psycopg2, JSON, Urlparse etc. most of which were applied in the server script development. A number of python scripts were developed for various purposes, this included scripts for raster search, elephant date filter, elephant analysis, elephant queries and chart analysis.

Several python scripts were developed for the purposes of searching for existing raster files in the geoserver databases which had been stored as geoserver raster mosaic granules. The eventual result displayed dates available for a particular raster type for the user to select and visualize in the map viewer.

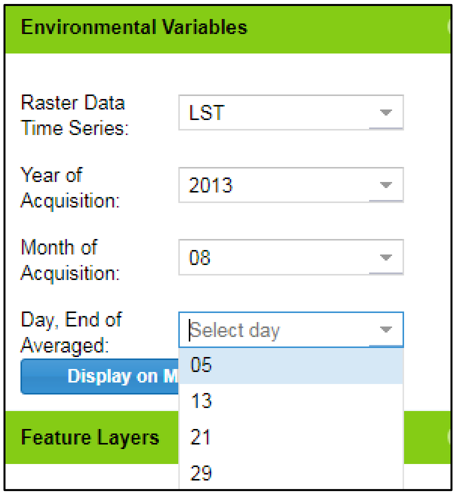


Fig 5: The RasterSearchForm displaying dates available from the geoserver raster mosaic

The elephant date filter script was developed for the purposes of searching and displaying of the elephant's GPS collaring points for a given period of time. This script allowed querying of a particular elephant points for a defined time range and thereafter comparing the points with raster files for the same time period.

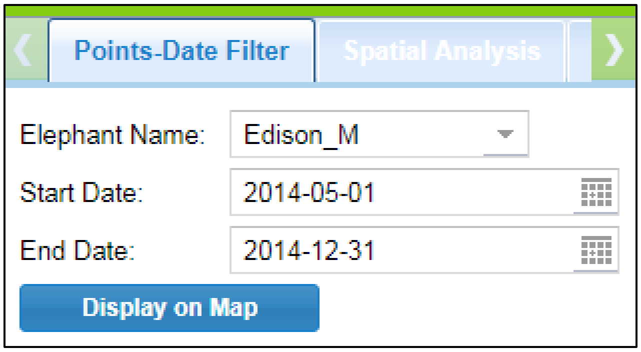


Fig 6: The ElephantDateForm for searching through the elephant points for a given time period

The elephant analysis scripts were developed for the purposes of running analytic computations or displaying analytic results from PostgreSQL database. This comprised of functions such as proximity tests and analysis, overlap analysis, percent UD analysis, ETD and KDE analysis.

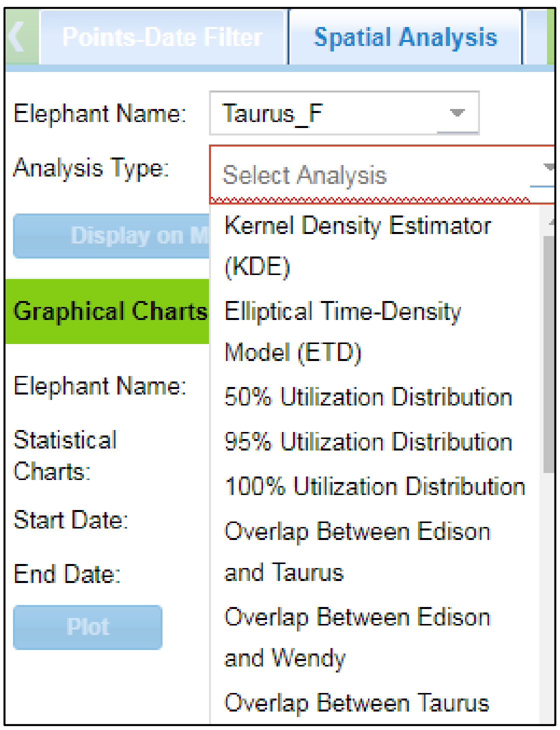


Fig 7: The ElephantAnalysisForm window for selecting analytic functions

The elephant queries scripts were mostly used for comparing elephant points with respect to both physical and anthropogenic features. The physical features included protected areas and river lines while anthropogenic features comprised of human settlements and other related features.

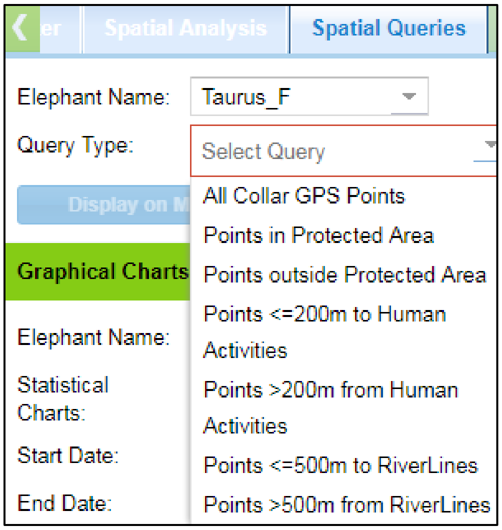


Fig 8: The ElephantQueryForm window for selecting different queries

The chart analysis script was used for creating graphical charts from statistical datasets such as the elephant daily distance coverage, mean NDVI, mean LST and Mean PPT. These graphs were used for the assessment of trends, behavioral changes and, comparisons between elephant distance coverage and environmental dynamics.

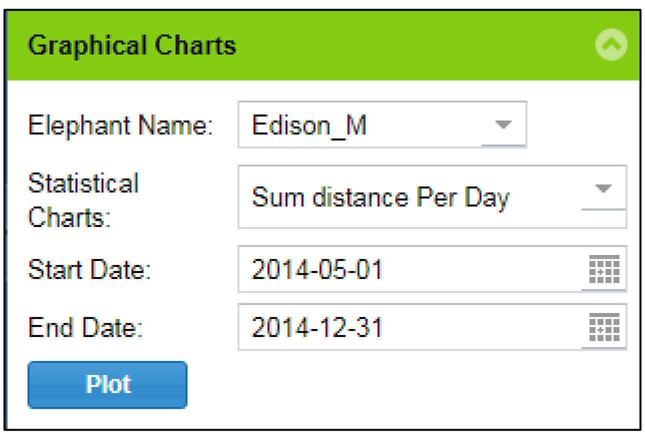


Fig 9: The StatisticalCharForm for selecting and displaying different statistics graphical charts

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4.0 Results and Discussions

4.1 Home Ranges, Utilization Distribution and Association

Home ranges were estimated using Minimum Convex Polygon and Taurus had the largest home range covering 2675 square kilometers, whereas, Edison's and Wendy's home ranges were 1985 and 1978 square kilometers respectively.

These results corresponds with previous studies conducted within Samburu-Laikipia ecosystems where 20 female elephants monitored for 25 months had their home ranges varied from 102 to 5527 square kilometers (Thouless, 1996).

Table 7: Home range areas of the three elephants

Edison Area (Km2)	**Taurus Area (Km2)**	**Wendy Area (Km2)**
1985	2675	1978

Additionally, the home ranges of the three elephants fell within the low elevation areas with altitude ranges of about 600 to 1300 meters above sea level as indicated in Fig 9 below.

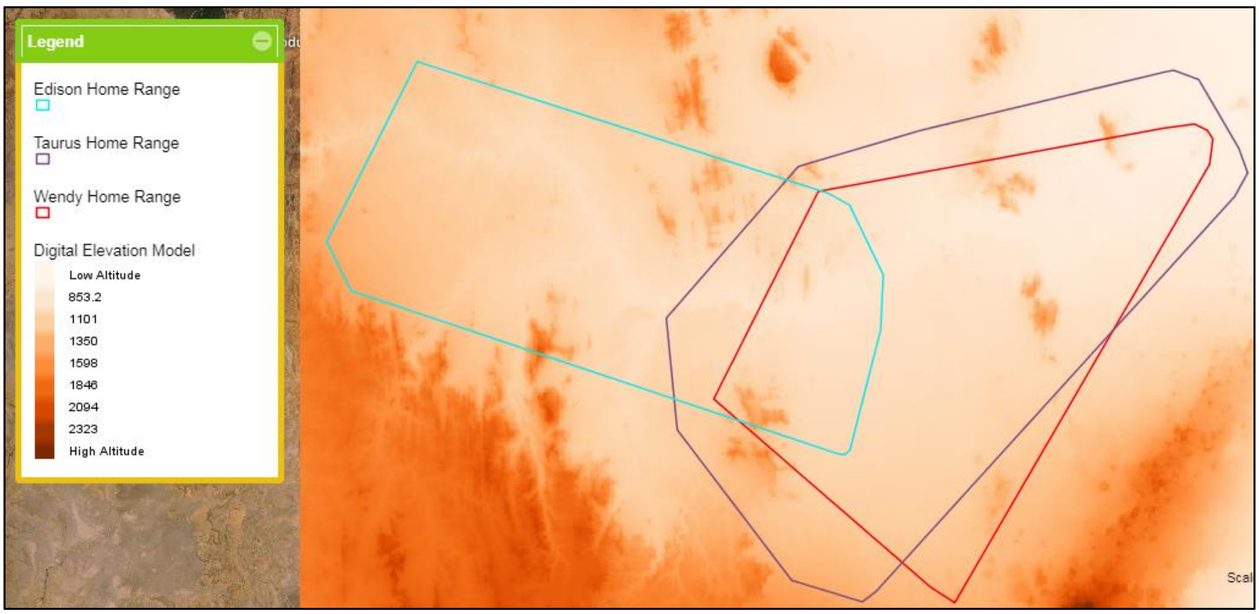

Fig 9: Overlay between elephant's home ranges and the DEM

This has also been recorded in previous studies within this ecosystem, where elephants were observed to avoid hilly and mountainous regions (Wall et al, 2006).

The Kernel Density Estimator and Elliptical Time Density functions were applied in utilization distribution analysis. The outputs of the two functions were closely related and gave quite a similar impression of how elephants utilize spatial resource within a given period of time.

These gridded map output results became clearer when combined with the UD Percent Contours. The 50% and 95% UD gave a vivid impression of the core range versus the peripheral range for a particular elephant.

In the gridded raster's output below, a higher concentration of red color indicated an increased presence of an elephant at a particular location while lighter shades of yellow indicated decreased presence.

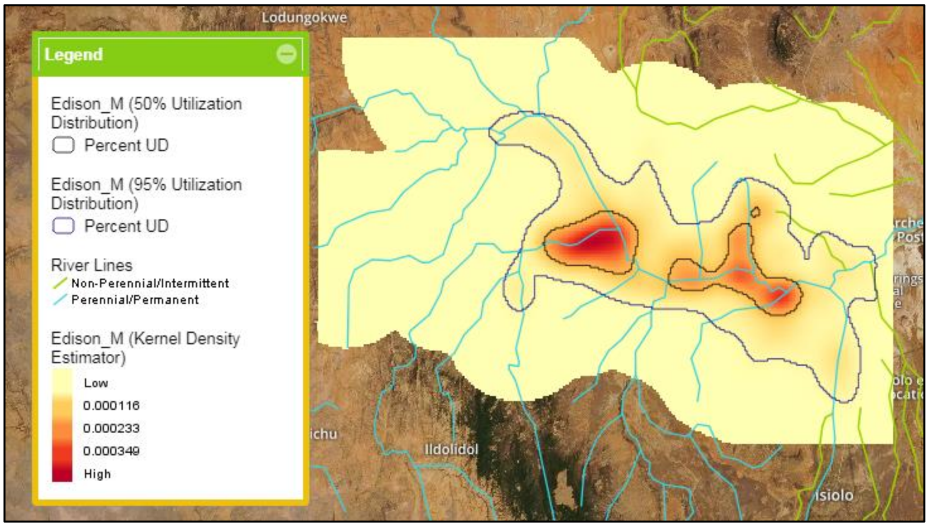

Fig 10: Edison KDE, 50%UD, 95%UD and river lines

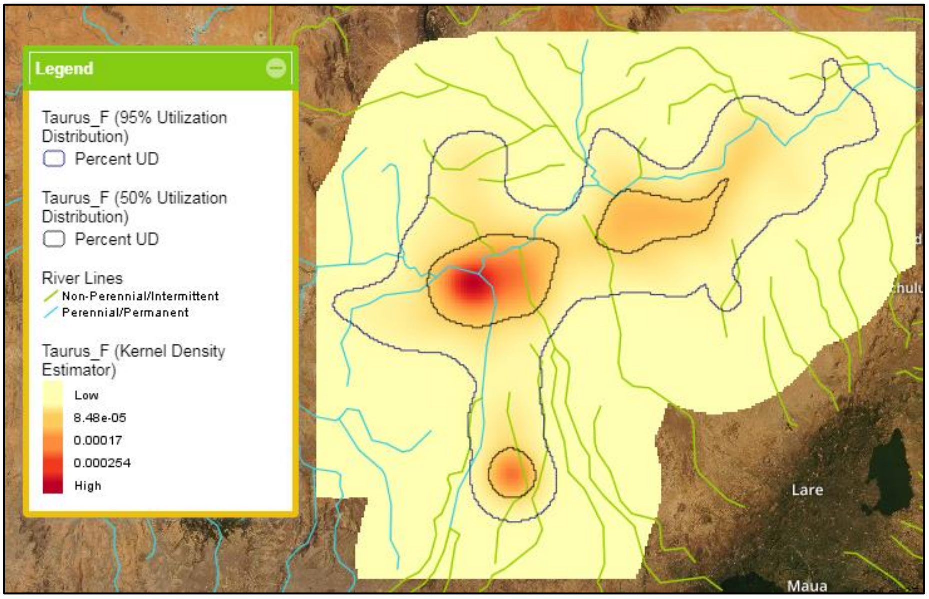

Fig 11: Taurus KDE, 50%UD, 95%UD and river lines

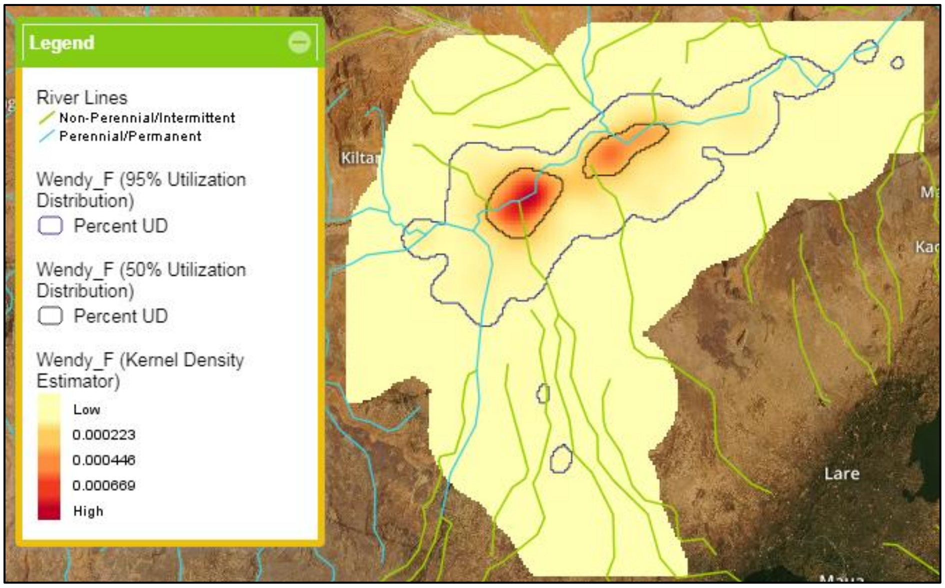

Fig 12: Wendy KDE, 50%UD, 95%UD and river lines

The core ranges (50% UD) for all the three elephants were mostly situated within the protected areas and closer to permanent riverine ecosystems while the peripheral ranges (95% UD) for the two female elephants (Taurus & Wendy) extended southwards, away from protected areas to other land use types such as municipalities and districts - that were deemed to have a higher human presence as shown in Fig 13.

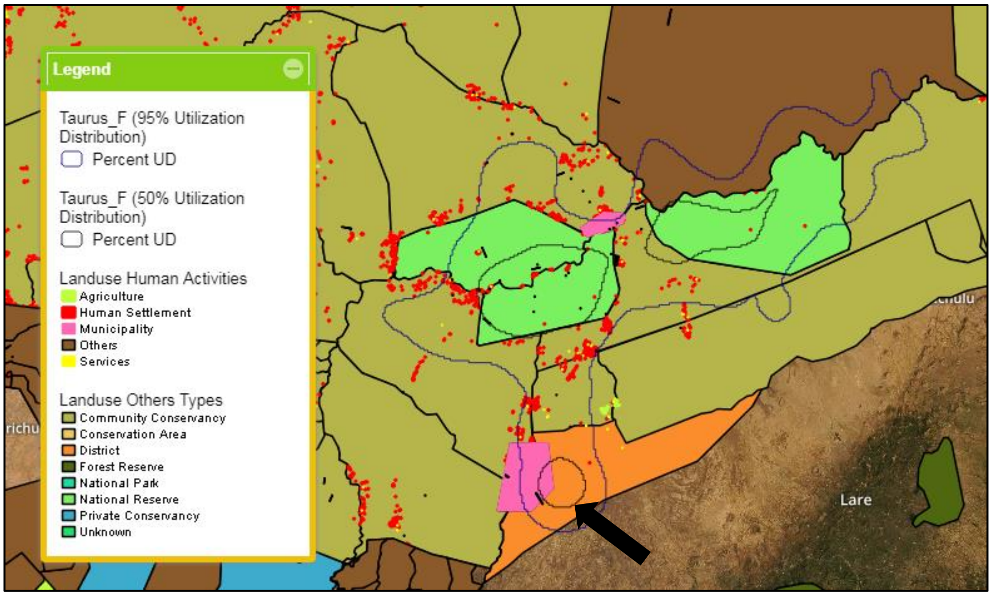

Fig 13: Taurus 50 & 95% UD, land use human activities and other types

This tendency to venture and spend time in high-risk areas is likely to point to the existence of an important resource such as salt licks that seems to attract elephant subgroups, thus of high conservation value in this ecosystem.

Association and interactions between elephants in Samburu-Laikipia ecosystems have been previously studied (Thouless, 1996; Wittemyer et. al, 2005a; Wittemyer & Getz, 2007). Most of these studies have pointed to a great deal of interactions within family units, subgroups, and groups.

Moreover, using the web GIS approach, we investigated the interaction between individuals, such as the male elephant (Edison) and his female counterparts (Taurus and Wendy).

Overlaps were observed from their MCP's derived home ranges as indicated in Fig 14 and closer analysis using point's buffered to within 1 KM of individual elephants revealed a closer association between Edison and his female conspecifics as shown in Fig 15.

Fig 14: Overlap between Edison – Wendy – Taurus MCP's

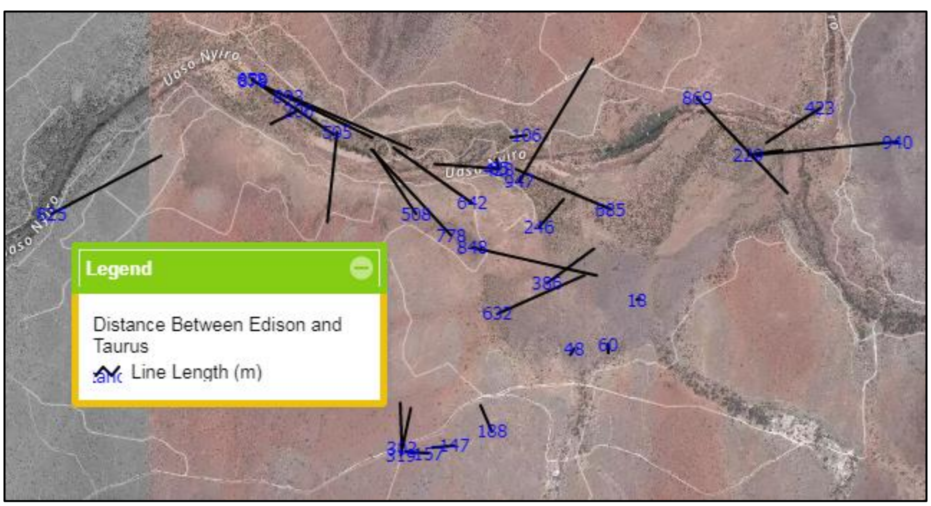

Fig 15: Edison – Taurus distance <1 km

These closer interactions may have resulted due to other factors such as resource requirements or safety in numbers, but we cannot completely overrule mating and other reproductive behaviors in such close encounters.

For instance, when distances between Edison and Taurus are computed from points of less than 1 km, we observed incidents where the two elephants were very close (less than 30 meters) to each other, suggesting a possible reproductive event.

Coincidentally, when the derived tables from this close encounters were compared with the sum of distances covered per day, Edison seemed to cover much longer distances at the same time period (e.g. May – June 2015) as shown in Fig 15, pointing to a possible hyperactivity episode experienced in male elephants referred to as musth.

Animal A Fix Date	**Animal B Fix Date**	**Animal A Name**	**Animal B Name**	**Proximity Distance (meters)**
2015-11-10	2015-11-10	edison	taurus	15
2015-05-30	2015-05-30	edison	taurus	19
2015-11-10	2015-11-10	edison	taurus	27
2015-05-30	2015-05-30	edison	taurus	48
2015-11-10	2015-11-10	edison	taurus	49
2015-11-09	2015-11-09	edison	taurus	54
2015-05-30	2015-05-30	edison	taurus	60

Table 8: Derived table of distance between Edison and Taurus

Bulls such as Edison (above 30 years) synchronize their musth with the onset of estrus period for most female groups. The must period normally lasts for about two to three months and bulls in musth have also been observed to largely increase their daily distance coverage (Rasmussen, 2001) as observed in Fig 15.

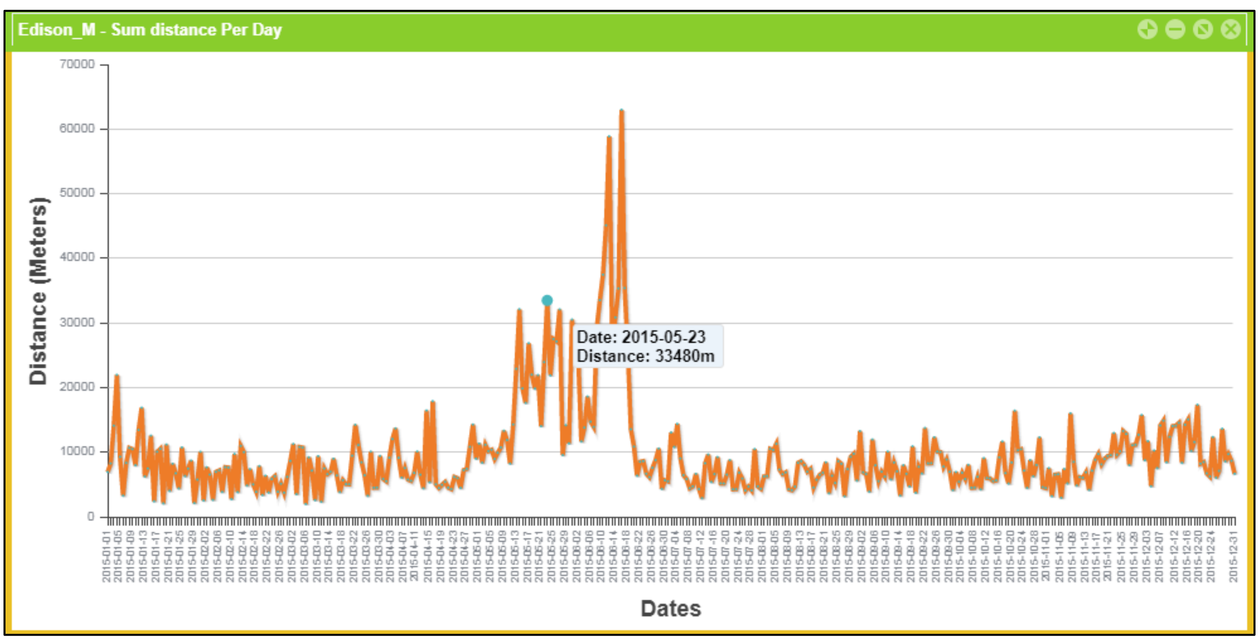

Fig 15: Edison sum of distance per day for the year 2015

Dominance in male elephants is experienced during the musth period, which is characterized by increased levels of testosterone, physical aggression and unpredictable tendencies (Schulte, 2000).

Interesting these spikes of high daily distance coverage by Edison came shortly after or during the long rain season (March – April – May) in all the four years (2014 – 2017) where his telemetry point data existed. Fig 16 shows the rainfall variations for the year 2015 and in particular the long rain season in April 2015.

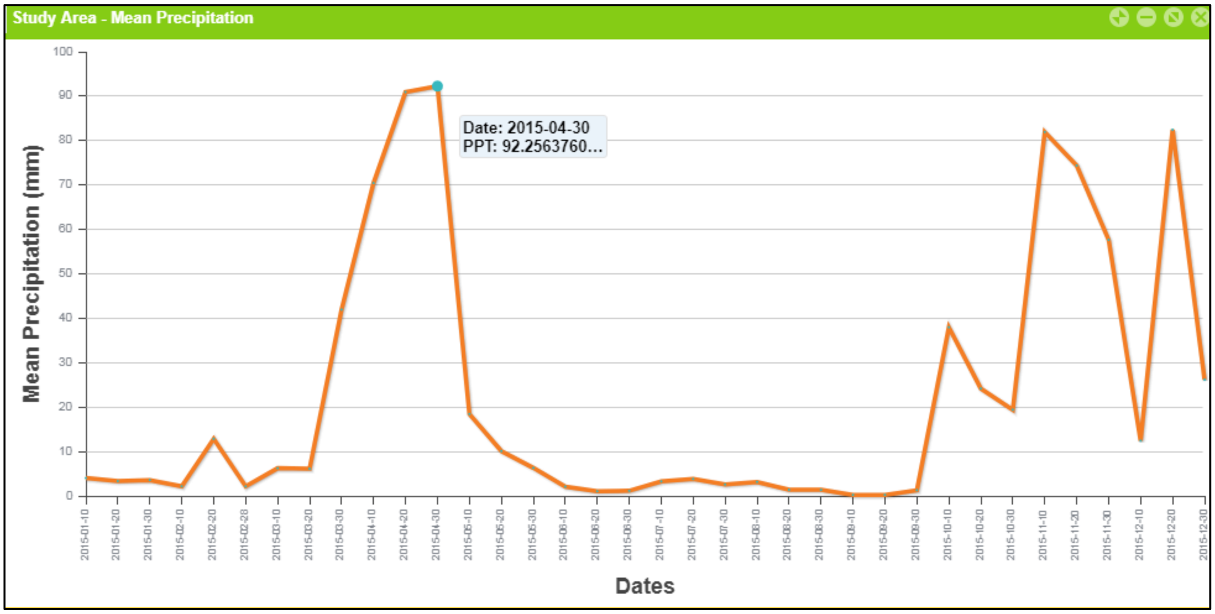

Fig 16: Mean Precipitation for the study area Jan 2015 – Dec 2015

However, this phenomenon was not observed in any of the female elephants and thus, this behavioral change could only be attributed to the perennial dominance musth phase observed in the male elephants. Fig 17 shows Taurus sum of distances for the year 2015, with limited variations in daily distances as observed in Edison graphs.

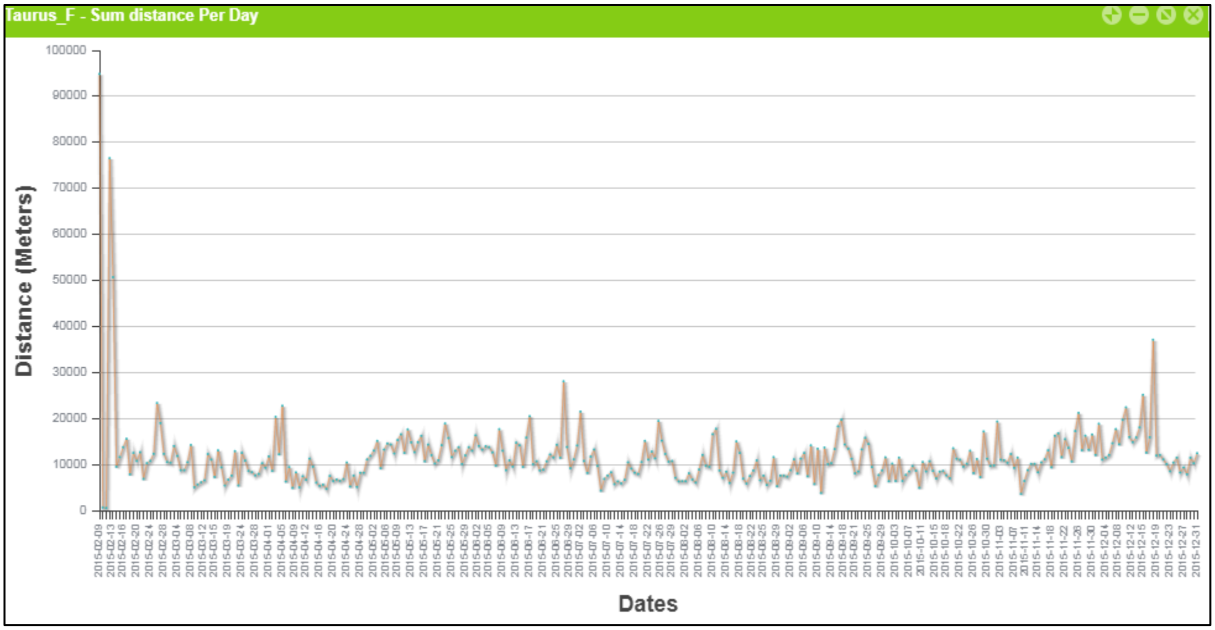

Fig 17: Taurus sum of distance per day for the year 2015

Male elephants in musth advertise their presence using unique rumbles (vocal calls), body odors and postures (Poole & Moss, 1981; Rasmussen, 1988). Musth is displayed by secretions on the temporal glands located below the mouth line and is mostly experienced during the wet season (Poole, 1982).

Nevertheless, male's reproductive success is quite low due to the underlying limitations to accessing the highly mobile female groups which rarely contain females in estrus and if available the estrus period lasts for only 3 or 6 days every 3 to 9 years (Moss, 1983). Another underlying factor is that elephant males tend to compete intensively towards the few estrus females and in some occasions, musth males fight to death (Hall-Martin, 1987; Poole, 1989). Before musth, most male elephants concentrate on feeding on feeding (Jainudeen et. al, 1972; Sukumar, 1989) and as observed in Cambodia, pre-must males are the most notorious crop raiders (Webber et al. 2010).

4.2 Elephant Movement versus Environmental Dynamics

This analysis involved selecting a given environmental variable for a particular period of time and comparing it with a specific elephant points covering the same time period. This was meant to ascertain the level of influences of each environmental variables in determining elephant's use of their spatial resources. Keeping in mind the 8, 10 and 16 days temporal resolution for LST, PPT and NDVI datasets respectively.

For NDVI, a 16-day cumulative telemetry points for each elephant were overlaid on top of NDVI dataset conceding with the end dates points. For instance, Edison points covering the time period 2014-05-09 to 2014-05-25 were mashed up with NDVI data for 2014-05-25 as shown in the preceding figure.

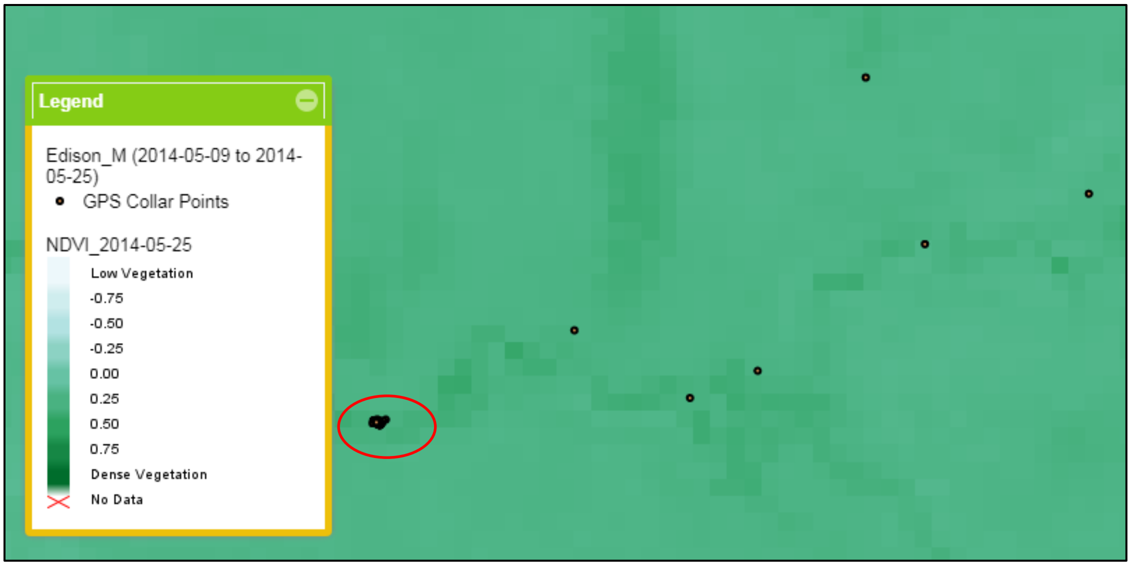

Fig 18: Edison points versus NDVI for 2014-05-25

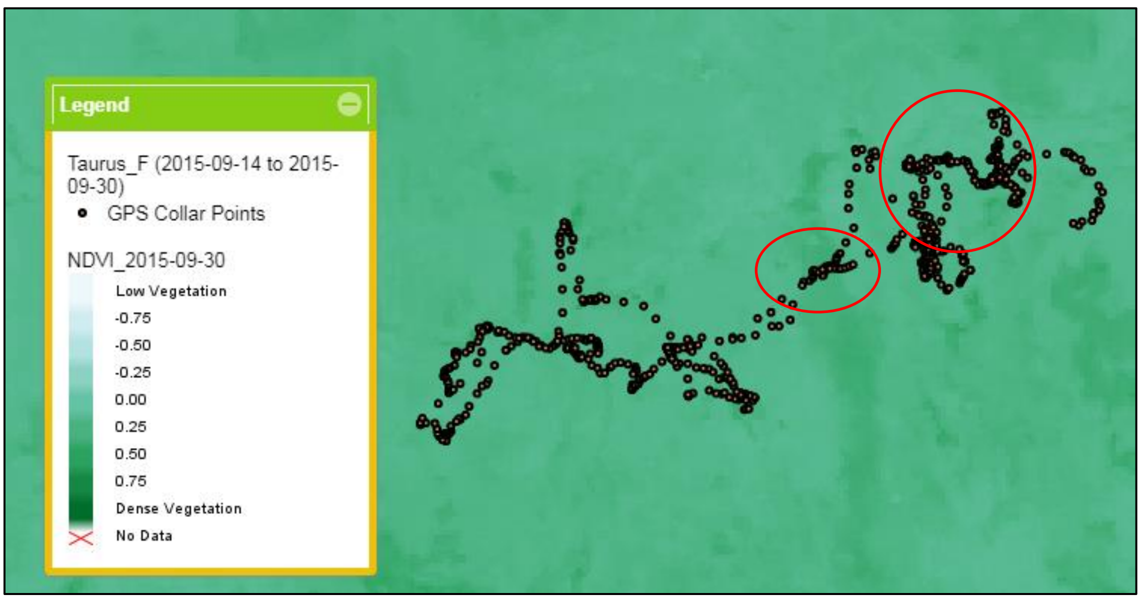

Fig 19: Taurus points versus NDVI for 2015-09-30

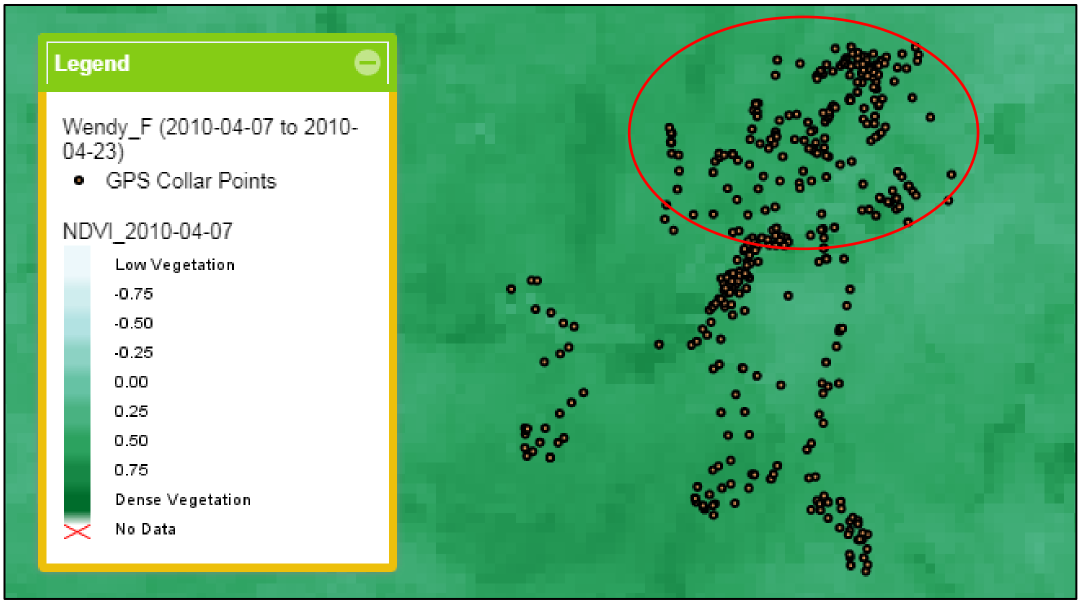

Fig 20: Wendy points versus NDVI for 2010-04-07

From the three maps above, it was clearly evident that elephant made quick movements in regions of decreased primary productivity (low NDVI) as indicated by single points showing tracks, but spend more time in areas with higher primary productivity (high NDVI) as revealed by clusters of points (marked in red circle) in these time periods.

On the other hand, there was no clear evidence of the immediate influence of temperature and rainfall as indicated in Fig 21 and 22 below, on the movement and distribution of elephants within the study area. However, this doesn't overrule the long-term effects of these two critical environmental variables in determining primary productivities and the resultant NDVI variations in a given ecosystem.

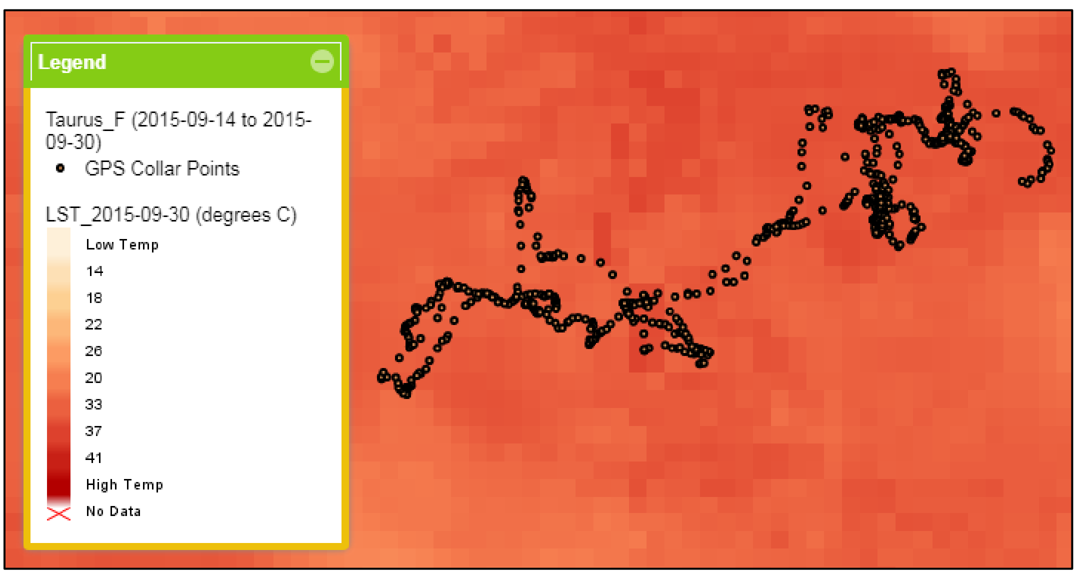

Fig 21: Taurus points versus LST for 2015-09-30

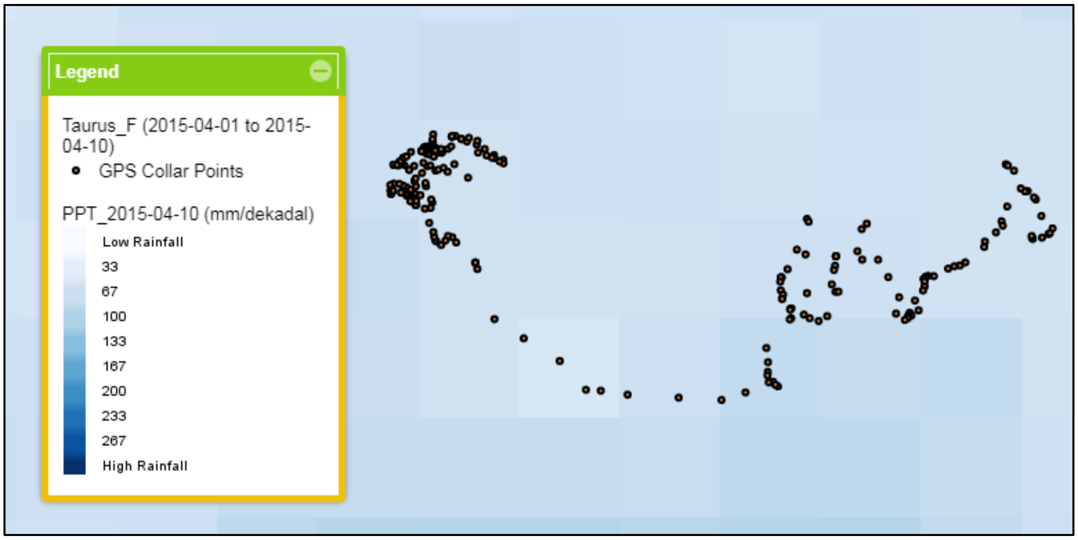

Fig 22: Taurus points versus LST for 2015-09-30

Of the three environmental variables that were used to for testing their levels of influences to elephant movement and distribution, NDVI seemed to be of greatest importance.

High concertation of elephant points coincided with regions of high NDVI values for all the three elephants. Precipitation and temperatures varied across the study area, but NDVI seemed to have a more direct impact on the eventual movement and distribution of the elephants.

However, all the three environmental parameters do have a significant effect on the movement and distribution of elephants in a given ecosystem (Scholes et al. 2003; Van Aarde & Jackson, 2007; Young et al. 2009; Duffy & Pettorelli 2012; Bohrer et al. 2014), however, using the map viewer alone, it proved difficult to observe the immediate impacts of rainfall and temperature which were expected to have a long term effect compared to NDVI (Birkett et al. 2012; Garstang et al. 2014).

4.3 Elephant Movement versus Feature Layers

This analysis involved comparing elephant movement and distribution with a number of important feature layers such as protected area boundary, anthropogenic activities and river lines and to visually assess their levels of impact in determining their eventual presence/absence within the study area.

The subsequent figures (Fig23 – Fig26) indicated the points inside the National Reserves versus the points outside the National Reserves for all the three elephants.

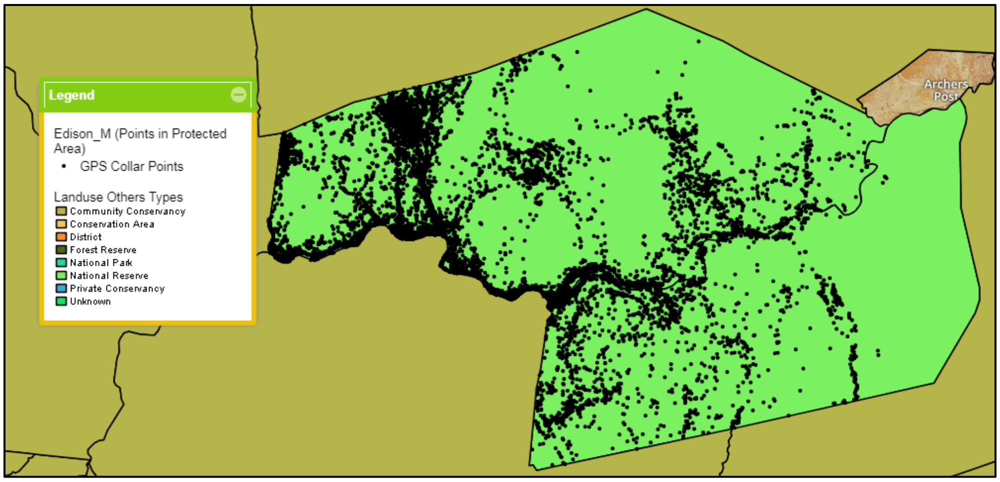

Fig 23: Edison points inside protected area

Edison mostly used the two adjacent National Reserves i.e. Samburu NR on the north and Buffalo Springs to the South. With a much higher presence along the borderline between the two neighboring NR, which basically constituted of the Ewaso Ngiro riverine ecosystem.

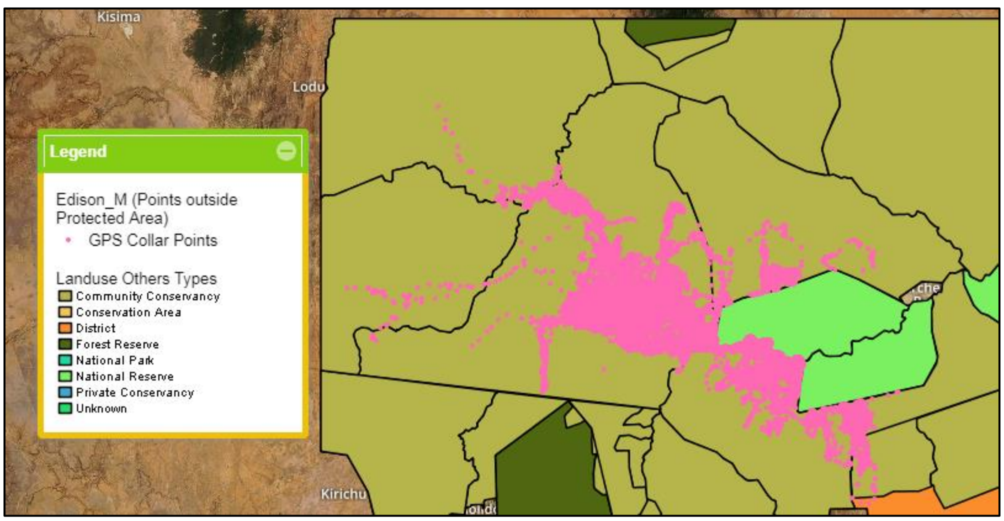

Fig 24: Edison points outside protected area

When an inverse query was conducted, it was noted that most of Edison points fell within community conservancy area, with some of his tracks extending far North West and South West of the National Reserves.

In terms of proportionalities, Edison spent about 30% of his time within the protected area and 70% of his time outside protected areas.

Taurus, on the other hand, utilized all the three National Reserves (Samburu, Buffalo Springs) in-addition to Shaba NR on the Far East (Fig 25). She seemed to have a higher presence in Buffalo Springs and Shaba NR, unlike Edison whose presence was much higher in Samburu NR.

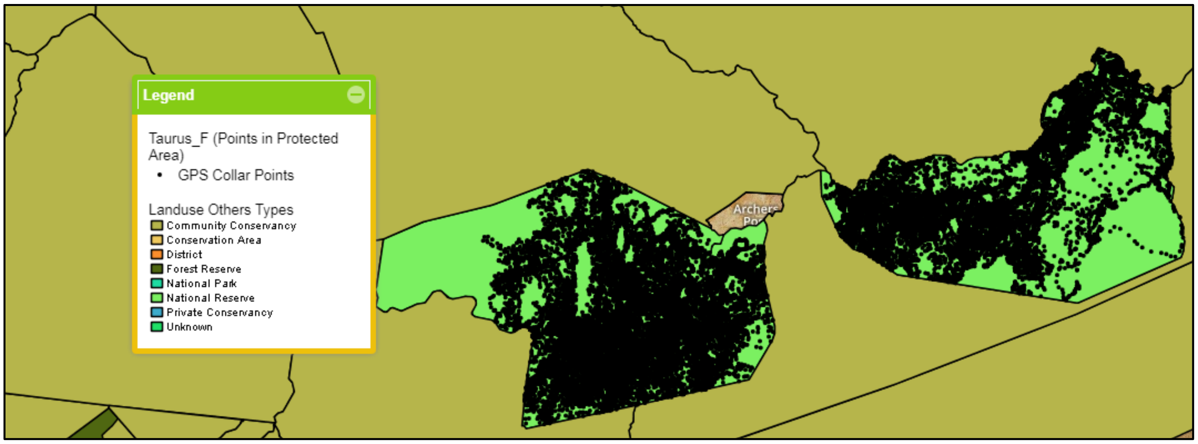

Fig 25: Taurus points inside protected area

Her spatial distribution outside protected area was even more extensive, as she seemed to venture outside community conservancy area to other land use types such as the District which is expected to have a high human presence.

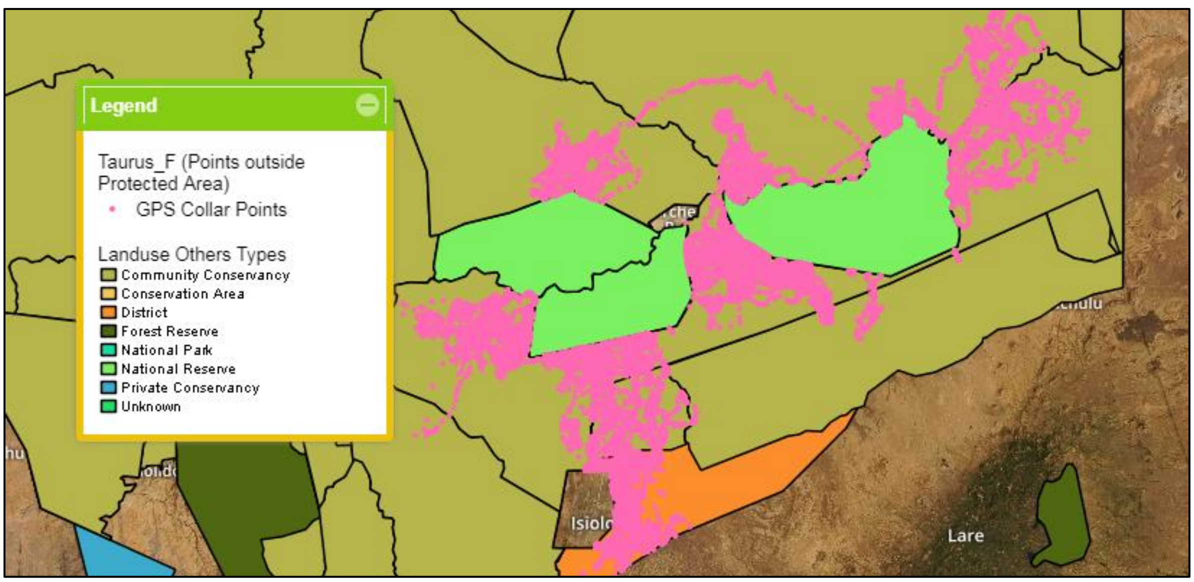

Fig 26: Taurus points outside protected area

However, in terms of proportionalities, Taurus spend about 65% of her time inside protected area and 35% of her time outside the protected area.

Wendy's utilization was similar to Taurus, with a presence in all the three National Reserves (Samburu, Buffalo Springs, and Shaba). She also spends more time in protected areas (70%) than outside protected area (30%).

In comparison, Taurus and Wendy (female) spend more time inside the national park in contrast to Edison who spends more time outside protected areas. This may be attributed to the fact that male elephants form loose social bonds, thus have more freedom to roam around unlike female elephants who are always constrained by their strong social bonds and nutritional requirements (Duffy et al. 2011). However, all the three elephants spend a considerable amount of time outside protected areas, a commonly observed behavior among African elephants (Douglas-Hamilton et al. 2005; Blanc, 2008).

Additionally, in all the conducted queries, elephant points fell exclusively within the National Reserves boundary and none of the elephants utilized either the Forest Reserve or the National Park. This could be attributed to the high-level ecosystem fragmentation and human disturbances along major elephant corridors that act as a link between the National Reserves, Forest Reserves and the National Park within the study area (Douglas Hamilton et al. 2005; Graham, 2009).

The second analysis involved comparing elephant GPS telemetry points with land use human activities feature layer. The land use - human activities layer consisted of classes such as Human Settlement, Agriculture, Aviation, Livestock, Industry, Municipality (towns), Military, Ranch, Transportation etc.

Of greatest importance in this assessment was the clear evidence of high encroachment levels around the protected areas and how they altered elephant movement and distribution within the study area. The following map (Fig 27) represents a marsh up between the Land use Human Activities and Land use other types feature layers.

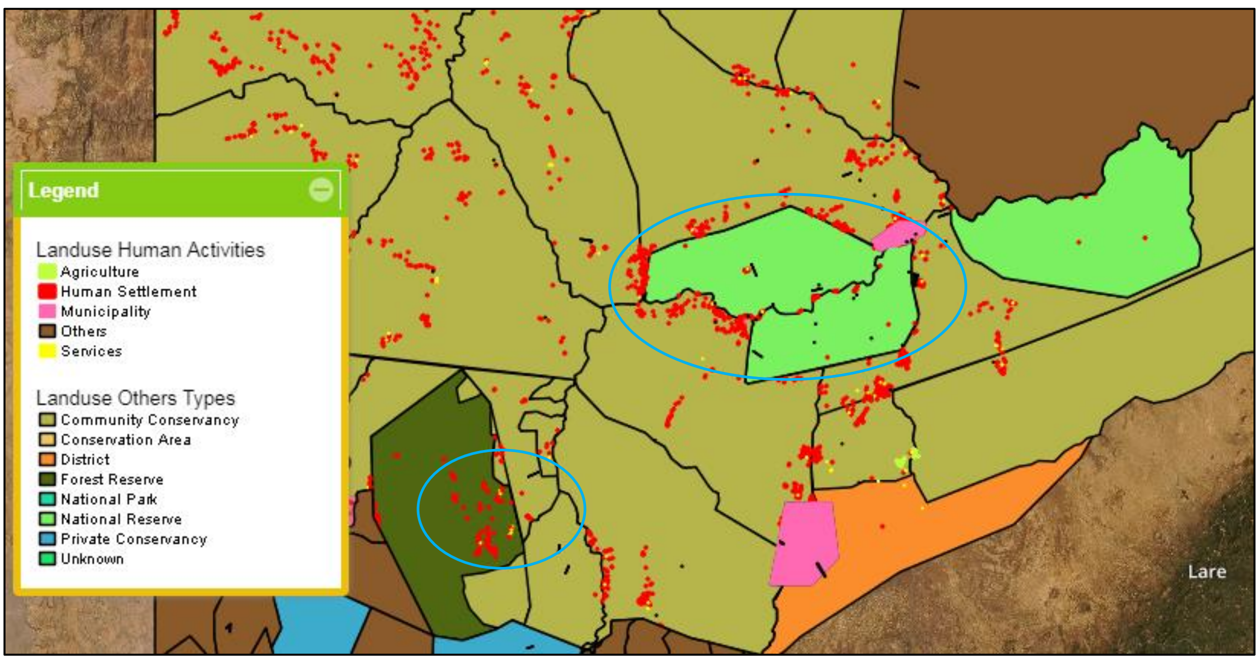

Fig 27: Anthropogenic activities around and within the study area

The map above indicated a high level of anthropogenic activities such as human settlement and aviation inside and around protected areas in this case both the National Reserves and Forest Reserve.

The subsequent query results (Fig 28 – 30) demonstrated how elephants interacted with human-related activities. In this case, elephant GPS points were overlaid on top of land use human activities feature layer to visually ascertain their level of interactions.

In this query, elephant points that were less than or equal to 200meters from human activities were considered to be closer to human activities while the rest (greater than 200meters) were considered to be away from human activities.

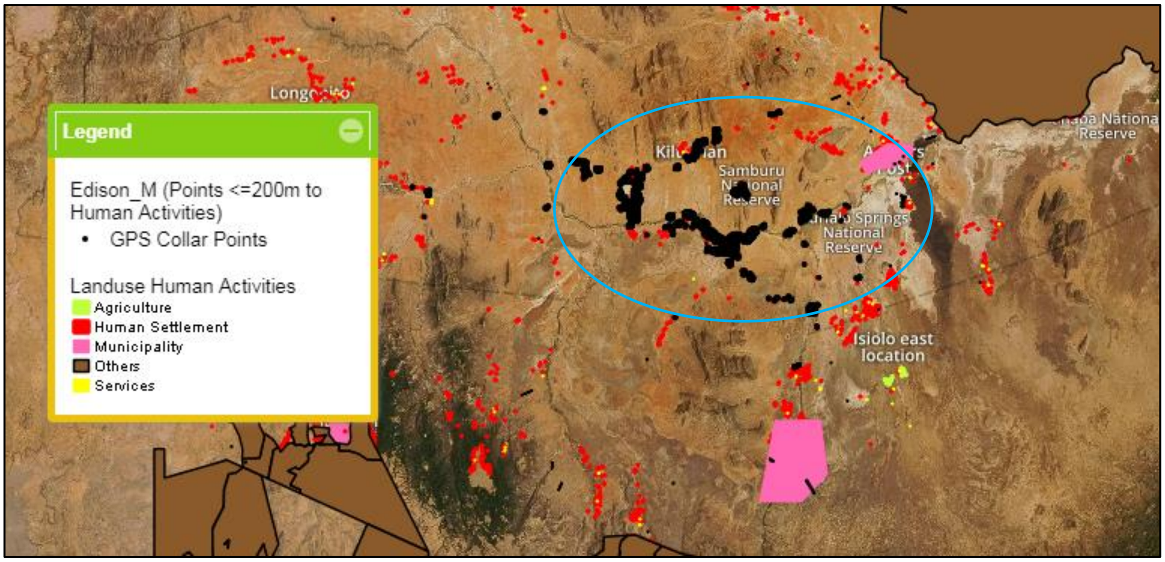

Fig 28: Edison Points closer to human activities

Edison's points seemed to be only closer to Human Settlements and Services (schools, hospitals, shops etc.) but were quite a distance from other land use - human activities classes such as Agriculture, Military, Municipality (town) and Ranch etc. He seldom moved to places with high human-activities and as indicated in the above map (Fig 28) his interaction with human-related activities mostly occurred where anthropogenic activities were situated closer to or inside National Reserves boundaries. In terms of proportionalities, only 24% of Edison's points fell closer to human-related activities whereas 76% of his points were away.

Taurus, on the other hand, ventured much further from the protected areas and much closer to regions with a higher human population such as Municipalities (Town) and Military camp as depicted in Fig 29.

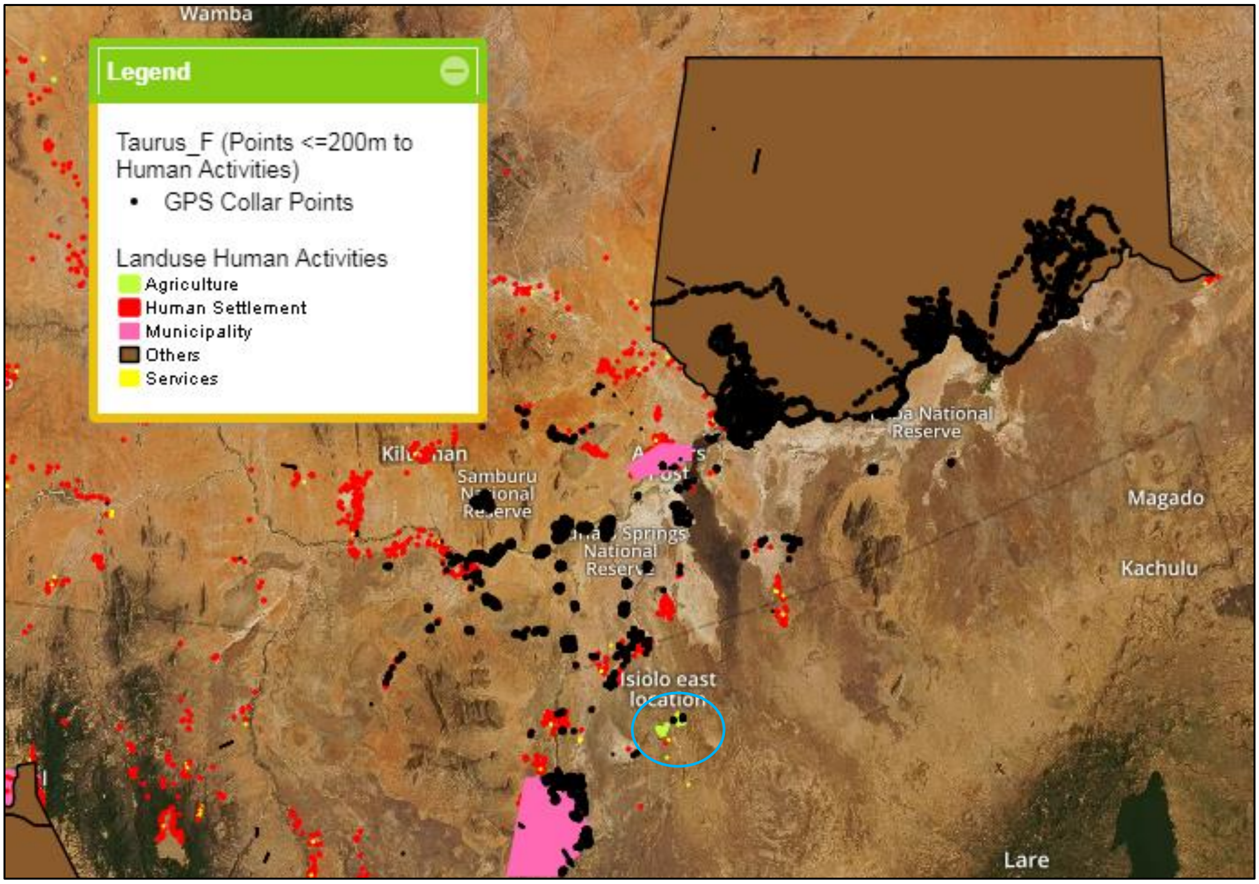

Fig 29: Taurus Points closer to human activities

However, she limited her time in this region by making quick movements across regions with high human-activities. Thus, in terms of proportions, Taurus spends only 13% of her time closer to human activities while the rest is spent away from any human-related activities.

A closer examination of Taurus points indicated that she may also have been involved in crop raiding (Human-wildlife Conflict) activities at some time, since, some of her points fell very close to Agriculture land use type as shown in the figure below (Fig. 30).

Fig 30: Taurus Points closer to Agriculture land use type

Wendy, had more-less the same story as Taurus, with quite a higher proportion of her human-related encounters occurring outside protected areas and in regions with a high human population such as Municipalities and Military camp.

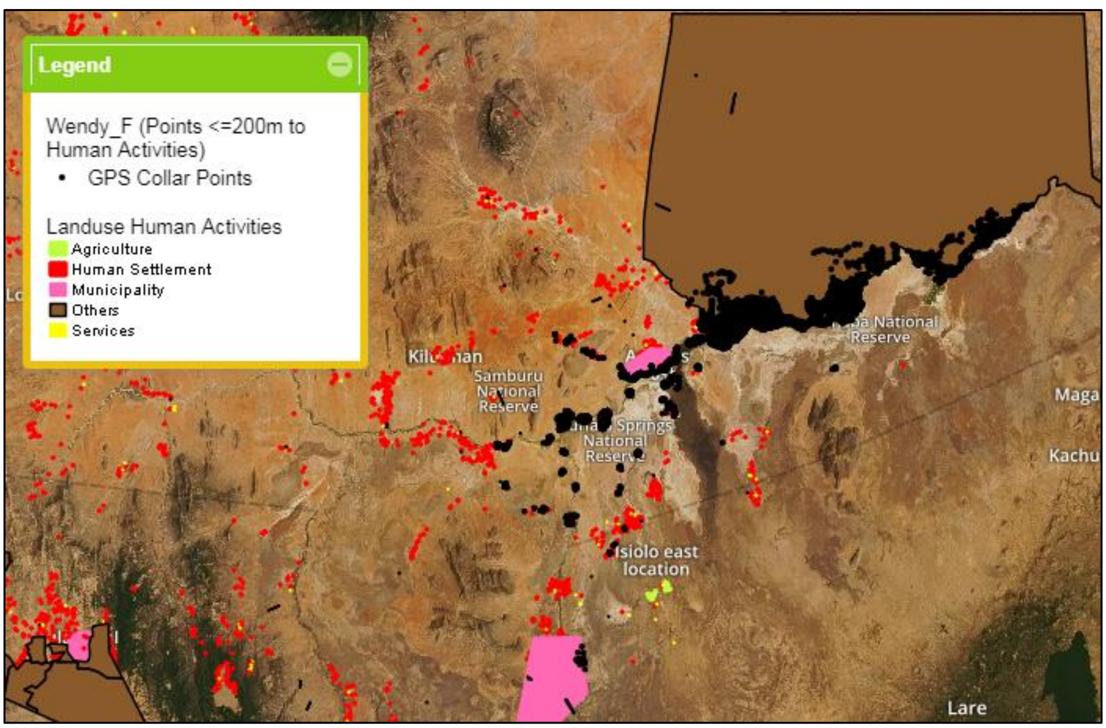

Fig 31: Wendy Points closer to human activities

However, she only seemed to dwell more on the fringes and rarely ventured deep into these land use types, just as Taurus. She also didn't seem to have any points close to Agriculture land use type. In terms of proportions, 28% of her points fell closer to human activities while 78% of her points were away from any human-related activities.

From these analysis, we concluded that all the three elephants spent limited amount of time closer to human-related activities, as they all tend to avoid contact/competition with humans, a commonly observed trend among African elephants (Van Aarde & Jackson, 2007; Jackson et al. 2008; Douglas-Hamilton et al. 2005; Lotoroh et al. 2009; Cook et al. 2015).

Another critical inference was the highly fragmented nature of the study area, which clearly limited the movement of elephants within its natural habitats as previously observed by Kumar et al. (2011). This encroachment to protected areas and other critical elephant corridors may also have contributed to the recent upsurge in human-wildlife conflict experienced in this region (abdulkadir et al. 2013).

The final analysis entailed making spatial comparisons between Elephant GPS points with river line feature layer. The river line layer had two major attribute classes i.e. perennial/permanent and non-perennial/intermittent.

In this query, elephant points that were less than or equal to 500meters from the riverine layers were considered to be within the riverine ecosystem while the rest (greater than 500meters) were considered to be far from the riverine ecosystem. The succeeding map figures (Fig 32 – Fig 34) demonstrated individual elephant within the riverine ecosystems.

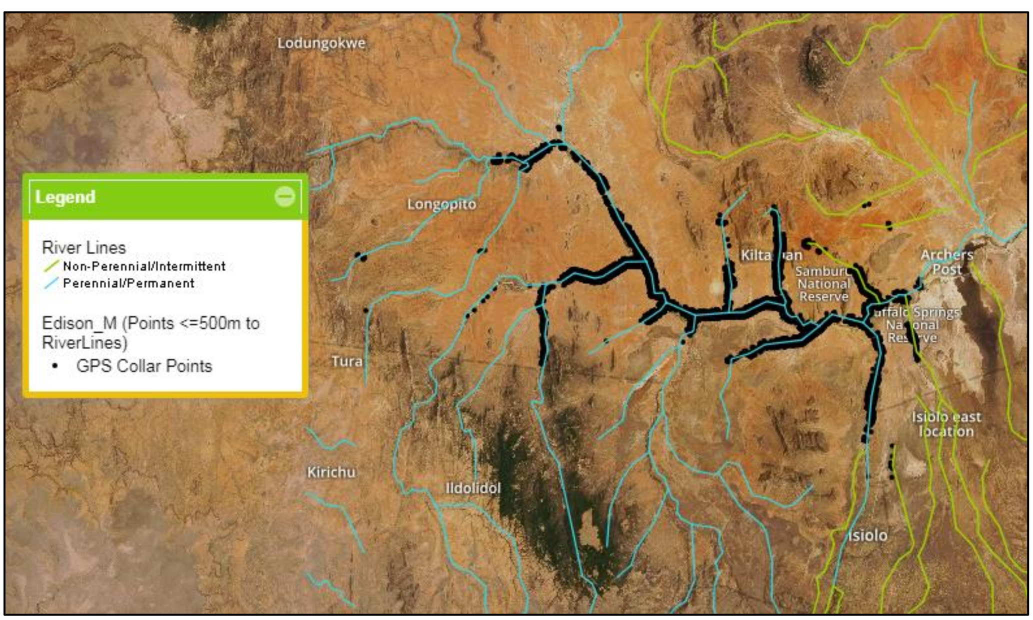

Fig 32: Edison Points within the riverine ecosystem

From the map above and resultant database tables, we deduced that Edison spent about 42% of his time in close proximities of the riverine ecosystems. The database table also indicated that over 95% of this time was spent within perennial/permanent riverine ecosystems.

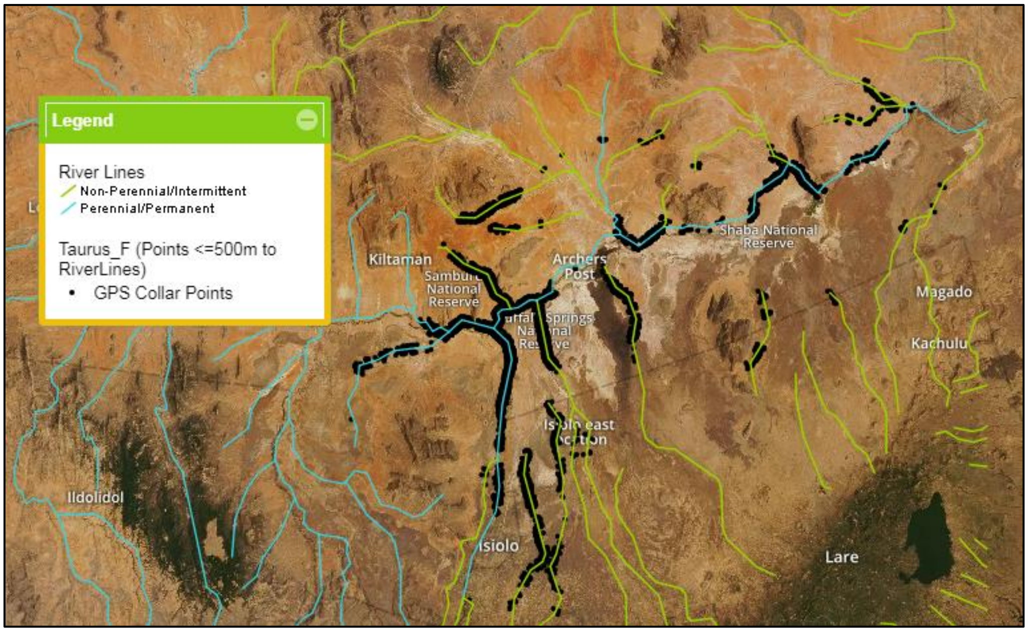

Fig 33: Taurus Points within the riverine ecosystem

Taurus also seemed to spend a significant amount of her time along the riverine vegetation, but lesser time compared to Edison. In terms of percentages, she had about 20% of her points falling within the riverine ecosystem, 60% of which were near permanent rivers.

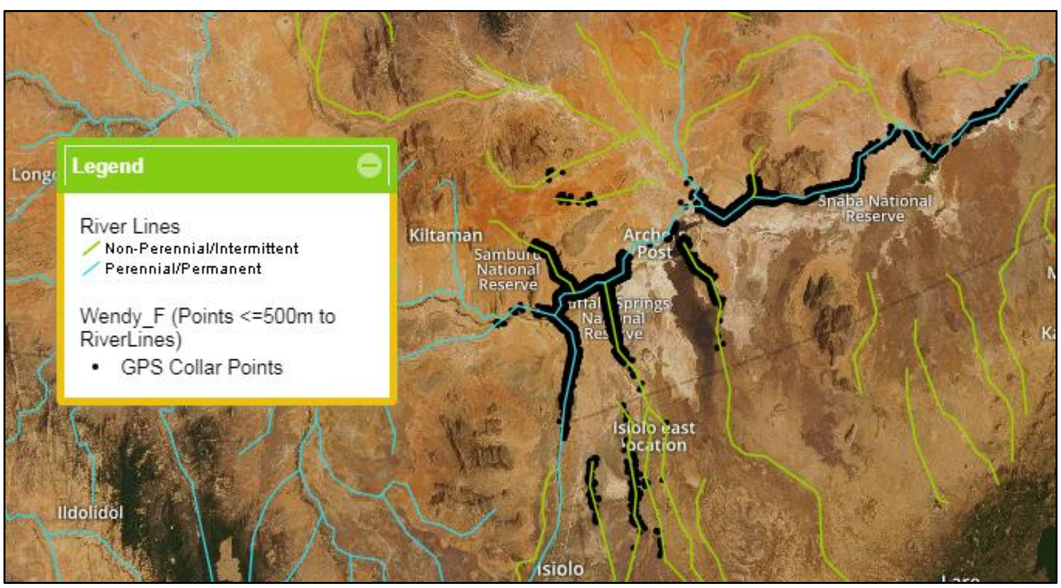

Fig 34: Wendy Points within the riverine ecosystem

Wendy's was similar to Taurus, spending about 28% of her time in close vicinities of riverine ecosystems, 70% of this time closer to permanent rivers. All the three elephants spent a considerable amount of time within the riparian ecosystem. A tendency commonly observed during the dry season, when water is scarce (Chamaillé-Jammes, 2007).

This is due to the fact that elephant's water intake is enormously high, with adults consuming about 160 liters a day (Macdonald, 2009). Elephants in this region have also been observed to have a preferential taste for feeding on the woody vegetation that grows along the permanent riverine ecosystem (Ihwagi et al. 2010).

Previous studies have also indicated that breeding herds amass within water holes, taking a drink at least twice a day (Young, 1970) in the dry season but disperse off during the wet season, when water is no longer a limiting factor (Harris et al. 2008).

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5.0 Conclusions and Recommendations

To conclude, all the results obtained using the web GIS application were consistent with reviewed literature and previous studies undertaken in this area. Therefore, the Web GIS offered a viable approach to the management of elephant and environmental datasets.

This web GIS application demonstrated the abilities to directly ingest datasets from various primary data sources, real time interactive querying and visualization using simple graphical user interface, without the need to manually scan through volumes of datasets and archives, like in a traditional desktop GIS application. This approach offers an opportunity to explore all the datasets (BIG data) at the click of the button, hence, new insights and understandings may as well be derived from using this tool.

This approach also offers an opportunity to sharing the web GIS tool and the existing datasets through the intranet or internet to accredited users within a working group or network, without the need for users to directly download and access the underlying datasets into their personal computers, hence harnessing on the advancements in the web GIS technologies.

This web GIS tool may also function as a reporting platform, where datasets from various sources and analytical products from other tools/applications can be shared through, and users may generate maps and tables in a standardized format. This can allow non-technical GIS users such as wildlife rangers and wardens, to derive quick analytical map products to complement decision making processes and derive sound conservation strategies for elephant management in this ecosystem.

This tool can also be used as an early warning system i.e. addition features as geo-fence may integrated to send alerts to the relevant authorities, incases of elephant encroachment to human settlement or agriculture lands. Wireless sensor networks can also be integrated to the system to detect elephant rumbles and alert the appropriate agencies of approaching or marauding elephants within the vicinity. This is a viable near future research opportunity.

In terms of recommendations, clear policies and guidelines are required to reduce encroachment to protected areas such as the establishment of about 5 – 10 Km's buffer zone from all known protected areas boundaries. This can also be complement by undertaking a proper land use plan to reestablish clear land user policies, to avoid land misuse which in turn results in increased fragmentation.

There's need to increase efforts in the conservation of wetlands and river lines as they play a pivot role in the existence of elephants in this ecosystem. More research is also required to understand why the female elephants groups are utilizing resources at high risk zones (near municipalities land user) and the need to heighten security to reduced HEC at this areas.

It’s appropriate to have a fully automated web GIS tool, where datasets from the elephant GPS telemetry and satellite sources would be programmatically accessed and ingested into the system. To enhance the use of this web GIS tool, additional datasets such as fence lines, poaching incidents and surface water bodies (dams, ponds) would be of great value, to asses’ elephant’s movement and distribution with respect to such critical variables.

Further improvements to the web GIS tool should consider animation of the time-series datasets (elephant GPS points and satellite products) to allow users to concurrently select different layers and visualize changes in an animated series kind of a visualization.

Additional features such as standard login windows with username and passwords would be also be required to restrict access to only a few accredited users. This is due to the confidential nature of elephant telemetry data and the irrefutable consequences of having it in the wrong hands.

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6.1 Appendices

End User License Agreement

The Scripts included in this publication are free to use with proper acknowledgement to the original author. For references use: "Patrick Kabatha, Lund University, Department of Physical Geography and Ecosystem Science, Center for Geographic Information System. June 2018[2]."

The Elephant GPS telemetry data remains under the sole responsibility of Save the Elephants[3] organization and are the only party responsible for sharing and/or distributing.

The Web GIS application source code remains under the responsibility of the developer and can be contacted through: Patrick Kabatha[4], Regional Center for Mapping of Resources[5] for Development, SERVIR Eastern and Southern Africa[6], P.O. Box 632-00618 Nairobi – Kenya.

The external software's and libraries mentioned in this thesis remain under the responsibilities of the owners/distributing companies.

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Appendix A - NDVI Time series python processing script

```
'''
Description:Python Script for processing MODIS NDVI input datasets from the MODIS
Reprojection Tool (MRT). The objective is to pass an argument in the function and the argument
would be the path to the workDir and the python script automate all the processing.
Author: Patrick Kabatha
Date: 23/03/2017
License: Open source – Acknowledge Author
'''
# Import system modules
import arcpy, os, glob, shutil, datetime
from arcpy import env
from arcpy.sa import *

arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

workDir = "D:\\Temp\\shapes\\modis\\temp"

def scaled(workDir): # scaling by multiplying raster files with a factor of 0.0001
    inputDir1 = "\\ndvi_prj"
    env.workspace = workDir + inputDir1
    outWorkspace = "{0}\\ndvi_scaled\\".format(workDir)
    if not os.path.exists(outWorkspace): #check & create output directory
        os.mkdir(outWorkspace)
    rasterList = arcpy.ListRasters("*.tif")
    for raster in rasterList:
        outTimes = Times(raster, 0.0001) #execute times
        outRaster = outTimes.save(outWorkspace + raster)
        print "Output raster files: ",raster
    return

def gregDates(workDir):# convert dates and rename scaled input raster files
    inputDir2 = workDir + "\\ndvi_scaled"
    os.chdir("D:\\Temp\\shapes\\modis\\temp\\ndvi_prj")#hard-code os.chdir != str concat
    outputDir2 = "{0}\\ndvi_greg\\".format(workDir)
    if not os.path.exists(outputDir2):
        os.mkdir(outputDir2)
    rasterList = glob.glob("*.tif")
    for raster in rasterList:
        print "Input raster file: ", raster
        src = os.path.join(inputDir2, raster)
```

```
        year = int(raster[9:13]) #define julian years
        day = int(raster[13:16]) #define julian days
        date=datetime.datetime(year,1,1)+datetime.timedelta(day-1) #julian dates to gregorian dates
        newname="ndvi_" + date.strftime("%Y%m%d") + ".tif" #generate new names
        dst = os.path.join(outputDir2, newname) # define dst path
        shutil.copy(src, dst)
        print "Output raster file: ", newname
    return

def noData(workDir): #assign value 255 to nodata cells
    inputDir3 = "\\ndvi_greg"
    env.workspace = workDir + inputDir3
    outWorkspace = "{0}\\ndvi_final\\".format(workDir)
    if not os.path.exists(outWorkspace): #check & create output directory
        os.mkdir(outWorkspace)
    rasterList = arcpy.ListRasters("*.tif")
    for raster in rasterList:
        arcpy.CopyRaster_management(in_raster = raster,
                    out_rasterdataset = outWorkspace + raster,
                    nodata_value="255", # no data = 255
                    #pixel_type="8_BIT_SIGNED" # use default pixel depth; to retain output data
quality
                            )
        print "Output raster file: ", raster
    return
```

Appendix B - NDVI Statistics python processing script

```
""
Description:
Python Script for generating statistics from NDVI raster time series and saving in a single DBF
file.
Author: Patrick Kabatha
Date: 23/03/2017
License: Open source – Acknowledge Author
'''
import os, arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

#extracts statistics from raster files using zonal statistics to tables
def createDBF():
    #define environment - chrps_final,lst_final,_ndvi_final
    env.workspace = 'D:/Personal/Luma_GIS/Thesis/data/modis/lst_final/'

    #define output dir path
    output_path = 'D:/Personal/Luma_GIS/Thesis/data/modis/stats/lst'

    #define in_zone_data which only accepts a raster or feature layer
    zone_shape = 'D:/Personal/Luma_GIS/Thesis/data/studyarea/study_area2.shp'
    arcpy.MakeFeatureLayer_management(zone_shape,"layer")
    layer = arcpy.mapping.Layer("layer")

    #get all the raster files
    rasters = arcpy.ListRasters()

    #loop through raster files and compute statistics within our study area
    for raster in rasters:
        destination_file = os.path.join(output_path, raster[0:12] + ".dbf")
        outTables = arcpy.gp.ZonalStatisticsAsTable_sa(layer, "Name", raster,
destination_file,"DATA","ALL")
        print outTables

#Aggreate all the dbf's derived from the zonal statistics above
def aggDBFs():

    #define new environment
```

```
    env.workspace = "D:/Personal/Luma_GIS/Thesis/data/modis/stats/lst"

    #get all the dbf files
    tables = arcpy.ListTables("*.dbf")

    #loop through the dbf files and merge them into a single dbf file
    for table in tables:
        tb = os.path.join(env.workspace,table)

        #create new field "Names" and add raster file names to it (ppt_20100110)
        arcpy.AddField_management(table, field_name="Names", field_type="TEXT",
field_length = 20)
        with arcpy.da.UpdateCursor(tb,"Names") as cursor:
            for row in cursor:
                row[0]=table[0:12]
                cursor.updateRow(row)
                print row[0]

        #create new field "Dates" and add raster file dates to it (2010-01-10)
        arcpy.AddField_management(tb, field_name="Date", field_type="TEXT", field_length =
15)
        with arcpy.da.UpdateCursor(tb,"Date") as cursor:
            for row in cursor:
                row[0]=table[4:8]+'-'+table[8:10]+'-'+table[10:12]
                cursor.updateRow(row)
                print row[0]

    #finally merge all the tables into one single table e.g. pptstats.dbf
    arcpy.Merge_management(tables,"lststats.dbf")
    print "Done!"
```

Appendix C - LST python processing script

```
'''
Description:
Python Script for processing MODIS NDVI input datasets from the MODIS Reprojection Tool
(MRT). The objective is to pass an argument in the function and the argument would be the path
to the workDir and the python script automate all the processing.
Author: Patrick Kabatha
Date: 24/03/2017
License: Open source – Acknowledge Author
'''

# Import system modules
import arcpy, os, glob, shutil, datetime
from arcpy import env
from arcpy.sa import *

arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

workDir = "D:\\Temp\\shapes\\modis\\temp"

def scaled(workDir): # scaling by multiplying raster files with a factor of 0.02
    inputDir1 = "\\lst_prj"
    env.workspace = workDir + inputDir1
    outWorkspace = "{0}\\lst_scaled\\".format(workDir)
    if not os.path.exists(outWorkspace): #check & create output directory
        os.mkdir(outWorkspace)
    rasterList = arcpy.ListRasters("*.tif")
    for raster in rasterList:
        outTimes = Times(raster, 0.02) #execute times
        outRaster = outTimes.save(outWorkspace + raster)
        print "Output scaled raster files: ",raster
    return

def average(workDir): #sum lst day and night and then average the output
    inputDir2 = "\\lst_scaled"
    env.workspace = workDir + inputDir2
    outWorkspace_sum = "{0}\\lst_sum\\".format(workDir)
    if not os.path.exists(outWorkspace_sum): #check & create output directory
        os.mkdir(outWorkspace_sum)
    outWorkspace_avg = "{0}\\lst_avg\\".format(workDir)
    if not os.path.exists(outWorkspace_avg): #check & create output directory
```

```
        os.mkdir(outWorkspace_avg)
    outWorkspace_degC = "{0}\\lst_degC\\".format(workDir)
    if not os.path.exists(outWorkspace_degC): #check & create output directory
        os.mkdir(outWorkspace_degC)
    rasterList1 = arcpy.ListRasters("*Day*")
    rasterList2 = arcpy.ListRasters("*Night*")
    for lstdy in rasterList1:
        for lstnt in rasterList2:
            if lstnt[8:16] == lstdy[8:16]: #select files with similar dates names

                outputName1 = "sumlst_" + lstnt[9:16]+ ".tif" #define output name1
                outSum = Plus(lstdy, lstnt)#compute sum of day + night raster
                outSum.save(outWorkspace_sum + outputName1)
                print "Output sum raster files: ", outputName1

                outputName2 = "avglst_" + lstnt[9:16]+ ".tif" #define output name2
                outAve = Divide(outSum, 2)#compute average of day + night raster
                outAve.save(outWorkspace_avg + outputName2)#save to avg workspace
                print "Output average raster files: ", outputName2

                outputName3 = "lstdegC_" + lstnt[9:16]+ ".tif" #define output name3
                outdegC = Minus(outAve, 273.15)#convert average outputs to degrees celsius
                outdegC.save(outWorkspace_degC + outputName3)#save to degC workspace
                print "Output degC raster files: ", outputName3
    return

def reclss(workDir):# reclassify lst <0 values to no data;clip same extent as ndvi;no data = 255
    inputDir3 = "\\lst_degC"
    env.workspace = workDir + inputDir3
    outWorkspace_reclss = "{0}\\lst_reclss\\".format(workDir)
    if not os.path.exists(outWorkspace_reclss): #check & create output directory
        os.mkdir(outWorkspace_reclss)
    outWorkspace_clip = "{0}\\lst_clip\\".format(workDir)
    if not os.path.exists(outWorkspace_clip): #check & create output directory
        os.mkdir(outWorkspace_clip)
    rasterList = arcpy.ListRasters("*.tif")
    for raster in rasterList:
        outputName4 = "lstreclss_" + raster[8:15] + ".tif" #define output name4
        outReclss = Con(raster,raster, "", "VALUE > 0")#lst <0 to nodata
        outReclss.save(outWorkspace_reclss + outputName4)
        print "Output reclss raster files: ", outputName4

        outputName5 = "lstclip_" + raster[8:15] + ".tif" #define output name5
```

```
        arcpy.Clip_management(in_raster = outReclss, # clip to rect extent (ndvi)
                    rectangle = "36.286 0.564 38.0815 2.517",
                    out_raster = outWorkspace_clip + outputName5,
                    nodata_value = 255, # no data values = 255
                    clipping_geometry = "NONE",
                    maintain_clipping_extent= "MAINTAIN_EXTENT")
        print "Output clip_nodata-255 raster files: ", outputName5
    return

def gregDates(workDir):# convert dates and rename scaled input raster files
    inputDir3 = workDir + "\\lst_clip"
    os.chdir("D:\\Temp\\shapes\\modis\\temp\\lst_clip")#hard-code os.chdir != str concat
    outputDir3 = "{0}\\lst_final\\".format(workDir)
    if not os.path.exists(outputDir3):
        os.mkdir(outputDir3)
    rasterList = glob.glob("*.tif")
    for raster in rasterList:
        #print "Input raster file: ", raster
        src = os.path.join(inputDir3, raster)
        year = int(raster[8:12]) #define julian years/string subset
        day = int(raster[12:15]) #define julian days/string subset
        date=datetime.datetime(year,1,1)+datetime.timedelta(day-1) #julian dates to gregorian dates
        newname="lst_" + date.strftime("%Y%m%d") + ".tif" #generate new names
        dst = os.path.join(outputDir3, newname) # define dst path
        shutil.copy(src, dst)
        print "Final LST output raster files: ", newname
    return
```

Appendix D - LST Statistics python processing script

```
'''
Description:
Python Script for generating statistics from LST raster time series and saving in a single DBF
file.
Author: Patrick Kabatha
Date: 05/04/2017
License: Open source – Acknowledge Author
'''
import os, arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

#extracts statistics from raster files using zonal statistics to tables
def createDBF():
    #define environment - chrps_final,lst_final,_ndvi_final
    env.workspace = 'D:/Personal/Luma_GIS/Thesis/data/modis/lst_final/'

    #define output dir path
    output_path = 'D:/Personal/Luma_GIS/Thesis/data/modis/stats/lst'

    #define in_zone_data which only accepts a raster or feature layer
    zone_shape = 'D:/Personal/Luma_GIS/Thesis/data/studyarea/study_area2.shp'
    arcpy.MakeFeatureLayer_management(zone_shape,"layer")
    layer = arcpy.mapping.Layer("layer")

    #get all the raster files
    rasters = arcpy.ListRasters()

    #loop through raster files and compute statistics within our study area
    for raster in rasters:
        destination_file = os.path.join(output_path, raster[0:12] + ".dbf")
        outTables = arcpy.gp.ZonalStatisticsAsTable_sa(layer, "Name", raster,
destination_file,"DATA","ALL")
        print outTables

#Aggreate all the dbf's derived from the zonal statistics above
def aggDBFs():

    #define new environment
```

```
    env.workspace = "D:/Personal/Luma_GIS/Thesis/data/modis/stats/lst"

    #get all the dbf files
    tables = arcpy.ListTables("*.dbf")

    #loop through the dbf files and merge them into a single dbf file
    for table in tables:
        tb = os.path.join(env.workspace,table)


        #create new field "Names" and add raster file names to it (ppt_20100110)
        arcpy.AddField_management(table, field_name="Names", field_type="TEXT",
field_length = 20)
        with arcpy.da.UpdateCursor(tb,"Names") as cursor:
            for row in cursor:
                row[0]=table[0:12]
                cursor.updateRow(row)
                print row[0]

        #create new field "Dates" and add raster file dates to it (2010-01-10)
        arcpy.AddField_management(tb, field_name="Date", field_type="TEXT", field_length =
15)
        with arcpy.da.UpdateCursor(tb,"Date") as cursor:
            for row in cursor:
                row[0]=table[4:8]+'-'+table[8:10]+'-'+table[10:12]
                cursor.updateRow(row)
                print row[0]


    #finally merge all the tables into one single table e.g. pptstats.dbf
    arcpy.Merge_management(tables,"lststats.dbf")
    print "Done!"
```

Appendix E – PPT Precipitation python processing script

```
""
Description:
Python Script for processing MODIS NDVI input datasets from the MODIS Reprojection Tool
(MRT). The objective is to pass an argument in the function and the argument would be the path
to the workDir and the python script automate all the processing.
Author: Patrick Kabatha
Date: 25/03/2017
License: Open source – Acknowledge Author
'''

# Import system modules
import arcpy, os, glob, shutil
from arcpy import env
from arcpy.sa import *

arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

workDir = "D:\\Temp\\shapes\\modis\\Final"

def clip(): # clip to study area extent and assign 255 to no data
  inputDir1 = "\\chrps"
  env.workspace = workDir + inputDir1
  outWorkspace = "{0}\\chrps_clip\\".format(workDir)
  if not os.path.exists(outWorkspace): #check & create output directory
    os.mkdir(outWorkspace)
  rasterList = arcpy.ListRasters("*.tif")
  for raster in rasterList:
    arcpy.Clip_management(in_raster = raster,
              rectangle = "36.286 0.564 38.0815 2.517",
              out_raster = outWorkspace + raster,
              nodata_value = 255, #no data = 255
              clipping_geometry = "NONE",
              maintain_clipping_extent= "MAINTAIN_EXTENT")
    print "Output cliped raster files: ",raster
  return
def rename(): #rename files from default values (chirps-v2.0.2010.01.1.tif)
  inputDir2 = workDir + "\\chrps_clip"
  os.chdir(inputDir2)
  outWorkspace = "{0}\\chrps_final\\".format(workDir)
  if not os.path.exists(outWorkspace): #check & create output directory
```

```
        os.mkdir(outWorkspace)
    rasterList = glob.glob("*.tif")
    for raster in rasterList:
        src = os.path.join(inputDir2, raster)
        nm1 = raster[12:21] #str is immutable; assign a variable
        nm2 = nm1.replace('.', '') # use str method replace
        nm3 = "ppt_" + nm2[:7] + '0' + ".tif" # string concatenation
        dst = os.path.join(outWorkspace, nm3)
        shutil.copy(src, dst)
        print "Output renamed raster files: ", nm3
    return
if __name__ == "__main__":
    print "chrps.py is running as the main program"
else:
    print "chrps.py is being imported into as a module"
```

Appendix F – PPT Statistics Python Processing Script

```
'''
Description:
Python Script for generating statistics from PPT raster time series and saving in a single DBF
file.
Author: Patrick Kabatha
Date: 05/04/2017
License: Open source – Acknowledge Author
'''
import os, arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

#extracts statistics from raster files using zonal statistics to tables
def createDBF():
    #define environment - chrps_final,lst_final,_ndvi_final
    env.workspace = 'D:/Personal/Luma_GIS/Thesis/data/modis/chrps_final/'

    #define output dir path
    output_path = 'D:/Personal/Luma_GIS/Thesis/data/modis/stats/ppt'

    #define in_zone_data which only accepts a raster or feature layer
    zone_shape = 'D:/Personal/Luma_GIS/Thesis/data/studyarea/study_area2.shp'
    arcpy.MakeFeatureLayer_management(zone_shape,"layer")
    layer = arcpy.mapping.Layer("layer")

    #get all the raster files
    rasters = arcpy.ListRasters()

    #loop through raster files and compute statistics within our study area
    for raster in rasters:
        destination_file = os.path.join(output_path, raster[0:12] + ".dbf")
        outTables = arcpy.gp.ZonalStatisticsAsTable_sa(layer, "Name", raster,
destination_file,"DATA","ALL")
        print outTables

#Aggreate all the dbf's derived from the zonal statistics above
def aggDBFs():

    #define new environment
```

```
env.workspace = "D:/Personal/Luma_GIS/Thesis/data/modis/stats/ppt"

#get all the dbf files
tables = arcpy.ListTables("*.dbf")

#loop through the dbf files and merge them into a single dbf file
for table in tables:
    tb = os.path.join(env.workspace,table)


    #create new field "Names" and add raster file names to it (ppt_20100110)
    arcpy.AddField_management(table, field_name="Names", field_type="TEXT", 
field_length = 30)
    with arcpy.da.UpdateCursor(tb,"Names") as cursor:
        for row in cursor:
            row[0]=table[0:12]
            cursor.updateRow(row)
            print row[0]

    #create new field "Dates" and add raster file dates to it (2010-01-10)
    arcpy.AddField_management(tb, field_name="Date", field_type="DATE")
    with arcpy.da.UpdateCursor(tb,"Date") as cursor:
        for row in cursor:
            row[0]=table[4:8]+'-'+table[8:10]+'-'+table[10:12]
            cursor.updateRow(row)
            print row[0]


#finally merge all the tables into one single table e.g. pptstats.dbf
arcpy.Merge_management(tables,"pptstats.dbf")
print "Done!"
```

Appendix G – Index HTML file

```html
<!DOCTYPE html>
<head>
    <title>Elephant Movement and Environmental Dynamics Viewer</title>
   <meta http-equiv="Content-Type" content="text/html; charset=utf-8" />
   <meta name="description" content="This web application is designed to allow visualization of
elephant telementry data alongside
        earth observation (environmental) data.It's meant for a front end user how has access to
these datasets & needs to display outputs in a web environment"/>
   <meta name="keywords" content="web GIS,intenet GIS, ecology, environment, elephants,
GPS, telemetry, location, ndvi, lst, rainfall, samburu, kenya"/>
        <meta name="author" content="Patrick Kabatha"/>
        <meta name="viewport" content="width=device-width, initial-scale=1.0"/>
        <!--Load HTML css styles & images-->
        <link rel ="stylesheet" type="text/css" href="assets/css/custom.css">
        <link rel="shortcut icon" href="assets/images/favicon.ico" />
        <!--Load Application lib-->
        <!-- Load ExtJS styles-->
        <link rel ="stylesheet" type="text/css" href="lib/ExtJS_4.2.1/resources/css/ext-all.css">
        <link rel ="stylesheet" type="text/css" href="lib/ExtJS_4.2.1/resources/ext-theme-
neptune/ext-theme-neptune-all.css">
        <!-- Load ExtJS modules-->
        <script type="text/javascript" src="lib/ExtJS_4.2.1/ext-all.min.js"></script>
        <script type="text/javascript" src="lib/ExtJS_4.2.1/ext-theme-neptune.js" defer></script>
        <!-- Load Google Maps API-->
        <script src="http://maps.google.com/maps/api/js?v=3&sensor=false"></script>
        <!-- Load OpenLayers lib-->
        <script type="text/javascript" src="lib/OpenLayers-2.13.1/OpenLayers.js" defer
></script>
        <script src="assets/js/LoadingPanel.js" type="text/javascript" defer></script>
        <script type="text/javascript" src="loader.js"></script>
</head>
</html>
```

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