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EFFECTS OF UPSTREAM WATER ABSTRACTION ON FLOODPLAINS

CASE STUDY: EWASO NG'IRO NORTH RIVER

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Declaration

I, Mukhwana Laura Vanessa, hereby declare that this project report is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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Name of student Date

This project report has been submitted for examination with our approval as university supervisor(s).

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Name of Supervisor Date

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Name of Supervisor Date

Dedication

I would like to dedicate this to the communities dependent on the floodplains of the Ewaso Ng'iro North River.

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Abstract

Ewaso Ng'iro North River basin is experiencing multiple stressors from water over-abstraction and over-exploitation, land use change and agricultural intensification. Agricultural intensification in upper basin is heavily reliant on water abstraction from river with detrimental impacts particularly reduced dry season flows into downstream areas. This study assesses the impacts of upstream water abstraction on the flooding extent in the downstream floodplains of the Ewaso Ng'iro North River. The methodology used to meet the objectives was reclassification of the Normalized Difference Vegetation Index (NDVI) generated maps to assess and identify the changes in the vegetation cover, NDVI differencing to determine the changed areas along with supervised classification for mapping the spatial extent of mesquite trees specifically, *Prosopis juliflora* (Sw)Dc. The efficient mapping of resulting changes in the floodplains is essential for monitoring the impacts of human activities like water abstraction and it gives crucial information for water resources planning and management. The results indicate that reduced flow has contributed to the reduction is some vegetation cover classes specifically the moderate and dense vegetation. Moderate vegetation has the greatest decline by 58% followed by dense vegetation by 51% from 2002 to 2015. The sparse vegetation on the other hand, increased by 3%. Results indicate that the area lost by the moderate and dense vegetation has been replaced by sparse vegetation, The NDVI image analyses also indicate that the vegetation biomass and health decreased over the period. There is also an increase in the vegetation NDVI reflectances of some vegetation covering 1% while 16% of the reflectances decreased. 83% of the area remained unchanged. *Prosopis juliflora* is also spreading in the floodplains and covers an estimated 19 671ha. This is evidence that the hydrology of the floodplain is changing. More research needs to be done on the impacts of climate change on the floodplains as well as morphological changes that have occurred due to reduced flow. The local authorities also need to find mechanisms for controlling the spread of *Prosopis juliflora*. In addition, the spread of Prosopis should be examined through analysis of more images from previous years so as to monitor its spread and estimate the rate of its invasion.

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Abbreviations

ASALS	Arid and Semi-Arid Lands
DPSIR	Drivers, Pressures, State, Impacts and Responses Framework
EROS	Earth Resources Observation and Science (EROS) Center
E MODIS	EROS Moderate Resolution Imaging Spectroradiometer (MODIS) products
FEWS NET	Famine Early Warning Systems Network
GPS	Global Positioning System
IWMI	International Water Management Institute
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
MEA	Millennium Ecosystems Assessment
USGS	U.S. Geological Survey
VIs	Vegetation Indices

Glossary

Abstraction: the temporary or permanent removal of water from water bodies such as rivers, reservoirs, and underground strata

Assemblage: collection or gathering

Aquatic macrophytes: an aquatic plant, large enough to be seen by the naked eye

Aquatic macro invertebrates: macro invertebrates that live on, under, and around rocks and sediment on the bottoms of lakes, rivers, and streams.

Benthic: occurring at the bottom of a body of water

Biota: the animal and plant life of a particular region, habitat, or geological period

Geomorphology: the scientific study of the origin and evolution of topographic and bathymetric features created by physical, chemical or biological processes operating at or near the Earth's surface)

Lentic: of, relating to, or living in still waters (as lakes, ponds, or swamps)

Macro inverterbrate: organisms without backbones, which are visible to the eye without the aid of a microscope

Morphology: the study of form and structure

CHAPTER 1: INTRODUCTION

1.1 Background

Floodplains are part of alluvial river basins therefore support rich ecosystems and are highly productive. They are critical habitats for various aquatic and terrestrial species and provide lots of services contributing to alleviation of poverty and human well being especially in the arid and semi arid lands (ASALs) around the world (Millennium Ecosystems Assessment (MEA), 2005; Milton and Dean, 2010). The benefits that people derive from floodplains include provisioning (fish, fiber and fresh water provision), regulating (water purification, climate regulation and flood regulation), supporting and cultural (recreational and tourism) services (MEA, 2005).

River basins worldwide are experiencing multiple stressors (anthropogenic and natural). These stressors include water over abstraction, over exploitation, infrastructure development like dams, land use change, pollution and eutrophication, as well as the introduction of invasive alien species (MEA, 2005). The stressors are indirectly driven by population growth and growing economic development therefore human activities are threatening freshwater systems. Wetlands are said to be degraded and lost more rapidly than other ecosystems (MEA, 2005).

Climate change is also a threat to freshwater systems and/or wetlands because it causes habitat degradation and destruction consequently leading to a shift in their species composition (MEA, 2005; International Water Management Institute (IWMI), 2007).

In many river basins, the use of water for agricultural, urban and industrial growth is approaching or in some cases has exceeded the amount of renewable water available (IWMI, 2007) and inducing alterations such as hydrological modifications. As IWMI (2007) points out the reasons for such over-commitment of water resources are disregard for environmental water requirements, insufficient hydrological knowledge, and uncertain water rights not to mention politically motivated projects with weak economic rationale.

The impacts of over-exploitation of water resources have been water quality reduction, degradation of dependent river ecosystems like floodplains, and increased water demand resulting in competition or even conflicts. These challenges are aggravated by a lot of poverty in river basins particularly in the developing countries and the resulting pressure on the allocation of water to the poor (IWMI, 2007).

In the second half of the twentieth century, river basin multi-purpose development focused on the construction of large dams. The number of large dams increased exponentially from 5000 in 1950 to 45,000 in 2000 (IWMI, 2007). The storage capacity of dams has also quadrupled. It is estimated that the water in large dams is three to six times that in natural river channels (MEA, 2005).

An estimated 60% of the world’s rivers have been diverted (IWMI, 2007) with diverse impacts such as water scarcity. Furthermore, water abstraction from lakes and rivers for irrigation, industrial and domestic use has doubled since the 1960s (MEA, 2005). Irrigated areas simultaneously doubled in the same period.

River flows are committed to other downstream uses such as water supply among other ecosystem services and outflow to the sea (for some rivers). Outflow into the sea has several frequently overlooked purposes like flushing sediments, controlling salty water intrusion and the maintenance of estuarine and coastal ecosystems. The increasing abstraction water in several river basins has approached and even exceeded the threshold of renewable water resources resulting in basin closing (IWMI, 2007). The phenomenon of basin closing occurs when river discharges are unable to meet downstream commitments. A basin is said to be closing or closed when its discharge is unable to meet downstream water use commitments during part or all of the year respectively. E.g The Chinas’ yellow river in 1997 dried up for 226 days reaching up to 700km upstream (IWMI, 2007). Closure can also occur in sub-basins or catchments while the wider basin stays open as demonstrated by Rufigi River basin in Tanzania. A sub-basin of the river, the Greater Ruaha Basin, is under stress but many other tributaries still have abundant flows.

Basin closure results in water scarcity for both ecosystems and humans. Water scarcity coupled with limited water access are described in the MEA (2005) as key challenges facing the human society and are major factors that limit the economic development of many countries. Close to 2 billion people globally are affected by water scarcity particularly in Arid and Semi-Arid areas of developing countries.

One of the most important and continuing impact of water abstraction on alluvial river systems has been changes or alterations to the natural flow regime.

The flow regime is important in the creation of river and floodplain morphology as wells as their associated biodiversity and ecosystem services. Substantial evidence exists of the harmful impacts that artificially low flow regimes have on fish, plants, macroinvertebrates and overall river morphology.

The natural flow mainly determines streams' physical habitat consequently determining the biotic composition. The geology and landforms in streams and rivers interact with the flow regime to determine the shape of the river channels. Changes to the form and structure of river channels due to flow regime changes may alter the habitat and consequently its biota. Alterations to the standard hydrological conditions have been found to change the composition, density and abundance of benthic macro invertebrates (Procipio, 2010). The habitat structure also influences the diversity and abundance patterns of fish. The growth of certain aquatic plants is also constrained by low flows. Flow regime changes can also increase the rate of sedimentation therefore affecting sediment loadings sensitive species like fish. Sediment loading affects the growth rates and spawning of fish.

Water chemistry determined by water temperature and dissolved oxygen, plays a role in the maintenance of habitats. Low flows can cause increases in the water temperatures affecting the aquatic plants and animals.

The river flows recharge the ground water and therefore reduced flows result in reduced ground water levels. Invasion of river systems by alien species has also been linked to hydrological changes caused by altered flow regimes. The loss of wet and dry cycles cause disturbances favouring invasion. Bunn and Arthington (2002) report that the greatest success of establishment of introduced invasive species is found in modified, highly disturbed ecosystems as well as in periods of fluctuations in resources (Milton and Dean, 2010). The reduced flows also results in a less flood pulse which leads to lost connectivity among various wetland water bodies.

Upstream water abstraction and its impact in the Ewaso Ng'iro River Basin

Rapid population growth, land conversion and agricultural intensification in this river basin

North River Basin and catchment in general are causing changes in use of land. The population growth in the upper parts of the basin can be attributed to immigration from the neighbouring areas (Blank *et al*., 2002).

Agriculture intensified in the upper parts of Ewaso Ngiro basin since horticulture became profitable in the 1980s. This population expansion combined with agricultural intensification has placed great demands on water and land resources (Ngigi *et al*., 2007). Agricultural production has thrived on the water abstraction particularly in the dry season. An estimated 60 to 90% of the entire river flow is at times abstracted during the dry season (Gichuki *et al*, 1998; Ericksen 2011).. Leeuw *et al*., (2012) examined the permitted water abstractions upstream and found an increasing trend from 1960 to 2010. However, their estimates only accounts legal abstractions not the illegal ones. Ericksen *et al*., (2011) found that almost 90% of water abstractions are illegal.

The ever increasing water abstraction has caused river flows to decline to ecologically unsustainable levels at times. The drought cycles experienced in the region have also aggravated the river flow declines since there is no equal fall in rainfall amounts for equal period. However, Aeschbacher *et al.*, (2005) noted that while there was increasing low discharge the mean discharge did not show a decreasing trend. They link this trend to the high flood peak flows as a result of accelerated run off generation due to land use change in the upper catchment or basin. Liniger *et al*., (2005) using three sub catchments (Burguret, Likii and Timau) of the river examined the trend of low flows. The decreasing flows were found to be mainly due to the water abstractions.

In the past decade the basin has reached and has exceeded water limits availability repeatedly with increasing frequency and duration of no flow beyond Archer's Post (Aeschbacher *et al*., 2005; Ericksen *et al*., 2011). The river is reported to have dried up for a stretch of almost 60 km upstream Buffalo Springs (upstream Archer's Post) in 1984, 1986, 1991, 1994, 1997 and 2000 (Blank, 2002). Likewise, the probability of the river not carrying water downstream to areas like Merti has increased from 2% in 1960 to 27% in 2010 (Ericksen *et al*., 2011). The Ewaso Ng'iro River basin can therefore be described as a closing basin because it at times fails to meet downstream water requirements.

The floodplains locally known as “chaafa” in the local Borana Language are a dry season grazing area for livestock with some parts being drought refuges (Tari and Pattison, 2014). They are a critical part of this rangeland ecosystem that allows the pastoralist to effectively utilize other parts of the rangelands during the wet season (Okumu, 2015). The reduced flows disrupts the provision of vital ecosystem services to the communities, for example, the provisioning services such as water and pasture for livestock therefore affecting the livelihoods of the predominantly pastoralist communities (Ericksen *et al*., 2011).

Reduced river flows coupled with the impacts of droughts cause water scarcity. Water scarcity affects the communities’ livelihoods, that is, pastoralism and subsistence farming. Herders are forced to migrate in search of water and pasture while farms experience failed planting seasons. Water scarcity also threatens human health because it inhibits proper hygiene thus favouring the spread of water borne diseases (Mukhwana *et al*., 2016).

Notter *et al*., (2007) also links water scarcity to the continued conflicts between various water users in the basin. Inter- communal conflicts over water and pasture are common especially during prolonged dry spells. (Ngigi *et al.,* 2007; Aeschbacher *et al*., 2005).

Biodiversity in the river basin is also affected by the reduced flows. The hippopotamus and crocodile population in the river basin have reportedly diminished (Mukhwana *et al*., 2016). Furthermore, the fish in the floodplain wetlands also die when the river dries up. The Lorian swamp, which in this study is considered part of the floodplains, also periodically dries due to reduced flows.

Ecological changes have been observed in the floodplains of the Ewaso Ng’iro North River as indicated by the disruption of the provision of ecosystem services, loss of biodiversity and invasion of the floodplains by mesquite trees specifically *Prosopis juliflora* (Sw)Dc. (invasive alien species) (Mukhwana *et al*., 2016). *Prosopis juliflora* was introduced into the area in 2002 and has since started colonizing the rivers banks and floodplains. It is locally known as “Mathenge”.

Prosopis juliflora is named among the International Union for Conservation of Nature (IUCN) list of top most problematic invaders in the world (Gitau, 2015). Most Prosopis species are native to South America and were introduced into various Kenyan rangelands to provide wood and non-wood products, mitigate the impacts of droughts and to protect natural vegetation from over-exploitation thereby improving the self sufficiency of the inhabitants of these regions (FAO, 2006). The shrub has since spread uncontrollably outside the planned rangelands, extensively invading other ecosystems like wetlands, riparian zones and flood zones (Gitau, 2015).

Although Prosopis species are well adapted to Arid and Semi-arid (ASALs) areas, they only establish in areas with a permanent supply of sub-surface water. Gitau (2015) supports this hypothesis by demonstrating that the existence of the water table and its depth is a decisive factor in the distribution, growth and size of *Prosopis juliflora.* The shrub's invasion also has negative impacts on the availability of grazing areas, biodiversity and herbaceous plant biomass.

The rapid invasion by the shrub into various ecosystems is linked to various factors (Gitau, 2015). It has massive seed dispersal ability through livestock and wild animal and its annual fruit production increasing the seed dispersal chances. *Prosopis juliflora* has wide ecological adaptation to various ecosystems and soil types including nutrient deficient ones due to its nitrogen fixing ability. In addition, its allelopathic properties suppresses the development and growth of other plants around it therefore reducing competition enabling its rapid growth. Disturbances to ecosystems (such as burning, changes to natural flow regime) also facilitate its encroachment.

Local livelihoods in ASALs are mainly dependent on pastoralism and subsistence agriculture and encroachment of the shrub negatively affects them in various ways. Gitau (2015) noted there is a negative relationship between *Prosopis juliflora* and undergrowth especially grasses therefore its continued encroachment will translate into more limited availability of pasture. It could possibly lead to an overall reduction in undergrowth species due to its allelopathic properties and dense and impenetrable bushes that prohibit light penetration therefore limiting the growth of undergrowth. Secondly, the invasion also have negative implications on biodiversity conservation because of reduced undergrowth that provides habitats for various wild animals and birds.

Thirdly, it could possibly result in lowering of sub-surface water levels because it has a higher water uptake as compared to native species. The reduced water levels consequently enable the establishment of Prosopis by promoting the survival of new plants into the floodplains and enabling livestock and wildlife to graze further into the wetland zones dispersing seeds even further (Gitau, 2015).

The shrub, however, has some positive impacts particularly in improving the soil nutrients through nitrogen fixing leaf litter addition and nutrient pumping from deeper soil layers to the top soil. Dense stands of *Prosopis juliflora* also have high carbon sequestration potential. The spread of alien wood species within grasslands has increased soil organic carbon storage.

1.2 Problem Statement

Upstream water abstraction is causing reduced flows of the Northern Ewaso Ng'iro River in the lower basin particularly the floodplains. The reduced flows are causing ecological changes in the floodplains as indicated by the loss of biodiversity disruption of the provision of ecosystem services to the communities like water and pasture as well as the invasion of the floodplains by the invasive alien species *Prosopis juliflora.*

Floodplains like other wetlands are key resource areas especially in arid and semi-arid areas (ASALs). The accurate and efficient mapping of changes in the floodplains is therefore essential for monitoring the impacts of human activities like water abstraction as well as climate change. Such information is vital for water resources planning and river basin management.

1.3 Objectives

1.3.1 Main objective

To assess the effects of upstream water abstraction on the floodplains of the Ewaso Ng'iro North River, Kenya.

1.3.2 Specific objectives

- To identify and assess the vegetation cover changes from 2002 to 2015.
- To create NDVI maps of the vegetation cover changes for the period.
- To map the spatial extent of *Prosopis juliflora* in the floodplains.

1.4 Justification for the Study

The study will contribute to the body of literature on the importance of a holistic approach to river basin water management by highlighting the effects that upstream water abstraction is having on the floodplains downstream.

1.5 Scope of work

The study focused on the impacts of reduced flow mainly due to upstream water abstraction on vegetation cover and not climate change. The vegetation change analysis for the Ewaso Ng'iro North River's floodplains was carried out for a period of 13 years from 2002 and 2015

CHAPTER 2: LITERATURE REVIEW

2.1 Floodplain River Systems

A floodplain can simply be defined as "*a strip of relatively smooth land bordering a stream and overflowed at a time of high water"* (Ganaie *et al*., 2013). They are part of alluvial river basins or systems where sediments are deposited and are seasonally flooded or inundated.

Ganaie *et al*. (2013) presents different perspectives from which floodplains can be defined.

- Topographically: a quite flat area which lies adjacent to a river.
- Geomorphologically: a land form primarily made up of material that is unconsolidated depositional originating from transported sediments by a stream.
- Hydrologically, "*.A land with different return periods of the parent streams"*.

Floodplains are formed through complex interactions of fluvial processes (Ghosal *et al*., 2010). Their character and evolution depends on factors like channel features, stream power and sediment behaviour.

The sedimentation and flow regimes of alluvial rivers interact with the vegetation and physiographic features in their landscape making alluvial floodplains dynamic features. (Ward and Stanford, 1995). Their persistence is dependent upon the interactions of its sub-systems and natural disturbance which is reliant on floodings' kinetic energy which maintains connectivity.

According to Ward and Stanford (1995), the common characteristic topographic features of the valley of an alluvial river basin are:

- Hilltops making the valley sides.
- An active floodplain (flooded annually)
- Natural levees are formed along the river channelsdue to sedimentation
- Permanent and temporary water bodies at various spatial and temporary scales.

Human activities such as water abstraction for agriculture, industry and human consumption as well as impoundment or damming are affecting alluvial river systems by altering the natural flow regime The flow regime of rivers and streams is vital for the maintenance of the ecological integrity of stream habitats and fluvial features. An estimated 60% of the world's rivers have been diverted with diverse impacts such as water scarcity.

According to Bunn and Arthington (2002), many aquatic ecologists regard the flow regimes as key floodplain and river drivers wetland ecosystems Flow regime alteration is thus the most continuing and serious threat to sustainability of floodplain river systems (Arthington and Bunn, 2002). Flow plays a major role in the creation of river and floodplain morphology as wells as their associated biodiversity and ecosystem services. There is substantial evidence of the harmful impacts that artificially low flow regimes have on aquatic biodiversity and overall river morphology (Salmon and Trout Association, n.d,).

Damming rivers for purposes like water supply or power generation lead to flow regulation that has overall effect of imposing equilibrium/stable conditions by altering the dynamic natural regimes on non-equilibrium floodplain animal and plant communities (Ward and Stanford, 1995).

Abstraction directly alters the natural flow regime on surface water flows or indirectly through the depletion of ground water levels consequently affecting flows to springs, rivers, lakes and other wetlands (Environmental Agency, 2013).

2.1.1 Impacts of natural flow regime alterations

Floodplain river ecology can be impacted by reduced river flows, ground water levels and natural flow regime alteration.

2.1.1.1 Hydrological and hydraulic changes

Changes in river channel morphology

The interaction between the flow regime, geology and landforms determines the size as well as the shape of river channels (Bunn and Arthington, 2002). Reduced flows and ground water levels alter the channel form and/or structure.

These changes include modifications to channel width, depth and velocity and shear stress (Ward and Stanford, 1995; Environmental Agency, 2013; Salmon and Trout Association, n.d).

Availability of habitats for aquatic organisms

Hydro geomorphic variables like river discharge channels depth and width, velocity of the stream, bed load flooding and sediment regime guide the availability of habitats within a river or stream. The loss of in stream habitats for various aquatic organisms may occur through the modification in the distribution and availability of habitats. According to Arthington and Bumm (2002), physical habitat and flows' complex interaction is critical in abundance ,diversity and organisms distribution.

Reduced flows cause changes in erosion and depositional pattern therefore loss of in-channel geo-morphological diversity. It may also cause channel narrowing when flows are reduced particularly below non-regulated tributaries.

Channel form and structural changes may alter the aquatic habitat and its biota as demonstrated by Procipio (2010) who found that changes in standard hydrological conditions altered the composition, abundance and density of benthic macro invertebrates. Flow velocity also significantly affects macro invertebrates' assemblage (collection or gathering) and distribution by affecting their feeding biology, behavior and respiration (Salmon and Trout Association, n.d). Fish diversity and abundance patterns are also strongly linked to structure of habitats . Bunn and Arthington (2002) reported on observations in regional differences in the assemblage structures of the fish in differing stream flow variabilities in Northern Mid Western US.

Low flows have also been found to hinder the growth of certain aquatic plants consequently affecting invertebrates, fish and river structure.

Sedimentation

Periodic high river flows are essential in the sustenance of in stream habitats by washing out fine sediments and maintaining the carrying capacity and structure of the channel (Salmon and Trout Association, n.d). Likewise, artificially reduced flows cause increase the depositional of fine sediment within the channel which can clog interstitial spaces within the substrate (bed) reducing available habitats. Species sensitive to sediment loadings such as fish are therefore affected. The spawning success of fish is said to be affected by increased sedimentation. Furthermore, changes in the velocity have impacts on the growth rates of fish as well as their abundance. Procipio (2010) found reduced abundance of fish species in streams where the annual flow had declined.

Changes in water chemistry

Environmental factors such as water temperature, water chemistry and dissolved oxygen play a role in the maintenance of aquatic habitats.

Water temperatures may increase due to low flows. Such increases will affect river flora and fauna by affecting their metabolic processes, raising biochemical reaction rates and causing wide fluctuations in dissolved oxygen. Increased water temperatures can possibly lead to changes in fish communities with the replacement of species requiring higher oxygen concentration by generalist species (Salmon and Trout Association, n.d).

The quality of water can also change through concentration of undiluted effluents.

Reduced ground water levels

River flows recharge the ground water levels thus reductions in flows results in the low water tables. In some cases, the consequence may be to induce the movement of poor quality water, that is, salt water into the ground water resources.

The combined effect of reduced floodplain inundation extent and frequency along with the lowering of the water tables negatively affects floodplain vegetation such as riparian trees adapted to the natural regime. The germination, survival and establishment of riparian vegetation is closely linked to the hydrological regimes.

The lowered water tables may result in induced drought stress that kills both old trees and seedlings while reducing surviving trees growth rates.

Invasion by alien species

The invasion of alien species has also been linked to changes in hydrology through the regimes of altered flow. The loss of wet and dry cycles in floodplain wetlands has major ecological implications that favors invasion by alien species.

Bunn and Arthington (2002) report that the greatest success in the establishment of introduced invasive is in modified and/or highly disturbed ecosystems. Fluctuations in resources such as water and nutrients can also cause disturbance that also favor their establishment (Milton and Dean, 2010). For example, introduced fish species have been found to successfully establish into environments with modified, dammed or diverted waters resulting in standing water like in reservoirs or more constant flow regimes (Bunn and Arthington, 2002). The probability of successful integration is higher in permanently altered systems than in lightly disturbed ones.

Successful invasive species are those that easily adapt to the modified flow regime. Native species not able to adapt to the changes are lost and replaced. For instance, invertebrate mortality or even replacement by more tolerant groups (like molluscs and chronomids) may occur during extended periods of artificially low flows. In addition, floodplain vegetation not able to adapt to flow regime changes may be lost or replaced by other upland species unable to withstand the changes resulting is invasion of floodplain habitats. For example, Typha and water hyacinth species are invading some Australian wetlands due to reduced growth of native aquatic macrophytes as a result of stable water levels (Bunn and Arthington, 2002).

Alien species invasions are regarded as one of the key causes of environmental degradation and biodiversity loss globally (Milton and Dean, 2010).

Gitau (2015) examined the invasion of woody alien species specifically *Prosopis juliflora* into Arid and Semi-arid Lands (ASALs) wetlands and floodplain ecosystems and found that they had negative effects on availability of grazing areas, biodiversity and herbaceous plant biomass in these key resource areas.

The three main drivers that promote the invasion of habitats by woody alien species are (Gitau, 2015):

- Natural or anthropogenic alterations to disturbance regimes.
- Low competition for space and resources.
- The high resource availability after the disturbance regime, for example, mechanical removal of native plants.

Other drivers include their rapid growth that enables them to out-compete native species for resources like water and light and their ability to suppress the growth of native plants through allelopathic effects (Gitau, 2015). Allelopathic effects refers to a mechanism by which some plant species release chemicals that hinder the development of other plant species.

The most problematic invasive species in Arid and Semi-arid Lands (ASALs) are the wetland and phreatic species with the ability to colonize wetlands. Key resource areas in arid areas like riparian areas and wetlands are vulnerable to invasion due to several factors such disturbance from flash floods, water withdrawal, and clearance of alluvial terraces for crop production and intensive use of vegetation by livestock (Milton and Dean, 2010). According to Milton and Dean (2010), 65% of the 101 invasive species in arid areas of South Africa are associated with watercourses or wetlands habitats where they easily access both ground and surface water.

2.1.1.2 Lost connectivity with floodplains and riparian margins

High connectivity ensures the habitat heterogeneity, biodiversity and the productivity of floodplain river ecosystems therefore sustaining their ecological integrity.

Lateral connectivity in the context of alluvial river floodplains refers to the exchange pathways of water, organic and inorganic materials, sediments, organisms and resources between the river channels, the floodplain and the adjacent uplands (Ward and Stanford, 1995).

Floodplains are seasonally flooded when the flood pulse moves across the plain consequently increase the productivity of the various ecosystems and enhancing connectivity among the different water bodies. Floodplains usually contribute significant amounts of living organisms to river channels. For instance, in periods of flooding, benthic macro invertebrates are washed out from productive floodplain water bodies into the river channels therefore re-establishment of the functional connectivies and providing food to organisms in the channel. Furthermore, there is also active migration of some inverterbrates between water bodies and rivers in the floodplain.

The movement of fish also shows diverse patterns. Not many floodplain river fish use the main river channels exclusively (Junk *et al.*, 1989 as cited in Stanford and ward 1995). Therefore, floodplain fishes can be placed into three categories based on their movement patterns:

- Fish completing all the life cycle stages in the river
- Flood dependent fish residing in the river channels in the floodplain and dry plain in

the wet phase.

- Fish residing in floodplain during the wet phases then move to the floodplains' lentic water bodies in the dry phase.

Reduced flow and lost connectivity therefore result in reduced fisheries production. Communities therefore lose social and economic benefits to local communities (Salmon and Trout Association, n.d).

Human or alterations of floodplain river systems often disrupts the frequency ,timing and intensity of the flooding regime. Reduced water volumes may prevent bank overtopping and inundation of the floodplains therefore reducing connectivity between the various water bodies.

On the other hand, longitudinal connectivity refers to connections between upstream and downstream sections of a river network (Cote *et al*., 2009). It ensures the viability of many aquatic species such as shrimps, crabs and diadromous fish by enabling them to freely move through the stream network and complete their life cycles (Bunn and Arthington, 2002).

2.1.1.3 Interruptions to organisms evolved life history strategies

Temperature regimes also play are role in these strategies and a directly affected by the flow regime. Various life events of aquatic species are harmonized with temperature and day length therefore natural flow regime changes may negatively affect them. In addition, a particular flows' timing and flooding events is also vital. Many aquatic species are triggered by flood levels that are rising and inundation, emerging from spawning or resting stages.

Junk et al., (1989) presented the "flood pulse concept" that provide theoretical frameworks for analyzing the strategies used by organisms to take advantage of the alternating dry and wet cycles in annually inundated floodplains (Ward and Stanford,1995). These cycles or phases are crucial in the enhancement of biotic diversity as well as their productivity.

The floodplain surface is referred to as the "aquatic/terrestrial transition zone (ATTZ)".

Terrestrial animals use the rich resources of the ATTZ in the dry phase and the aquatic ones during the wet phase. During the wet phase, terrestrial animals migrate to the uplands and only those adapted to cope with extended periods of inundation remain. Aquatic animals such as fish then inhabit the floodplain to exploit the high productivity and habitat diversity.

Lateral connection occurs during flooding creates suitable spawning areas and conditions for fish from the accumulated dung and plant debris as well as the influx or river borne nutrients. They provide an immediate source of organic matter therefore stimulate aquatic organisms' productivity. Protection for the young fish in the floodplain water bodies is provided by the rapidly growing aquatic macrophytes as well as the recently submerged terrestrial vegetation.

Those that fail to migrate perish because majority of floodplain fish do not to stagnant conditions. The duration and extent of the flooding determines whether and for how long the fish can access spawning habitats and food as well as if they will remain trapped in the floodplain.

2.2 Change detection and analysis

The detection of changes in the earth's surface features is crucial in the understanding of the interactions and relationships between phenomena (human and natural). This understanding helps better decision making promotion(Lu *et al*., 2004).

In recent decades, remote sensing data has become the primary source of data for change detection. The use of remote sensing data and remote sensing change detection techniques is useful in detecting changes in land use and/or land cover, forest or vegetation, wetlands, urban areas, monitoring natural disasters, landscape and the environment. Other applications include: crop monitoring, forest fires monitoring, road segments, changes in glaciers and shift cultivation.

In the context of remote sensing and Geographic Information Systems (GIS), change implies a difference in land surface characteristics between two dates, uncharacteristic of the normal variation that may occur from time to time (Eastman, 2012). It also suggests that there is some degree of permanence in the changed characteristics.

Change detection can be defined as "the *process of identifying differences in the state of an object or phenomenon by observing it, at different times*" (Singh, 1989). It generally involves the application of multi-temporal datasets to analyze temporal effects. Change detection not only determines the specific feature change within certain time intervals but provide the spatial distribution of the information and feautures on how they have changed.

According to Shaoqing and Lu (2008), change detection is also concerned with quantitative analysis and the identification of the characteristics and processes of surface change in different time periods.

2.2.1 Change detection methods /techniques

Several studies have classified techniques of change detection (Lu 2004; Eastman, 2012; Shaoqing and Lu, 2008).

Eastman (2012) groups these techniques based on the type of data involved, that is, qualitative or quantitative. Depending on the number of images compared it can be a pairwise comparison (change analysis) or a time series analysis. Qualitative data represent the differences in kind (different categories) while quantitative data represent the differences in degree, it has values that indicate an amount or measurement. For example, Digital Elevation Model (DEM) contains quantitative data while a land use/land cover map has qualitative data. Change analysis is concerned with the comparison of changes between two dates while time series analysis involves multiple dates (Eastman, 2012).

For the pairwise comparison of quantitative data, the following techniques can be used: image differencing, image ratioing, regression differencing and change vector analysis (CVA). Cross tabulation or cross classification technique can be used for the change analysis with qualitative data.

On the other hand, Shaoqing and Lu (2008) classify methods of change detection of multi band remote sensing images into:

- Image subtraction methods, for example, PCA, changing vector analysis, spectral features variance and Image subtraction, .
- Change detection after classification (post classification comparison)

Lu *et al.*, (2004) reviewed change detection techniques and their application. In their review, they found that change detection techniques can generally be placed in two groups:

- Techniques that detect binary change or non-change information: image ratioing, image differencing, PCA and vegetation index differencing,

- Techniques that detect detailed from-to change: CVA, hyprid change detection methods and post classification comparison.

More specifically they can be classified into the following seven categories (Lu *et al*., 2004):

- **Algebra based**: image differencing, image regression, image ratioing, vegetation index differencing and change vector analysis
- **Transformation**: Principal Component Analysis (PCA), Tasseled Cap (KT), Gramm – Schmidt (GS) and Chi- Square.
- **Classification based**: Post classification comparison, Spectral temporal combined analysis, EM transformation, unsupervised change detection, hybrid change detection and Artificial Neural Networks (ANN).
- **Advanced models:** Li- Strahler Reflectance Model, Spectral Mixture Model and Biophysical parameter model
- **GIS :** Integrated GIS and Remote Sensing method and GIS
- **Visual analysis**

The most commonly used change detection techniques are: image differencing, Principal Component Analysis (PCA) and Post–Classification comparison/analysis (Lu *et al*., 2004). Lu *et al*., (2004) recommend the combination of different change detection techniques to improve the accuracy of change detection.

2.2.2 Selection of change detection techniques

A good change detection research should provide information on:

- The area change and the rate of change
- The spatial distribution of changed types
- The change trajectories of land cover types
- The accuracy assessment of change detection types

According Lu *et al.*, (2004) the following factors should be taken into account when selecting a change detection technique:

1. The objective of the change detection, that is, is it to monitor and identify specific changes? More efficient mapping? Improved quality mapping?
2. The type of change information to extract, for example, spectral changes? Land use changes? Shape changes? Changes in long temporal series?
3. The type of change in consideration, that is, is it land use/land cover change? Vegetation change? Wetland change? Urban areas change? Environmental change?
4. The expected amount of changes
5. The data available
6. Environmental considerations, for example, atmospheric conditions, soil moisture conditions and phenological states.
7. Accuracy of requirements

In practice, several methods are often selected to implement change detection then compared to identify the best results through accuracy assessments. However, the conclusion on the suitable method for specific areas remains unanswered. Therefore no single method is suitable in all cases and the selection depends on the analysts' knowledge of the change detection method, skill in handling remote sensing data, the imagery used and study area characteristics.

Research has shown that the combination of two techniques generally improve the results.

2.2.3 Change detection in wetlands

Over the millennia, floodplain river systems have been extensively used for various human activities such as settlement, agriculture and industry. As a result, they are vulnerable to morphological changes. Changes in floodplains may either be slow and progressive or rapid in the geological sense. They can be caused by human activities or may occur naturally.

Several remote sensing technologies are now increasingly being used in the analysis of fluvial landforms and processes. Information on the morphology of rivers and their changes overtime is required for water resources planning and river management (Ghosal et al., 2010). The accurate and efficient mapping changes in wetlands and riparian areas is also essential for monitoring the impacts of climate and humans on them (Baker et al., 2007).

The availability of multi-temporal satellite data has provided more opportunities for monitoring wetlands and riparian zones (Smith, 1997). Moreover, the satellites have precise spectral band widths, repetitive flight paths as well as accurate georeferencing procedures (Baker et al., 2009).

A range of passive and active sensors can be used to estimate the inundation area and definition of flood boundaries. It is even possible to obtain river discharge estimates using satellite data and ground measures to construct empirical curves relating the discharge to the surface area of the water.

Active sensors consist of radar altimeters and imaging radars. Radar altimeters are useful in the direct measurement of stage variation in large rivers. On the other hand, Synthetic Radar Aperture (SAR) sensors penetrate clouds and detect standing water through emergent aquatic plant and forest canopies therefore providing excellent temporal coverage. In some cases, SARs are even able to determine the inundation or flooding extent through forest canopies and emergent plants.

Passive sensors include high, medium and low resolution visible/infrared sensors providing good delineation of flood areas where trees, emergent plants and clouds do not hide the water surface. High resolution passive sensors are also useful in the interpretation of SAR data.

Remote sensing techniques have been increasingly used to delineate and analyze fluvial landforms like floodplains as well as their processes.

Baker et al., (2007) used landsat Satellite imagery to map changes between two dates (1988 and 2001) in wetland ecosystems in Gallantin Valley. The techniques used were Stochastic Gradient Boosting (SGB) for classification and Change vector analysis for identifying potentially changed areas.

Ghosal et al., (2010) examined changes in the channels and floodplains of the Lower Yuba River California over a 100 year period. The river system experienced rapid changes due to massive sedimentation by hydraulic mining activities. Remote sensing and GI science methods were used in the measurement and evaluation of the geomorphological changes and sediment budgets.

Ganaie et al. (2013) mapped out riverine water bodies using the Transect Method and Normalized Difference Water Index (NDWI). The data used for this was a Landsat 5 TM image and Shuttle Radar Topography Mission (STRM) Digital Elevation Model (DEM). The delineation of flood areas requires two sets of satellite data, that is, one before the flood event and another acquired during the flood.

Image differencing change detection

Image differencing or subtraction is the simplest form of change analysis and the most extensively applied techniques. The subtraction image is derived from subtracting a gray value of corresponding pixel images and it shows the extent of the change of the two images.

In analysis, the changed or unchanged regions are determined through the selection of appropriate threshold values of gray in the subtracted image. A suitable threshold will help to separate the areas of real change from others influenced by the impact of random factors. A commonly used value for the threshold is 1 Standard deviation (STD) (Eastman, 2012). In the subtracted image, positive or negative values of the image denotes the region whose radiation value has changed. When there is no change the image value is 0.

The advantages of image differencing are:

- It is a simple and straight forward method that is easy to understand as well as use.
- When compared to the method of post classification comparison, it reduces the probability of errors.
- It has a good practical value so it is widely used to detect and monitor changes in various forest types, coastal environmental changes and phenomena like desertification.

However, simple differencing does have the following disadvantages:

- It does not reflect changes in categories like the classification based techniques.
- The value of subtraction does not always reflect the change of the features due to a

variety of factors such as atmospheric conditions, sensor calibration, ground water conditions etc.

- It is too simplistic for change detection of natural images or its features.
- It requires accurate time, domain standardization and image registration.
- During the image differencing process, some information will be lost making it difficult to evaluate the nature of the changes.
- There might be too much noise in the subtracted image attracted by image correlation. Differencing of vegetation indices such as Normalized Difference Vegetation Index (NDVI) is less susceptible to noise interference. Index differencing is also more spectrally dynamic than simple differencing. However, index differencing techniques are heavily dependent on the radiometric resolution of only two spectral bands. Moreover, vegetation indices (VIs) are altered by atmospheric influences, soil background effects, and the presence of moisture and viewing angles (Jackson and Huete, 1991).

Vegetation indices enables the monitoring of seasonal, inter-annual and long term variations of vegetation structure, phenological and biophysical parameters (Al-doski *et al*., 2013). Spectral vegetation indices are widely used in various disciplines for vegetation assessment examining aspects like vegetation fresh or dry biomass, plant stress, plant health, water content and use, internal leaf structure, soil moisture, crop production and plant surface temperatures (Jackson and Huete,1991 ; Al-doski *et al.*, 2013). VIs are designed to enhance the contribution of vegetation properties and allow reliable spatial and temporal inter comparisons of terrestrial photosynthetic activity and canopy structural variations.

Vegetation indices (VIs) can be generally classified into:

- Ratios: made by the simple ratio of any two spectral bands or the ratios of the sums, differences or products of any number of bands, for example, Normalized Difference Vegetation Index (NDVI) and Ratio Vegetation Index (RVI)
- Linear combinations: orthogonal sets of linear equations like tasselled cap

The most widely used VI is the NDVI to measure biomass and vegetation vigor. It is a quantitative measure related to the amount of living vegetative matter. NDVI is derived from the red and near infrared wavelength bands of satellite data.

It’s calculated as follows: NDVI = (Infrared-Red) / (Infrared + Red)

2.3 Research Conceptual Framework

The DPSIR Framework (Figure 1) for water resources issues was adopted as the conceptual framework for this study. The framework provides a structure to present the indicators required to enable responses on environmental quality and impacts of political choices to policy makers.

The DPSIR framework describes a chain of causal links beginning with driving forces through pressures to states and impacts on the ecosystems, human health and functions, eventually leading to political responses.

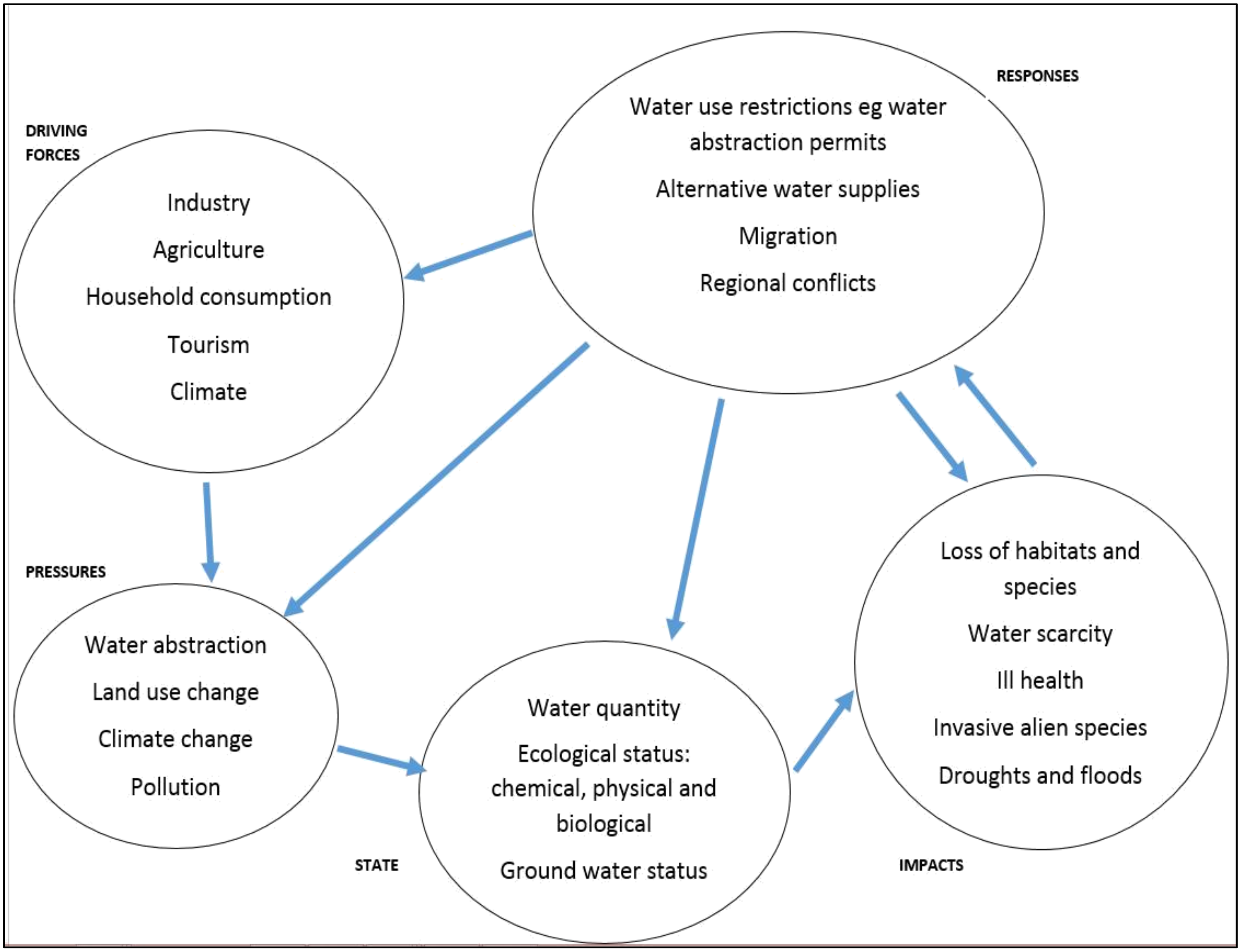

Figure 2.1: The DPSIR Framework for water (modified from Kristensen, 2004)

Components of the DPSIR framework

Driving force

A driving force can be described as a need. For example, in the case of the water issues, the need for water for agricultural production and household consumption are driving forces.

Pressures

The driving forces result in human activities that exert pressures on the environment. Land use changes, over exploitation of environmental resources, and waste emissions are the three main types of pressures.

States

The state of the environment is a combination of its biological, physical and chemical conditions. The pressures on the environment affect these states by altering them. For instance, a change in the hydrological state due to reduced flows in the Ewaso Ng'iro River.

Impacts

Alterations to the state of the environment determine ecosystem integrity and human welfare. Therefore, the alterations have both environment and economic impacts such as habitat loss, water scarcity that often increases the incidences of water borne diseases. An example of an impact is the invasion of the floodplains by *Prosopis juliflora* due to hydrological changes.

Responses

A response is an action taken by the policy makers or society due to an undesired impact or effect of environmental state changes. These responses can have an impact on any part of the chain between driving forces and impacts. For example, migration of the pastoralists in search of water as a response to water scarcity.

CHAPTER 3: METHODOLOGY AND MATERIALS

3.1 Area of study

3.1.1 Location and topography

The floodplains of the Ewaso Ng'iro North River are located in the Ewaso Ng'iro North

Catchment Area (ENNCA), specifically, Merti, Garbatulla and Sericho divisions of Isiolo County.

ENNCA covers some 210, 226 km^2 and is the largest catchment area in Kenya. It is named after the Ewaso Ng'iro North River, the only significant river that flows through its predominantly Arid and Semi-Arid Lands (ASALs). It geographically extends from 0.5^0 S to 3^0N and from 36^0 E to 41^0E.

The altitude of the catchment ranges from 150 m to 5199 m above mean sea level at the Lorian Swamp and the peak of Mount Kenya respectively (Water Resources Management Authority, 2015). Isiolo County generally lies between 200-300 m with Lorian swamp being its lowest point.

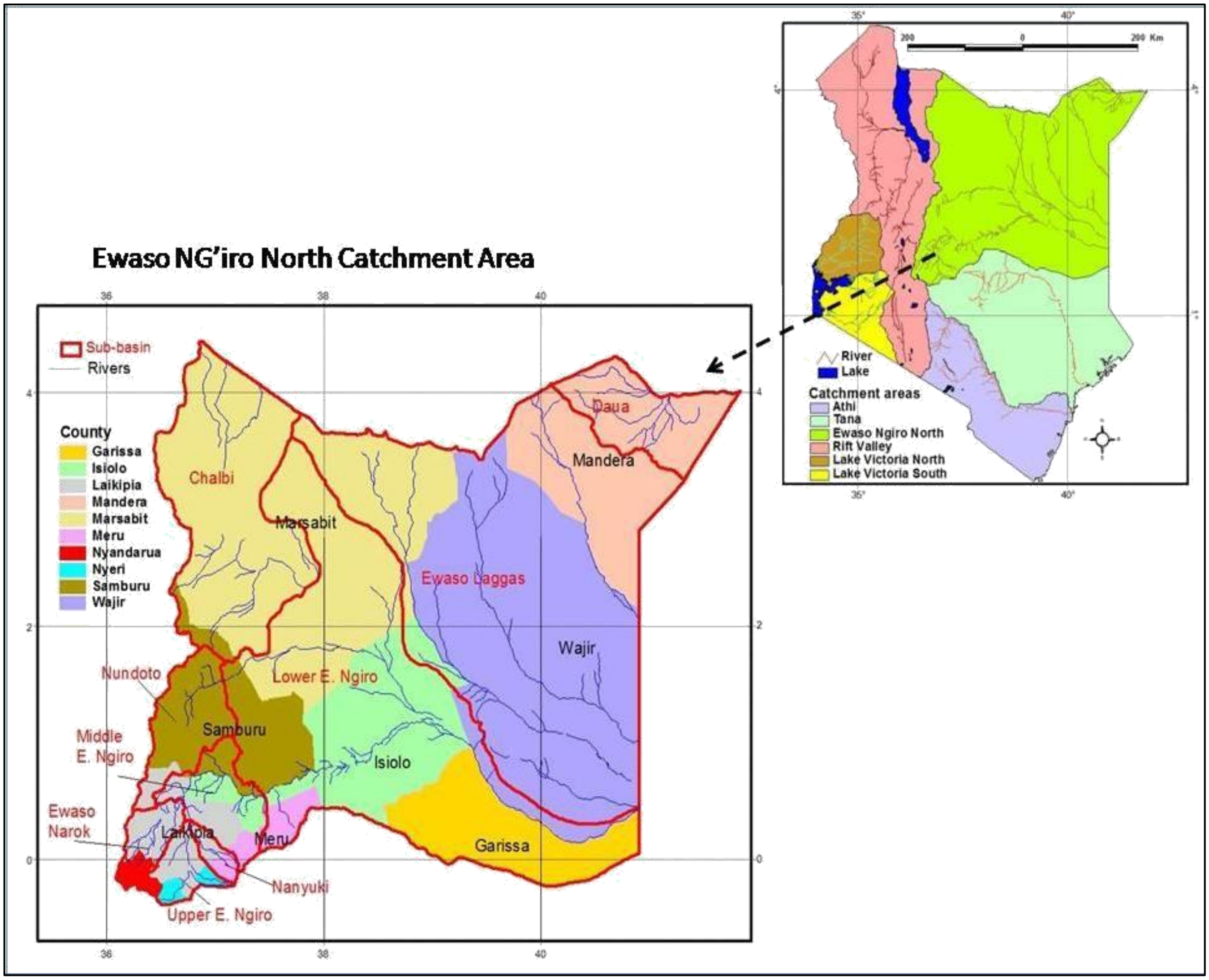

Figure 3.1: The extent of the ENNCA and its constituent counties (Source: Water Resources Management Authority, 2015)

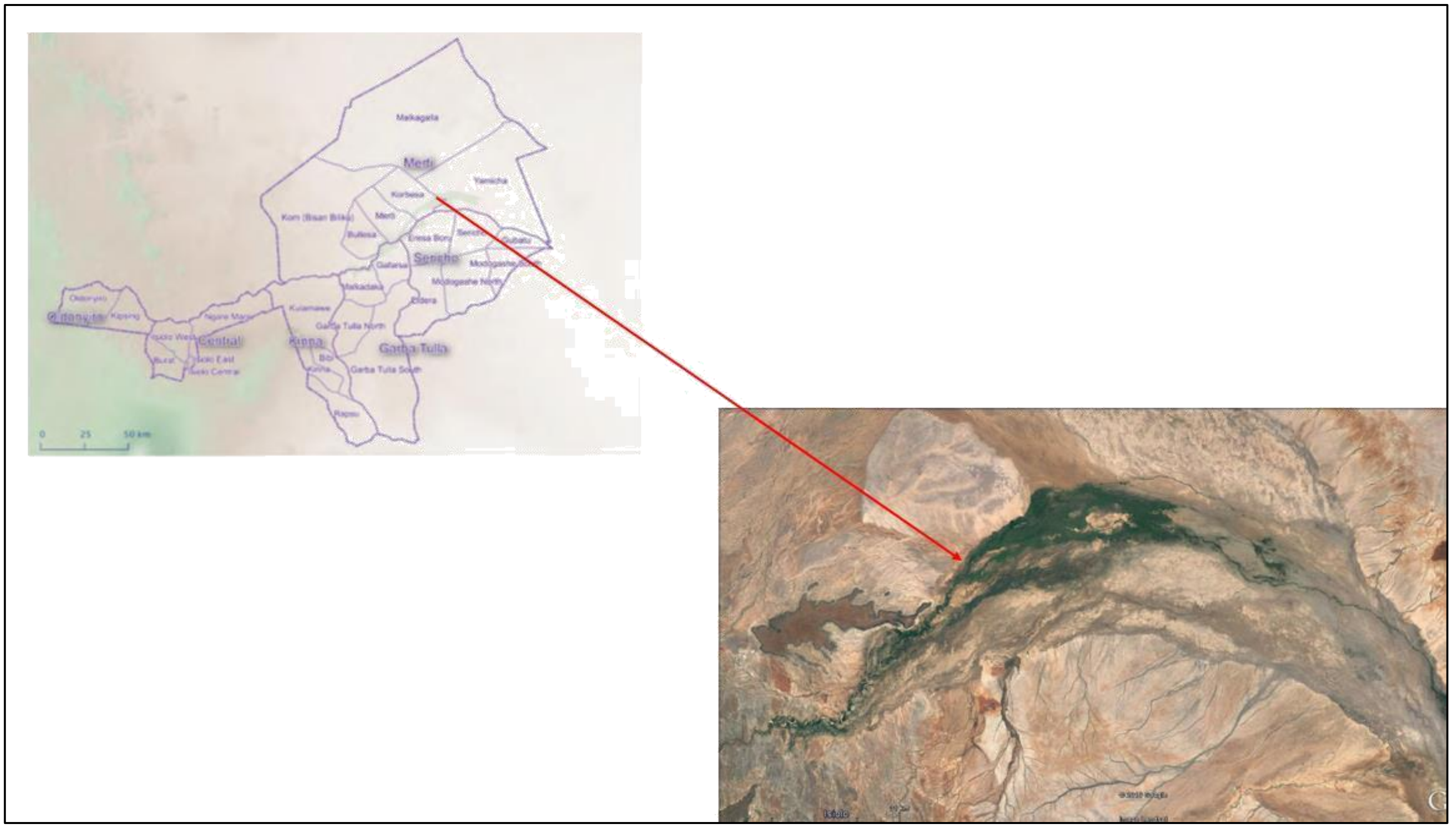

Figure 2.2: Area of Study (Source: Tari and Pattison, 2014: Google earth)

3.1.2 Hydrology and Drainage

The Ewaso Ng'iro North River is the largest river in this system. Its drainage area or basin covers nearly 85,000 km^2.

This endorheic (does not flow all the way to the sea) river derives its water from the high rainfall areas in the Aberdare Mountains and Mt Kenya and descends through Nyandarua, Laikipia, Isiolo, Samburu, Wajir and Mandera Counties and ends its course in the Lorian swamp, after which it continues flowing below the surface eastwards to recharge groundwater below seasonal rivers inside Somalia (Mati *et al*., 2006).

3.1.3 Climate and rainfall

The catchment has bimodal rainfall varying from 1200 mm per year (in the highlands) to less than 300 mm in the East (ASALs) which comprise more 90% of the total area (WRMA, 2015).

It lies in Kenya’s dry corridor therefore has double maxima rainfall in March- May (long rains) and October- December (short rains).

Isiolo County is arid and experiences low rainfall of between 300-500 mm per year with temperature ranging from 12^0- 28^0 C. Most parts of the county receive less than 150mm per annum.

3.1.4 Biodiversity

Isiolo County is known for its abundant wildlife and magnificent game reserves. Five conservation areas make up the tourist attraction sites in the county: Lewa Downs, Buffalo Springs, Shaba and Bisanda game reserves.

The catchment contains significant biodiversity. It provides a habitat for the greatest diversity and density of wild ungulates in the East Africa region outside the Serengeti-Mara Park system (Georgiadis *et al*., 2007) including significant populations of globally endangered species such as

grevy’s zebra (*Equus grevyi*) and wild dog (*Lycaon pictus*). It is home to more than 6000 elephants and the largest population of Rhinoceros outside the national populations in protected areas.

3.1.5 Land use/land cover

Livestock production is the dominant land use/land cover in the entire catchment (82%), followed by mixed crop-livestock production, conservancies (both conservation and livestock keeping are practised), wildlife conservation, conservation forestry, production forestry and irrigated crop production respectively (Ericksen et al., 2011).

Land ownership and use in the catchment is a complex mosaic of communal and trust lands, private wildlife conservancies, government-run protected areas, cattle ranches and agricultural land, including wheat-producing areas and high intensity flower and vegetable farms for export.

3.1.6 Socio-economic characteristics

Population

According to KNBS (2009), the population of the entire catchment was estimated at 3.87 million while the one of Isiolo county was 143 294 people with 51% male and 49% female.

High poverty rates above the Kenyan average are prevalent throughout the catchment (Ericksen *et al*., 2011).

People and culture

The upper catchment is home to the Borana, Mukogodo, Maasai, Turkana, Samburu, Gabra and Rendille. Alongside these communities are the Kikuyu, Meru and Europeans. The northern part of the catchment is inhabited by traditional pastoral communities; the Samburu, Gabra, Rendille and Borana. The Borana, Somali, Samburu and Rendille and the Meru are found in the lowlands of the catchment to the east. Isiolo County where the study focuses is inhabited mostly by the Borana, Ameru, Somali and Turkana with Borana being the majority.

Majority of the residents of Isiolo County practise Islam (most of the Borana and Somali). While the rest are Christians.

Economic activities

Pastoralism is the dominant activity in the drier parts of the basin while agriculture is mostly practiced in the high rainfall areas such as around Mt. Kenya and the Aberdare Ranges. The agricultural activities consist of:

- Commercial farming (horticulture, floriculture and wheat farming)
- Ranching
- Subsistence farming (both cultivation and livestock rearing)

Isiolo county is arid therefore the major economic activity practiced there is pastoralism. In the wetter parts of the county the Ameru practice some subsistence agriculture and business involving crop cultivation and livestock rearing. Around Isiolo town, women engage in craft making for tourists.

Infrastructure

Several large dams are planned in the catchment, including the Crocodile Jaws dam to supply the planned resort city of Isiolo as well as irrigation schemes and infrastructure projects, in line with the Kenya Vision 2030 such as the Lamu Port Southern Sudan-Ethiopia Transport (LAPSSET) Corridor project. LAPSSET is a transport and infrastructure project which will be Kenya's second transport corridor.

3.2 Data sources and tools

3.2.1 Data Sources

Primary data

Primary data was derived from satellite imagery and 65 GPS waypoints taken during a field survey using a Garmin eTrex Global Positioning System (GPS) receiver and 71 points picked from Google Earth imagery.

One satellite image was downloaded from the USGS Earth Explorer website

(http://earthexplorer.usgs.gov/).

Table 3.1: The characteristics of the downloaded Landsat image

Acquisition date	27th September 2015
Mission	Landsat 8
Sensor	OLI TIRS
Resolution	30m
Scene ID	LC81670592015270001GN00
Path	167
Row	059
Band 1	Visible – deep blue (Coastal)
Band 2	Visible - blue
Band 3	Visible - green
Band 4	Visible - red
Band 5	Near-Infrared
Band 6	Shortwave Infrared 1
Band 7	Shortwave Infrared 2
Band 8	Panchromatic
Band 9	Cirrus
Band 10	Thermal Infrared (TIRS) 1
Band 11	Thermal Infrared (TIRS) 2

In addition, two EROS Moderate Resolution Imaging Spectroradiometer (e Modis) NDVI Images for the East African region were downloaded from the USGS Famine Early Warning Systems Network (FEWS NET) website

(http://earlywarning.usgs.gov/fews/datadownloads/East%20Africa/eMODIS%20NDVI).

Table 3.2: The e MODIS NDVI images downloaded

SATELLITE/ PLATFORM	SENSOR	SCENE ID	PROJECTION	RESOLUTION	ACQUISITION MONTH/YEAR
TERRA	**MODIS**	**Ea1554**	**Geographic WGS84**	**250m**	**SEPTEMBER 2015**
TERRA	**MODIS**	**Ea5502**	**Geographic WGS84**	**250m**	**OCTOBER 2002**

Secondary data

Secondary data was derived from a comprehensive literature review on:

- River basins and floodplains
- Impacts of upstream water abstraction on river basin systems
- Change detection methods
- Wetlands change analysis and detection techniques

3.2.2. Tools

Software used in the Digital image processing were IDRISI Selva 17.00 for the remote sensing and ArcGIS 10.3.

3.3 Data processing

The following methodological approach was taken to achieve the objectives of the study.

3.3.1 Normalized Difference Vegetation Index (NDVI) Differencing

NDVI differencing was used to explore the differences in the quantitative distribution of vegetation or biomass change over the time period.

Before the index differencing was performed the two e MODIS images were first resampled to NDVI format using the raster calculator tool in ArcMap 10.3. The formula used was ((Raster*0.004) – 0.1)

The Area of Interest (AOI) was then created using the clip tool. Then index differencing was performed and involved the subtraction of the 2002 image from the 2015 image.

DNDVI= NDVI 2015- NDVI 2002

The Raster calculator was used to perform the differencing. A simple differenced image, ndvi2015-2002.tiff, was the output of this process.

Thresholding was then performed to distinguish areas of true change from random variations. This process establishes upper and lower limits to normal variation beyond which true change is considered to have occurred. The second standard deviation ($\mu \pm 2\ \sigma$) was selected to identify changes. Once the thresholds were determined, a threshold image (Change/no change map from 2002 to 2015) was then created using the RECLASS Module. The resulting image had three classes:

- Class 1: all values less than the lower threshold
- Class 0: all values between the lower and upper thresholds
- Class 2: All values greater than the upper threshold

3.3.2 NDVI Reclassification

The NDVI maps were then classified independently using RECLASS module in ArcMap 10.3 using the NDVI values into three land cover classes: dense vegetation, moderate vegetation and sparse vegetation.

The values used in the reclassifications were derived from literature sources for the various land cover types and validated using points selected on the land cover classes on the NDVI images. The areas under the various land cover types were computed as well as the changes in the different covers.

Table 3.3: The typical NDVI values for various land cover types (Source: Arulbalaji and Gurugnanam, 2014)

S. No	Cover type	NDVI
1	Dense Vegetation	0.6 - 0.9
2	Shrub land and grasslands	0.2 – 0.5
3	Dry bare soil	0.025
4	Clouds	0.002
5	Snow and Ice	-0.046
6	Water	-0.257

3.3.4 Supervised classification

Supervised classification was used to determine the spatial distribution of *Prosopis juliflora* in the area of study. Idrisi Selva 17.00 was used to perform this classification.

The bands of the satellite imagery 27th September 2015 Landsat 8 image were imported into IDRISI by converting them from the TIFF format to Raster format that is acceptable in Idrisi. The Area of Interest (AOI) was created using the WINDOW tool which clipped the bands using selected geographical coordinates.

A false color composite of the image was used in the creation of training sites. The composite was derived from overlaying bands 3, 4 and 5. Training sites for the five identified land cover classes were digitized using the field GPS points and Google earth points. Google earth and field measurements were used to improve the accuracy and precision of the training site selection.

The creation of training sites involved the generation of polygons comprising of a maximum of 15 pixels and each training site had a minimum of 60 pixels since six bands were used in making signatures for classification. These signatures for the training sites identifiers were created with the MAKESIG module.

Supervised classification was then performed using the created signature using the hard classifier, Maximum Likelihood.

Table 3.4: The five land cover types used for the supervised classification

Land Cover Type	***Description***
Prosopis juliflora	Stands of the invasive species "*Prosopis Juliflora*"
Acacia mixed zone	Acacia trees as emergent trees among bush and thickets
Grasslands	Grasslands particularly in the flood zone that grow after the recession of the floods
Shrubland	Open shrublands
Open bareground	Bareground without any vegetation and with loose soil

3.4 Accuracy assessment

To assess the accuracy of the supervised classification, the error matrix and the Kappa Index of Agreement (KIA) were used.

3.5 Methodological overview

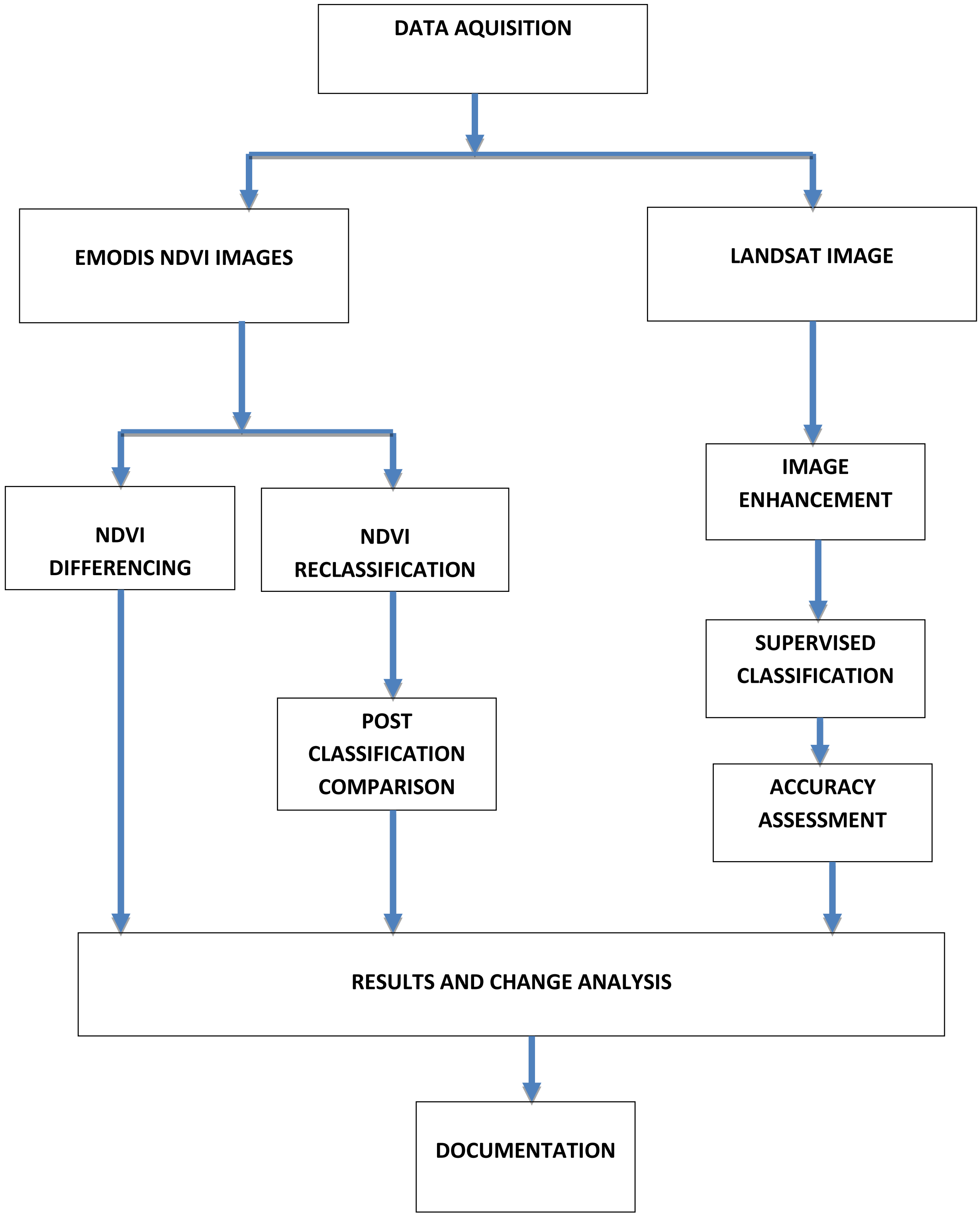

Figure 3.3: Methodology scheme

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Results

Vegetation cover changes

Examining the NDVI provides a simplistic way of assessing the progression of vegetation.

In the grey scale images shown in Figure 4.1, areas with healthy vegetation are white while darker areas represent areas with sparse vegetation. The white areas have stronger reflectance in the Near Infrared (NIR) wavelengths due to the absorption of the visible light for photosynthetic processes resulting in the production of vegetative biomass.

Healthy vegetation can be described as vegetation in good condition, high chlorophyll content, high leaf content and canopy closure (Al-doski, 2013).

The darker areas with sparse vegetation have lower NDVI values due to their higher absorption in the NIR bands and stronger reflection in the visible bands due to the presence of soil, grasses or bare ground in between the vegetation.

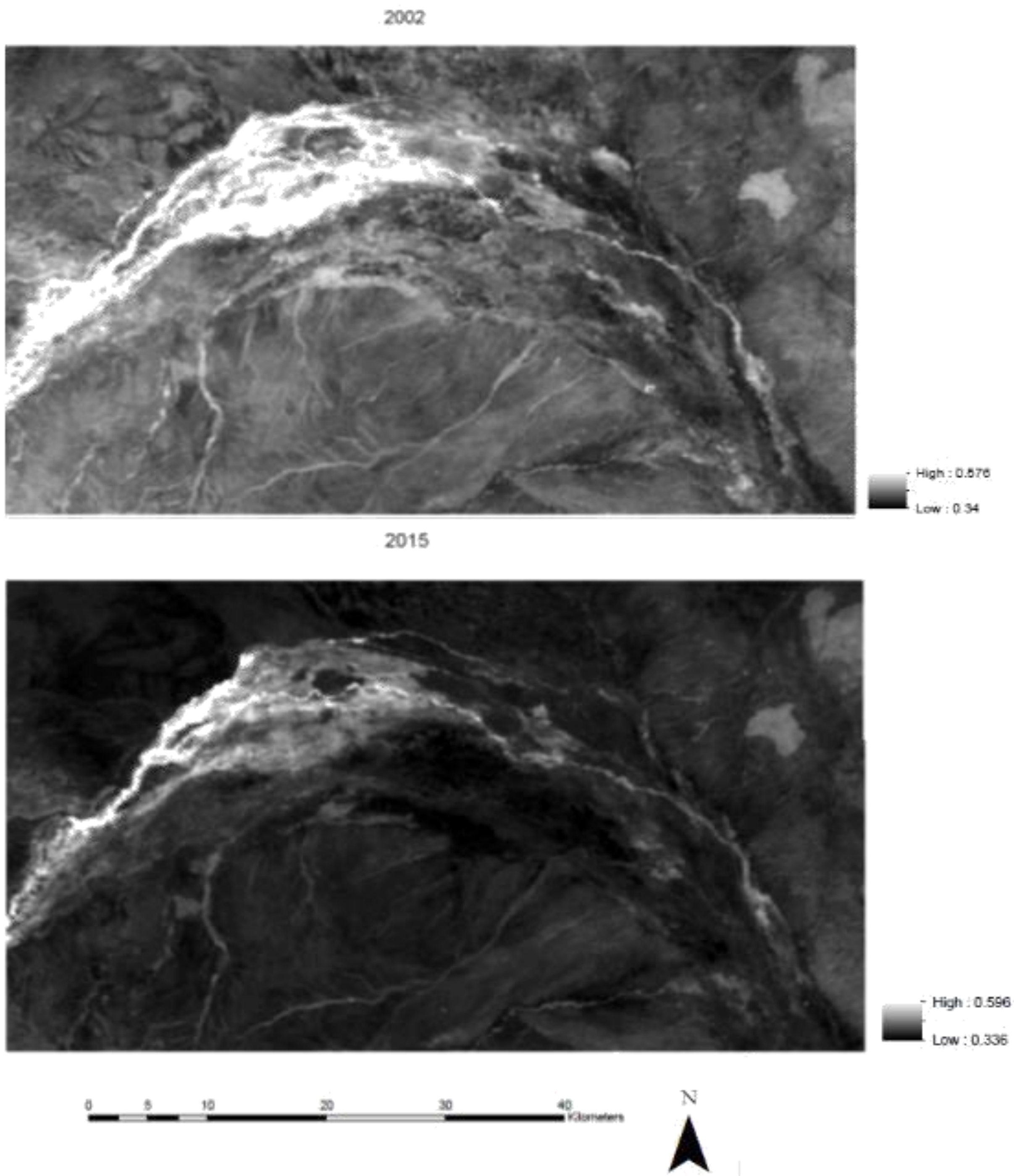

Figure 4.1: NDVI maps in grey scale

The NDVI images were then displayed in color to show slight details or variations. In the colored images, the red areas represent areas with healthy vegetation. The colored images show additional details particularly three distinct areas of sparse vegetation area in orange brown, yellow and green. The orange brown has the highest NDVI values followed by the yellow areas while the green had the least values.

Furthermore, the colored images show that the vegetation in 2002 was generally healthier or less stressed than in 2015.

Table 4.1: Statistics for 2002 and 2015 NDVI maps

Statistics	**2002**	**2015**
Maximum	0.576	0.596
Minimum	0.344	0.336
Mean	0.3804	0.3654
Standard deviation	0.0207	0.0187

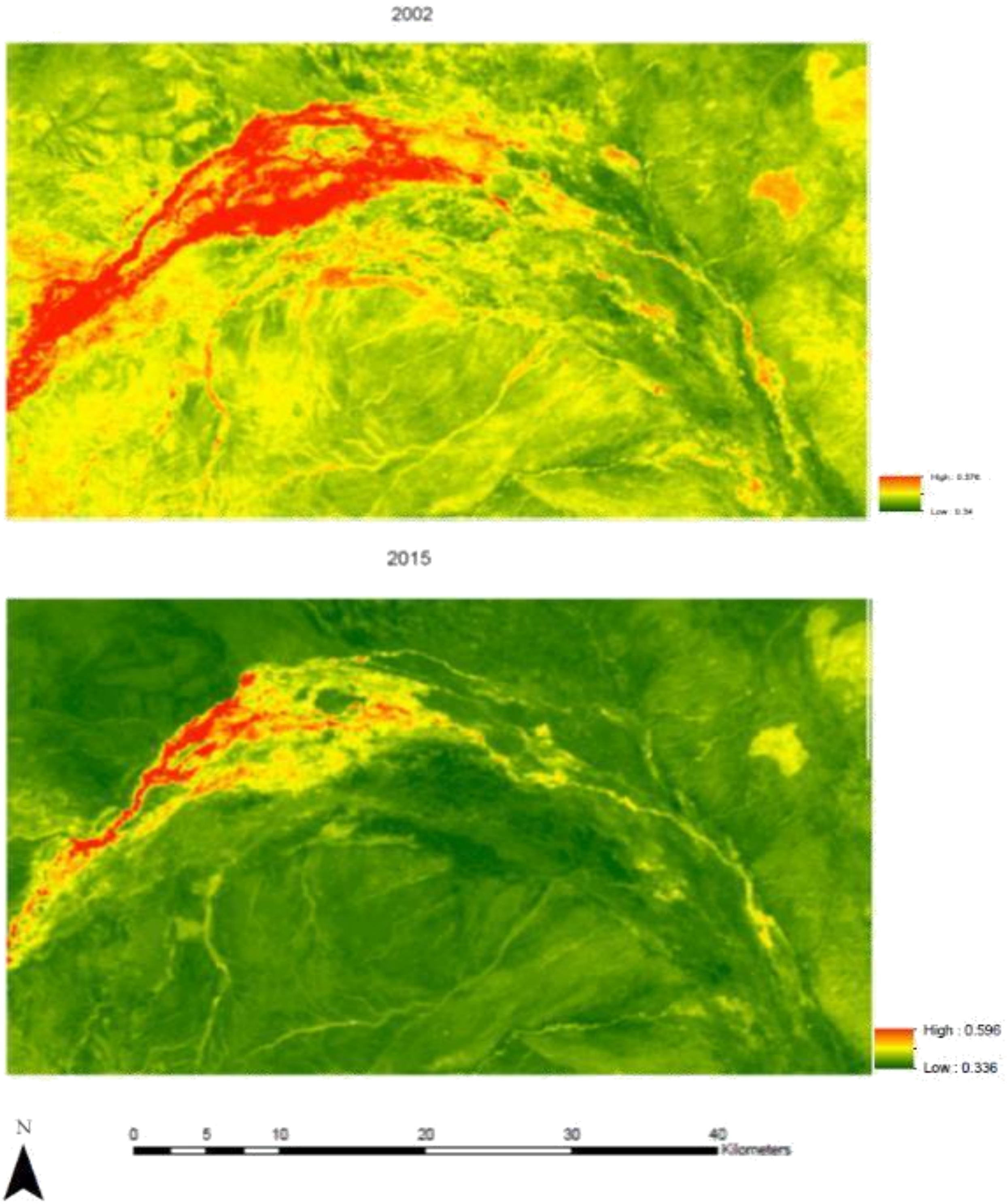

Figure 4.2: NDVI maps in color

NDVI Reclassification

The assessment of the vegetation changes was done through the reclassification of NDVI values. The NDVI values were reclassified into three land cover classes: Sparse vegetation, moderate vegetation and dense vegetation.

The generated reclassified NDVI maps are shown in figure 4.3.

The reclassification results show that in 2002 the sparse, moderate and dense vegetation covered an estimated 877 284 ha, 43 836 ha and 2 227 ha respectively. By 2015, sparse vegetation was approximately 903 322 ha, moderate vegetation 18 299 ha and dense vegetation 1 095 ha respectively.

From the results, the moderate and dense vegetation are the land cover classes that showed decreases. The greatest decrease from 2000 to 2015 was in the moderate vegetation which decreased by 25 537 ha (58%) followed by dense vegetation that decreased by 1 131 ha (51%). On the other hand, sparse vegetation increased by 26 038 ha (3%).

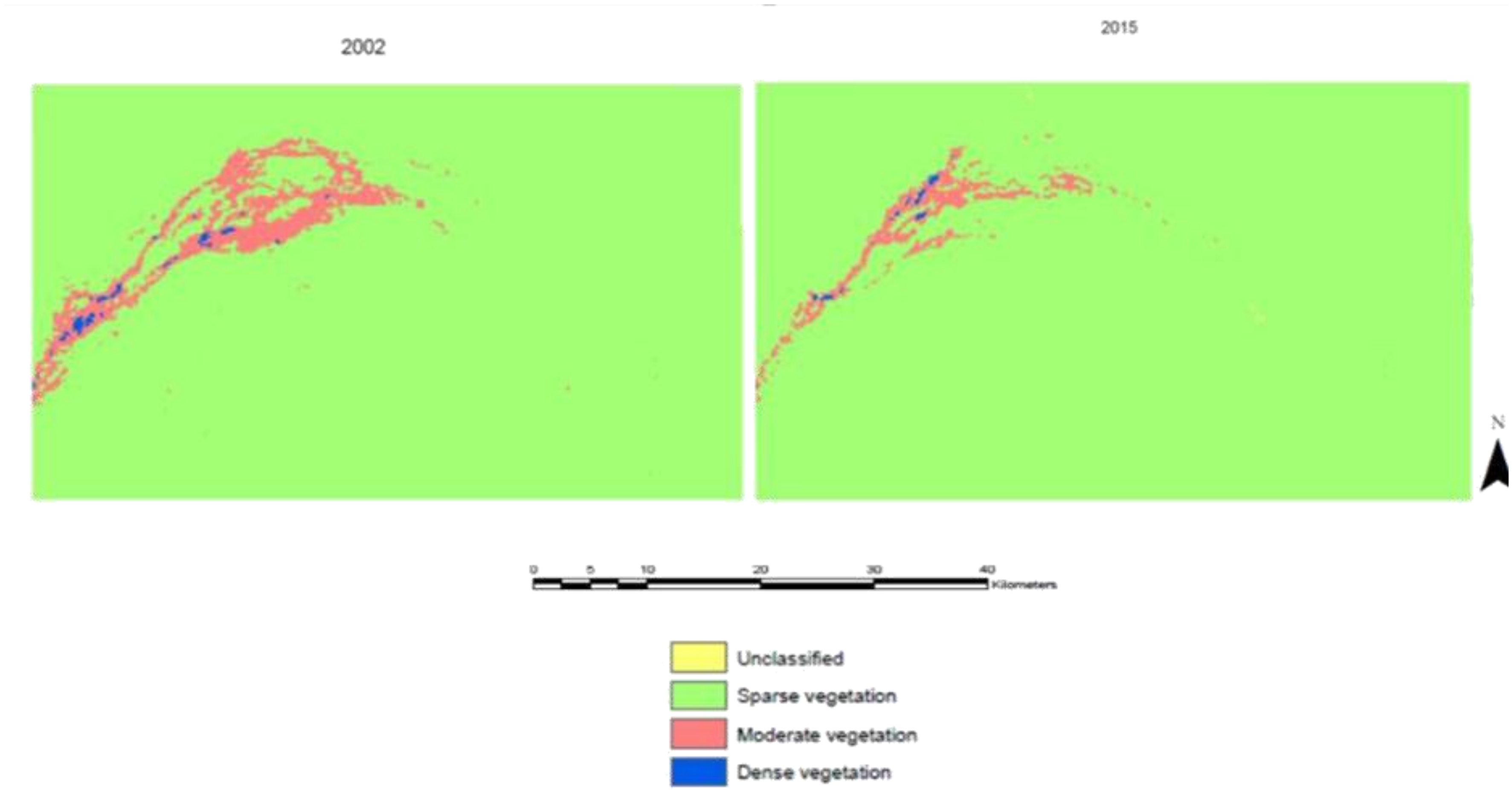
2002
2015
N
0
5
10
20
30
40
Kilometers
Unclassified
Sparse vegetation
Moderate vegetation
Dense vegetation

Figure 4.3: NDVI Reclassified Maps

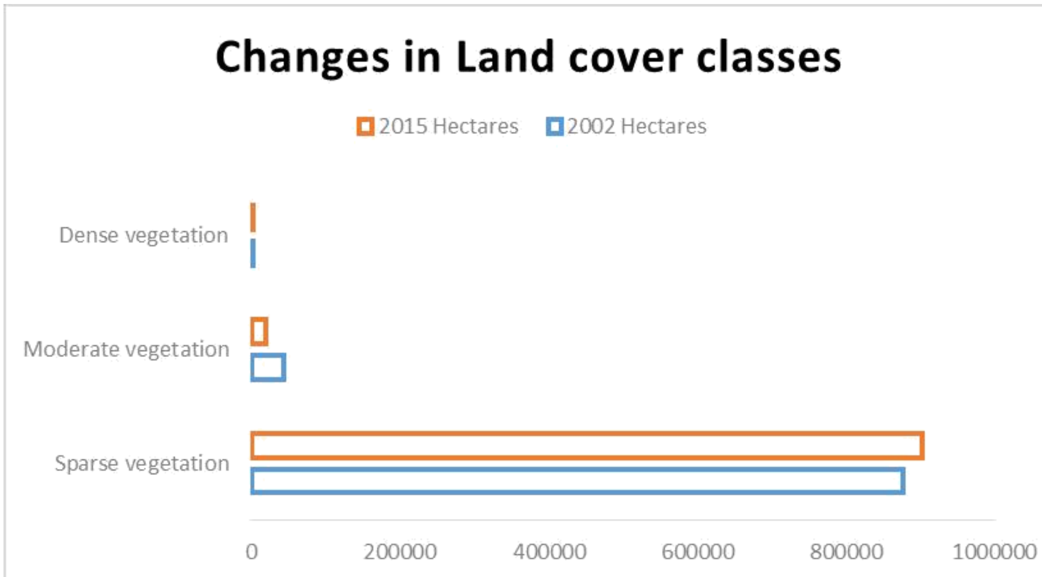

Figure 4.4: Changes in Land Cover classes

NDVI Differencing

The results of the NDVI differencing (Figure 4.5 and 4.6) shows areas of change either positive (increase) or negative (decrease) and those that experienced no change. There was an increase in the NDVI reflectance of some floodplain vegetation by 1 %. 83 % of the vegetation cover remained unchanged while 16 % decreased.

Majority of the decreases in the map corresponds with the NDVI values that show decreases in the mostly moderate vegetation as well as some decreases in the sparse vegetation.

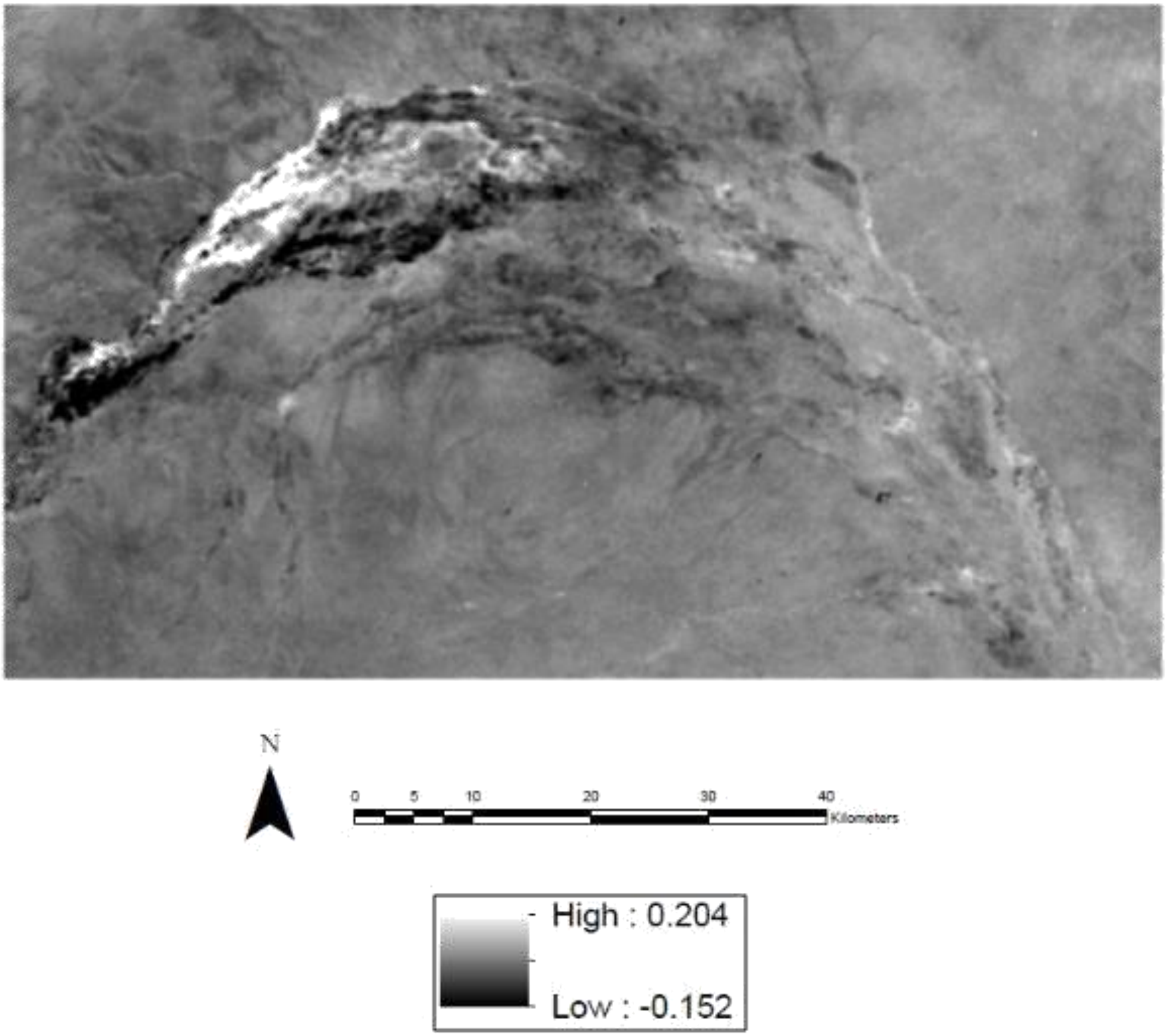

Figure 4.5: NDVI Differenced image in greyscale

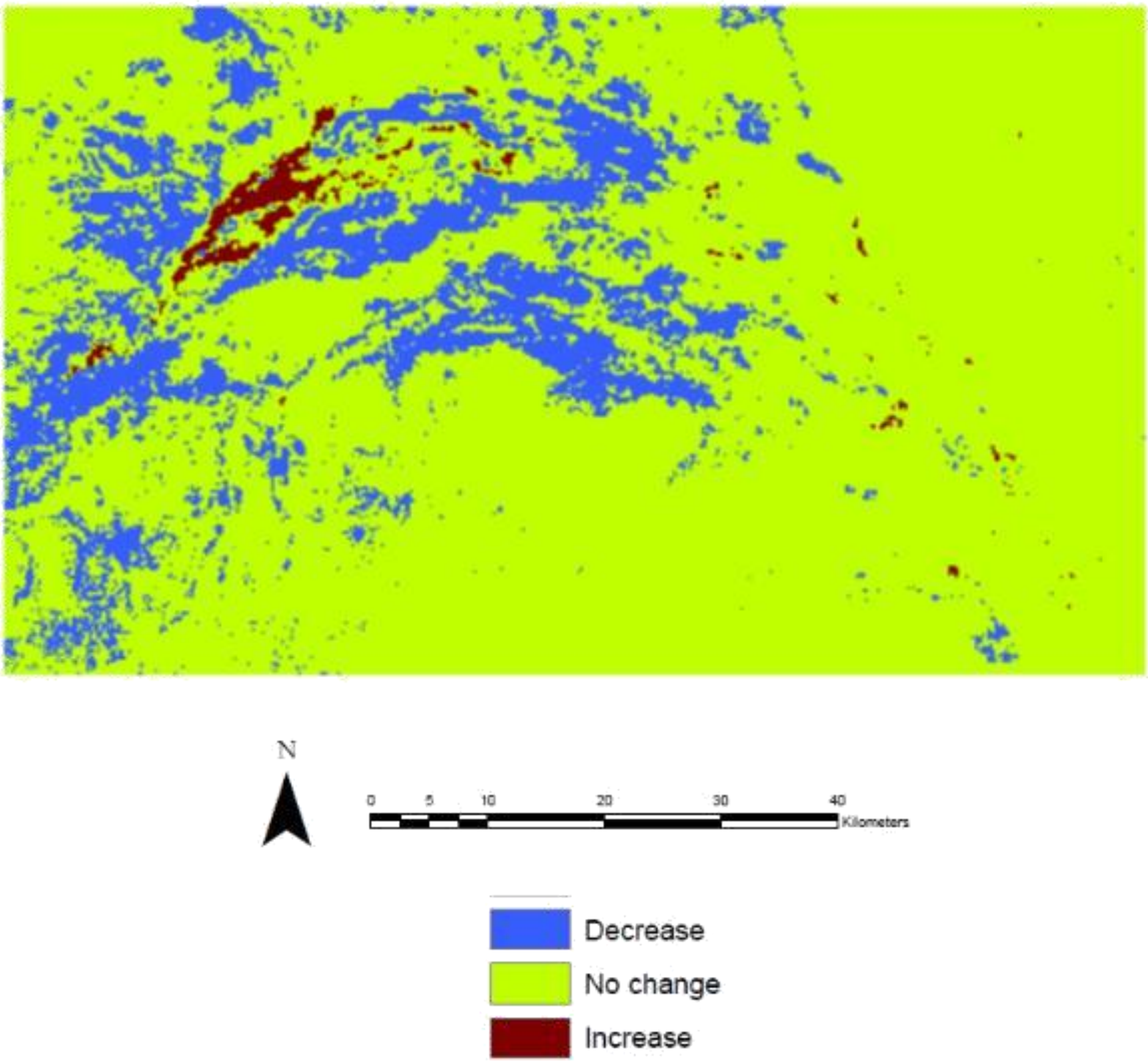

Figure 4.6: Change/ No change map from 2002 to 2015

The spatial extent of *Prosopis juliflora* in the floodplains

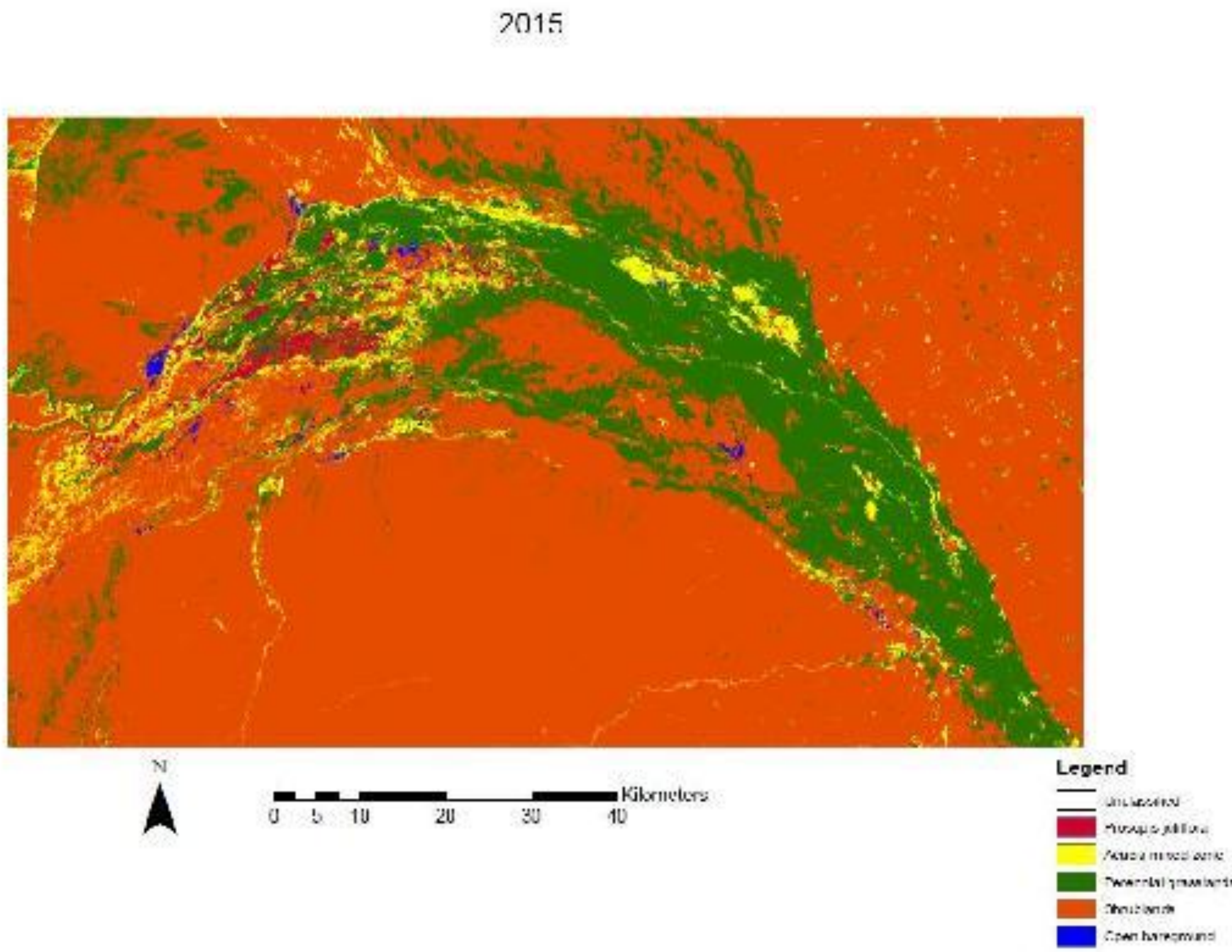

Figure 4.7: Land cover map of the Area of study

The September 2015 Landsat 8 image was classified and the results showed that *Prosopis juliflora* occupies an estimated 2% (19 671 ha) of the entire land cover. On the other hand, Acacia mixed zone, grasslands, shrub lands and open bare ground occupy 7.84% (63 083 ha), 8.58% (79 049 ha), 82.3% (758 685 ha) and 0.15% (1 357 ha) respectively. Shrubland is clearly the most extensive land cover type.

Table 4.2: Accuracy assessment of land cover map for 2015

Land cover class	***Users Accuracy (Error of commission) %***	***Producers accuracy (Error of omission)%***
Prosopis juliflora	28.57	100
Acacia mixed zone	11.67	28.57
Perennial grasslands	100	10.00
Shrublands	21.43	100
Open bareground	100	50

The overall Kappa Index of Agreement (KIA) for the supervised classification is 0.7856.

4.2 Discussion

The amount or magnitude of NDVI is related to the photosynthetic activity level in vegetation that indicates the health status or greenness of vegetation therefore stress level. As a result, high NDVI values indicate greater vigor and amounts of vegetation. It can also be used in the estimation of vegetation cover as well as vegetation change patterns (Gandhi *et al*., 2015).

The analysis of the statistics (Table 4.1) and visual analysis of the NDVI images (Figures 4.1 and 4.2) indicates a general decline in the vegetation biomass from 2002 to 2015. Majority of the vegetation in 2002 had higher NDVI values than in 2015 indicating the presence of more green with higher photosynthetic activity therefore less stressed. The lower values in 2015 can be attributed to the fact that the vegetation may have been stressed or in poor health since the region was experiencing a drought at the time. Ritter (2006) also observed a direct correlation between NDVI and the amount of stress in vegetation. However, an important observation from the analysis was that despite the decline the maximum NDVI values for 2015 were greater than the 2002 values and the NDVI range for both years only varied slightly. This is can be explained by the fact that the higher NDVI values for 2015 compensated for the generally lower NDVI values in other areas.

Vegetation change patterns from 2002 to 2015 (Figure 4.3) show a major decline in the dense (51%) and moderate vegetation (58%) in the floodplain which had reduced by more than a half in 2015. It appears that the sparse vegetation is encroaching into the dense and moderate vegetation zones. These declines in vegetation cover types can be linked to reduced flows of the Ewaso Ng'iro River in the region. Most of the green healthy vegetation with high NDVI reflectances during the dry season is found in the Ewaso Ng'iro riverine areas and floodplain since they thrive on the river flow and flooding regime not rainfall. The health of vegetation in the floodplains is therefore strongly correlated to the river's flow and flooding regime. The river emanates from the highland areas that experience high rainfall thus it would flow almost throughout the year even during the dry season However, it now frequently dries up for extended periods of time, for example, in September 2015, the water flow in the river did not reach Merti town in the study area since it was dry (Mukhwana *et al*., 2016). The changes in the river flow have not only led to the shrinkage of the dense vegetation types in the floodplain but the loss of biodiversity both flora and fauna like hippopotamuses and crocodiles (Mukhwana *et al*., 2016).

The results of the NDVI differencing (Figure 4.7) are significant in two ways. They show that there have been increases in the vegetation reflectance during the period and correspond to the reduction in the floodplain vegetation as shown in the NDVI images. The observed increases in the reflectance of some vegetation in the floodplains not observed in 2002 are unexpected because the 2015 image was derived from a drought period. This points to the presence of *Prosopis juliflora*. Kyuma *et al*., (2016) found that NDVI is useful in the identification of *Prosopis juliflora* because it was photosynthetically active during the drought conditions. They used high NDVI values from vegetation found during the dry periods to isolate Prosopis from other vegetation types since it remains green when all other vegetation have dried or shed their leaves. Its drought resistant nature enables it remains productive during dry periods while most plants are less productivity due to stress from water deficit. Kyuma *et al.*, (2016) also used the shrubs preference for floodplains, riverine areas and saline soils in its identification. The spread of *Prosopis juliflora*, covering an estimated 19 671ha, is evidence of the floodplain's changing hydrology. Mukhwana *et al*., (2016) reports that Prosopis has colonized the river banks as well as section of the floodplains particularly close to the river's channels. This invasion may have been facilitated by various factors:

- The floodplain system is highly disturbed and modified due to the alterations in natural flow regime from water abstraction.
- The floodplains are a dry season grazing area for livestock therefore facilitating invasion through increased dispersal of its seeds by livestock through their dung as they venture into the floodplains in search of water and pasture.

The colonization of some sections of the floodplains by *Prosopis juliflora* has restricted access to the river since it has colonized the river banks and channels as well as in the floodplains displacing grazing areas (Mukhwana *et al*., 2016). Its allelopathic properties and dense impenetrable bushes hinder the growth of other vegetation under its canopy. Gitau (2015) also found a negative correlation between the presence of Prosopis and undergrowth of grass species.

According to Mukhwana *et al*., (2016), some residents in the study area have reported that it is harmful to livestock especially donkeys with some dying after eating its fruits as well as humans. However, it has some minor benefits to small livestock such goats especially during dry spells. Dense stands of *Prosopis juliflora* have also become a hideout for wildlife like lions which attack livestock. Furthermore, its expansion is also displacing human settlements.

The spread of Prosopis needs to be monitored and controlled because it is highly invasive. In South Africa, Wakie *et al*., (2014) reports that a hybrid of Prosopis is expanding its range by 18% per annum therefore doubling its extent every 5 years. It has the potential to colonize the entire floodplain with detrimental impacts on the vital pasture and water resources and consequently the predominantly pastoral livelihoods of the communities. It also has the potential to invade other vegetation cover types, Prosopis has reportedly increased the mortality of some Acacia species in South Africa by depleting water resources (Wakie *et al*., 2014).

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objectives of the study as se out in Chapter one were met.

Upstream water abstraction in the upper Ewaso Ng'iro North River Basin is altering the natural flow regime of the river as indicated by the trend of reduced dry season flows to downstream areas including the floodplains.

The reduced flow and even drying of the river has contributed to an overall reduction in the dense and moderate vegetation cover in the area of study from 2002 to 2015 as shown in the NDVI maps. However, the changes cannot be entirely attributed to the water abstraction because the impacts of climate change such as the more frequent and prolonged droughts experienced in the region also play are role.

The altered regime flow has also led to hydrological changes which has favored the spread of *Prosopis juliflora* which has colonized its river banks, and sections of the floodplains.

5.2 Recommendations

The following recommendations arise from the study:

- The changes in the spatial distribution of *Prosopis juliflora* should be examined to enable an assessment of the invasion rate and the land cover classes being invaded.
- A more comprehensive ground truthing exercise should be carried out to get more validation points or high resolution images be acquired for the study area for the assessment in the spread of *Prosopis juliflora*.
- A time series analysis of the NDVI should be done to monitor the phenological changes of the vegetation in the floodplains in response to the reduced flow of the Ewaso Ng'iro North River.
- Local authorities need to examine ways controlling the spread of *Prosopis juliflora*
- The following areas should also be studied:
    - The impact of climate change on the floodplains because it will further reduce the discharge of the river downstream and its will also cause ecological changes as well.
    - The morphological changes in the floodplains.

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