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Mapping and valuing ecosystem services in the Ewaso Ng'iro Watershed

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Chapter One: Introduction

The Arid and Semi-Arid Lands (ASALs) cover 80% of Kenya's land area, include over 36 districts, and are home to more than 10 million people (25% of the total population) (GoK 2004). A vast majority (74%) of ASAL constituents were poor in 2005/06; poverty rates in the ASALs have increased from 65% in 1994 (KIHBS 2005/6 cited in MDNKOAL 2008), which contrasts with the rest of Kenya -- national poverty rates fell from 52% to 46% in the decade 1996- 2006. Similar stark inequalities between the ASALs and other areas of Kenya are found in health and education as well as infrastructure development and services provisioning (MDNKOAL 2010a).

After decades of neglect, the government is committed to close the development gap between the ASALs and the rest of Kenya. To do so, it charged the Ministry of State for Development of Northern Kenya and other Arid Lands (MDNKOAL) to develop policies and interventions addressing the challenges specific to ASAL, mostly regarding their climate, pastoral and agro-pastoral livelihood strategies and low infrastructure, financial, and human capitals (MDNKOAL 2008). Unlike line ministries with sectoral development planning, MDNKOAL has a cross-sectoral mandate, which requires a holistic approach to development, weighting trade-offs and promoting synergies between sectoral objectives.

Planning and development for ASAL

Based on the three pillars of Vision 2030, the national development plan covering 2008 to 2030, and the ASAL policy, the Ministry has the overarching goal of developing effective policy and capable institutions that create wealth, build resilient livelihoods and reduce inequality in Northern Kenya and other arid lands (MDNKOAL 2010b). The Ministry will focus on:

Strengthening integration of Northern Kenya and other arid lands with the rest of the country and reduce inequality (see Revenue redistribution, Fiscal incentives, …)

Improving the enabling environment for development in Northern Kenya and other arid lands (Infrastructure development, Human capital, Security and the Rule of law)

Developing approaches to service delivery, governance and public administration that accommodate specific realities of Northern Kenya and pastoral areas (Access to public services, Education, Health)

Improving the standard of living of communities in the ASALs and ensure sustainable livelihoods (Drought management and climate change, Land and natural resource management, Livestock production and marketing, Dryland farming, Livelihood diversification, Poverty and inequality)

While infrastructure, financial, and human capitals are low in the ASALs, the current natural capital has a big potential in improving the standard of living of local communities and contributing to national GDP. Indeed, ASALs, with 24 million hectares of land suitable for livestock production, are home to 80 percent of Kenya's livestock, a resource valued at Ksh 173.4 billion. The current annual turnover of the livestock sector in the arid lands of Kenya of Ksh 10 billion could be increased with better support for livestock production and marketing. Since livestock is the main source of livelihood of ASAL constituents, any improvement in livestock value could substantially reduce poverty. While rainfed crop production is quite marginal and restricted to pockets of higher potential areas within ASAL districts, there is a sizeable area that could support crop production if there were a greater investment in irrigation ("Pulling apart" and ASAL Draft Policy 2007 cited in MDNKOAL 2008). Wildlife-based tourism, which contributed 10% to GDP in 2007/2008 (World Bank 2010) is largely generated in the ASALs (MDNKOAL 2010a). While tourism revenue has been constantly on the rise (21.5 Million Ksh in 2000 to 65.4 Million Ksh in 2007 (Ministry of Tourism 2007)), the sector would benefit, among others, from improved road and tourism infrastructure (World Bank 2010).

Reliance of the ASAL on their natural capital for their development: the importance of ecosystem services

In most of Kenya's arid and semi-arid areas, pastoral livelihood strategies dominate. This involves moving livestock periodically to follow the seasonal supply of water and pasture. Agro-pastoralism, combining cropping with pastoral livestock keeping, is a livelihood strategy in areas where rainfed agriculture is possible and around more permanent water sources. In areas with slightly more rainfall, there is mixed farming with sedentary livestock. These agricultural lands are typically dominated by a mix of food, livestock and increasingly cash crops, such as flowers and high value vegetables which are often destined for export. The cash crops often rely on irrigated agriculture. Wildlife conservation and tourism are also important land uses with an increase in the dryland area under a protected status.

All of these livelihood strategies are directly dependent on ecosystem services, the benefits people get from ecosystems. As described, dryland ecosystems supply food from livestock and crops, water for domestic use and irrigation, and wood for fuel and construction (*provisioning services*). Beyond contributing to people's livelihood strategies, healthy dryland ecosystems contribute to their standard of living (health, physical security) by delivering *regulating services* such as mitigating the impacts of periodic flooding, preventing erosion, sequestering carbon, purifying water, and affecting the distribution of rainfall throughout the region. These, in turn, all depend on *supporting services*, such as soil fertility that underlies the productivity of dryland and crops in particular and the production of biomass (vegetation) that sustains livestock and wildlife grazing. Moreover, Kenya's dryland ecosystems provide important *cultural services* that maintain pastoral identities and support wildlife tourism.

ASAL ecosystems must be managed effectively so that they continue to provide these services. In developing land use planning, decision-makers need to understand and holistically manage the complex linkages between ecosystems, ecosystem services and people. The ecosystem services approach will provide tools to integrate socio-economic and bio-physical aspects providing a holistic approach to look at synergies and trade-offs in terms of land and water between land uses across the catchment.

Project

One of the challenges the Ministry faces in taking the most of ASAL's ecosystem services is to manage the various uses of water and land, as both are and will increasingly be the major limiting factors in improving standards of living in ASAL. In this context, the Ministry needs tools to compare alternative land and water uses between livestock, crop production, and wildlife-based tourism to enable its future assessments of how and how much each use will improve standards of living and whose standard of living.

This project first compiled and mapped existing data regarding key inter-related ASAL ecosystem services (water, biomass, livestock, wildlife, irrigated crops). Based on the quantification of and the demand for these services, we estimated their economic value. Finally, we obtained downscaled climate change projections for Northern Kenya and assessed their impact on crop conditions and surface water hydrology.

Chapter Two: Ecosystem services and spatial planning

This section introduces the logic and conceptual framework of this project. We first explain why a spatial mapping approach was used. Next we describe in more detail what ecosystem services are, and the "ecosystem services approach" taken in this project. We then explain how such an approach could aid the Ministry of Northern Kenya and other government decision makers in planning for future sustainable land use.

Why map natural resources?

The first objective of this project is to describe and map the natural resources characteristic of Northern Kenya. Maps are a useful decision tool because they help people to visualize a number of issues that influence natural resource management. For example, maps can show where key natural resources such as rivers and wetlands are in relation to human and animal populations. They can illustrate which geographic locations in a region have greater or lesser resource endowments, and whether people have equal access to scarce resources. Maps can also display what infrastructure is in place that enables or constrains the use and/ or conservation of natural resources. Finally, maps can show how a landscape might change if key driving factors such as climate or road networks or land tenure change. Access to certain important resources might be affected, or the supply of such resources might be threatened. It is also important to map the natural resources of an area as a first step in describing, quantifying and valuing the ecosystem services.

What are ecosystem services?

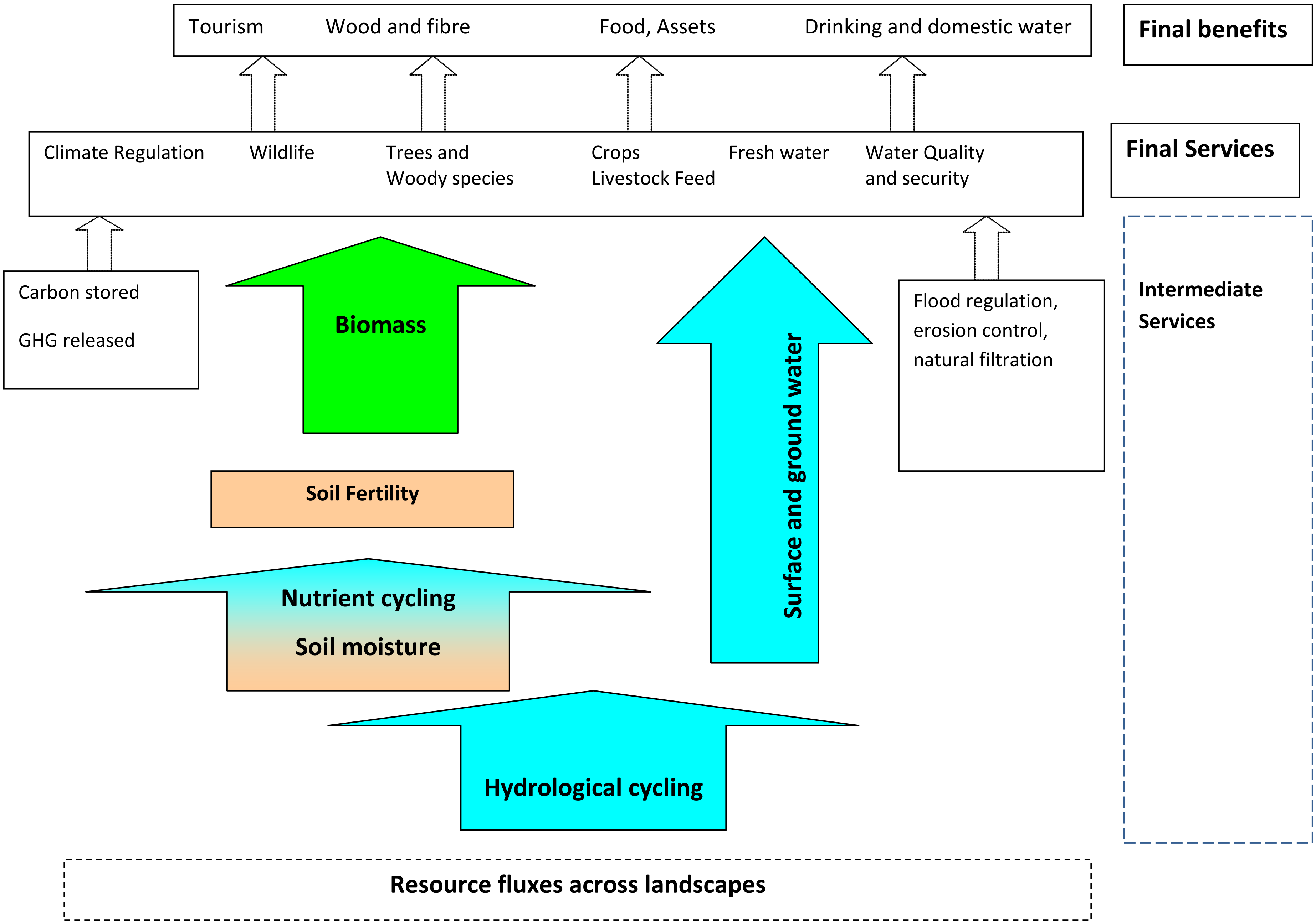
People use natural resources in their daily activities, for example to produce food, to earn money, and to relax. We can describe these natural resources as part of ecosystems, which are the plants, animals, and microorganisms found throughout landscapes, distributed differentially by geology, climate, and geography, and interacting with sun, water, air and minerals in complex systems (MA 2005). As plants, animals and other organisms interact with their environment and each other via characteristic functions or processes they produce a number of services that humans utilize, such as food, clean air, clean water, and natural beauty. Ecosystem services are thus defined as "the aspects of ecosystems utilized to produce human well-being" (Fisher et al 2009). For example, forest ecosystems provide soil retention, air quality, carbon sequestration, and habitat for animals, in addition to wood and fruits from trees. Wetland ecosystems filter water, produce nutrients and are home to certain key plant species. Rangelands provide forage for livestock and wildlife, which in turn provide humans with food, income, and recreation. Agro-ecosystems provide food and income for humans. Human beings depend upon the many services provided by ecosystems for our survival.

Although it is obvious that humans benefit from using many different ecosystem services, we are still learning how best to quantify and value these services. A first step is always to classify ecosystem services so as to better understand the how human well-being benefits from them. How to classify ecosystem services is still a subject of discussion in the literature, with a couple of different popular frameworks in use. The most well-known report on the state of ecosystem services and human well-being, The Millennium Ecosystem Assessment (MA) identified four types of ecosystem services.

- Provisioning services: services from products obtained from ecosystems. These products include food, fuel, fibre, biochemicals, genetic resources, and fresh water. Many, but not all, of these products are traded in markets.
- Regulating services – services received from the regulation of ecosystem processes. This category includes services that improve human well-being by regulating the environment in which people live. These services include flood protection, human disease regulation, water purification, air quality maintenance, pollination, pest control, and climate control. These services are generally not marketed but many have clear value to society.
- Cultural services – services that contribute to the cultural, spiritual, and aesthetic dimensions of people's well-being. They also contribute to establishing a sense of place.
- Supporting services – services that maintain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, and provisioning of habitat. These services affect human well-being indirectly by maintaining processes necessary for provisioning, regulating, and cultural services (US Environmental Protection Agency Science Advisory Board 2009, p. 12).

This classification includes both final products that benefit humans or that they consume directly (e.g. drinking water) as well as the inputs and processes that contribute to the final benefits (e.g. nutrient cycling or water purification). Some argue that this creates confusion when trying to value ecosystem services. A slightly different classification separates benefits services, and divides services into intermediate and final (Fisher et al 2009). Humans directly consume benefits produced by ecosystems, such as food or drinking water or recreation, and they often have a market value. These benefits are produced by final services such as clean and sufficient water or crops. Other services such as soil retention, forage biomass production, or flood regulation, are inputs into final services; these are termed intermediate services. This classification is simpler and allows services and benefits to be classified according to the context and benefits of interest. It also avoids double counting when valuing the benefits. It also facilitates mapping of supply and demand of services and benefits.

In this study, we use the framework of intermediate services, final services and benefits to classify ecosystem services. Figure 2.1 below illustrates how the services are linked in the dryland ecosystems of Northern Kenya.


Tourism
Wood and fibre
Food, Assets
Drinking and domestic water
Final benefits
Climate Regulation
Wildlife
Trees and Woody species
Crops Livestock Feed
Fresh water
Water Quality and security
Final Services
Carbon stored
GHG released
Biomass
Surface and ground water
Flood regulation, erosion control, natural filtration
Intermediate Services
Soil Fertility
Nutrient cycling
Soil moisture
Hydrological cycling
Resource fluxes across landscapes

What is an ecosystems services approach?

Human beings have a long history of modifying ecosystems in order to manipulate the services they produce. For example, agriculture intentionally enhances food and fibre production through modifying landscape vegetation, enhancing soil properties, redirecting water flows, applying fertilizers and pesticides, etc (Defries et al 2004). However, often this modification results in the loss of other ecosystem services, for example biodiversity or clean water. In the past 50 years, although we have seen economic growth in many places, this growth has often relied on unsustainable use of ecosystem services and the negative consequences are widespread and in some cases alarming. For example, the MA reports significant loss of wildlife, increased soil erosion, increased water scarcity, and most critically global warming which is a loss of the climate regulation function (MA 2005). Too much modification of ecosystems is actually threatening their ability to continue to provide services for human well-being in the future. Although economic growth is good, and many people benefit from agricultural development and water infrastructure improvements, for example, we are also reaching the limits of ecosystem exploitation and seeing negative implications for human well-being, more so in some places than others. One of the conclusions of the MA was that poorer people suffer more from ecosystem service losses. Concern over irreversible losses and inequitable distribution of the consequences of those losses has triggered considerable research efforts on ecosystem services, and in developing countries these efforts also incorporate poverty and sustainable livelihoods.

The ecosystems services approach is a research framework that explicitly links the benefits and services provided by ecosystems to human well-being (Turner et al 2008). In so doing, a number of issues can be addressed. First, the approach makes users and providers of ecosystem services aware of what they are using. Second, by specifying ecosystem benefits for human well-being and linking them to certain land uses or ecosystems, the approach can be used to identify which parts of a landscape provide these critical services and need to be well-managed if this service delivery is to continue. This can also be used to identify distributional differences in services, for example forests rich in carbon sequestration and flood regulation may be located only in the upper part of a watershed, while downstream wetlands are important habitats for bird and animal species and also provide important nutrient cycling services. Third, the approach is also useful for looking at the locations of supply of services in relation to the sources of use or demand for services. The wood produced by forests is often used far away, for example. This means that users may not be aware of how their demand for services affects the supply. Fourth, the approach tries to explain the processes or intermediate services required to deliver the final benefits. Again, if these are spatially mapped, people can be made more aware of the full area and number of services involved. Perhaps most importantly, it identifies services that will be lost if a particular part of a landscape is modified, even if to enhance a particular ecosystem service. Thus if wood is harvested from forests, the carbon sequestering service will decline. If wetlands are drained and used for agriculture, then wildlife may lose habitats and nutrient cycling and water quality will be changed.

Following Fisher et al (2009) ecosystem services and benefits depend upon the geographic as well as social and economic context. Thus the services of interest for a highland forest-dwelling community will not be the same as those for pastoral communities in low-lying drylands. This is not only because forests provide different ecosystem services (e.g. timber, carbon sequestration, surface water retention) than rangelands (livestock, forage biomass, groundwater recharge), but also because the use of those services is different and very often the policy and institutional issues governing their use are very different. For example in a forest the concerns may centre on extracting timbre and the resulting losses of biodiversity and carbon, while in pastoral rangelands maintaining access to key dry season grazing areas and water sources may be the major concerns.

Once the ecosystem services of interest for a given context have been described, the next step is to map their supply, and then the use of and demand for the services. Many argue that the final step is to calculate the economic value of ecosystem services in order to get them considered in policy decisions. Ecosystem service valuation allows accounting for the economic benefits derived from ecosystems, but also makes explicit the economic costs of losing services. Finally such an approach also allows for compensation schemes. At the heart of the ecosystems services approach is an understanding that in most ecosystems, modifications to enhance one set of services almost always result in the loss of others; thus there are tradeoffs to be considered in every land use choice, planning and infrastructure development decision (Daily et al 2009).

How is such an approach helpful to ASAL planning issues?

Demonstrating the value of ecosystem services is important because these services are critical for key aspects of human well-being, such as food provisioning, climate and water quality regulation, cultural and recreational experiences, etc. Yet without quantitative assessments, and incentives for land managers to provide ecosystem services, these services tend to be ignored by decision makers (Nelson et al, 2009). In the case of Northern Kenya, a map of ecosystem services has never been made. Such a set of maps can help the Ministry and other departments to understand the current situation regarding ecosystem services and human well-being. It also enables the Ministry to demonstrate to others the richness and value of ASAL resources and livelihood strategies.

In addition there are emerging agendas to enhance and value the provisioning of alternative environmental services such as storage of carbon or production of biofuel crops, which may have synergies or compete with more traditional land uses. Our project could help answer questions such as does demand for one ecosystem service lead to loss of another? Which services are in competition currently or might be in future? How will future "investment" in land, water infrastructure and development, transport infrastructure, population movements, etc., affect ASAL ecosystem services? Which users will benefit from changes in land use and management, and which users will suffer?

Study Area

To demonstrate the value of ecosystem services in the ASALs we chose a case study: the Ewaso Ng'iro watershed (see Map 1), which extends from the high potential areas of Mt. Kenya and the Aberdares down across seven ASAL districts (Meru, Laikipia, Samburu, Isiolo, Wajir, Marsabit and Garissa), ending in semi-arid lowlands. There are several reasons for choosing this particular catchment. It is a critical area for the ASALs as it is at the crossroads of many wildlife and livestock corridors as well as roads. It is the largest of the five major catchments in Kenya. There is a stark contrast throughout the catchment in terms of land use, population density, rainfall and evapotranspiration. We can thus tell very different stories about the availability and demand for ecosystem services across the catchment, including competition for water and land between up and down stream areas for agriculture, wildlife, livestock and human consumption. It is also contains significant biodiversity in terms of wildlife and vegetation. As most of the catchment is arid and semi-arid shrublands and rangelands, wildlife and livestock move regularly around the catchment to find forage and water. Finally, the government of Kenya is considering a number of infrastructure investment opportunities in the area, include a railroad to Sudan and a road from Lamu to Ethiopia (the proposed Lamu Port-Southern Sudan-Ethiopia Transport (LAPSSET) Corridor project).

Study approach and conceptual model

Although much has been written about the need to quantify and value ecosystem services, there are fewer spatially explicit studies that delineate the supply and demand areas for ecosystem services and assess the tradeoffs between services over space and time (e.g. Nelson et al 2009). This study draws upon multiple databases for Northern Kenya to delineate and map areas of supply and demand for key ecosystem services in pastoral drylands: livestock production, irrigated agriculture, wildlife and tourism, and the water supply service which underlies the other three. We deliberately chose these from among the multiple services because they are the most important for human well-being.

To construct maps of ecosystem services, this study follows the approach of several recent studies (Egoh et al 2008, Balmford et al, 2008, Nelson et al 2009) by first delineating and describing the natural resource base, as well as the physical and human geography of the Ewaso Ng'iro catchment. The ecosystem services are then described and mapped. The demand is then mapped, and a preliminary effort to value some of the commodities derived from ecosystem services is made. Then an assessment of the current tradeoffs and synergies between ecosystem services is made. Finally, we consider the impact on ecosystem services of climate change.

Chapter Three: Physical and Social Geography of Ewaso Ng'iro

Introduction

The Ewaso Ng'iro catchment is a landscape comprised of communal and trust lands, cattle ranches and private wildlife conservancies managed by both by pastoralist communities and commercial enterprises, as well as agricultural plots managed by agribusinesses and smallholder farmers. Although parks and protected areas cover less than 10% of the catchment it is home to the greatest diversity and density of wild ungulates in East Africa outside of the Serengeti-Mara park system (Georgiadis et al. 2007, Ojwang' and Wargute 2009). It has more than twenty species of indigenous large mammals with several endangered species. There are more than 6,000 elephants, and the area hosts the largest remaining population in the world of Grevy's zebra and Jackson's hartebeest, as well as the largest national populations outside of protected areas of rhinoceros and reticulated giraffe (Ojwang' and Wargute 2009, Georgiadis et al. 2007). The greater Ewaso Ng'iro is an important livestock area. The camel population of Ewaso Ng'iro catchment is estimated at about 830,000 animals (Ewaso Nyiro North Project).

However, the Ewaso Ng'iro catchment faces challenges related to increasing human pressure, unsustainable land use practices, and declining wildlife ranges (Ojwang' and Wargute 2009). Land-use changes in the Ewaso landscape have occurred primarily as a result of once-nomadic pastoralists shifting to sedentary lifestyles (due to multiple factors that are both favourable and unfavourable) which have resulted in increases in stocking densities, fencing, habitat fragmentation, and depletion of grass, browse and water - all of which have negative implications for livestock and wildlife management (Ojwang' and Wargute 2009). Also in the uplands of Laikipia the abstraction of river water for irrigation has an impact on the livestock in the lowland areas. Analysis of the rainfall and stream flow data within the Ewaso Ng'iro Basin have shown that in the lower reaches within Isiolo, dry season flows are declining (Mati et al. 2005). This has been attributed to the high levels of irrigation abstraction upstream, which can reach 60 percent of the river flow during the dry seasons (Gichuki et al. 1998). We discuss this in more detail in chapter 5.

In this study we focused on the Ewaso Ng'iro catchment including the upper catchment as defined by Mati (1990), the sub-catchments in Marsabit and the downstream plains and swamps in Isiolo and Garissa districts. In this section we describe the human and physical geography and the natural assets of the catchment, including historical trends and changes.

Physical geography

The territory falling under the greater Ewaso Ng'iro watershed management authority makes up the largest drainage basin in Kenya, covering a total of 210,226 km^2 which is predominantly ASAL (Mati et al. 1998). It lies north to north east of Mt. Kenya and the Nyandarua (Aberdare) range. The catchment of the Ewaso Ng'iro river proper, which forms part of this larger administrative entity (Map 1), covers seven districts in Kenya: Laikipia, Samburu, Isiolo, Garissa, Wajir, Meru and Marsabit going from the highlands of Mt. Kenya and the Aberdares in the West and Mt. Marsabit in the North, to arid lowlands in the East, covering an area of 83,847[2] km^2. Although the main river originates from the Nyandarua range, the tributaries originating from Mt. Kenya supply most of the flow. Whereas the surface flow from the Ewaso Ng'iro river disappears into the Lorian Swamp in Kenya, subsurface flows continue eastwards to recharge rivers inside Somalia, which eventually drain into the Indian Ocean (Mati et al. 2005).

There is significant variation in elevation throughout the catchment, with altitudes ranging from 5200 masl at Mt. Kenya to 138 masl in Garissa. Map 2 shows the river network with permanent rivers emerging from the slopes of Mt. Kenya and the Aberdares, draining into the Ewaso Ng'iro. Towards the north, Mt. Marsabit stands. In addition, a large number of ephemeral rivers which mostly carry water for extremely short periods after rains can be found throughout the drier parts of the catchment (coming down from the Matthews Range, and Mt. Marsabit and after Merti when the river disappears). The Ewaso Ng'iro drains into the semi-permanent Lorian Swamp while several smaller wetlands of unknown wetness status but most likely more short-lived nature occur along the rivers in the North. Note that we use the term wetland to describe areas classified as wetlands in the Africover 2000, but many of these "wetlands" do not regularly flood, as will be discussed in chapter 5.

The larger part of the catchment classifies as arid and semi arid lands (ASAL), but small pockets of more humid areas exist. The 83,000 km^2 catchment has0.5% (386 km^2) humid zone, 1% (815 km^2) sub-humid zone, 2.4% (2,011km^2) semi-humid zone, 4.3% (3,568 km^2) semi-humid to semi-arid zone, 12.9 % (10,855 km^2) semi arid, 16.8% (14,124 km^2) arid and 62.1% (52,088 km^2) in the very arid zone. The distribution of land use and of people mirrors the potential of these lands for the various agriculture, livestock and conservation activities.

Population and social aspects of communities in Ewaso Ng'iro

Ewaso Ng'iro has ethnically diverse communities. The districts in the upper parts of the catchment (Laikipia, Meru and Nyeri) are home to the Mukogodo Maasai, Kikuyu, and Meru, who live side by side with Europeans, Turkana, Samburu and Pokot. The northern part of the catchment is mainly inhabited by traditional pastoralists consisting of the Samburu, Gabra, Rendille and Boran, while the lowlands to the east are mostly inhabited by Boran, Somali, Samburu and Rendille (all pastoralists) and the Meru (agro-business). Approximately 1.85 million people reside in the catchment according to the 2009 census, versus the low population of about 282,300 people in 1969.

[2] The administrative catchment known as the Ewaso Ng'iro covers a larger area of about 210,000 km^2 (Mutiga 2010)

The highest population increases during the last 40 years in the catchment were observed in Garissa, followed by Laikipia, Marsabit, Samburu and Isiolo. In Garissa the largest increase in population was during the period 1989 and 1999. However, during the period 1999 to 2009 Marsabit had the highest annual population growth rate of 6.7%, followed by Garissa (5.9%), Samburu (5.6%), Isiolo (4.2%) and Laikipia (2.4%). Laikipia had the highest increase in population during the period 1969 to 1989 compared to the other 4 districts in the study site.

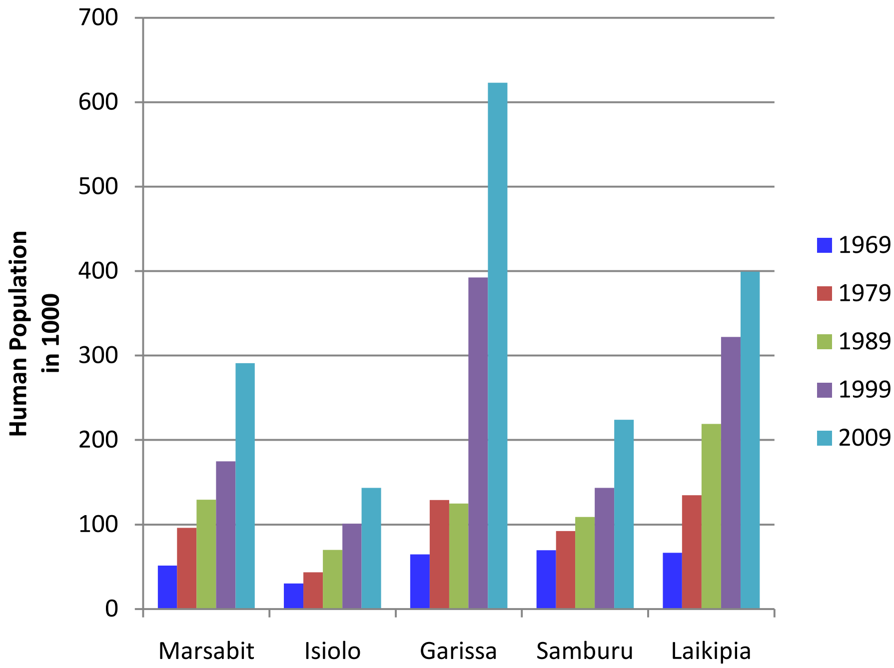


Figure 3.1: Human population in the six districts between 1969 and 2009 (Source of Information CBS, 1994, CBS 2002, KNBS 2010).

Map 3 shows the spatial distribution of human population in 1962, 1979, 1989 and 2009. There is significant variation in human population density with densities greater than 100 people per km^2 in the highlands, and densities of 10 people per km^2 and below in many parts of the dry lowlands. This geographic variation in human population density relates to the differences in climate, agroclimatic potential and rural urban markets.

In the last 50 years a number of urban centres have emerged in the ASAL (see Map 4). In this study we compiled and mapped the population of these centres from 1962 to 2009. Again we see an increase in population of many of the urban centres in the high agriculture potential areas. Dadaab jumps out in the drylands, as it has see a five-fold from 1989 and 2009 to reach 284,306 in 2009 following an influx of refugees from Somalia since 1991 (Enghoff et al, 2010; see Figure 3.2). Daadab is a cluster of refugee camps and today Dagahaley, Hagadera and Ifo camps in Dadaab comprise the largest refugee site in the world. The current population is triple the designated capacity, making the Dadaab complex one of the world's oldest, biggest and most congested refugee sites. Dadaab, some 90km from the Kenya-Somalia border, has seen a large number of asylum-seekers fleeing years of conflict in Somalia. Most of these refugees fled into Kenya following the collapse of the Siad Barre government and subsequent outbreak of civil war in Somalia in 1991 and recently because of insecurity in Somalia.

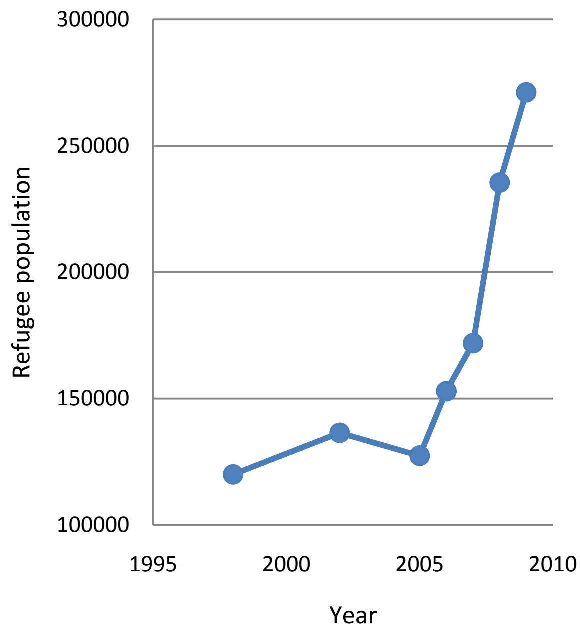


Figure 3.2: Trend of population in Dadaab refugee camps 1998 - 2009 (Source of information: UNHCR Statistics)

Poverty

Map 5 shows the poverty rates and density both in Kenya and the catchment. The maps shows poverty rates for the smallest administrative areas available, combing estimates at three different scales: 2,056 rural location (covering most of Kenya), 80 urban sublocations (Nairobi, Mombasa, Nakuru, Kisumu and Eldoret), and 14 constituencies (covering the northeastern part of the country, WRI et al. 2007). Poverty rates express the percentage of people that live below poverty line. In the rural areas poverty is defined as spending less than Ksh 1,239 per month (about US$0.59 per day) and whereas in the urban areas, the poverty lines is defined as spending less than Ksh 2,648 per month (about US$ 1.26 per day, WRI et al. 2007).

Kenya has high rates of poverty especially in the arid lands. In the catchment we observe high poverty rates of more than 55% in Isiolo, Garissa and Marsabit, while Laikipia and parts of

Samburu have moderate poverty rates of between 35 to 45%. The map of poverty densities (persons per km^2) shows the dry areas have low density of poor people as compared with high productive agriculture areas of Laikipia and surrounding high rainfall areas of Nyeri, Nyandarua and Meru. These high productive agriculture areas have moderate poverty rates but still have large concentrations of poor people as they are more densely populated (WRI et al. 2007).

Rainfall and Evapotranspiration

Water is a critical resource in any landscape, but particularly in the ASAL districts of Kenya. As Map 6 shows, rainfall is very high in the extreme upper part of the catchment; along Mt. Kenya it is over 1200mm per year. This annual amount drops off in the lower elevations, with part of Laikipia, most of Samburu and Isiolo receiving between 300 and 600 mm annually. The eastern most part of the catchment in Isiolo and Garissa, receives less than 300 mm. Much of the catchment is in rainfall deficit for the majority of the year (except April and December). This is reflected in the graphs in Figure 3.3, which shows that January and February, and June through September are very dry months for in the lower part of the catchment.

The seasonality of rainfall varies across the catchment (Figure 3.3). To the north, Marsabit and North Horr have two rainy seasons with the long rains (March to May) being of greater importance than the short rains which are from October to December. The higher parts of Laikipia and parts of Samburu have a trimodal rainfall pattern, consisting of 'long rains' (April to June), 'short rains' (October to December) and a third but smaller and more unpredictable rainfall peak in July and August. Rainfall is bimodal in Isiolo and Garissa, with the short rains being most important (see Figure 3.3).

In conclusion we observe that the seasonal distribution of rainfall differs between the highland and lowland parts of the catchment. There is also difference in predictability of the rains, which relates to differences in topography. In the highlands, rainfall is more predictable; rains occur almost daily during the rainy season, due to orographic uprising of humid air. In the lowlands, rainfall is more unpredictable as it occurs during a few thunderstorms which build up because of convection of moisture-laden air over heated land.

Conversely, the potential evapotranspiration (PET) is relatively low in the upper, high rainfall, part of the catchment, at less than 1200 mm per year. But over the dry lowland areas, PET is greater than 1800mm (Map 7). On an annual basis, all of the catchment apart from Mt. Kenya has a water deficit. There is significant seasonal variation in the intensity of the water deficit. The ratio between rainfall and evapotranspiration is called the “aridity index”. Map 7 describes the variation in this index over an average 12 month period.

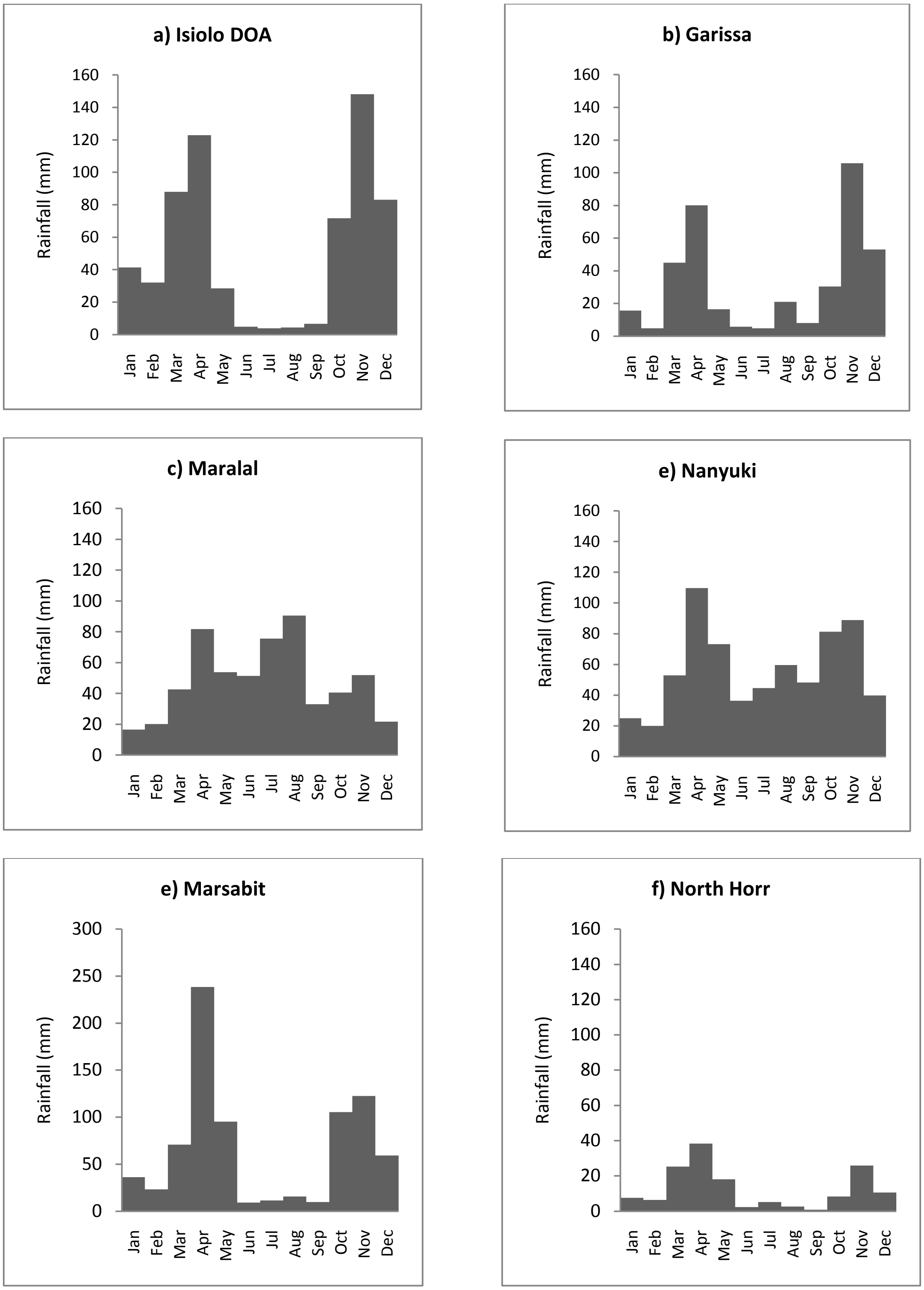


Figure 3.3: Long-term average monthly rainfall for 6 stations in the study area

Climate and agroclimatology

Kenya is divided into seven agro-climatic zones based on the above described aridity index (Sombroek *et al.,* 1982). Areas with an aridity index greater than 50% have high potential for cropping, and are designated as high agricultural potential areas and consists of agroclimatic zones I, II, and III. These zones account for 12% of Kenya`s land area. The semi-humid to arid regions (zones IV, V, VI, and VII) have indexes of less than 50% and a mean annual rainfall of less than 1100 mm. These zones are generally referred to as the Kenyan ASAL (arid and semi arid lands) and account for 88% of the Kenyan territory.

Table 3.2 summarizes the area of land in the Ewaso Ng'iro catchment falling in the seven agro-climatic (AC) zones according to Sombroek et al. (1982, see Map 8). The potential for land use is highly dependent on the aridity index and we reclassified the seven original AC zones into three zones. Zone A, included the humid to semi-humid areas (ACZ I, II and III); Zone B, included the semi-humid and the semi-humid to semi-arid zone (ACZ IV and V); and Zone C included the arid to very arid and the very arid zones (ACZ VI and VII). Across the catchment 3.9% (3212 km^2) of land was classified as Zone A, 17.2% (14,423 km^2) as Zone B and 78.9% (66,212 km^2) as Zone C.

Table 3.2: Area (km2) of the seven agro-climatic zones (ACZ, Sombroek et al, 1982) in the Ewaso Ng'iro catchment.

Agroclimatic Zones	ACZ	Zones	Area (km^2)	Area (%)
Humid	I	a	386	0.5
Sub-humid	II	a	815	1.0
Semi-humid	III	a	2011	2.4
Semi-humid to semi-arid	IV	b	3568	4.3
Semi-arid to arid	V	b	10855	12.9
Arid to very arid	VI	c	14124	16.8
Very Arid	VII	c	52088	62.1

Land cover

The generalized land cover map for the catchment was derived from the Africover database (FAO 2000). The 26 classes that occurred in the catchment in the original map were aggregated into 12 classes. The 12 main land cover classes were forest 2.3%, woodland 2%, bushlands 7.3%, shrublands 23.5%, shrub savannah 41%, grasslands 10.3%, rainfed crop 2.9%, irrigated crop 0.06%, scattered rainfed crops 5.3%, wetlands 5.3%, bare areas 0.3% and urban and settlement 0.05%.

Table 3.3: Original land cover classes and aggregated classes used in the study

Land cover class	Land cover description	Aggregated land cover	Class
1	Closed trees	Forest	1
2	Closed trees on temporarily flooded land	Forest	1
3	Forest plantation - undifferentiated	Forest	1
4	Multilayered trees (broadleaved evergreen)	Forest	1
5	Open trees (65-40% crown cover)	Woodland	2
6	Very open trees (40-15% crown cover)	Woodland	2
7	Closed to open woody vegetation (thicket)	Bushlands	3
8	Closed shrubs	Shrublands	4
9	Open low shrubs (65-40% crown cover)	Shrublands	4
10	Open shrubs (45-40% crown cover)	Shrublands	4
11	Shrub savannah	Shrub savannah	5
12	Sparse shrubs	Shrub savannah	5
13	Trees and shrubs savannah	Shrub savannah	5
14	Closed herbaceous vegetation on permanently flooded land	Grassland	6
15	Open to closed herbaceous vegetation	Grassland	6
16	Open to closed herbaceous vegetation on temporarily flooded	Grassland	6
17	Rainfed herbaceous crop	Rainfed crop	7
18	Rainfed shrub crop	Rainfed crop	7
19	Rainfed tree crop	Rainfed crop	7
20	Irrigated herbaceous crop	Irrigated crop	8
21	Isolated (in natural vegetation or other) Rainfed herbaceous crop (field density 10-20% polygon area)	Scattered rainfed crops	9
22	Scattered (in natural vegetation or other) Rainfed herbaceous crop (field density 20-40% of polygon area)	Scattered rainfed crops	9
23	Scattered (in natural vegetation or other) Rainfed tree crop (field density 20-40% of polygon area)	Scattered rainfed crops	9
24	Bare areas	Bare areas	10
25	Natural water bodies and swamps	Wetlands	11
26	Urban and associated areas, rural settlements	Urban and Settlement	12

Map 9 shows the distribution of land cover across the catchment and Table 3.4 summarizes the land cover and its distribution within the various agro-climatic zones. In Zone A the main land cover are forest (31%), rainfed crop (28%) and scattered rainfed crop (18%). Zone B is dominated by shrub savannah (29%), scattered rainfed crop (19%), shrublands (16%) and rainfed crop (11%). Natural vegetation prevails in Zone C, with dominate land types of shrub savannah (45%), shrublands (26%), grassland (12%), bushlands (7%) and wetlands (7%). The wetlands located in Zone C and are critical for livestock and wildlife.

Table 3.4: Summary statistics for the area of land cover in the three agro-climatic zones described in table 3.2

	Total		**Zone A**		**Zone B**		**Zone C**	
Land Cover	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Forest	1907.2	2.28	970.8	30.76	785.2	5.45	151.2	0.23
Woodland	1663.5	1.99	56.5	1.79	692.1	4.80	914.9	1.38
Bushlands	6075.5	7.26	310.7	9.85	1237.3	8.59	4527.5	6.85
Shrublands	19666.6	23.50	100.7	3.19	2335.0	16.21	17230.8	26.06
Shrub savannah	34099.9	40.74	162.4	5.15	4209.1	29.21	29728.4	44.95
Grassland	8605.4	10.28	79.2	2.51	756.4	5.25	7769.8	11.75
Rainfed crop	2422.8	2.89	885.4	28.06	1517.2	10.53	20.3	0.03
Irrigated crop	51.5	0.06	8.6	0.27	42.9	0.30	0.0	0.00
Scattered rainfed crops	4434.4	5.30	563.2	17.85	2719.7	18.88	1151.5	1.74
Bare areas	269.6	0.32	13.9	0.44	10.2	0.07	245.5	0.37
Wetlands	4458.9	5.33	3.8	0.12	90.5	0.63	4364.6	6.60
Urban and Settlement	40.1	0.05	0.4	0.02	12.6	0.09	27.0	0.04

Geology and parent material

The mineral composition of the bedrock (the parent material from which soil is derived) have great influence on the fertility and physical properties of the soils (Thurow and Herlocker 1993). Information on the geology and parent material of the site thus provides insight about soil formation processes that influence such as plant growth and the potential for crop and livestock production.

The catchment has four major lithology classes: igneous rocks, sedimentary rocks, metamorphic rocks and unconsolidated rocks. Igneous rocks are formed from molten lava, sometime referred as volcanic rocks. The texture of igneous rocks is determined by how fast the molten material cool and how large the mineral crystals grow within the rock. Basalt is fine-textured and granite is coarse textured. Weathering of fine-grained rocks produces soils containing fine material such as clay and silt, while coarse textured rocks develop into sandy soils. Sedimentary rocks are formed either by accumulation of fragments of rocks, minerals and/or organisms which are cemented together, either chemically or by compression. Metamorphic rocks are formed within igneous or sedimentary rocks are buried deep within the earth and are subjected to high amounts of heat, pressure and /or chemical activity.

Table 3.5: Summary of lithology in the catchment

		Zone A		**Zone B**		**Zone C**	
Major group		Area (km^2)	Area %	Area (km^2)	Area %	Area (km^2)	Area %
Igneous rock		1,745	54.34	9,009	60.48	14,800	21.92
	Acid igneous	916	28.53	2,687	18.04	5,340	7.91
	Basic igneous	791	24.64	1,983	13.31	8,470	12.55
	Intermediate igneous	38	1.18	4,340	29.13	989	1.47
Metamorphic rock		357	11.11	4,912	32.97	21,551	31.93
	Basic metamorphic					135	0.20
	Acid metamorphic	357	11.11	4,736	31.79	21,416	31.73
Sedimentary rock		48	1.49	125	0.84	16,772	24.85
	Organic					61	0.09
	Clastic sediment	48	1.49	125	0.84	16,711	24.76
Unconsolidate		1,062	33.06	842	5.66	14,380	21.30
	Pyroclastic	1,052	32.75	299	2.01	108	0.16
	Fluvial	0	0.01			8,091	11.99
	Eolian	10	0.30	543	3.65	5,870	8.70
	Lacustrine					312	0.46
No data	No data			7	0.05		

Land use

The land use map (Map 11), which was derived from combining information from the land cover map with ancillary information on protected areas (parks, forest reserves, and conservancies), and distribution maps of livestock and wildlife (from Department of Resource Surveys and Remote Sensing), identifies seven land use classes. Conservation forestry, practiced in and restricted to Forest Reserves, and production forestry, confined to forests and woodlots outside protected areas is mostly located in agro climatic zone A. In this high rainfall zone we further observe considerable area under mixed crop-livestock production, located on the foot slopes of Mount Kenya, the Aberdares and the Matthews range. Also, scattered around these footslopes are small areas of irrigated crop production. As rainfall is relatively high in these areas there is mix of both indigenous livestock and exotic breeds of cattle. Most of these lands are under private ownership.

Livestock production is by far the dominant land use, occupying 82% of the catchment area. While in Laikipia livestock production is mostly on private ranches, it is practiced mostly on communal and trust land in the rest of the catchment. These land tenure conditions are important, as several private ranches are fenced, thus compromising animal mobility. The communal and trust lands are not fenced, thus allowing mobility of livestock which is an important strategy allowing communities to move around with their animals to avoid the adversaries of erratic rainfall in these arid to very arid lands.

Mixed crop-livestock production, the second most important land use in the catchment overall (6.2% of the area, Table 3.6) is restricted mostly to higher rainfall areas in ACZ's A and B. Conservancies, where people practice conservation and livestock keeping, are the third largest land use category. Conservation forestry and wildlife conservation are other important land uses, while irrigated crop production (less than 0.1%) is a little practiced land use.

Table 3.6 summaries the land use and its extent in each of the zones. In terms of agroclimatic zones, wildlife conservation is mostly practiced in zone C, in the arid to very arid land. Conservation forestry is practice in zone A and B where rainfall is high, though still we observe forests in the dry lands. Livestock production, although practiced in all zones, is more widespread in zone C (91%) than in zone B (51%) and A (43%). The combination of livestock production and wildlife conservation occurs in conservancies which are located in zone B (5.3%) and C (4.3%) but the animals are spread throughout the landscape (see maps 21 and 22).

Table 3.6: Summary statistics of the area of the catchment under seven land use classes for agroclimatic zones A, B and C

	Zone A		Zone B		Zone C		Total	
Land use	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area %
Wildlife Conservation	25	0.8	137	0.9	2708	4.1	2869	3.4
Conservation forestry	394	12.3	1924	13.3	330	0.5	2648	3.2
Livestock production	1368	42.6	7296	50.6	60299	91.1	68963	82.2
Production forestry	157	4.9	370	2.6	0	0.0	526	0.6
Mixed crop-livestock production	1265	39.4	3893	27.0	0	0.0	5158	6.2
Irrigated crop production	2	0.1	43	0.3	0	0.0	45	0.1
Livestock production and wildlife conservation	0	0.0	761	5.3	2875	4.3	3637	4.3
	3211	100.0	14423	100.0	66212	100.0	83847	100.0

Physical infrastructure

Markets and road infrastructure

We used maps developed by the International Food Policy and Research Institute (IFPRI) on travel times to assess market access. Travel time was defined as the time in hours required travelling from a given point to the nearest market centre. The market centres were defined as cities with a population of 100,000 or more (2000 year estimate) based on CIESIN's GRUMP alpha data. Travel time to market centres is used as a proxy for market accessibility and shows the likely extent to which households are physically near or far away from markets. It is important that the producers (framers or pastoralist) have access to markets in order to trade/sell their goods. The more accessible markets are to the given population the greater the population's ability to remain economically self-sufficient and maintain food security (IFPRI).

The map of travel time was estimated based on the combination of different global spatial data layers which represent the time required to cross each single point. These dataset include: SRTM30 elevation, Slope in degrees (derived from SRTM30 elevation data), GLC2000 land cover, urban areas from GPW3-GRUMP, roads from VMAP0, Railways from VMAP0, rivers from WDBII, borders from VMAP0, major water bodies from GLWD layer 1, Major sea routes data, and "high seas" from GLC2000 (see Nelson 2008, available at http://www-tem.jrc.it/accessibility).

Map 12 shows an overlay of travel time, roads, markets centres, rivers and elevation. Most of the areas of southern Laikipia are within a travel time to a market centre of 6 hours. The area is endowed with various types of roads and the network is dense compared to other areas within the study area. Pastoral areas in Marsabit and north of Wamba, Isiolo and Wajir have between 10 to 26 hours of travel to a market centre.

Tourism infrastructure in and around the Ewaso Ng'iro

Map 13 shows the tourism infrastructure in the catchment. The maps was composed based on a number of data layers including airstrips (gathered from Kenya Airport Authority), protected areas (Kenya Wildlife Services), land tenure, hotels, camp sites, tented camps (Kenya Wildlife Services, Tourist maps, WRI et al., 2007), conservancies (Northern Rangeland Trust, Kenya Wildlife Services).

Most of the wildlife facilities are around Isiolo, Nanyuki, Mount Kenya and Aberdares. These facilities also coincide with areas of high wildlife diversity and densities in the region. In Laikipia most of the big ranches have airstrips and provide additional tourism facilities in the region (see the detail tourism Map 14). Some areas in Garissa, Marsabit and north eastern Isiolo with have high wildlife have almost no tourism infrastructure.

Water infrastructure: Boreholes, wells and springs (Maps 15, 16, and 17)

Rural Focus has carried out an extensive survey of nine different types of water sources in Northern Kenya, the most extensive survey since the GTZ Rangeland Management Handbook in the 1990s. A brief description of each type of water source is given below. While we recognize that survey data has inherent biases, this is the most up to date and complete water sources dataset for the region. As a result, this section relies primarily on survey data collected by Rural

Focus. The data reported here are limited to only those divisions that fall within the catchment. Tables 3.7 to 3.10 provide details of the water sources in each district.

Water source	**Description**
Boreholes	Deep (>20 m) wells dug to access groundwater; require pumping
Dams/pans	Shallow water storage structure; dams have a structural wall that stops the water, whereas pans are generally excavated below ground
Wells	Shallow (<20 m) wells to access groundwater close to the surface; often hand-dug and located close to water courses
Springs	Natural flow of groundwater accessible at the surface
Seasonal rivers	Surface water courses that do not flow permanently (year-round)
Permanent rivers	Surface water courses that flow year-round
Rainwater storage	Storage units typically built on roofs to collect rainwater
Underground tanks	Storage built below ground to collect surface water runoff
Emergency water tankering points	Water tanks often provided by relief agencies
River access points	River abstraction point, often governed by customary access rights
Rock catchment	

a. Garissa

The Ewaso Ng'iro watershed forms the border between Garissa and Wajir districts and covers parts of four divisions in Garissa: Dadaab, Liboi, Modogashe, and Shant-Abak. Rural Focus identified a total of 192 water sources in these four divisions, of which approximately 86% were operational as of the survey date (January – March 2004). Table 2 presents data on water sources and operational status by division. It is clear from this table that dams and pans represent the vast majority of water sources (67%) and account for 77% of all operational sources. Boreholes are also an important resource in this region, representing nearly a quarter of all water sources. However, less than 60% of the boreholes surveyed were operational at the time. Of the 24 boreholes that are non-operational, four were reportedly "temporarily" non-operational. This may indicate that they are in fact functional but are used as "contingency" boreholes only under extreme drought situations. Nonetheless, Rural Focus determined that the number of operational boreholes in Shant-Abak, Dadaab, and Liboi divisions is currently sufficient, noting that non-operational boreholes could be rehabilitated to meet future demand. In contrast, Modogashe has no boreholes due to low groundwater potential and thus relies on numerous water pans and natural depressions to provide water.

b. Isiolo

Since the watershed covers most of Isiolo District, except for its most extreme northern and southern tips, data for all divisions are reported here. Rural Focus surveyed a total of 172 water sources, of which nearly half (47%) were operational as of the field study (December 2002 – January 2003). Of these, boreholes represent the highest proportion (46% of operational sources), with wells (29%) and dams/pans (13%) accounting for most of the rest. Unfortunately, only 32% of boreholes in Isiolo District are operational, while less than half (47%) of dams/pans are fully functioning. However, Mati (2003) reports that four boreholes in the district are managed as contingency boreholes for livestock watering during severe drought conditions.

Most of the boreholes and shallow wells are clustered along the Ewaso Ng'iro river and near the town of Isiolo. Water sources are particularly scarce in Merti and Sericho Divisions. Given that a number of ephemeral water courses traverse the district, it is likely that developing shallow dams and infiltration galleries around these areas could improve water supply despite limited groundwater potential in the district (B. Mati 2003).

c. Samburu

Only the divisions of Wamba and Waso are located primarily within the Ewaso Ng'iro catchment. Table 4 displays water source distribution by operational status across these two divisions. Of the 75 operational water sources in these two divisions, boreholes account for just less than one third (31%), rooftop storage represents 27%, and dams/pans and wells 16% and 15%, respectively. However, overall 85% of all boreholes in these divisions are operational with 2 permanently non-operational and 2 temporarily non-operational. It is clear from Map XX that Waso Division is underserved by operational water sources. This region is only used for dry season grazing, and it has also recently been affected by conflict as reported by Rural Focus (February-March 2007).

d. Wajir

The divisions of Hadado, Habaswein, and Sebule border the Ewaso Ng'iro catchment to the north. As shown in Table 5, a total of 88 water sources were identified during field work (2003), of which 88% were operational. The majority of these operational sources are dams/pans (70%), though boreholes represent a further 22%. Roughly 63% of all boreholes were reported to be operational; in addition, one borehole was reported as being temporarily operational in Habaswein Division. In contrast, fully 98% of the 55 dams/pans in this region were reportedly operational. Most of the operational boreholes exploit the Merti aquifer, which extends north from Garissa into southern Wajir. Beyond this zone, groundwater becomes increasingly saline moving northeast toward Diff.

Table 3.7: Water sources in Garissa District within the study area

Garissa	Borehole		Dam/Pan		River		Well		Roof	E Tankering	Total			
	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Op	Nop
Dadaab	23	74	28	96									44	7
Liboi	10	50	3	100			1	100	1	100			10	5
Modogashe	3	0	16	100			10	90			1	0	25	5
Shant-Abak	11	27	81	100	1	100	2	100			1	0	87	8
Total	**47**	**59**	**128**	**100**	**1**	**81**	**13**	**48**	**1**	**24**	**2**	**75**	**166**	**25**

Table 3.8: Water sources in Isiolo District within the study area

Isiolo	Borehole		Dam/Pan		River		Well		Spring		U Tank		E Tankering		Total	
	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Op	Nop
Central-Isiolo	35	54	3	0					**4**	100					23	17
Garba Tulla	13	38					5	100							10	7
Kinna	7	29	7	29			12	83	**2**	100	**1**	100	**1**	100	18	12
Merti	35	20	3	0			1	100					**1**	100	9	22
Oldonyiro	7	29													2	5
Sericho	18	11	8	100	1	0	7	100					**1**	100	18	17
Total	**115**	**32**	**21**	**48**	**1**	**0**	**25**	**92**	**6**	**100**	**1**	**100**	**3**	**100**	**80**	**80**

Table 3.9: Water sources in Samburu District within the study area

Samburu	Borehole		Dam/Pan		River		Well		Rock		Spring		Roof		E Tankering		Riv Access		Total	
	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Total	% Op	Op	Nop
Wamba	15	87	13	69	1	0	4	25	2	50	5	100	18	83	1	100	2	100	47	11
Waso	12	83	6	50	3	100	7	43			2	100	5	100			2	100	28	6
Total	**27**	**85**	**19**	**63**	**4**	**75**	**11**	**36**	**2**	**50**	**7**	**100**	**23**	**87**	**1**	**100**	**4**	**100**	**75**	**17**

Table 3.10. Water sources in Wajir District within the study area

Wajir	**Borehole**		**Dam/Pan**		**Well**		**Roof**		**U Tank**		**Total**	
	Total	%Op	Total	%Op	Total	%Op	Total	%Op	Total	%Op	Op	Nop
Habaswein	9	44	21	95	1	100					25	6
Hadado	7	100	5	100			3	100	2	100	17	0
Sebule	11	55	29	100							35	5
Total	**27**	**63**	**55**	**98**	**1**	**100**	**3**	**100**	**2**	**100**	**77**	**11**

Chapter Four: Geography of Ecosystem Services in Ewaso Ng'iro

As explained in chapter two, ecosystems deliver services that humans depend upon for their well-being. In this chapter we map the distribution of key ecosystem services to estimate the potential supply in the Ewaso Ng'iro catchment. We start with the distribution of water, an underlying ecosystem service, which supports primary production and supplies drinking water that supports the livelihoods of people and animals. Next we map forage provided in rangelands. This is then followed by description of the distribution of livestock, wildlife and cropping systems, as these are the final benefits to people.

In the next four chapters, we refer to eight subcatchments within the Ewaso Ng'iro basin, which are shown in Figure 4.1 below. The delineation of the boundaries of the catchment and the sub-catchments is based on a digital elevation model (DEM) derived from ASTER.

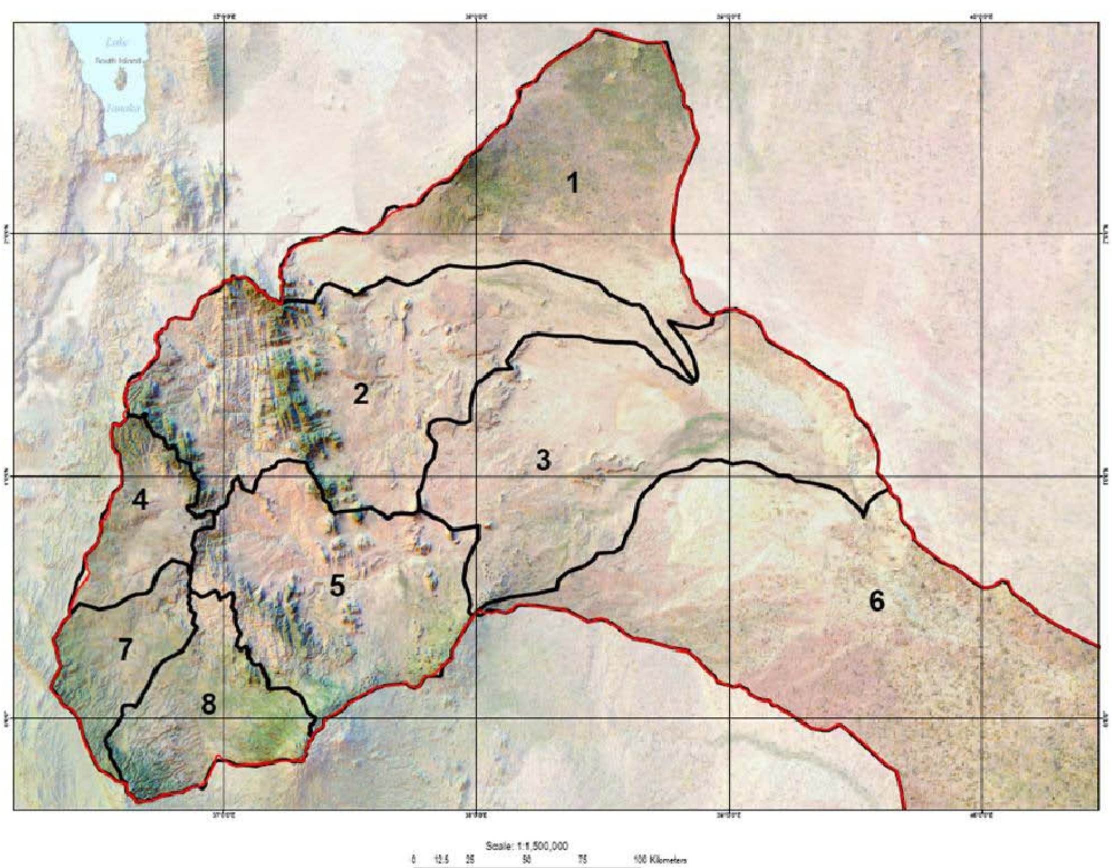


Figure 4.1: The 8 subcatchments of Ewaso Ng'iro

Water supply

The rainfall entering a basin is the ultimate source of water that supports all water dependent ecosystem services. The support function of rain water can take different forms: **Green water** is the water that supports transpiration of plants, leading to the production of green biomass. **Blue water** is the water in surface and groundwater reservoirs, which may be used as drinking water, for sanitation or industrial production or for irrigated agriculture (see www.waterfootprint.org).

The average annual volume of rain entering the 83,847 km^2 Ewaso Ng'iro catchment, considering an average annual rainfall over the catchment of 444 mm, equals 37.2 km^3. A relatively minor fraction ends up as blue water. For example, the volume of water flowing through the Ewaso Ng'iro at Archers Post, which equals 0.67 km^3 per year (1960-2010), represents 1.81% of the total volume of rainfall entering the catchment. A smaller volume of water recharges the groundwater, such as the Merti aquifer (see Map 15). Other sources of blue water include water stored in pans. With the volume of recharge and stagnant surface water poorly known, it is difficult to estimate the fraction of total rainfall that ends up as blue water, but based on the flow of the Ewaso Ng'iro river, and assuming that less water resides in ephemeral rivers, pans and aquifers, we estimate that less than 5% of the water in the catchment ends up as blue water, leaving a dominant more than 95% of the water balance in the form of green water. See Figure 4.2 below for a diagrammatic depiction of the catchment hydrologic balance. This figure depicts the different ways that precipitation is partitioned in the catchment, among land uses, the Ewaso Ng'iro river, and groundwater recharge.

The catchment is a virtually closed system, with an as yet unknown but presumably relatively small amount of groundwater flowing out of the system towards Somalia. The water balance would thus have on average annually 37.2 km^3 entering the system in the form of rainfall and an evapotranspiration equalling the amount of rainfall minus the outflow of ground water.

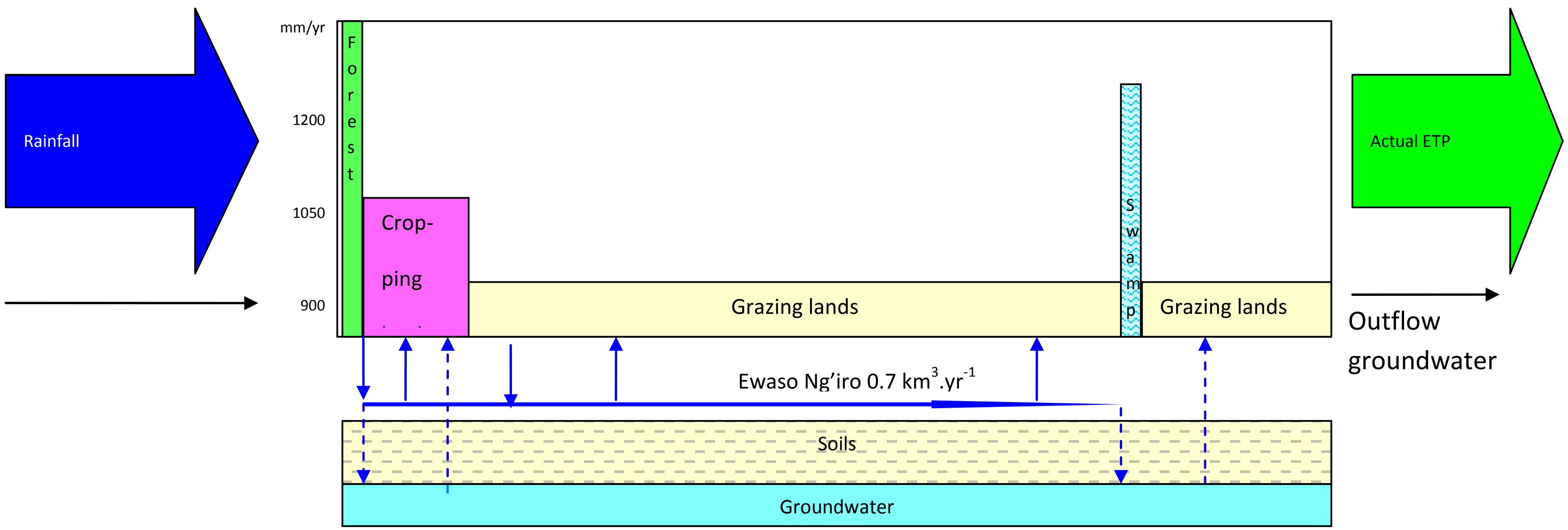


Figure 4.2: Graphic depiction of hydrologic balance, Ewaso Ng'iro catchment.

Rainfall and green water

Rainfall varies across the catchment, as does potential evapotranspiration (Map 8). A few pockets on the slopes of Mount Kenya have annual rainfall that exceeds potential evapotranspiration. Map 8 is showing the location of these volcanic slopes with over 1200 mm of rainfall and less than 1200 mm evapotranspiration. It is these humid and semi humid areas with a rainfall excess that contribute significantly to the waters of the Ewaso Ng'iro river. The sub-humid to semi-arid and the semi-arid zones, with rainfall between 600 and 900 mm occupy a larger part of the catchment, notably the Laikipia plateau. The largest part of the catchment is in the semi-arid to arid and in the very arid zone (Map 8), with average annual rainfall below 600 mm.

Rainfall is a good proxy for green water, as there is little run off and losses to the ground water. Not surprisingly, the distribution of land cover (map 9) and land use (map 11) is tightly coupled to this spatial variation in rainfall. Forests under conservation and production forestry dominate the humid agroclimatic zones, while mixed crop livestock systems dominate the sub-humid to semi-arid zone. Dryland, mostly under mobile pastoral livestock production systems, wildlife conservation and mixtures of these two land uses (e.g. livestock production and wildlife conservation) dominate the semi-arid to the arid zones.

Rainfall supports primary production of natural vegetation and croplands. The seasonal variation in rainfall largely determines the seasonality in crop and rangeland production. Map 6 displays the seasonal variation in rainfall across the catchment. Map 7 reveals variation in aridity index, or the ratio of rainfall over potential evapotranspiration, the lower the index, the higher the aridity. Intermediate aridity index conditions for three months are a minimum for dryland crop production, and the map shows that the higher areas in West of the catchment match this requirement. The other areas in the central and east of the catchment have rainy seasons with too little and too variable rainfall to sustain a crop reliable, and livestock production and wildlife conservation are the only suitable options here.

Natural springs and infrastructure for blue water

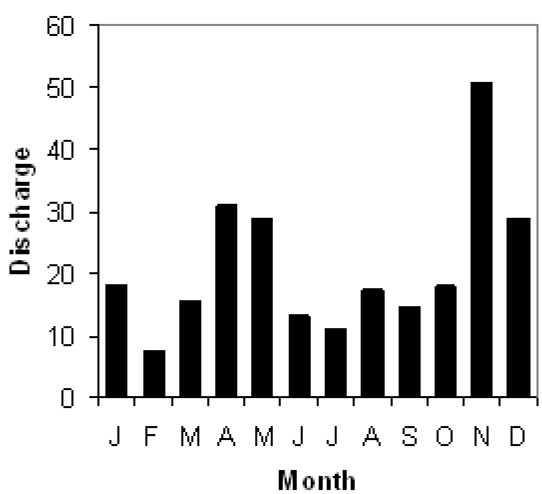
Maps 15 to 17 show the distribution of various sources of blue water: boreholes, pans and dams and wells and springs. These maps show that the infrastructure to provision blue water is not equally distributed across the catchment. The more humid western part of the catchment is endowed with a relatively dense network of water point infrastructure. This contrasts with the Central and the Eastern side of the catchment where such infrastructure is scarce. Blue water is however not only provisioned through boreholes, pans and dams and wells and springs. Rivers also play an important role, and the water available in the Ewaso Ng'iro river is discussed below in some more detail.

The blue water provisioned through boreholes depends on the groundwater resources in the catchment. The catchment hosts the Merti aquifer (map 15), which has numerous boreholes being developed. This raises the question whether the exploitation of the aquifer is sustainable, in other words is the water withdrawn by boreholes sufficiently replaced by discharge, or is the current use sustainable? Looking into the future, how much abstraction could the aquifer sustain? This question is highly relevant as refugee camps and settlements at the lower end of the catchment are leading to rapidly increasing demand for water and a spurt of withdrawals. The recharge of the Merti aquifer is by far not fully understood, but a recent study (GIBB 2004) considered that the current withdrawals were sustainable.

Surface water in the Ewaso Ng'iro river

The Ewaso Ng'iro has a remarkable seasonal discharge pattern (Figure 4.3), with high discharges at Archer's Post in April and May following the long rains in March to May with some delay. The high discharges in November and December follow the short rains in October – November. Lower discharges occur from January to March and from June to October.

Figure 4.3. Average monthly discharge ($m^3.sec^{-1}$) of the Ewaso Ng'iro at Archer's Post, based on monthly records 1960-2010.



The water in the river originates from the well watered slopes of Mount Kenya and the Aberdares. The forests in the upper sub-catchments have an important regulatory function of the water cycle as they are regulating the gradual discharge of water and allow the river to flow even during the dry season. This regulating function is under pressure as forests have been cut and replaced by tree plantations and arable crop systems that withhold the water less efficiently.

Land use changes in the upper parts of the catchment have also led to an increased demand for blue water, particularly during dry spells when local rainfall is insufficient to supply the demands of the people and their land use. Abstraction of water, which started in colonial times, has increased to levels such that significant volumes of water, that used to flow down, are now withhold upstream, with a reduction of the flows to the downstream areas as a result.

Chapter 5 presents a more detailed analysis of the changes in discharge of the Ewaso Ng'iro, and the consequences of this on water users downstream. Chapter 8 also assesses the possible impacts of future climate change on the water related services provided by the Ewaso Ng'iro River.

Supply of groundwater

We obtained data from Rural Focus on the quantity of water supplied only by operational boreholes according to four seasons as defined by Rural Focus: wet, early dry, late dry, and drought conditions. Although these do not reflect actual rainfall patterns, as there can be more than one rainy season in this area, this system is a useful way to classify groundwater supply based on seasonal demand.

Table 1 shows the hourly yield (m^3/hr) of operational boreholes in Isiolo, Garissa, Samburu, and Wajir (Rural Focus). Median values range from just 0.7 in Waso Division, Samburu District to a high of 15 in Dadaab Division, Garissa District. The latter value is undoubtedly influenced by the presence of several large refugee camps along the border between Garissa and Wajir near Dadaab Town. Median hourly yield for the 11 operational refugee boreholes sampled by Rural Focus is 16 m^3/hr, nearly twice the median value of 8.4 m^3/hr for all non-refugee area boreholes in Garissa, Isiolo, and Wajir.

The data collected on boreholes included the yield in m3/hour and the average number of pumping hours per day in each of the four seasons (Table 4.2). The number of pumping hours for each borehole was not collected in Isiolo, thus limiting the analysis of daily supply to Garissa, Wajir, and Samburu. Nonetheless, with the exception of Waso Division, the pumping hours data demonstrate a clear upward trend from the wet season to drought conditions (Figure 4.4). The maximum daily yield was registered for drought conditions in Dadaab Division (240 m^3/d), while the minimum (2 m^3/d) was calculated for wet season conditions in Wamba Division, Samburu.

Table 4.1: Hourly yield of operational boreholes

				m³/hr			
District	**Division**	**No. BH**	**No. BH Operational**	**Max**	**Min**	**Mean**	**Median**
Isiolo	Central-Isiolo	35	19	18	1.0	9.6	10.0
	Garba Tulla	13	5	12	2.9	8.8	12.0

	Kinna	7	2	0	0.0		
	Merti	35	8	13	3.0	7.4	6.5
	Oldonyiro	7	2	1	0.9	0.9	0.9
	Sericho	18	2	1	1.4	1.4	1.4
Garissa	Dadaab	23	17	24	7.2	15.1	15.0
	Liboi	10	5	20	8.0	12.8	9.0
	Modogashe	3	0	0	0.0		
	Shant-Abak	11	3	15	1.5	6.1	1.7
Wajir	Habaswein	9	4	14	7.2	9.6	7.2
	Hadado	7	7	14	4.8	9.8	8.6
	Sebule	11	6	9	6.8	7.4	7.2
Samburu	Wamba	12	13	4	0.4	1.3	0.9
	Waso	15	10	2	0.4	0.9	0.7

Table 4. 2. Median daily yield of operational boreholes by season

					hrs/d				m3/d			
District	**Division**	**No. BH**	**No. BH Operational**	**m3/hr**	**Wet**	**Early Dry**	**Late Dry**	**Drought**	**Wet**	**Early Dry**	**Late Dry**	**Drought**
Garissa	Dadaab	23	17	15.0	8	11	16	17	8	9	15	16
	Liboi	10	5	9.0	4	11	14	21	2	9	14	21
	Modogashe	3	0									
	Shant-Abak	11	3	1.7	4	9	22	19	4	9	22	22
Wajir	Habaswein	9	4	7.2	3	9	19	24	3	10	18	24
	Hadado	7	7	8.6	3	8	15	24	2	7	16	24
	Sebule	11	6	7.2	3	6	15	21	3	7	18	24
Samburu	Wamba	12	13	0.9	2	6	6	9	2	5	6	12
	Waso	15	10	0.7	15	14	11	8	15	14	11	8

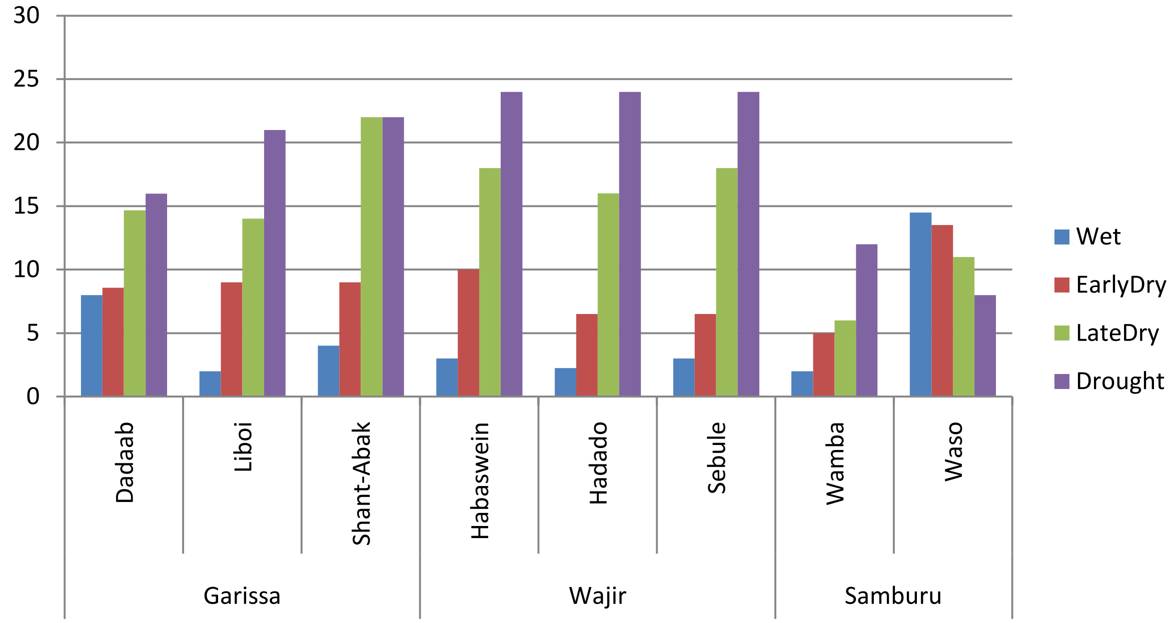


Figure 4.4: Median hours pumped from operational boreholes by division and season

Forage resources

Forage is the second critical resource for livestock and wildlife after water. The map of land cover indicates that over 90% of the catchment is covered by shrubland and grasslands, which are where forage is produced. The production of forage varies geographically with rainfall and hence forage availability and productivity varies temporally and spatially. The rangelands in the study areas occur over a wide range of altitudes, receive widely varying amounts of rainfall and are characterized by different soils, vegetation types and geomorphological features (Herlocker et al., 1993). These rangelands are also used by different livestock species having distinctly different forage and water requirements as well as different capacities to harvest feed from natural pastures (Herlocker et al., 1993). As just discussed, the distribution of surface and groundwater resources also varies among the rangelands.

To understand the dynamics of forage resources we mapped forage based on model developed by the Ministry of Livestock and GTZ in northern Kenya. The data used was long-term median rainfall. However, we know there is variability in rainfall from one year to another. To capture the variability of forage distribution in space and time we also mapped changes in forage and forage deviation over the period 2000 to 2010. This data was sourced from Livestock Early Warning Systems (LEWS) that is based at Texas A&M. We also analysed the temporal trends over the last 30 years using Normalized Differential Vegetation Index (NDVI) that was derived from satellite imageries.

Biomass production

We calculated forage biomass for both herbaceous and shrubby vegetation based on range units as mapped by Herlocker et al. (1993). The range units were delineated on the basis of the major landforms and primary vegetation types and the boundaries were recognizable by topographic features such as hill ranges, lava flows or seasonal watercourses and by distinct changes in the vegetation. Note that Laikipia and Garissa were not mapped in this handbook.

To calculate the total forage biomass production the median rainfall figures were used. The calculation was based on the regression equations (separate for herbs and shrubs) developed by LeHourerou and Hoste (1977), modified for the conditions in northern Kenya.

$$Y = a + bx$$

Y = dry matter production (kg/ha/year or season)

x = annual or season precipitation (mm)

a = regression constant (-180 for herbs and – 400 for shrubs)

b = regression constant (6.3 for herbs and 10 for shrubs)

The seasonal variation in biomass varies across the catchment in relation to topography, rainfall and soils. Range units with a large proportion of land under relatively higher rainfall and with higher proportion of woody perennials and/or perennial grasslands offer safe forage supply to grazers for more than 180 days per annum. These range units have a high development potential for livestock production and for rainfed agriculture (Herlocker et al. 1993). Most of these areas are located in Samburu, around Mount Marsabit and Laikipia. Some of the range units have less than 180 days of forage supply and are manly used by pastoralist to graze goats, sheep and camel. These are drier areas of Marsabit, Isiolo and Garissa.

The seasonal herbaceous and shrub biomass varies between seasons. Due to seasonal variation in rainfall the biomass production was mapped both for 1st rains and 2nd rains. The 1st rains biomass production is high throughout the study areas except for Isiolo. As discussed in chapter 3 in Isiolo the 2nd rains are higher than the 1st rains, which is reflected in the forage maps (see Map 20). The long rains are important for biomass production for districts such as Samburu and Marsabit, while the short rains are important for parts of Isiolo and Garissa.

Forage biomass and spatial distribution over time

LEWS is an early warning system for monitoring nutrition and livestock health for food security of humans in east Africa. LEWS was a sub-project within the Global Livestock Collaborative Research Support Program (GL-CRSP), being implemented by Texas A&M University. LEWS uses satellite weather and Normalized Difference Vegetation Index (NDVI), ground information on soils, plants, and grazing rules that are incorporated into an analytical system to stimulate forage conditions over large regions. LEWS uses a simulation model called the Phytomass Growth Model (PHYGROW – see Stuth et al 2003 and Angerer at al. 2001 for detail on the methodology).

In East Africa LEWS has more than 350 forage monitoring sites have been established across the region - the data collected includes: plant species, livestock numbers, soil data, weather data and grazing preferences for the plant species. The data from the sites are entered into databases for use in forage modelling (PHYGROW Model) for early warning analysis.

A simulation model PHYGROW is used to model forage conditions at the monitoring sites. The model outputs include total forage available per grazer, standing crop by species, animal diets and other outputs that can be use by other models. This model has been used successfully in East Africa as a primary component of Livestock Early Warning Systems (LEWS) since 1998. The model runs in near-real time using rainfall (derived from METEOSAT) and temperature data (maximum and minimum) provided on a daily basis by the US National Oceanic and Atmospheric Administration (NOAA). The model outputs are integrated with satellite greenness (NDVI) data using statistics to create regional maps of current forage conditions. NDVI provides a measure of green biomass on the ground as seen from the AVHHR satellites. A linear relation was established between the model and forage values and NDVI data. Using geostatistical techniques of co-kriging the model generates regional maps of forage standing crops and forage deviation from normal. Ground truthing to verify accuracy of maps is carried out by monitors in the various countries through cutting, clipping, oven-drying and weighing of vegetation at the monitoring points, visual estimations from photo-guides and comparison with model results (Jama et al 2003).

In this project we extracted the biomass estimates for northern Kenya from the LEWS database and generated forage maps for the years 2000 to 2010. We also generated maps of forage deviation from the ten year average for the same region. The maps show a clear spatial variation of forage across the landscape with the western section of the study site (Laikipia, eastern Samburu, eastern and northern Marsabit) having high biomass compared to the eastern section of the study site. The biomass production varies from as less than 800 kg/ha in the more arid lands to over 1600 kg/ha in the relatively higher rainfall areas.

The maps of forage biomass and forage biomass deviations show heterogeneity in terms of forage production and deviations from year to year. Even in a good rainfall year, not all places green up and even in dry years we still see patches of green vegetation. High rainfall periods were observed in 2003, 2007 and 2010. However, in 2010 not all areas had good rainfall, some areas north of Samburu, southern Marsabit and southern Ethiopia had poor forage as indicated by the forage deviation maps. The pattern of 2000 and 2008 are almost similar in that the deviation was normal in the eastern parts of the study area, while in the western section covering Laikipia, Samburu and Marsabit the deviations were very high. We also observed poor rains and range conditions in 2001 and 2005. Most of the area had low forage biomass with few scattered areas of good conditions in Wajir, Isiolo, Samburu and Laikipia and Marsabit districts. 2006 and 2009 were drought years and the higher rainfall areas of Laikipia and Samburu were mostly affected. In 2006 few areas had good forage and that was in Mandera and southern Ethiopia, while 2009 more than a third of the northern Kenya had condition of scarce forage (Figures 4 and 5). Most affected areas were Laikipia, Samburu, and parts of Garissa, and Marsabit. This was the worst drought in Laikipia and Samburu in the last 40 years where communities lost large numbers of livestock and wildlife (Western 2010).

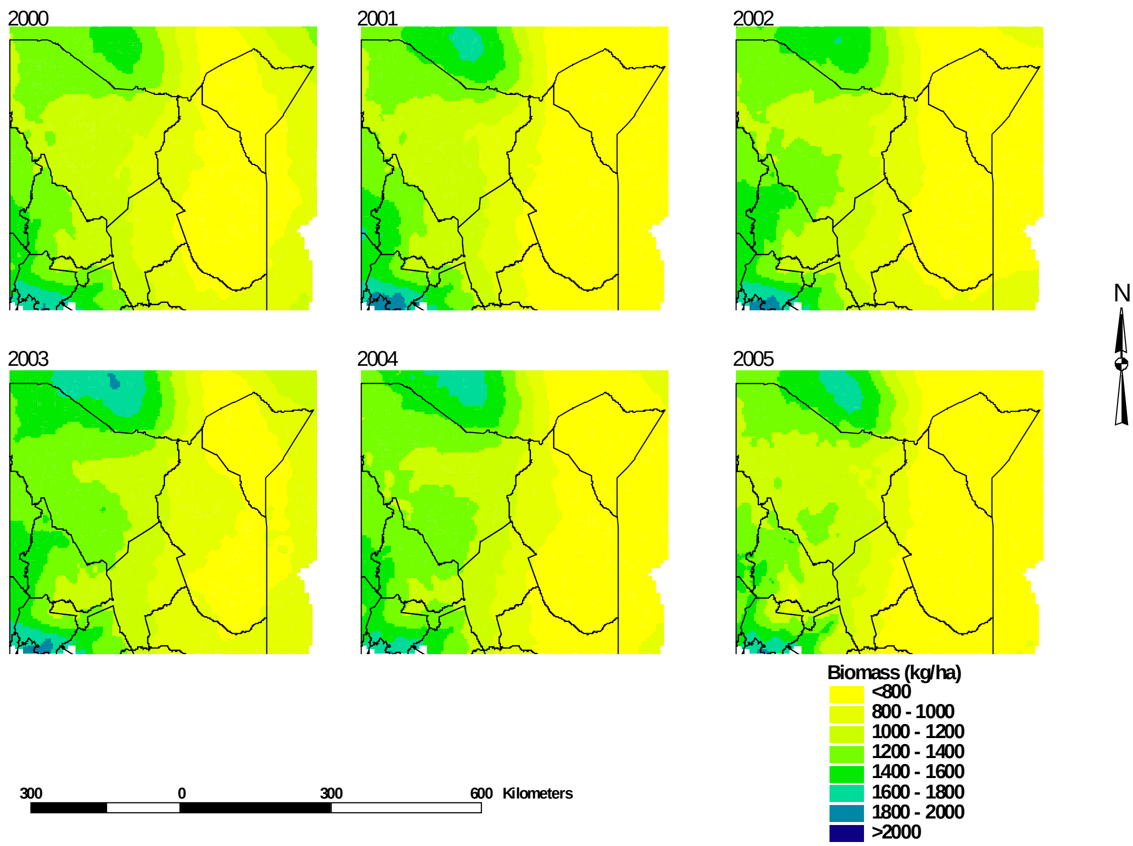


Figure 4.5: Forage biomass 2000- 2005

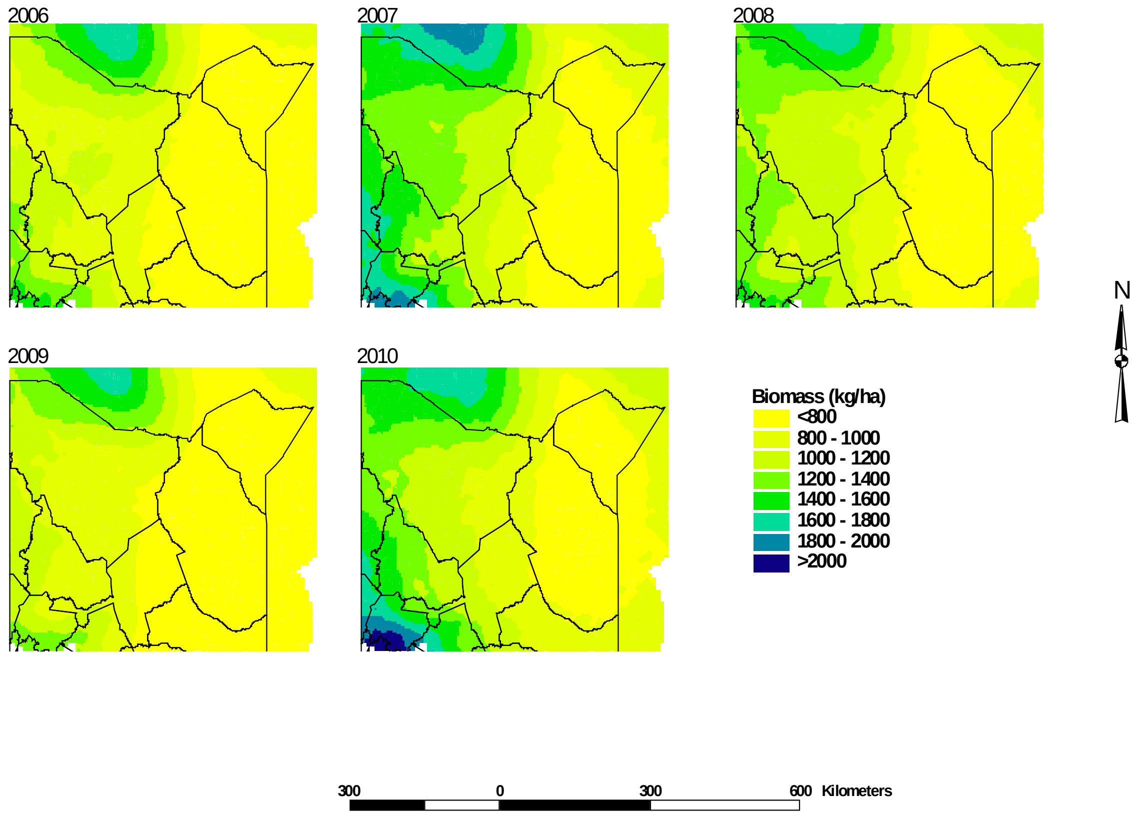


Figure 4.6: Biomass 2006-2010

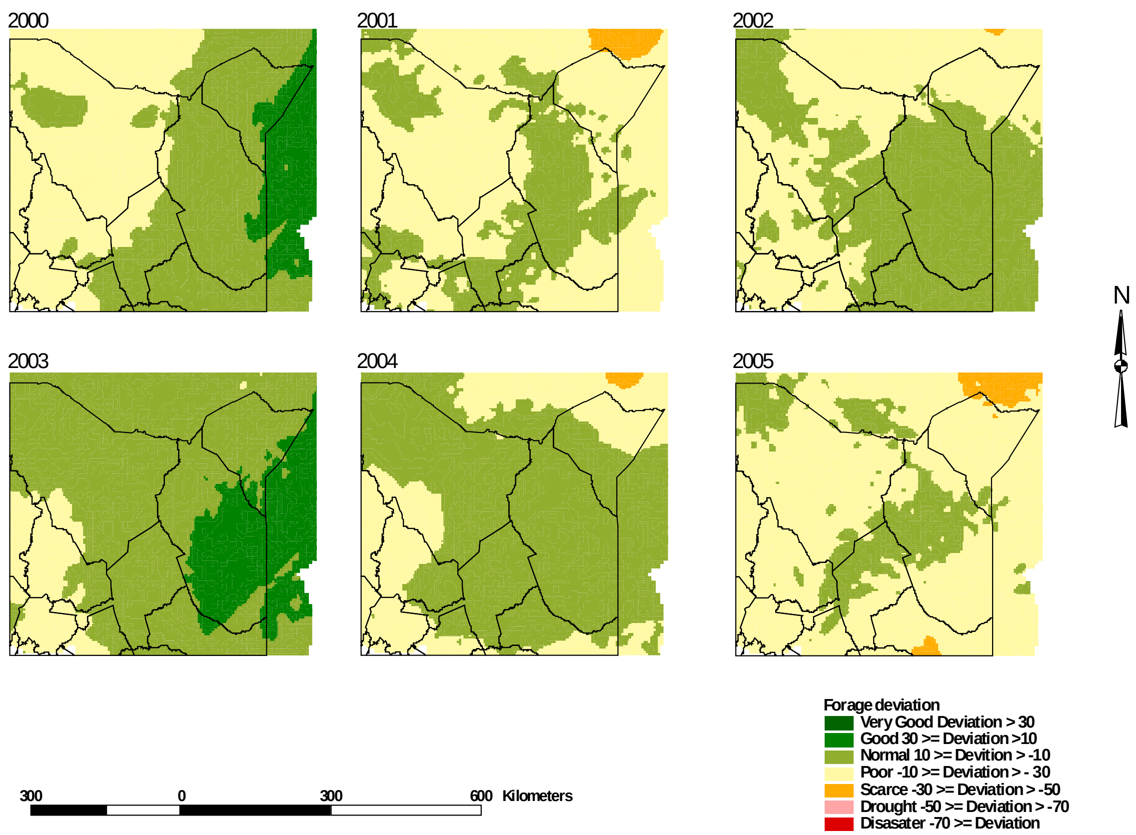


Figure 4.7: Forage deviation from the ten year average

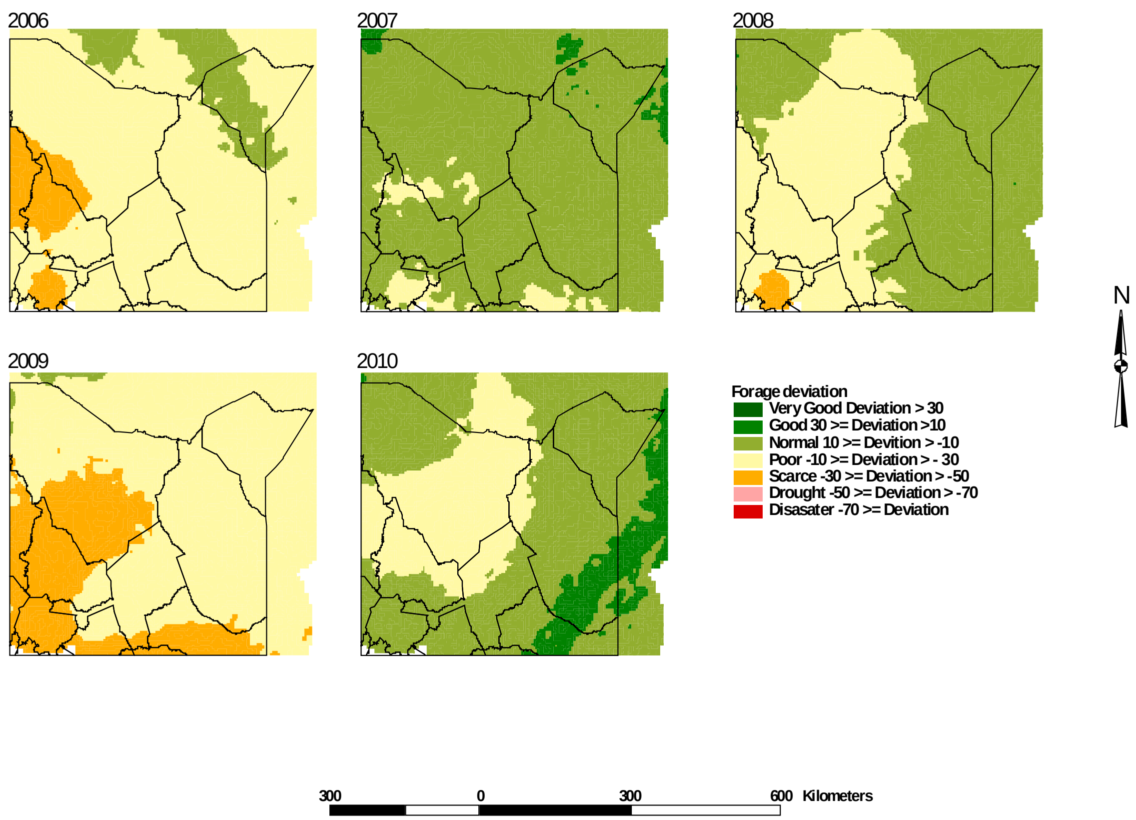


Figure 4.8: Forage deviation from the ten year average

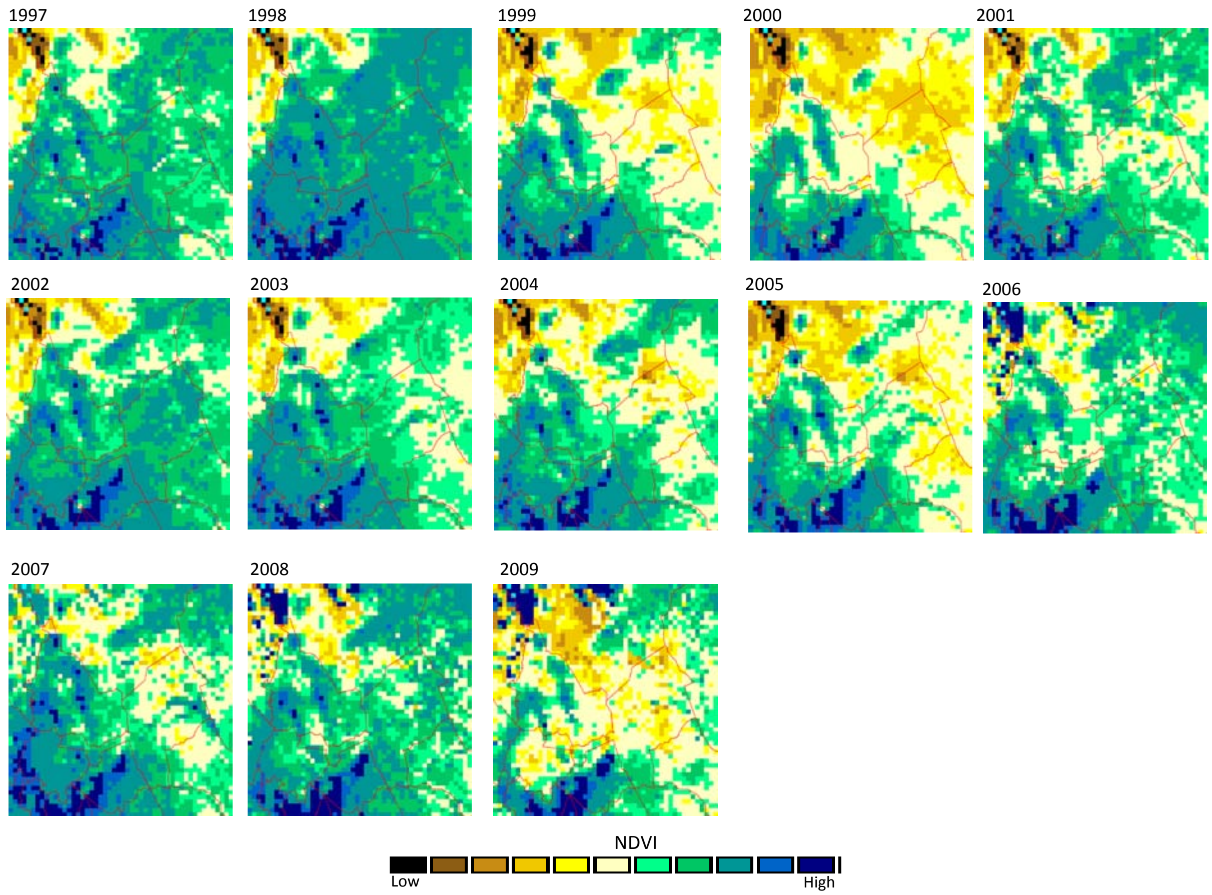


Figure 4.9: Annual NDVI

Since we could only analyse spatial trends in forage for the period 2000 to 2010, we further analysed the long-term temporal trends of vegetation using NDVI. As historical rainfall records for the ASAL districts are sparse and where available not very good, we use NDVI data, for which there is a 30 year record, to monitor the temporal variation of NDVI and identify the inter-annual variation in availability of forage. NDVI is a remotely sensed index that can be used to evaluate the availability of green vegetation. In the analysis we used the NOAA-AVHRR data downloaded from Africa Data Dissemination Service (ADDS) website. The data is generated every 10 days and for our purpose we computed annual NDVI maps (shown above) and for trend analysis we computed monthly NDVI maps and derived the value of NDVI for each month covering the 4 districts namely Laikipia, Samburu, Marsabit and Isiolo. We standardized the monthly NDVI values by subtracting the mean and dividing by the standard deviation so that we could compare the trends in the 4 districts.

Figure 4.10 shows 12 month running averages of monthly NDVI, expressed in standard deviations from the long term mean. Where the $NDVI_{12}$ fell below the long term average were years in which droughts occurred. Conversely, high peaks indicate intense greening of vegetation associated with high rainfall, occurring in part during El Nino years such as 1989-1990, 1998-1999 and 2007. Droughts occurred in 1984, 1986, 1988, 1992, 1994, 1997, 2000-2001 with the most recent droughts in 2004 to 2006 and 2008 to2009. The $NDVI_{12}$ allows for distinguishing of drought according to duration and depth. For example, the 1984 drought in Laikipia lasted for 12 months and reached a depth of two standard deviations. The drought in 2000 and 2001 was not as deep (-1.5 s.d.) but lasted two years. The graph shows the scarcity of green vegetation in those dry years, which contrasts with the high $NDVI_{12}$ values in good rainfall years (for example 1998).

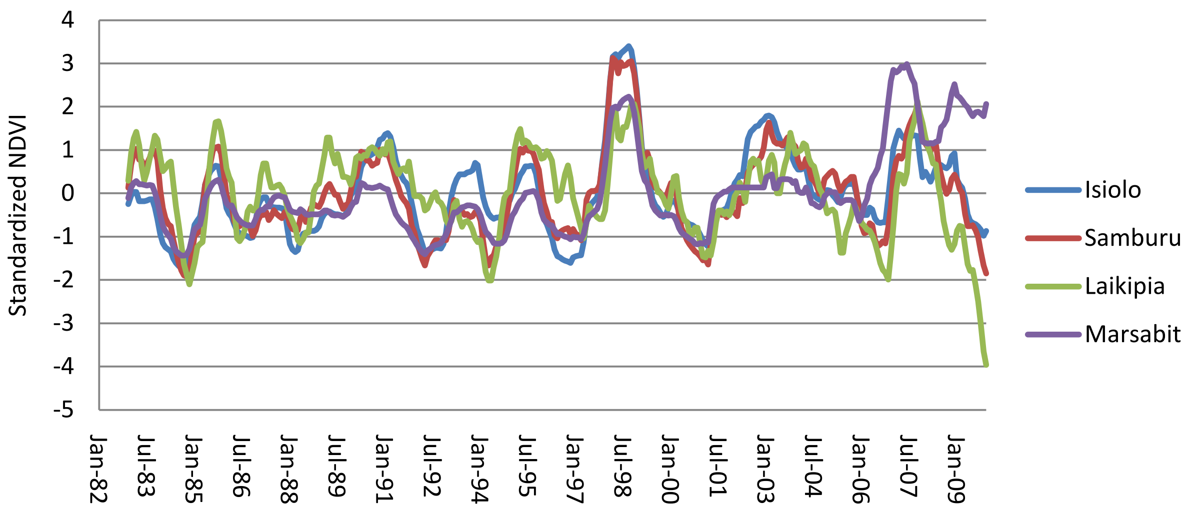


Figure 4.10: Twelve month running average of the Normalized Differential Vegetation Index ($NDVI_{12}$, expressed in standard deviation from the long term mean) for Isiolo, Samburu, Laikipia and Marsabit from 1982 to 2009.

Wildlife and livestock populations:

The Ewaso Ng'iro basin is renowned for its wildlife species, which provide an ecosystem service with high cultural and recreational value, as well as important for biodiversity. To map these services, we averaged the number of wildlife over the period 1995-2010 so as to get overview of both the distribution and also densities of animals within the catchment. This data was collected by Department of Resource Surveys and Remote Sensing (DRSRS) and Mpala Research Centre and is based on aerial censuses. We mapped the density of four important species: the Grevy's zebra, elephants, giraffes and oryx. Map 21 shows the distribution of these species. We see large assemblages as well as diversity of species in Laikipia, Samburu, eastern and northern parts of Isiolo and southern parts of Marsabit. In Garissa and Wajir there are high concentrations of giraffe and oryx.

Livestock are the other important type of animal in the catchment. Map 22 shows the distribution of livestock in Kenya, cattle density in the study area and the relative species mix (cattle, camels, sheep and goats) in each sub-catchment. The livestock density was generated by averaging all the livestock data in the Kenya rangelands. This data was gathered by DRSRS and covers the period from 1978 – 2010. The number of surveys varied across the district. Though the data was collected at 5km by 5km grids we aggregated the data to 10km by 10km.

The national map gives an overview of the average densities of livestock in the Kenyan rangelands. The southern rangelands have high livestock densities throughout the landscape. In northern Kenya we see pockets of high density livestock in Laikipia, southern Samburu, central Wajir, southern Garissa, along the Tana River, central Isiolo and in Moyale, Mandera, West Pokot and north western Turkana. Conversely there are areas with very few or no livestock ever recorded, for example in Marsabit.

We further focused on the distribution of cattle in the Ewaso Ng'iro and observed high numbers of cattle in Laikipia, Samburu and around Merti in Isiolo. In the high rainfall areas we see more cattle than small stock, while in the drier areas camels contribute almost half of the total animal biomass. Shaabani et al (1992) points out that in the median rainfall year no single range unit in the area can support grazing or browsing without seasonal nutrient deficiencies due to declining forage quality over time. They further indicate that cattle are the least suited species to exploit this environment, while camels and goats find quality forage for longer periods and can be kept with lower risk. Further they suggest that since forage biomass production of the shrub layer is much lower than that of the herb layer only moderate stocking densities can be tolerated on any given range unit. This is mirrored in the composition of the livestock biomass in the arid to very arid sub-catchments located mostly in Isiolo, Garissa and Marsabit. In the high rainfall areas of Laikipia and Samburu the length of the growing period exceeds 180 days annually and cattle can feed throughout the year (Shaabani et al. 1992). The map on the distribution of cattle in the study area shows high density of cattle mostly in the high rainfall areas.

Cropping area and extent in the EN catchments:

The crop area maps were generated from Africover (see the statistics in Chapter 3). We computed the area under crop for the sub catchment for the year 2000.

Table 4.4: Cropping areas in 2000

	2000	
Sub catchment	**Area (km^2)**	**Area (%)**
1	161	2
2	943	11
3	227	3
4	958	11
5	2247	25
6	53	1
7	1327	15
8	2911	33
Total	8827	

Chapter Five: Current use of intermediate ecosystem services

In chapter four the *supply* of ecosystem services in the catchment was described, mapped and quantified in so far as possible using available data. The next step in our approach is to describe, map and quantify the *use* of these ecosystem services. The use by humans of ecosystem services is the major factor affecting their status, quality and quantity. Conflicts may arise because of tradeoffs between the supply and use of ecosystem services. These tradeoffs may occur in the same location, between different locations, and among current and future land use decisions. There may be competition between the supply of services in the same place: for example provisioning of timber versus maintenance of certain wildlife habitats. There may be competition between the supply of services in one place and the supply in another place: for example timber provisioning from forests can create water runoff which adversely affects water availability downstream, or conservancies may restrict access to land in order to provide wildlife tourism which constrains provisioning of livestock production. Second, the use of services in one place can constrain the use of services elsewhere, as when surface water is used upstream for irrigation and then downstream surface water quantity is less. Third, use of services today can mean fewer services available in the future, as is the major concern for example with endangered species, loss of soil fertility and unsustainable rates of wild fish harvesting.

To map the current use of ecosystem services, we distinguished between intermediate and final services (see Figure 1 in Chapter 2). Not all ecosystem services are directly consumed by humans. In this study, forage and water are inputs into the production of crops, livestock and wildlife, which are the final benefits consumed by humans (these are valued in the next chapter). Forage is an intermediate ecosystem service, as it is a food source for livestock and wildlife (final benefits). Similarly water is largely an intermediate service, as it is an input into forage production, livestock production and crop production. A small amount of water is used directly for human consumption. In this chapter we describe how water and forage are allocate among different uses within the Ewaso Ng'iro catchment.

We were not able to obtain all the necessary data to do a full calculation of the use of intermediate ecosystem services. We give examples how this could be done with more complete data.

Water use

We calculated five categories of water use in the catchment: to grow crops, for human consumption, for forage production, for livestock consumption, and for wildlife consumption. As described in chapter four, the supply of both green and blue water is differentially distributed throughout the catchment, and population density and land use to some extent reflect this.

Water required for crops

Both green and blue water are used to grow crops in the catchment. In 2000, 8,827 Km^2 of the catchment was under crops, with the majority of this in the upper part, or subcatchments 7 and 8 (also see Maps 9 and 11).

We could not find estimates of crop water requirements for the entire catchment, so we relied on numbers for Laikipia, where a significant portion of the crop production is located (Maps 9 and 11). Based on Karanja (2010) the crop water use and irrigation requirement in are given in Table 5.1. Actual crop water use is the highest for potatoes (230.2mm) and the lowest for millet (116.6mm). Wheat, maize and beans gave actual crop water use figures of 144.2mm, 128.5mm and 117mm respectively. Based on these requirements, Karanja estimated also irrigation water requirement per crop. Results show that wheat had the highest irrigation water requirement (58.1) and millet the lowest (4.9). Potatoes and beans had irrigation water requirements of 18.5 and 17.5 respectively. The field water supply (FWS) was highest for wheat (0.07l/s/ha) and lowest for millet (0.01l/s/ha) for the category of crops that registered irrigation water requirements. Potatoes and beans indicated field water supply values of 0.02l/s/ha and 0.03l/s/ha respectively.

Table 5.1 Crop water requirement in Laikipia per hectare

Crop	**Actual Crop water use (mm)**	**IWR[1] (mm)**	**FWS[2] (l/s/ha)**
Beans	117.0	17.5	0.03
Maize	128.5	0.0	0.0
Millet	116.6	4.9	0.01
Potatoes	230.2	18.5	0.02
Wheat	144.2	58.1	0.07

[1]IWR (Irrigation water requirement in mm), [2]FWS (Field water supply in l/s/h)

In order to calculate the total water requirement for crops, we would need to multiply the crop water requirement by the area under each type of crop. In table 5.2 below we show the area devoted to irrigated and rainfed crops for each subcatchment, but we were not able to calculate the total water used for these crops.

Table 5.2: Area by subcatchment devoted to irrigated and rainfed crops

	Area (Ha)	
	Irrigated crops	Rain-fed crops
S/C1	0	88.7
S/C2	0	27,751
S/C3	0	12,978.4
S/C4	0	69,253.4
S/C5	228.6	160,190.1
S/C6	0	2,604.5
S/C7	3366.6	81,717.9
S/C8	692.2	160,084.6

Human water requirements

Map 19 shows the distribution and increase in human population density across the sub-catchments from 1962 to 2009. The highest densities are in the high agriculture potential subcatchments 5, 7 and 8. Here the densities increased from less than 10 persons per km^2 in 1960 to more than 72 persons per km^2 in 2009. The analysis of population growth indicates that in Laikipia the population growth rate is about 2.4%, which presents limitations of land availability for both farming and grazing. In the drier parts of the catchment the population densities are lower, but in subcatchments 3 and 6 (Isiolo and Garissa) the densities are increasing rapidly, and both have rural markets with large concentration of population in these centres as depicted in the urban map, as well as the Daadab refugee population whose growth was noted in Chapter 3.

According to WHO standards, people require a minimum of 30 to 40 litres of water per day. In 2009 the total population of the catchment was 1.85 million people. Thus the total human water requirement for the catchment is 74 million litres of water per day if they are to meet the requirement of 40 litres per day. This equals 0.027 km^3 annually, or 0.1% of the total rainfall over the catchment.

One indication of how well human consumption requirements are met is the distance from settlements to operational water points, which includes both surface and groundwater. Map 18 illustrates the difference in these distances between the upper and lower sub-catchments. The buffer zones around the water sources are drawn for 5, 10 and 15 km. Five km is the maximum distance for humans to fetch water from a source and 10 km is the normal distance no-stressed cattle regularly travel to water; 15 km is the maximum distance for cattle to access a water source; 30 km is the maximum distance for camels and goats to access a water source.

Major population centres are also shown on the map. As the number of sources is greater in the upper part of the Ewaso Ng'iro catchment, there are few places without a source within 10 km. This is very different in the lower part, where a significant area is without a water source within 10 km. In the upper part of the catchment most villages have a domestic water source within 5 km distance. But in the lower part, for example, in Isiolo, Mati et al (2004) estimate that 93% of the district lacks water sources for domestic supplies within a 5 km distance (this represents 73% of all villages). They further estimate that livestock lack access to water within a 15 km distance in about 63 percent of the area (38% of villages).

Livestock and wildlife water requirements

Animals require both drinking water and the water that is used for feed production. Typically, one tropical livestock unit (TLU= 250 kg live weight) requires an intake of less than 50 litres/day of water, including both drinking water and the moisture in animal feeds (Peden et al, 2003).

Livestock water requirement per sub catchment has been defined taking into account an average amount of water needed for 1 TLU, based on estimation of van Breugel et al., 2010. This study assessed the water requirement for different livestock production systems (LPS) and agro-ecological zones on Nile basin. The areas of our study are similar to the type of LPS classified as LGA (livestock grazing arid systems), so we used the value associated with that type. There are differences in livestock water use among livestock species, and the water requirements per TLU are considerably higher for small ruminants. The quality of the diet appears to have a small effect on water requirement; an important part of the variation in livestock water requirements is related to the cost in terms of water to produce the required feed.

Table 5.3 illustrates the annual water requirements for LGA from the study of van Breugel et al., 2010. The study calculated the annual water requirement excluding and including water for feed production from residues. In the case of LGA the annual water requirement is the same when water from residues is included or not in the estimation. Camels' water requirement has been identified on the basis of the study of Peden et al (2003) which estimates a consumption of water equal to 2.8 m^3/TLU per year (x1000).

Table 5.3: Annual water requirements to produce the feed per animal for cattle, small ruminants and camels in m^3/years/TLU (x 1000).

LPS	Cattle		Small ruminants		Camels
	Excluded residues	Included residues	Excluded residues	Included residues	
LGA	2.2	2.2	3.3	3.3	2.8

In Table 5.4, we calculate the livestock water requirement by subcatchment (and agroecological zone) for cattle, small ruminants (sheep and goats) and camels. The cattle in the catchment require the highest amount and small ruminants the smallest. Total water used by cattle is 2,002,220 m^3/year (x1000).

Table 5.4: Livestock water requirements to produce the feed per animal for cattle and small ruminants

	Livestock water requirement m^3/year (x 1000)			Livestock water requirement m^3/year/ha (x 1000)		
Subcatchment	Cattle	Shoats	Camels	Cattle	Shoats	Camels
1	44,302	21,167	76,311	4.0	1.9	6.9
2	90,582	70,162	156,648	7.7	6.0	13.3
3	191,524	89,428	267,728	13.2	6.2	18.5
4	101,154	30,751	4,011	40.4	12.3	1.6
5	88,935	55,032	27,191	10.4	6.5	3.2
6	155,892	94,313	252,925	7.1	4.3	11.5
7	66,782	12,116	4,801	23.7	4.3	1.7
8	78,814	14,318	7,334	20.1	3.7	1.9
TOTAL	**817,984**	**387,287**	**796,949**	**10.6**	**5.0**	**10.3**

Forage requirement for water

Calculating the water used to grow forage is difficult as the water requirement varies by species. All the forage in the Ewaso Ng'iro is rainfed, so in drought years there is no production, as we discussed in chapter 4. Desmukh (1984) estimated that every one mm of rain above 20 mm produces 8 kg biomass per hectare. Another assumption is that every additional mm of rainfall results in an increase of 6.3 kg of forage biomass per hectare. It thus requires ten m^3 of water to produce 6.3 kg of forage biomass. Approximately 75,460 km^2 or 7.5 million hectares (90%) of the catchment is under livestock and wildlife production which rely on forage.

Location of demand relative to supply

Land uses and livelihoods are typically supported by ecosystem service bundles that vary across the landscape. For instance, arid areas with access to groundwater sustain pastoral livelihoods, semi arid to semi -humid areas with good water and nutrient cycling support crop production, while the humid zone supports forestry related livelihoods. It is important to note that these land uses and livelihoods may be dependent on ecosystem services generated in another part of the catchment, such as surface water runoff from upstream. As such, land uses and livelihoods in one area may impact (positively or negatively) the provision of ecosystem services elsewhere, for example by reducing access to grazing areas or by recharging aquifers. In chapters three and four we described the differential distribution of water sources (wells, springs, boreholes, dams and pans) throughout the catchment. Here we discuss a different tension between demand and supply.

Impact of abstractions upstream on downstream supply

Abstractions of water in the upstream part of the catchment, which are withholding water upstream, are thought to reduce the discharge to downstream water users. The hydrological records of the Ewaso Ng'iro river at Archer's Post reveal a change in the average and the variability of monthly discharge. We compared the discharge from 1960 to 1979 as a baseline to the discharge from 1980 till 2010 (Fig. 5.1). Average monthly discharge declined from 24.1 $m^3.s^{-1}$ during the baseline period (1960-1979) to 18.8 $m^3.s^{-1}$ during the post 1980 period, a reduction of 5.3 $m^3.s^{-1}$. Figure 1 shows the probability distributions of discharge for these two periods; the steepness of the slope of these probability functions is an indicator of the variability in discharge. The greater steepness of the post 1979 probability distribution compared to the 1960 to 1979 period indicates higher variability of discharge in the period 1980-2010 than in the baseline period.

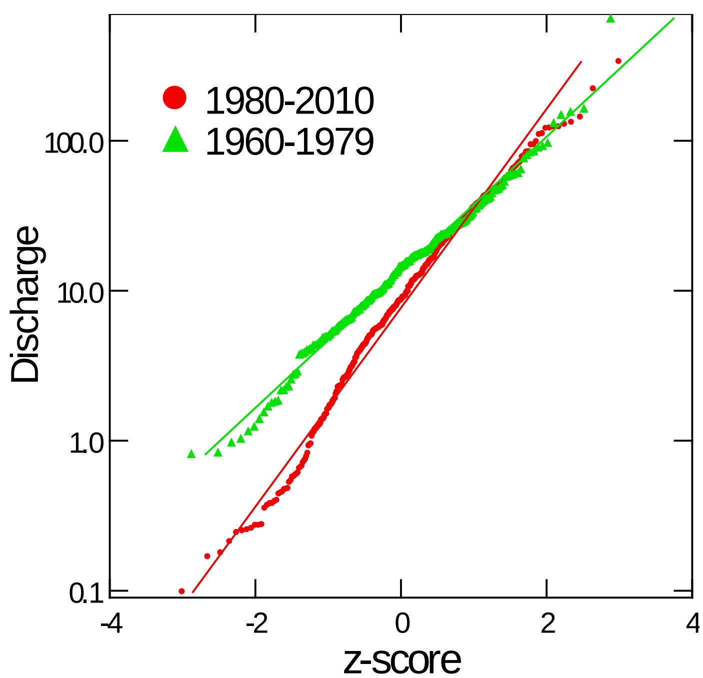


Figure 5.1. Probability plot of monthly discharge at Archer's Post for 1960 - 1979 and for 1980 - 2010.

The impact of abstractions

Figure 5.2 displays that the volume of permitted abstractions increased from below 10% of the discharge at Archer's Post to above 10% of discharge most of the years in the period since 1990. The figure also reveals variability between years, abstractions monopolize a larger fraction of the discharge in years of drought, such as 2000 and 2001 and 2008 and 2009, than in years of good rainfall such as the El Nino years of 1998 and 2007.

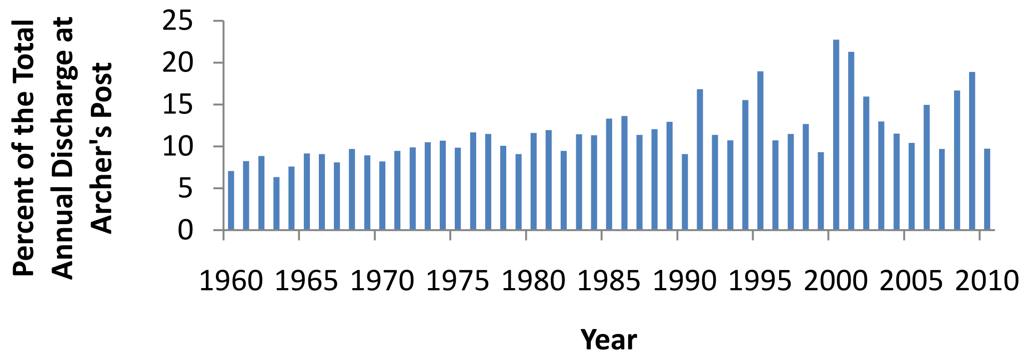


Figure 5.2. Volume of permitted abstractions ($m^3.s^{-1}$) as a percentage of the total annual discharge at Archer's Post.

We next used the WEAP[3] model for the upper part of the basin (Mutiga et al. 2010) to assess the impacts of the abstractions on the water discharge at Archer's Post. WEAP is an integrated and water resources management tool designed for simulation of water resources systems and trade-off analysis (SEI, 2008). The model was calibrated for 1960-1970 and validated with data from 1970-1990. Figure 4 shows the performance of the model. The validation revealed that the discharge as predicted by the WEAP model explained 98.8% of the variation of the discharge observed at Archer's Post.

[3] WEAP: water evaluation and planning system, a software environment to model water resources

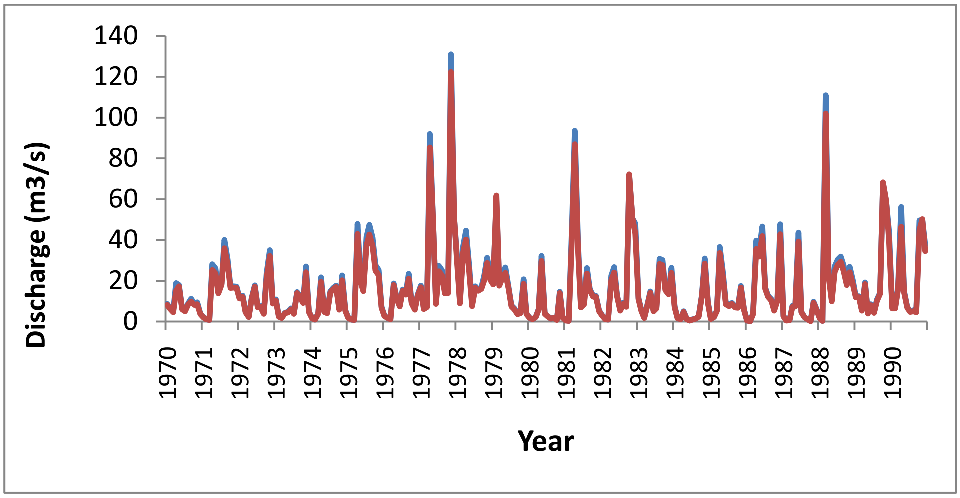


Figure 5.3. Relation between monthly discharge (m^3.s^{-1}) predicted by the WEAP model with abstractions (—) and the actual discharge observed at Archers Post (—).

Figure 5.4 shows that the average discharge recorded at Archer's Post over the 1980-2010 period (19.5 m^3.s^{-1}) was 4.6 m^3.s^{-1} lower than the discharge over the 1960-1979 period of 24.1 m^3.s^{-1}. To what extent can this reduction be attributed to abstractions upstream?

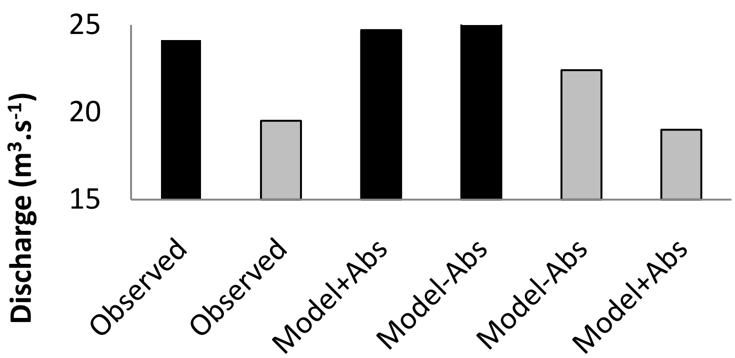


Figure 5.4. Observed discharge and predicted (Model) discharge with and without abstractions for 1960-1979 (black) and 1980-2010 (gray).

The WEAP model, when applied to simulate the discharge for the period before 1980, predicted discharge of 24.1 m^3.s^{-1}, a prediction corresponding well with the actual discharge of 24.7 m^3.s^{-1} over the same period. The model without abstractions yielded a somewhat higher discharge (26.8 m^3.s^{-1}) than the model with abstractions.

We then ran the model for the period 1980 - 2010 with and without abstractions. The discharge predicted by the model with abstractions (19.0 m^3.s^{-1}) was close to the average discharge observed at Archer's Post between 1980-2010 of 19.5 m^3.s^{-1}. The model without abstractions predicted a discharge of 22.4 $m^3.s^{-1}$, 3.4 and 2.9 $m^3.s^{-1}$ higher than the situation with abstractions, as predicted and observed respectively. Hence, the model suggests that the permitted abstractions upstream resulted in a reduction of average discharge at Archer's Post of 3.4 $m^3.s^{-1}$.

The effect of abstractions on downstream water discharge is not the same at all times of the year. Figure 5.5 shows that abstractions have a higher impact on the discharge in drier months (e.g. Jan-Feb and Jun – Oct) than in months with higher rainfall (Mar-Apr and Nov-Dec).

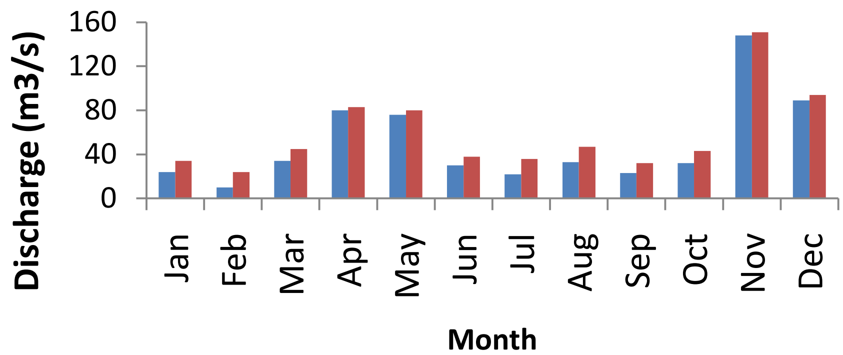


Figure 5.5: Monthly discharge ($m^3.s^{-1}$) at Archer's Post according to the model with (■) and without (■) legal abstractions.

The effect of abstractions is larger in reality, as the model only considers the effects of the permitted level of abstraction. Illegal abstractions cannot be overlooked and need to be measured and managed. Indeed, there is recent evidence that illegal abstraction escalates in dry periods. About 60% to 95% of the available river water in the upper reaches of the Ewaso Ng'iro basin is abstracted during the dry season with up to 90% of the total abstractions being illegal, resulting in decreased river flows in the lowlands (Kiteme and Gikonyo, 2002; Notter et al. 2007 and Mutiga et al. 2010).

Reduced probability of the river servicing downstream water users

Thus, there is evidence that the greater variability and increased frequency of low water discharges of the Ewaso Ng'iro at Archer's Post is attributable to abstractions in the upstream. What are the implications of this on downstream water users?

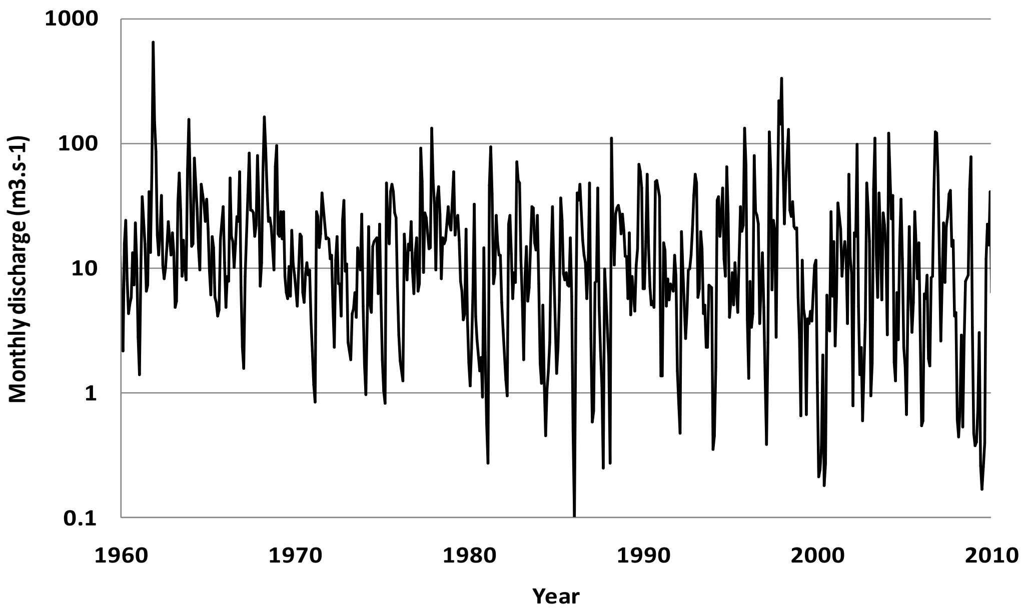


Figure 5.6: Variation in monthly discharge of the Ewaso Ng'iro at Archer's Post 1960 -2010.

Figure 5.6 shows that discharges below 1 $m^3.s^{-1}$, which were rare in the 1960's and 1970, have become increasingly more frequent since the early 1980's. Also the frequency and duration of having periods with discharge below 10 $m^3.s^{-1}$ was low in the 1960's and 1970's but more frequent and longer since 1980. This affects the downstream water users as follows.

The increased occurrence of low discharge events has a significant impact on the length of the stretch of the river between Archer's Post and Merti with surface water. The example below demonstrates this for Merti, a town 160 km downstream of Archer's Post. As the river loses about 1000 m^3 per day for every km, it requires a daily discharge at Archer's Post of 160,000 m^3 for the water to reach Merti. This discharge corresponds to 1.8 $m^3.s^{-1}$, and we thus reviewed daily discharge data at Archer's Post, counting the number of days when the river discharge was such that the river would not reach Merti. Figure 7 reveals that discharge events below 1.8 $m^3.s^{-1}$, which were rare in the 1960's and 1970's, became more frequent since the 1980s, when permitted abstractions started to increase. The number of days without water in the river is generally low in El Nino years, such 1998 and 2007, but increases sharply during drought episodes such as 1984, 1999 and 2000, and 2008 and 2009.

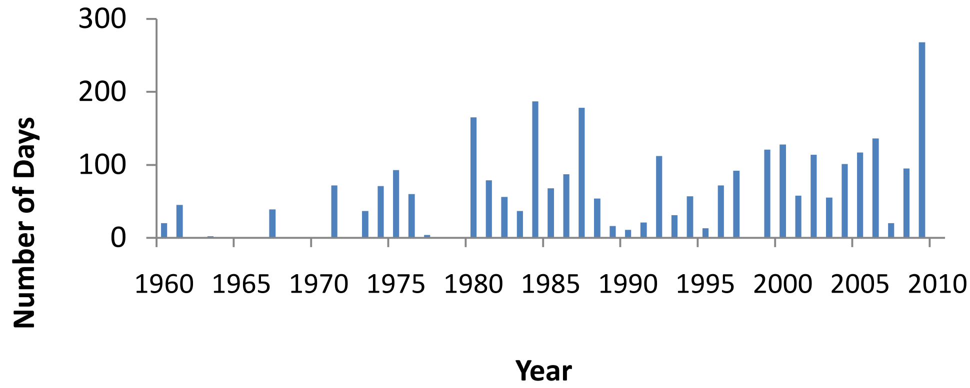


Figure 5. 7: Recorded number of days with discharge at Archer's Post below 1.8 $m^3.s^{-1}$, the discharge required for the river to reach Merti.

We summarized this while calculating the length of the river carrying water in the 1960's, 1970's, 1980's, 1990's and 2000's, while using the historic recorded discharge at Archer's Post and a loss of surface water of 1000 m^3 per day for each km of river length[4]. Table 5.5, which gives the resulting probability of the river carrying no water at Archer's Post, Merti and Habaswein, reveals a significant reduction of the probability of having surface water below Archer's Post. The probability of the river carrying no water at all, which was low (2%) in Merti in the 1960's, had increased to 27% in the first decade of the 21st century.

Table 5.5: Probability (%) of the Ewaso Ng'iro carrying no surface water at Archer's Post, Merti and Habaswein for five decades since 1960.

Location	1960's	1970's	1980's	1990's	2000's
Archer's Post	0	0	0	0	0
Merti	2	8	21	11	27
Habaswein	43	55	67	61	66

The shortening of the length of the river which always contains water has impacts on livelihoods of pastoral and other water users along the river, as while they were secure to find surface water in the past, they now have to turn to other ways to satisfy their demand for water.

[4] The Gibb report provides an estimate of a loss of 1000 $m^3.km^{-1}.day^{-1}$ along the 180 km of the Ewaso Ng'iro river from Archer's Post up to Merti. This is largely a result of evaporation while along this stretch there is thought to be little groundwater recharge.

Impact on downstream grazing resources

In chapter four we discussed the distribution of forage biomass in the catchment. One way that livestock and wildlife are able to survive dry periods or years is through the exploitation of key resource areas. Wetlands are one important example of this, and the Lorian swamp which is shown on many of the maps is a critical area. However, the abstractions of water upstream may also have an impact on the forage biomass.

Swarzenski and Mundorff (1977) reported that the Ewaso Ng'iro reaches Habaswein at the lower end of the Lorian swamps when the flow at Archer's post exceeds 35 to 40 million m^3 per month, corresponding to a flow of 13.5 to 15.5 $m^3.s^{-1}$, or 14.5 $m^3.s^{-1}$ on average, a threshold which between 1950 and 1979 used to be surpassed in 45% of the months (Table 5.5); the probability of a monthly flow exceeding 14.5 $m^3.s^{-1}$ had reduced to 34% of the months for the period 1980 to 2010. Water thus passed through the swamps more frequently in the 1960s and 1970s than in the post 1980 period.

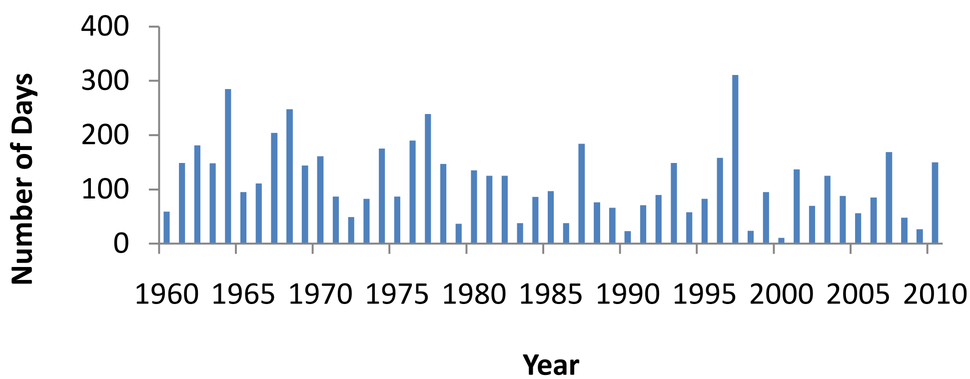


Figure 5.8: Number of days when discharge at Archer's Post exceeded 14.5 $m^3.s^{-1}$, the minimum discharge required for the river to reach Habaswein at the end of the Lorian swamps.

Figure 5.8, which displays the number of days when sufficient water is discharged to make the river flow up to Habaswein, might give the impression that the volume of water flowing through the Lorian swamps has declined over time. This is not necessarily so, as the bulk of the water entering the swamp comes with a few peak floods every year; the number of days when the river enters the systems might thus not be a good indicator of the volume of water entering the system. Figure 5.9 displays the total volume of water that entered the Lorian swamp every year since 1950. There is a variation in water inflow between years of two orders of magnitude, but regression analysis revealed there was no significant trend towards lower volumes of water entering the swamp (Linear regression; H_0: $\beta = 0$; $b = 1.71$; $se_b = 5.13$; $t = 0.33$; $P = 0.74$).

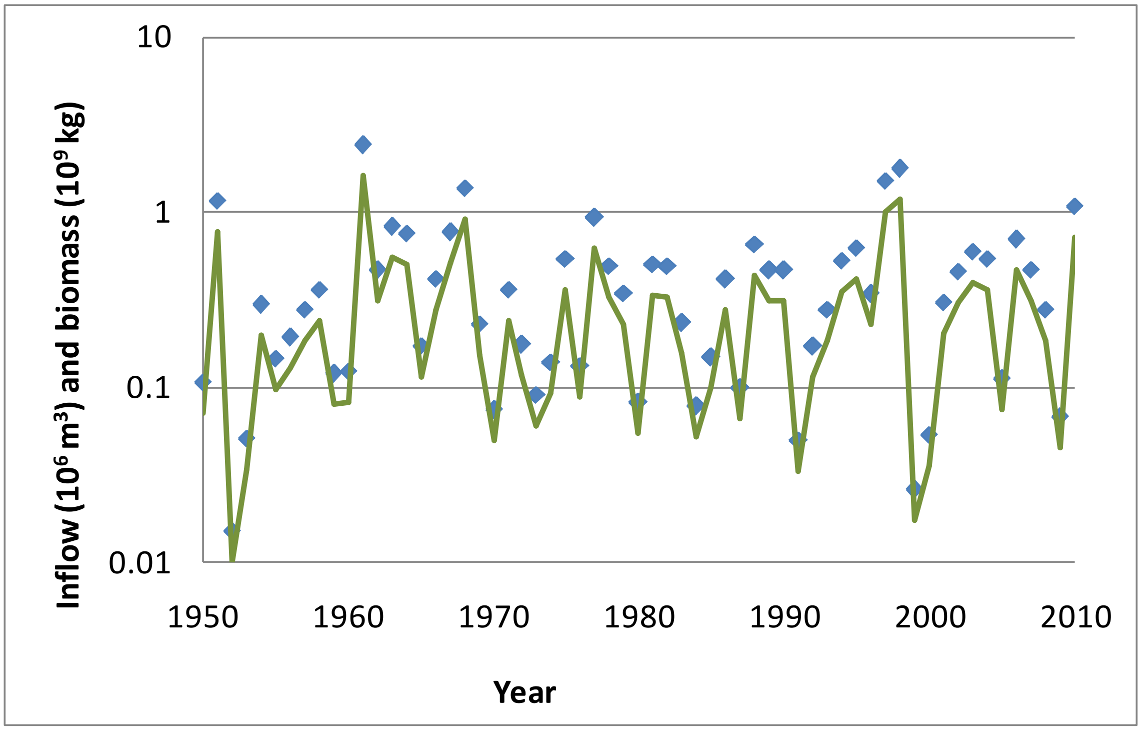


Figure 5.9: Annual inflow of water (■) into the Lorian swamp from 1950 until 2010 and estimated additional vegetation biomass (—) that could be produced with this inflow.

What is the production of vegetation biomass in the Lorian swamps and what is the additional impact of this inflow on the production of the swamp vegetation? Let's first consider the biomass production when considering rainfall only. The Range Management Handbook of Kenya (Herlocker *et al*., 1993) estimates that the 2,225 km^2 Ewaso Ng'iro range unit has a median rainfall of 50 and 75 m for the long and short rains, resulting in a herb biomass production[5] of 135 and 292 $kg.ha^{-1}$ or 427 $kg.ha^{-1}.yr^{-1}$. The handbook estimates that 30% of this range unit (e.g. approx. 660 km^2) consists of highly productive seasonally flooded grassland, but provides no information on the productivity of this particular ecosystem. The map accompanying the handbook indicates around 1,000 km^2 of flooded grassland. The Herlocker data thus suggest, when considering rainfall only, a biomass production of the 100,000 ha (1000 km^2) swamps of $0.427 * 10^5$ $T.yr^{-1}$.

How many tropical livestock units (TLU) could the biomass produced by this rainfall sustain? The DRSRS data reveal that the herds in the Lorian swamp area are composed of 50% camel biomass, 45% sheep and goats and less than 5% cattle biomass. Using the daily animal forage

[5] Forage biomass production was derived from rainfall according to Herlocker et al. (1993): Y = -180 + 6.3*X and Y = -400 +10*X for the grass and shrub layer respectively, where Y = dry matter production ($kg.ha^{-1}.yr^{-1}$) and X = precipitation (mm).

requirements[6] we estimate that the herds in the Lorian swamp require 2.2 ton of forage per year to sustain one TLU. Proper range management considers that only a fraction of the available biomass could be used in order to avoid degradation of the range. Herlocker recommends a permissible off-take of 30% of the available biomass. This leads to a biomass requirement of 7.5 tons for one TLU. The forage biomass of $0.427 * 10^5$ $T.yr^{-1}$ in a median rainfall year without inflow of water could thus sustain 5,700 TLU, in other words, one TLU for every 17.5 ha. Six aerial surveys carried out between 1979 and 2005 by DRSRS[7], resulting in an almost three times higher stocking density of one TLU per 6.9 ha, indicate that the swamps accommodate a higher stocking density than what could be explained by its median rainfall only.

What is the additional effect of the inflow of water in the Lorian swamp? An inflow of one km^3 of water, when used for evapotranspiration and primary production, would flood the approximately 1,000 km^2 swamps with 1 m of water[8], enough to keep primary production of the swamp vegetation going two hundred days when considering a daily evapotranspiration (ETP) rate of $5mm.day^{-1}$. An inflow of 0.1 km^3 by contrast, would flood the swamp with 100 mm of water, enough for twenty days of evapotranspiration only. The Lorian swamps have witnessed years of high inflows of one km^3 and above and the according high productivity in 2010, 1997 and 1998, 1968, 1961 and 1951. Years with low inflows of below 0.1 km^3, occurred in 2009, 2001 and 2000, and 1991, while the lowest inflow ever occurred in 1952 and 1953. The system is thus exposed to high year-to-year variation in inflow of water from outside.

The inflow of river water into the Lorian swamps must have positive implications on the production of forage biomass, and one would thus expect a positive relationship between the greenness of the vegetation of the swamps and the discharge of water at Archer's Post. A plot of water discharge against vegetation greenness of the swamps (Figure 10) reveals a significant relation between the two. The regression model suggests that the greenness (NDVI) of the swamps increases at discharge above approx. 10 $m^3.s^{-1}$, which matches the threshold of 14.5 $m^3.s^{-1}$ required for the waters to reach the lower end of the swamp.

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[6] Animal forage requirements ($kg.TLU^{-1}.day^{-1}$, Herlocker et al., 1993): cattle 4.8, sheep 6.2, goats 6.4 and camels 6.1.

[7] We used data here courtesy of the Department of Resource Surveys and Remote Sensing (DRSRS), Nairobi, Kenya, which has carried out regular aerial surveys of livestock and wildlife since the late 1970's.

[8] Assuming the swamps were completely flat, which is obviously not the case. We use this calculation here to assess the importance of the ecosystem support function of the waters of the Ewaso Ng'iro with respect to sustaining the primary production of the Lorain swamp vegetation and the livestock depending on this.

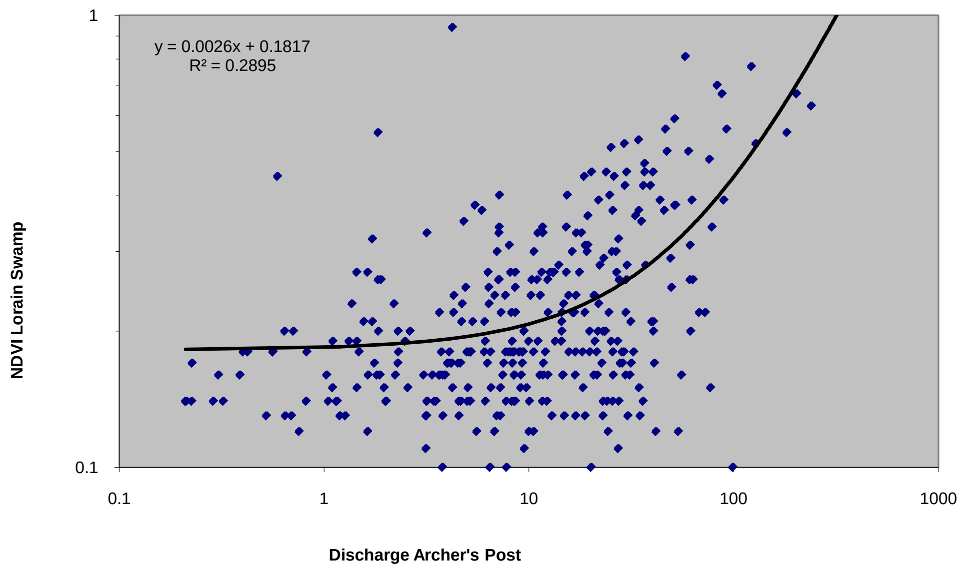

Figure 5.10: Relation between water discharge at Archer's Post and vegetation greenness (NDVI) of the Lorian swamp.

How much additional biomass could be produced with this inflow of water? The regression equation used above assumes that every additional mm of rainfall results in an increase of 6.3 kg of forage biomass per hectare. It thus requires 10 m^3 of water to produce 6.3 kg of forage biomass. The vegetation has, in other words, green water use efficiency (GWUE) of 1.58 m^3 of water for a kg of biomass[9], which corresponds well with the GWUE values for plant biomass in the literature in the order of 1 to 2 $m^3.kg^{-1}$. We applied this GWUE, assuming that the water lost to groundwater recharge is negligible, to calculate the additional biomass produced as a result of the influx of water into the Lorian swamp.

The average annual inflow of water from 1950 to 2010 was $4.43*10^5$ m^3 would result in an additional 280,400 ton of forage per year. Following the same method as used on the previous page we estimate that this could sustain an additional 37,000 TLU in addition to the 5,700 TLU which can be accommodated when considering rainfall only. This approximately 43,000 TLU corresponds to a density for the 2,700 km^2 swamps of one TLU per 6.3 ha, a stocking density remarkably close to the empirical average stocking density of one TLU per 6.9 ha emerging from the six DRSRS aerial surveys.

The correspondence between this calculated and observed stocking density is remarkable. There are however a few reservations to be made. Our model ignores the possibility that a significant, but as yet poorly quantified volume of water lost through outflow at the lower end

[9] Deshmukh (1973) provided a regression equation for eastern and southern Africa where every mm of rainfall resulted in 8.4 kg of grass biomass.

or recharge of the groundwater would not be available to sustain primary production of the swamp. Secondly, the model assumes that more water has positive implications for livestock. This is not necessarily so. The grassland vegetation of the flooded grasslands is of high biomass but also of poor quality (Herlocker et al. 1993) and typically avoided by livestock in all but the driest years. Another shortcoming is that the calculations are based on averages. The inflow of water in the Lorian swamp fluctuates greatly between years, which may impact the number of livestock in the swamp.

Is there any relation between the inflow of water and the density of livestock in the swamps? Figure 5.11 shows that livestock density follows a skewed uni-modal response with regards to water inflow. We observe very low livestock densities in the swamp area at low water inflow, high livestock density of up to 1 TLU per 4 ha at intermediate inflow and reduced livestock density at inflows above inflows of 20 $m^3.s^{-1}$.

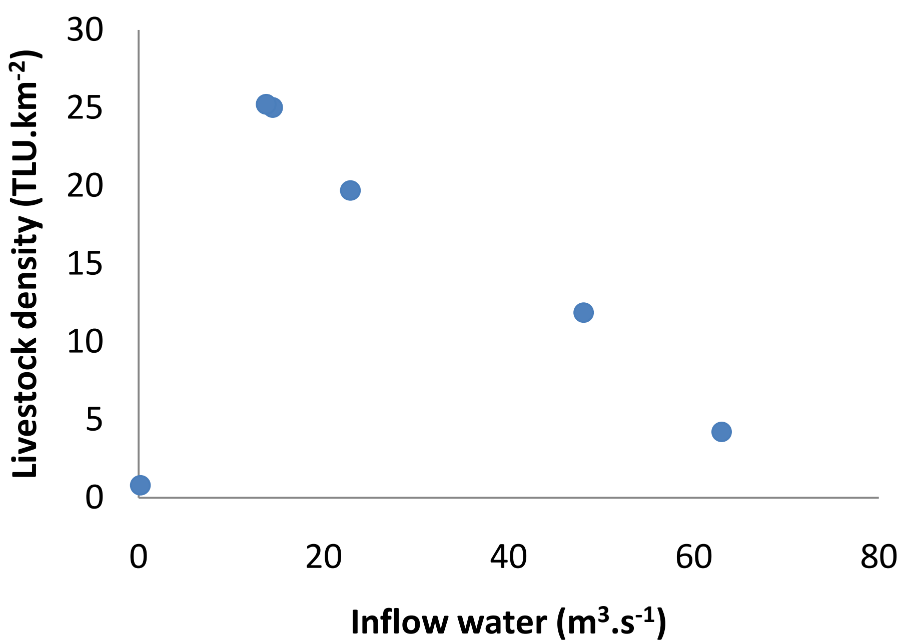

Figure 5.11: Relation between the density of livestock (TLU /km2) in the Lorian swamp and its 20 km buffer zone and the inflow of water into the system over the previous month.

This uni-modal relation is surprising. It challenges the simplistic assumption that more water automatically attracts more livestock. The highest livestock densities do apparently not occur during peak flow but instead at intermediate flows. There is a possible explanation for this. The absence of livestock in the absence of water flowing appears logical and presumably the result of lack of drinking water. Highest livestock densities do occur at inflows of around 20 $m^3.s^{-1}$. The consistent pattern of reduced livestock densities at high discharge might be the result of livestock being driven out of the swamps when these are flooded by water. This may be a result of physical unsuitability of the flooded areas for grazing livestock or the presence of animal disease.

These results suggest that livestock stocking is thus not a simple function of water dependent production of forage biomass. Our data suggest that more complex patterns characterize the relation between inflow of water and actual terrain use by livestock. We postulate that the pattern described above might be the result of attraction to the swamps at intermediate inflow due to accessibility of drinking water and availability of forage, and expulsion from the swamps at low and high inflows due to lack of drinking water or constrained accessibility at high inflows. It would be challenging to investigate the ecohydrological basis underpinning this animal production system in more detail.

Low resolution MODIS satellite imagery (Figure 5.12) reveals indeed that the swamps had open water[10] in 2010, when the average annual discharge of 41.8 $m^3.sec^{-1}$ was far above the threshold for the river to reach the swamp. The satellite imagery did not reveal any open water in the Lorian swamps in the drought year of 2009, when discharge of 4.6 $m^3.s^{-1}$ at an annual basis remained below the threshold of 14.5 $m^3.s^{-1}$ for the river to reach the lower end of the swamps for all but the last three months of 2009, when the rains returned.

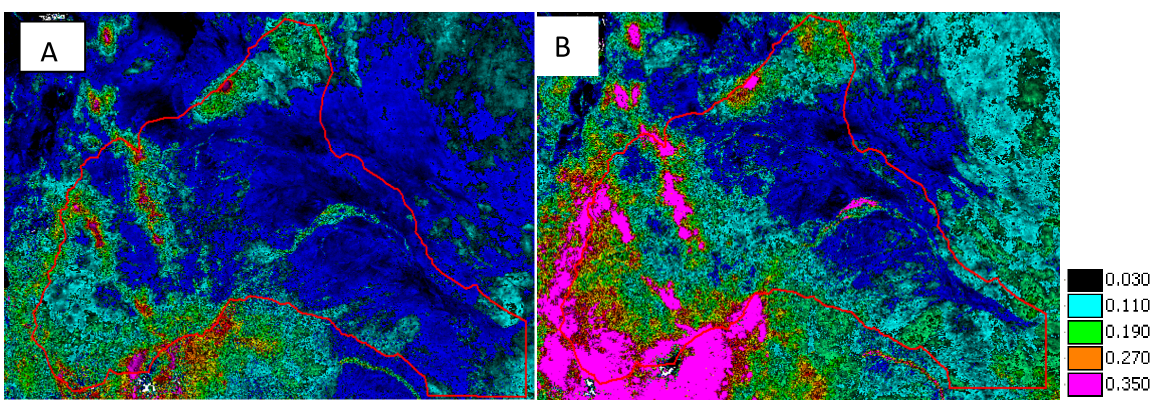

Figure 5. 12: Average annual Normalized Difference Water Index (NDWI) for the Lorian Swamp area in 2009 (drought) and in 2010 (wet year).

Requirement for open space

Both livestock and wildlife need to move regularly to find forage and water. Map 23 illustrates how pastoralists move their livestock in search of forage and water, using a map of such

[10] We used the Normalized Difference Water Index (NDWI), a dimensionless index that indicates the presence or absence of surface water. NDWI is calculated by comparing the shortwave and near-infrared sunlight reflected by the surface (reflectance). NDWI is also sensitive tochanges in liquid water content within the vegetation canopies.

movements in 2009 which was a drought year. We also show these movements relative to water sources, as it is very difficult to move livestock unless there is sufficient water on the route. It is also important to note that some livestock move into the catchment from elsewhere and that some livestock move out of the catchment. Recall from chapter four that 2009 was a dry year and there were serious forage shortages across Northern Kenya.

Some wildlife species cover quite long distances between the lowlands and forests. As mentioned in chapter 3 Ewaso N'giro catchment has the largest elephant population in Kenya outside its system of protected areas. Map 24 show the distribution of elephant in relation to land cover and the arrows shows the movement of elephants across the landscape. The movements of elephant were mapped by Save the Elephant Project through radio collaring a number of elephants (www.saveelephants.org). Most of the elephants move to the forests during the dry season in search of forage and water (Ngene et al., 2009) and in doing so has been known to cause destruction of farms but also a number of people have lost their lives through tramping by elephants.

Chapter Six: Allocation and valuation of final benefits

The economic assumption that underpins the ecosystem approach is that people demand services from which they derive benefit. However, such demand can lead to degradation of ecosystem services in two ways. First, demand can be greater than available supply, leading to overuse. Second, demand for one service can cause people to enhance the supply of that service to the detriment of other services both immediately and in the future. Often different groups of people demand different ecosystem services, which can lead to conflict. Additionally, competition between groups for the same service can lead to conflict.

The main advantages of economic valuation of ecosystem benefits are: i) to compare benefits to costs of using the indicator of value (monetary value); ii) provide stakeholders with an estimate of the value that they can use to compare with other uses of the resources; iii) indicate the relative importance of benefits to prioritize interventions; iv) understand the beneficiaries from these interventions. In addition, mapping these benefits adds a spatial dimension about the location and distribution of the benefits and their users.

Figure 1 shows the economic values associated with the various functions of drylands. The total economic value of ecosystem services and goods in a given location is the sum of its direct, indirect, option/future and existence values (Pagiola et al. 2004; Silvestri and Kershaw 2010).

- Direct values are related to direct uses, which include commercial products and non commercial products such as food (provisioning function). Tourism revenues and recreational values also contribute direct use value (cultural function).
- Indirect values are benefits that individuals experience indirectly or as a consequence of the primary function of a given resource. These values include carbon sequestration, defence against soil erosion, flood control and water regulation (regulation function).
- Non use value is the benefit people derive from the natural environment without having direct contact with it. Existence value is due to the benefits that the people have from aspects of the natural environment they don’t expect to experience personally, while bequest value that individuals derive from providing desirable features of the natural environment to the future generations.
- Option value has to do with choosing not to use a resource today, while retaining the option to use it in the future. As result, it can be considered as a non use value in the current period with an option for use value in the future.

Livestock and crops have direct values as they directly benefit people by providing food and income. Wildlife provide a direct benefit to tourists who have travelled to northern Kenya to see them; the revenue from these tourists is an income source for hotel owners, tour guides, managers of conservancies, and the government entities managing national protected areas. In a few cases, local communities may also benefit if they are involved in conservancy management or have employment in the tourism sector.

Approaches conventionally used to assess ecosystem services and goods are as follows:

- Market prices analysis (or financial analysis): this is an appropriate technique to assess the value of natural resources. It is best use when the good or service in question is traded in the open market. Observed market prices are used to assess the value.

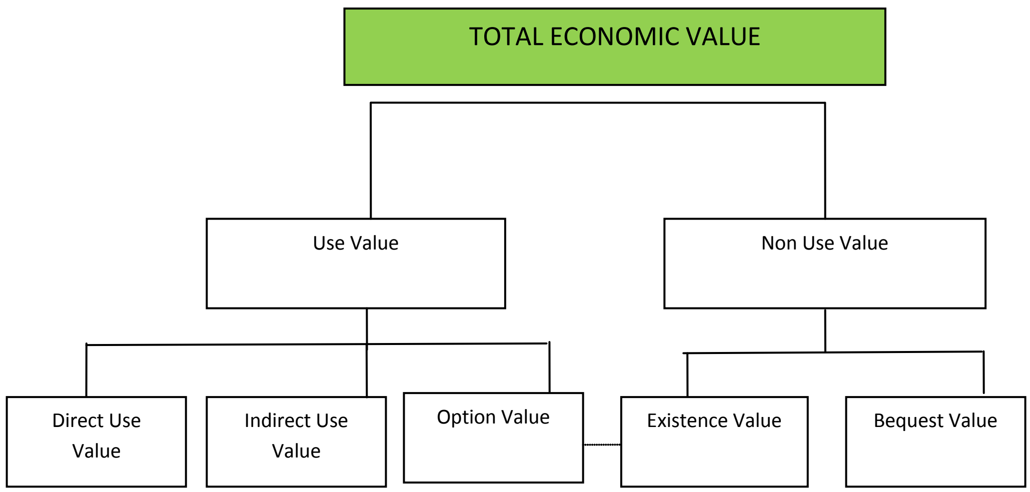

Figure 6.1. Economic values of ecosystem services

- Cost based values: valuation technique uses market costs (prices) for maintaining the environment in the absence of the ecosystem service, such as vegetation. The value of erosion mitigation, for example, could be estimated by the cost of preventing sediment filling in a dam.
- Travel cost method (TCM): it serves to measure the value of an area or facility, such as for recreation, and other social relations. Contingent valuation and contingent behaviour: consumers are requested, through choices in a survey, to state their preferences, they are asked to express their willingness to pay (WTP) for selected goods and services or also their willingness to accept (WTA) compensation for their loss.

In this chapter we adopted an approach where only final benefits are valued to avoid double counting. The values of intermediate goods (water) are presented in the next chapter (chapter 7). The final benefits are ecosystem services or commodities which have an economic value; the selected ecosystem services and goods are crops, livestock and livestock products and wildlife-based tourism. For these selected benefits market price analysis (to derive gross income) was applied to crops, livestock and livestock products, whereas travel cost and contingent valuation were used to value tourism (public parks) benefits. In addition, we acknowledge where appropriate non-economic values (in boxes) for some services or goods such as social and cultural values of livestock.

Market value of crop products

The gross agricultural product (crops and fruits) has been estimated using monetary values; this requires statistics on the type of crops, yields, market prices and total area in each district and for each sub catchment.

- Statistics on crop yields and area were collected from official sources; these data are available at the administrative division or district level; we then had to disaggregate these data from district to sub catchment levels for the Ewaso Ng'iro[11]. We used crop yield during the period 1990-2009 to compute an average yield per crop and by district.
- Prices were collected at the major markets for food crops such as: Nairobi, Mombasa, Nakuru, Eldoret and Nyahururu. Nyahu, Nakuru and Nairobi are the closest to Laikipia and the study area, so we used the Nairobi price to compute average crop values. Aggregate values are expressed in nominal terms using 2010 market price[12].
- The total crop area (irrigated and rain-fed /mixed crop-livestock) is estimated based on GIS mapping (see chapter 3). This area was used to derive subcatchment level total values; the study area is subdivided in 8 subcatchments, each included parts of between 2 to 5 districts. The contribution of each district to the sub catchment is expressed as proportions, which are given in appendix (Table A1).

The value of agricultural crop production is then computed as follows: first, the value is assessed at the district level to derive a weighted average value (based on crop areas) per hectare and per district (Table 1). Second, the proportions as specified above were used as weights to compute a subcatchment level weighted average value for the relevant districts. Third, the crop areas (irrigated and rain-fed /mixed crop-livestock) estimated based on GIS mapping, were used to derive subcatchment level total values.

We start by showing, for comparison reasons, the value for each crop in the main districts of the study area (Table 6.1). Crops cultivated in the basin range from fruits (avocados, bananas, passions etc), horticultural crops (carrots, tomatoes, potatoes etc) and staples (maize, millet, sorghum etc). Laikipia appears to have the most crops, whereas Garissa, Isiolo and Sumburu have fewer crops, which may depend on the availability of water for crop agriculture. The value

[11] Sources of data for crops:
http://www2.kilimo.go.ke/reports/Introduction%20Volume%20I.pdf
http://www2.kilimo.go.ke/reports/VolumeII.pdf

[12] Wholesale commodity prices are based on the daily bulletin published by the Market Research and Information department at the Ministry of Agriculture.

per ha for these crops depends mainly on crop yield. Crops found to yield the highest values (>400,000 Ksh/Ha) are tomatoes, cabbage, pineapples, passion, onion and wheat. Crops with the lowest values (<35,000 Ksh/Ha) are cassava, maize, beans and sorghum.

Total value by district

Based on the above values (per crop), we computed a weighted average value for the range of crops present at each district (the basin comprises parts of 11 districts). These values are given in the appendix (Table A2). The values show high variability (Standard deviation =69,000). The highest values (+ 130,000 Ksh/Ha) are found in Meru, Nyandura and Laikipia districts and the lowest values are found in Wajir, Marsabit, Isiolo and Garissa (< 60,000 Ksh/Ha). Such values reflect first the crop mix in each district and, second, the yields in the respective districts where water availability (irrigation vs. rain fed crops) and market development may play an important role.

Table 6.1: Value of crops in main districts

	Value per Ha (1000Ksh)			
CROPS	GARISSA	ISIOLO	LAIKIPIA	SAMBURU
TOMATOES	576.2	741.6	652.5	146.6
CABBAGE			506.2	
PINEAPPLES			488.3	
PASSION FRUIT			470.3	
ONION DRY	380.7	409.5	422.1	
WHEAT			417.0	720.2
ONION GARLIC			372.2	
BANANAS RIPE			304.1	159.9
MANGOES	129.5	43.2	196.4	0.0
FRENCH PEAS			172.3	
AVOCADOS		13.1	167.6	142.2
KALES		103.7	130.0	32.3
IRISH POTATOES			116.6	81.0
CARROTS			110.9	
MILLET		19.2	94.3	383.9
SWEET POTATOES		53.3	80.0	
PAWPAW	58.0	92.9	57.8	41.5
SPINACH			35.8	50.0
CASSAVA			34.2	
MAIZE (DRY)	14.1	9.2	25.3	73.7
BEANS		31.6	22.7	20.6
SORGHUM	13.3	14.7	21.3	7.3
CITRUS	3.0	3.5	18.1	6.2
COW PEAS	26.5	31.0	11.8	0.0
PEGION PEAS		11.9	11.1	
GREEN GRAMS	71.6	20.3	0.0	

Total value by sub catchment

On the basis of the total crop values by district, and the weights given in appendix (Table A1), we computed sub catchment level weighted average of crop values. The total value is based on crop areas (irrigated and rain-fed /mixed crop-livestock) which were estimated using GIS mapping. The total value is then computed by summing irrigated crops and rain fed crops (based on land cover maps). Table 6.2 shows the value per Ha for each sub catchment. On average, the value per ha is 91,660 Ksh. Owuor (1996) gives a 19996 value estimated at 29,948 Ksh/acre or 74,000 Ksh/ha in North arid Kenya which, given inflation, is comparable with the present value. The first results show the spatial distribution of crop values; we can distinguish three categories based on geographic location and characteristics: subcatchments 2, 7, and 4 have values greater than 125,000 Ksh per ha; subcatchments 5, 8 have values around 100,000 Ksh/ha and finally subcatchments 1, 3 and 6 have values below 50,000 Ksh/ha.

Table 6.1: Crop values by sub catchment (Total value and value per Ha)

	Value/Ha	Area (Ha)		Total value (1000 Ksh)		Total value (1000 Ksh)	Total value (1000 $US)
	(1000 Ksh)	Irrigated crops	Rain-fed crops	Irrigated crops	Rain-fed crops	All crops	All crops
S/C1	56.697	0.000	88.739	0.000	5031.27	5031.278	62.891
S/C2	123.410	0.000	27751.042	0.000	3424764.95	3424764.953	42809.562
S/C3	53.260	0.000	12978.357	0.000	691224.13	691224.139	8640.302
S/C4	125.368	0.000	69253.389	0.000	8682152.96	8682152.963	108526.912
S/C5	109.025	228.638	160190.093	24927.145	17464660.76	17489587.906	218619.849
S/C6	34.098	0.000	2604.460	0.000	88807.48	88807.488	1110.094
S/C7	125.667	3366.569	81717.914	423066.450	10269241.39	10692307.840	133653.848
S/C8	105.773	692.084	160084.554	73203.953	16932661.21	17005865.166	212573.315
Average	91.66*			65149.69347	7194818.023	7259967.717	90749.596

These "geographic clusters" are a logical reflection of agro climatic conditions but also infrastructure development. The spatial distribution of agricultural crop values reflects in particular the availability of water for irrigation, even at small scale levels along the river. The high values show the importance of resources' quantity and quality and particularly water resources around mountain areas of Laikipia and Samburu. We discuss the link between resources and infrastructure more at the end of this chapter.

The estimates of these ecosystem service values could provide the basis for a more effective allocation of water resources based on economic values and spatial distribution. Since water is scarce in these dry areas, it would be more economically rationale to use it (reallocate) for crops with the highest values. This reallocation would depend on agro-ecological conditions but also on market mechanisms to reflect the true signals (economic values) to help farmers make better decisions.

Market value of livestock and livestock products

In Kenya, the livestock sub-sector contributes 50% of the total agricultural income and employs about 50% of the agricultural labour force (Republic of Kenya 2002). Kenya's national livestock herd is estimated at 33.4 million, with about half of this herd managed by pastoralists in the ASALs. Barrow and Mogaka (2007) estimated the value of pastoral livestock holdings at $860 million, with an annual meat and hide slaughter off-take value of $69.3. Milk production from pastoral dryland systems was estimated to have a value of $134.6 million annually.

Livestock are a source of income, indicator of social status, source of food and means of establishing social ties. They are valued in multiple ways. Livestock and especially cattle are considered as capital goods that are held by producers (pastoralists). Pastoralists hold onto their assets as they value them for their breeding capacity and for their social and cultural significance (bride price, as loans), as well as for the income that can be generated from selling them. They also value breeding stock to have milk all year round (Nyariki 2004). Finally livestock are a type of insurance against drought or other shocks and savings. The savings function is increasingly important for educating children, etc. In the present study we analyzed the following species: cattle, goats, sheep and camels.

Asset value of livestock

Livestock and especially cattle are considered as capital goods that are held by producers (pastoralists). Pastoralists value livestock assets for their breeding capacity and for their social and cultural significance (bride price, as loans), as well as for the income that can be generated from selling them. They also value breeding stock in order to have milk all year round (Nyariki 2004). Finally livestock are a type of insurance against drought or other shocks and savings. The savings function is increasingly important for educating children, etc.

In order to compute livestock asset value we collected data on market prices and statistics on livestock number and distribution. Market prices are available from official sources[13] at the

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[13] Sources of data: Kenya's Agricultural Sector Data Compendium website. Ministry of Agriculture and Kenya Institute for Public Policy Research and Analysis (KIPPRA).
http://www2.kilimo.go.ke/DisplayData.asp?idcategory=1030
Muthee, A.M (2006). Kenya Livestock Sector Study: An Analysis of Pastoralist Livestock Products Market Value Chains and Potential External Markets for Live Animals and Meat, AU-IBAR & NEPDP, Consultancy report: Deloitte Consulting Ltd.AU-IBAR &NEPDP, 2006.
http://www.value-chains.org/dyn/bds/docs/552/KenyaLivestockValuechainReport.pdf
Manitra Rakotoarisoa, Stella Massawe, Andrew Mude, Robert Ouma, Ade Freeman, Godfrey Bahiigwa, and Joseph Karugia, October 2008. *Investment Opportunities for Livestock in the North Eastern Province of Kenya: A Synthesis of Existing Knowledge.* ReSAKSS Working Paper No. 12, IFPRI.

district level. We used the prices from sales in the Garissa market to compute livestock values. Garissa is the largest livestock market in the region. The value of livestock and livestock products is first assessed at the district level where statistics are available to derive a value per subcatchment and an average value per hectare. Based on the landuse map, livestock are distributed in the areas classified under “livestock production”, “livestock production and wildlife conservation” and “mixed crop-livestock production” so the extension of the areas classified under those categories has been taken into account in order to define an average value per ha.

Recently an Index-Based Livestock Insurance (IBLI) has been developed to derive the value of a herd insured (see box 6.1 for reference). Table 6.3 reports the asset value of livestock based on market prices, while table A3 in appendix compares the value of livestock calculated considering as proxy the value established under the Index-Based Livestock Insurance (IBLI), which assigns a price for TLU equal to 15,000 Ksh.

Box 6.1: Asset value computed from IBLI

Index-Based Livestock Insurance (IBLI) is a product that is designed to protect against drought-related livestock mortality, it covers the standard livestock types for a pastoral herd: camels, cattle, sheep and goats. The geographical coverage of the contract is limited for now to upper and lower Marsabit. The value of the herd insured is derived by transforming the four livestock types into a standard livestock unit know as Tropical Livestock Unit (TLU). The TLU for IBLI is calculated by assigning 1TLU to 1Cattle, 1.4 TLU to 1 Camel, 0.1TLU to one goat or sheep. Using average prices for livestock across Marsabit it is has been settled a price per TLU of Ksh 15,000. IBLI works in a way to make different payments across all the divisions, for example in the upper part of Marsabit where the level of mortality is higher the premium has been fixed at 5.5%, while for the lower part the premium has been fixed at 3.25%. On 2010 the number of IBLI contracts amounted to 1979 and the number of insured animals to 20,073 (3,908 cattle, 15826 shoats and 339 camels), for a total value of 1,193,040 USD.

Table 6.3: Asset value of livestock (USD)

	Value (USD$)			Value (USD) per ha		
Subcatchment	Cattle	Shoats	Camels	Cattle	Shoats	Camels
1	5,833,925	2,299,276	7,907,036	528	208	716
2	11,928,386	7,621,516	16,231,206	1,015	648	1,381
3	25,220,916	9,714,303	27,740,793	1,743	671	1,917
4	13,320,471	3,340,421	415,589	5,319	1,334	166
5	11,711,442	5,977,908	2,817,430	1,375	702	331
6	20,528,686	10,244,861	26,206,939	932	465	1,189
7	8,794,254	1,316,132	497,417	3,117	467	176
8	10,378,633	1,555,306	759,920	2,647	397	194
TOTAL	**107,716,714**	**42,069,723**	**82,576,331**	**1,398**	**546**	**1,071**

Note: An average market price for the years 2008, 2009 and 2010 has been applied for the computation.
The exchange rate applied is 1 USD = 80 Ksh.

Value of livestock products

Economic value is also derived from the sale of livestock products. Table 6.4 shows the value of selected products per each subcatchment: milk for cattle and meat for cattle and shoats.

Table 6.4: Value of livestock products in USD (milk and meat from cattle and meat from shoats) for the 8 sub catchments

	Value (USD$)			**Value per ha (USD$)**		
Sub-catchment	Milk from cattle	Meat from cattle	Meat from shoats	Milk from cattle	Meat from cattle	Meat from shoats
1	332.6	279.3	178.4	0.28	0.23	0.15
2	9,836.40	299.3	527.9	6.58	0.2	0.35
3	2,905.10	1,410.60	587.9	2	0.97	0.41
4	2,076.60	856.6	235.1	7.33	3.03	0.83
5	21,711.00	4,790.00	1,341.20	23.08	5.09	1.43
6	663.8	807.4	1,575.60	0.3	0.36	0.71
7	13,908.70	2,267.00	643.3	46.34	7.55	2.14
8	13,202.30	2,726.90	660.3	30.82	6.37	1.54
TOTAL	64636.5	13437.1	5749.7	14.59	2.98	0.95

Socio-cultural value of livestock

Non market functions of livestock have been well acknowledged recently in the literature (Stein et al. 2009; Ayantunde et al. 2009). Box 6.2 offers an overview of non market values/functions of rearing livestock as perceived by local communities.

Box 6.2: socio-cultural value of livestock

The contribution of livestock to rural livelihoods have been under estimated in the past because of the focus on productivity and limited consideration of no monetized products and services, but poor and subsistence households obtain multiple benefits from the use of livestock (landelfield and Bwttinger, 2005). The value of livestock is derived from (Anderson, 2003): cash income from sales of animals and their products and services as well as non-income functions e.g. saving, insurance, transport, and social and cultural functions. Non market functions have been well acknowledged recently in the literature (Stein et al. 2009; Ayantunde et al. 2009). According to Gibson and Pullin (2005) (cited by Ouma et al. 2007), 80% of the value of livestock in low input systems is attributed to non-income, socio-cultural functions, while only 20% is attributed to market products such as meat, milk and wool.

Results from a study in the Gambia (Zaibet et al. 2010) point to the importance of non market values/functions of rearing livestock as perceived by local communities (Table 1). This study shows that the objective of savings and insurance scored the highest for all species. For cattle the next highest scoring objectives were draught and manure, followed by (for cows) domestic milk consumption and milk sale, and then ceremonial / dowry. For sheep and goats the next highest scoring objectives were income and ceremonial / dowry, followed by manure.

Table 2. Production objectives by livestock category in the Gambia

Objective	Cows		Bulls		Sheep		Goats	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Savings / insurance	9.61	8-10	9.86	9-10	7.75	6-10	7.79	5-10
Manure	6.67	(4-10)	6.67	(4-10)	4.49	(2-8)	5.27	(2-9)
Draught	6.28	(0-10)	7.13	(2-9)	0.00	(0-0)	0.00	(0-0)
Domestic milk consumption	6.07	(2-9)	0.00	(0-0)	0.56	(0-5)	0.93	(0-5)
Milk sale	5.86	(2-9)	0.00	(0-0)	0.00	(0-0)	0.00	(0-0)
Ceremonial / dowry	5.34	(2-10)	4.77	(3-7)	6.68	(2-10)	7.30	(2-9)
Income	2.93	(1-9)	3.33	(1-9)	6.30	(5-8)	7.65	(6-9)
Transport	2.06	(0-8)	2.84	(0-8)	0.00	(0-0)	0.00	(0-0)
Hides / skin	0.56	(0-4)	0.56	(0-4)	0.99	(0-9)	1.11	(0-10)
Domestic meat consumption	0.56	(0-2)	0.56	(0-2)	1.79	(0-5)	2.73	(0-10)

Source: Zaibet et al. 2010.

Values of wildlife/ tourism

Tourism value was assessed at two levels: 1) private benefits related to the provision of benefits by private conservancies. In this case, the value of tourism is derived from market prices and the number of visitors to these conservancies; 2) total benefits (areas under public domain, i.e.

national parks), the value is derived using non-market valuation methods (Travel cost and contingent methods) and the total number of visitors to the region.

For the private benefits to conservancies, the assessment of tourism revenues is based on the number of visitors to private/community based conservancies in Samburu, Laikipia and Marsabit (Table 6.5). Note that we received data only for conservancies that belong to the Northern Rangelands Trust, so this is an underestimate of the total revenue for the Ewaso Ng'iro. Table 6.5 shows also an estimate of the number of beneficiaries based on communities involved in conservation schemes. The benefits are therefore attributed to the number of beneficiaries.

Table 6.5: Conservancies revenues and beneficiaries (Ksh)

	LAIKIPIA	MARSABIT	SAMBURU
Total value	2,652,500	834,000	12,998,697
Beneficiaries	25,000	6,000	21,500
Total area	58,675	33,111	40,155
Value/ha (Ksh)	45.20665	25.188	323.713

At the subcatchment level we used the same methodology described in the section on agricultural products to estimate a weighted average of tourism revenues (Table 6.6). On average, the revenue from conservancies-based tourism is estimated at a total of 3.27 Million Ksh or 77 Ksh/ha. Most of these benefits are captured by districts of Laikipia and Samburu. The value per ha reach up to 2.5 $US in sub-catchments 2 and 4 and is nil in sub-catchment 6 (Garissa region). This current value is low and given the very high number of beneficiaries the contribution to household income is very limited; tourists spend more in food and sociocultural services provided by these communities but not accounted for in these values which are based exclusively on the number of beds. This limitation could be improved by with better data collection.

Table 6.6: Tourism revenues (from conservancies) at sub catchment level

	Total value	Value/Ha (1000 Ksh)			Value/Ha ($US)	
	(1000 Ksh)	Total area	Conservancy area		Total area	Conservancy area
S/C1	852.923	0.001	0.025		0.009	0.311
S/C2	8555.972	0.006	0.214		0.071	2.680
S/C3	1055.277	0.001	0.026		0.009	0.330
S/C4	7590.391	0.027	0.179		0.335	2.233
S/C5	4194.022	0.004	0.101		0.056	1.264
S/C6	0.000	0.000	0.000		0.000	0.000

S/C7	2231.388	0.007	0.038		0.093	0.475
S/C8	1682.362	0.004	0.029		0.049	0.358
Average	3270.292	0.006	0.077		0.078	0.956

Note: 1 USD = approximately 80 Ksh

Tourism revenues are not limited to community conservancies. A larger number of tourists visit parks and game reserves outside conservancies. The value of tourism to national parks was assessed based on revenues from the total number of visitors to Northern Kenya. Table A4 shows major parks in Kenya and those located in Ewaso Ng'iro such as Meru and Samburu.

More specifically, using statistics on the total number of visitors to Northern Kenya, i.e. Garissa, Laikipia, Isiolo, Sumburu and Turkana (Ministry of tourism, 2010), the value of tourism in these areas was assessed based on travel cost and contingent valuation methods, using available literature (Table 6.7). Consumer surplus, as mentioned in the Table are defined by the difference between WTP (maximum amount a consumer is willing to pay) and what they actually pay (expenditure). In other words, WTP is the sum of actual expenditure and CS.

Table 6.7: Willingness to pay for wildlife viewing - review of literature

Author/source	**WTP / expenditure and consumer surplus (CS)**	**Habitat and animals**	**Approach**
Brown (1990)	US$ 182-218 mpa	African elephant in Kenya	Contingent valuation Foreign visitors only
Moran (1994)	US$ 450 mpa	Protected areas in Kenya	Contingent valuation Foreign visitors only
Brown et al. (1994)	US$ 52-86 per visitor day (CV) US$ 77-134 per visitor day (TC)	Game parks, Kenya	Contingent valuation & Travel cost (TC)
Navrud and Mungatana (1994)	US$ 114-120 per visitor (TC) US$ 68-84 CS US$ 53.25 per visitor (CV)	Lake Nakuru, Kenya	Contingent valuation & Travel cost (TC)
Barnes et al.	US$ 1413 per visitor trip	Namibia wildlife	Travel cost

1997	US$ 169 CS	viewing	Consumer surplus

Table 6.8 shows the evolution of number of visitors from 2003 to 2009 and associated value using the different methods as shown in table 12. The number of visitors has decreased from 42900 in 2003 to 5,700 in 2008 but there is a trend to the increase starting 2009). Total value varied from 5.7 Million USD in 2003 (CV method) to 1.78 Million in 2009 (TC method). The total tourism revenue in Kenya is 702 Million $US in 2006, (World Bank, 2007). Our values are approximately proportional to the official percentage of visitors to Northern Kenya (Parks of Meru and Samburu) of 0.3 to 0.4% of total visitors. So, the low value is attributed to the current scheme and organization of tourism in Kenya.

Table 6.8: Value of wildlife based on the number of visitors to Northern Kenya and WTP in Brown et al. (1994)

		2003	2004	2005	2006	2007	2008	2009
Method	Number of visitors	42,900	48,800	81,200	83,700	86,300	5,700	13,300
CV	value @ $52/visitor	2230800	2537600	4222400	4352400	4487600	296400	691600
CV	value @ $86/visitor	3689400	4196800	6983200	7198200	7421800	490200	1143800
TC	value @ $77/visitor	3303300	3757600	6252400	6444900	6645100	438900	1024100
TC	value @ $134/visitor	5748600	6539200	10880800	11215800	11564200	763800	1782200

Summary of total values

The mapping of total values gives more detail about the regional and spatial distribution within the Ewaso Ng'iro catchment. Map 25 shows the market value of selected ecosystem services. The figure "b" of map 25 illustrates the value derived as the sum of crops sold in the market plus livestock asset and livestock products sold. On average the market value of those selected ecosystem services is greater in the upstream part of the basin, where cropping is the main activity contributing to the economic value of the sub-catchments located in this area. Sub-catchments located in the downstream part of the basin derive their value principally from livestock asset and in minor part from the selling of livestock products and crops. It seems that livestock are kept downstream for subsistence and products are consumed by farmers instead of being sold in the market. The surface allocated to cultivation of crops is really limited downstream, due to the low suitability of these areas that are classified as very arid.

Based on this representation we can distinguish two major areas: the upper part of the catchment basin where agricultural values are very important and another (comprising

Marsabit, Isiolo and Garissa) where these values are almost insignificant when compared to the first region. The high agricultural values are clearly linked to regions of distinctive climatic conditions and also market access and infrastructure. These sub-catchments comprising Laikipia, Nyandura, Meru are located at more than 1500 m of altitude, and receiving between 1200 to 2000 mm/year of rain. These areas are also well endowed with road and market infrastructure. An additional factor leading to the scarcity of products sold in the market in the lower basin may be the poor infrastructure and limited access to the markets. The map number 12 on travel time distance to the market shows in fact that the number of hours spent to reach the market is bigger downstream, when farmers may need up to 12 hours to reach a market. Improved infrastructures and access to the markets should be promoted. Although the value of agriculture and livestock depend mostly on climatic conditions, market access is also an important determinant to improve these values.

Looking at the asset value derived from livestock across the basin, it is appreciable how it is related to the different composition in terms of presence of camels, shoats and cattle. A major asset is derived in those areas where camels are more concentrated, which is typical of the arid and very arid lands. For what concerns the value derived from the selling of livestock products, figure “d” of map 25, in the downstream part of the basin there is the significant consumption of meat from shoats. In the upper basin the availability of water and consequently cropping together with a big concentration of cattle allows for a significant production of milk from cattle.

The value from tourism is shown for private conservancies. The spatial distribution based on private conservancies is an underestimate of the total value, for this reason, we included an estimate of tourism value based on total visitors to Northern Kenya, mainly Meru and Samburu National parks. These values are high in sub-catchments 2, 4 and 5 where are located most of the tourism facilities, as showed in map 14. In particular these sub catchments are the location of most private conservancies and also National parks in the area. Such distribution is a fair reflection of the agro ecological characteristics and landscape available at the altitudes. The maps on elephants and livestock movements (Map 23 and 24) also demonstrate the competition over water resources, which are concentrated upstream. Tourism’s contribution depends on infrastructure (conservancies, national parks etc), and the number of visitors may depend more on organizational and institutional factors, such as operating tours. It would be therefore important to investigate the tourism value chain and the determinants of tourism in the drylands areas.

The map of distribution of value is super imposable with the map on demography and poverty (map 5), which shows that the percentage of population below the poverty line increases from upstream to downstream. The upstream regions are densely populated areas. But in recent years the lower basin areas have seen increased population growth leading to cities of equal population density to that in the upper subcatchments (e.g. Mado Gashi and Dadaab in Garissa in 2009). Current and future demographic factors, competition over resources and distribution of ecosystem benefits along the river and across sub catchments are strong factors in future regional development plans.

Mapping ecosystem services involves spatial distribution of benefits and requires the same distribution with regard data collection Data are prerequisite for natural, water resources and land development planning, design, operation and maintenance. This aspect should receive the attention it deserves.

Table 6.9: Value per hectare crops, livestock asset, livestock products and tourism (USD/HA)

	Crops	Cattle	Shoats	Camels	Milk from cattle	Meat from cattle	Meat from shoats	Tourism	Total
S/C1	708.7156	528	208	716	0.28	0.23	0.15	0.311411	2161.687
S/C2	1542.629	1015	648	1381	6.58	0.20	0.35	2.679726	4596.439
S/C3	665.747	1743	671	1917	2.00	0.97	0.41	0.329666	5000.457
S/C4	1567.099	5319	1334	166	7.33	3.03	0.83	2.23267	8399.522
S/C5	1362.808	1375	702	331	23.08	5.09	1.43	1.263873	3801.672
S/C6	426.228	932	465	1189	0.30	0.36	0.71	0	3013.598
S/C7	1570.837	3117	467	176	46.34	7.55	2.14	0.47537	5387.342
S/C8	1322.165	2647	397	194	30.82	6.37	1.54	0.358407	4599.253
Average	1145.779	2084.5	611.5	758.75	14.59	2.98	0.94	0.95639	**4619.996**

Table 6.10: Total value of crops, livestock asset, livestock products and tourism (1000 USD)

	Crops	Cattle	Shoats	Camels	Milk from cattle	Meat from cattle	Meat from shoats	tourism	Total
S/C1	62.89	5833.93	2299.28	7907.04	332.6	279.3	178.4	10.66	16904.1
S/C2	42809.56	11928.39	7621.52	16231.21	9,836.4	299.3	527.9	106.95	89361.23
S/C3	8640.30	25220.92	9714.30	27740.79	2,905.1	1,410.6	587.9	13.19	76233.1
S/C4	108526.91	13320.47	3340.42	415.59	2,076.6	856.6	235.1	94.88	128866.6
S/C5	218619.85	11711.44	5977.91	2817.43	21,711.0	4,790.0	1,341.2	52.43	267021.3
S/C6	1110.09	20528.69	10244.86	26206.94	663.8	807.4	1,575.6	0.00	61137.38
S/C7	133653.85	8794.25	1316.13	497.42	13,908.7	2,267.0	643.3	27.89	161108.5
S/C8	212573.31	10378.63	1555.31	759.92	13,202.3	2,726.9	660.3	21.03	241877.7
Average	90749.60	13464.59	5258.72	10322.04	8,079.6	1,679.6	718.7	40.88	**130313.7**

Appendix tables used to calculate economic values

Table A1: Proportion district-Sub catchment (SC)

SC	Garissa	Isiolo	Kirinyaga	Laikipia	Marsabit	Meru central	Meru north	Moyale	Nyandarua	Nyeri	Samburu	Wajir
1		10.1			83.1			4.6			1.2	
2		6.39			29.5						63.9	
3	0.6	80.5			2.1		2.1				8.0	6.6
4				49.9							48.2	
5		27.0		16.0		10.0	17.0				29.0	
6	70.5	19.7					0.3					9.3
7		0.02		84.1					15.7			
8			0.06	63.43		10.09			4.91	14.2		

Table A2 Cropped area and values (1000 Ksh per ha) at district level

	Embu	Garissa	Isiolo	Kirinyaga	Laikipia	Marsabit	Meru central
Cropped area	8283.694	14063.9	3067.3	6490.597	50906.8	10188.6	340906.33
Average value/ha	97.9589	126.3	106.6	179.8864	176.4	161	379.2947
Weighted average	111.94	28.4	39.9	129.79	93.7	56.42	151.17
	Meru north	Meru south	Moyale	Nyandarua	Nyeri	Samburu	Wajir
Cropped area	416616.2		8720	84061.16	150644	3705.1	2232.35
Average value/ha	345.85		249	246.183	479.4695	109.4	69.463
Weighted average	122.78		81.3	298.83	114.81	163	63.58

Table A3: Asset value of livestock based on IBLI index

	Value (USD$)				**Value (USD) per ha**	
Subcatchment	Cattle	Shoats	Camels	Cattle	Shoats	Camels
1	4,027,450	1,282,834	5,450,808	484	191	656
2	8,234,760	4,252,268	11,189,172	797	509	1,085
3	17,411,256	5,419,896	19,123,440	1,739	670	1,912
4	9,195,785	1,863,719	286,491	4,704	1,180	147
5	8,084,992	3,335,251	1,942,228	1,245	636	300
6	14,171,976	5,715,910	18,066,060	922	460	1,177

7	6,071,112	734,309	342,900	2,930	439	166
8	7,164,888	867,751	523,860	2,423	363	177
TOTAL	74,362,219	23,471,938	56,924,960	1,293	505	991

Table A4: Number of Visitors to Parks and Game Reserves

Parks/Reserves	**No. of Visitors**	**% of Total**
Lake Nakuru	344,600	16.20%
Masai Mara	285,200	13.40%
Animal Orphanage	257,800	12.10%
Tsavo East	180,100	8.40%
Nairobi Safari Walk	127,500	6.00%
Amboseli	126,200	5.90%
Tsavo West	105,700	5.00%
Haller's Park	100,800	4.70%
Nairobi National Park	99,900	4.70%
Impala Sanctuary (Kisumu)	87,900	4.10%
Lake Bogoria	65,700	3.10%
Kistie/Mpunguti	59,200	2.80%
Aberdare	48,300	2.30%
Mount Kenya	39,500	1.90%
Mombasa Marine	36,200	1.70%
Hell's Gate	35,600	1.70%
Malindi Marine	32,800	1.50%
Watamu Marine	32,400	1.50%
Others	22,500	1.10%
Shimba Hills	17,300	0.80%
Mt. Longonot	11,500	0.50%
Meru	8 ,900	0.40%
Samburu	7 ,300	0.30%
Total	2,132,900	100%

Source: Economic Survey, 2006

Chapter Seven: Value of water as an intermediate ecosystem service

In drylands, water is the limiting factor of production and it is therefore a core ecosystem service for livelihoods in these areas. Products and services from crops, livestock and wildlife are considered as final benefits; water, on the other hand, is a major input into these services. Water contributes to crops, livestock, wildlife and tourism and recreation activities. The value of water can be approximated by the contributions to the livelihood activities of local communities and interlinked sectors. The value of water is a derived demand; derived from the demand of final products and services from livestock, wildlife and crops.

Water scarcity and increasing demand in drylands call for effective tools to guide its allocation among competing users. The demand for water is a derived demand and therefore the value of water is derived from the value of end products. Decision makers need information on water use and the unit value of water in different activities. This will allow to adequately assess potential trade-offs amongst existing and potential competing users.

There has been increasing emphasis on the need to explore the sources of water use inefficiencies to design institutions and policies to improve water use performance. Increasing efficiency of water use would improve its contribution to local economies as well as to overall sector growth. Valuing water use in agriculture and other sectors is also used to implement incentive-based interventions and pricing schemes, which can ensure sustainable, efficient and equitable allocation of water.

The value of water in drylands

The economic principle for water allocation is that optimal water application occurs at a level where the value of marginal product (VMP) of applied water is equal to its price. The value of water in agriculture is often estimated by the VMP. The VMP is function of the output price and the physical marginal productivity. This allows comparison of different allocations, for example to crops, different technologies, etc. Approaches commonly used for estimating the value of water include mathematical modelling and optimisation techniques, and econometric models to estimate production functions and derive the value of marginal product. There are also experimental studies which assessed water productivity under different irrigation schemes, different crops and crop varieties. In the absence of experimental data, some researchers used average gross crop values and crop water requirement to compute average water value, which is the approach adopted in this study.

In chapter 5, we discussed water requirement for the different activities (crops, livestock and wildlife). And, by mapping water sources, irrigation domains, and land cover (crops, livestock and wildlife) we were able to produce maps of gross production values for these activities. In the following sections, we show the associated water values.

Value of water for crops

As explained in chapter 5, in the absence of crop water requirement estimates for crops that are cultivated in every sub-basin, we used the available values in Laikipia and the total value of agricultural goods to assign a specific water value per ha. The value of water for crop was computed considering the gross product divided by water requirement.

Table 7.1 shows the corresponding values for selected crops. According to these results, it is clear that wheat has the highest value per ha (289 Ksh) while beans and maize have the lowest (19 Ksh). These values indicate in particular the respective crop yield per ha. These figures are particularly important for potential reallocation of water toward higher value products where appropriate.

Table 7.1: Water value in Laikipia (where crop water requirement CWR is available)

Crops	Total value (1000 ksh/ha)	CWR m^3/Ha	Water value (Ksh/m^3)
Beans	22.7	1170	19.42
Irish Potatoes	116.6	2302	50.64
Maize (dry)	25.3	1285	19.71
Millet	94.3	1166	80.89
wheat	417.0	1442	289.17

Value of water for livestock

The value of water in livestock was computed following the same methodology for crop products; i.e. gross product divided by water requirement by TLU. The value of water per ha has been derived on the basis of the total asset value for cattle and shoats and the total water requirement per ha. The water requirement per ha for cattle, shoats and camels in the areas of study is shown in table 7.2 (taken from chapter 5).

Table 7.2: Summary of water requirement per subcatchment and per ha.

	Livestock water requirement m^3/year (x 1000)			**Livestock water requirement m^3/year/ha (x 1000)**		
Subcatchment	Cattle	Shoats	Camels	Cattle	Shoats	Camels
1	44,302	21,167	76,311	4.0	1.9	6.9
2	90,582	70,162	156,648	7.7	6.0	13.3
3	191,524	89,428	267,728	13.2	6.2	18.5
4	101,154	30,751	4,011	40.4	12.3	1.6
5	88,935	55,032	27,191	10.4	6.5	3.2
6	155,892	94,313	252,925	7.1	4.3	11.5

7	66,782	12,116	4,801	23.7	4.3	1.7
8	78,814	14,318	7,334	20.1	3.7	1.9
TOTAL	**817,984**	**387,287**	**796,949**	**10.6**	**5.0**	**10.3**

Table 7.3 compares for crops and livestock the value of water requirements and the economic value of water in USD/m3 as an input into livestock and crops sold in the market place. The estimated value of water per m^3 across livestock species is almost similar, while with respect to crops, it varies. Field crops, such as beans and maize, show lower value with respect to the other crops considered.

Table 7.3: Value of water requirements for crops and livestock.

Final benefit	Average water requirement (m3/year)	Value of water per ha (USD)
Cattle	10,600	0.197
Sheep/goats	5,000	0.122
Camels	10,300	0.074
Beans	1,170	0.243
Irish Potatoes	2,302	0.633
Maize (dry)	1,285	0.246
Millet	1,166	1.011
Wheat	1,442	3.615

Summary

Water is used for crops, livestock, wildlife and tourism as well as human consumption. Whereas water is mainly produced upstream, benefits are distributed along the river basin. Therefore, a basin wide integrated water management approach would support a careful use of this resource.

Water values differ according to competing uses, mainly crops and livestock. Values for crops are much higher than those for livestock. Valuing water use in agriculture and other sectors has to be promoted as tool to implement incentive-based interventions and pricing schemes, which can ensure sustainable, efficient and equitable allocation of water.

There is the need to explore the sources of water use inefficiencies to design institutions and policies to improve water use performance. Increasing efficiency of water use would improve its contribution to local economies as well as to overall sector growth. Developing water harvesting techniques and appropriate infrastructure would contribute to improve such a contribution.

Chapter Eight: Ecosystem services under climate change

Impact of climate change on cropping conditions

Both changing land use and future climate change will affect the availability of ecosystem services in pastoral areas. The impacts of climate change are uncertain, but plausible scenarios of possible impacts can be developed using down-scaled information. Water is a key ecosystem service that will be directly affected by climate change. Changing land use upstream will also affect downstream water availability. Climate change will also affect other ecosystem services.

Africa is generally witnessing temperature rise and irregular and unpredictable rainfall which is evident from the downscaled climate data. This increasingly erratic rainfall as a result of climate change is a major threat to food security and economic growth for Africa. The Ewaso Ng'iro basin has not been spared by the effects of climate variability. We assessed the impacts of climate change specifically for the surface water resources (lifeline of the people and livestock) in the basin. To do this, we used the downscaled climate data (rainfall, maximum and minimum temperature) from the existing Global Circulation Models (GCMs) covering our area of study based upon data Jones and Thornton (2010). Monthly data covering the basin with a resolution of 1 degrees latitude and longitude for the period 2011 to 2050 was used for simulation purposes. Of the 22 or so climate models used for the IPCC's (2007) Fourth Assessment Report, output data are not always readily available for the basic "core" variables that are needed to drive many crop and pasture models: precipitation, maximum daily air temperature, and minimum daily air temperature. From the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, we obtained data for three GCMs: the CNRM-CM3 model from France, CSIRO-Mk3.0 from Australia, and MIROC 3.2 (medium resolution) from Japan. We also obtained data for the ECHam5 model (from Germany) from the Climate and Environmental Retrieval and Archive (CERA) database at the German Climate Research Centre (DKRZ). These and other climate models are extensively described in Randall et al. (2007).

We first used these downscaled data to map the changes in rainfall, maximum and minimum temperatures across the catchment in 2030 and 2050 (Map 26). The long-term mean annual temperature in the lowlands of Ewaso Ng'iro basin is 27 °C while it is 17 °C in the highlands. Mean annual precipitation currently ranges from under 400 mm in the lowland areas to over 1,200 mm in the highlands. However, with the effects of climate change as projected by the GCMs for the next 50 years, both rainfall and temperature in the basin are expected to increase on average by about 40 mm and 0.4^{0} C per decade respectively. For example by 2050 Merti will have annual precipitation of 50 to 100 mm per year, and Samburu will also see increases. However, both minimum and maximum temperature will also increase, and this effect is most notable in the highland areas, where minimum temperature will increase to 16-19 C. Maximum temperature also increases significantly.

Map 27 shows the impact these changes may have on aridity in the catchment by 2050, indicating wetter conditions in the centre of the catchment. We also translated this into potential maize yield changes by 2050; the combined effect of wetter conditions and increased minimum temperatures leads to increases in potential maize yields, particularly in the highland areas. There is no effect on either aridity or potential maize yields in the lower subcatchments.

Impact of climate change on surface water

The downscaled data was then put in the WEAP model to predict the effects of climate change on the surface water resources. For comparison purposes, two scenarios were generated to enable comprehensive evaluation of the future situations in the basin. These scenarios included a reference, which was generated with the assumption that there are no changes in climate over the next 50 years, and a second scenario which accounted for the effects of climate change on flow discharges at Archer's Post. These two scenarios were also compared with the baseline flow data for the period 1960 to 2010 (Figure 14).

Figure 8.1 reveals that both downscaled global circulation models under-predicted the incidence of high rainfall events. The forecast for 2010 to 2050 without climate change led to predicted discharge that had a probability distribution which resembled the distribution recorded at Archer's Post over the past decades. The climate change scenario resulted in predicted discharge lower than the historic record and the model without climate change. This reduction of discharge is likely attributable to increased evapotranspiration in the upper part of the catchment.

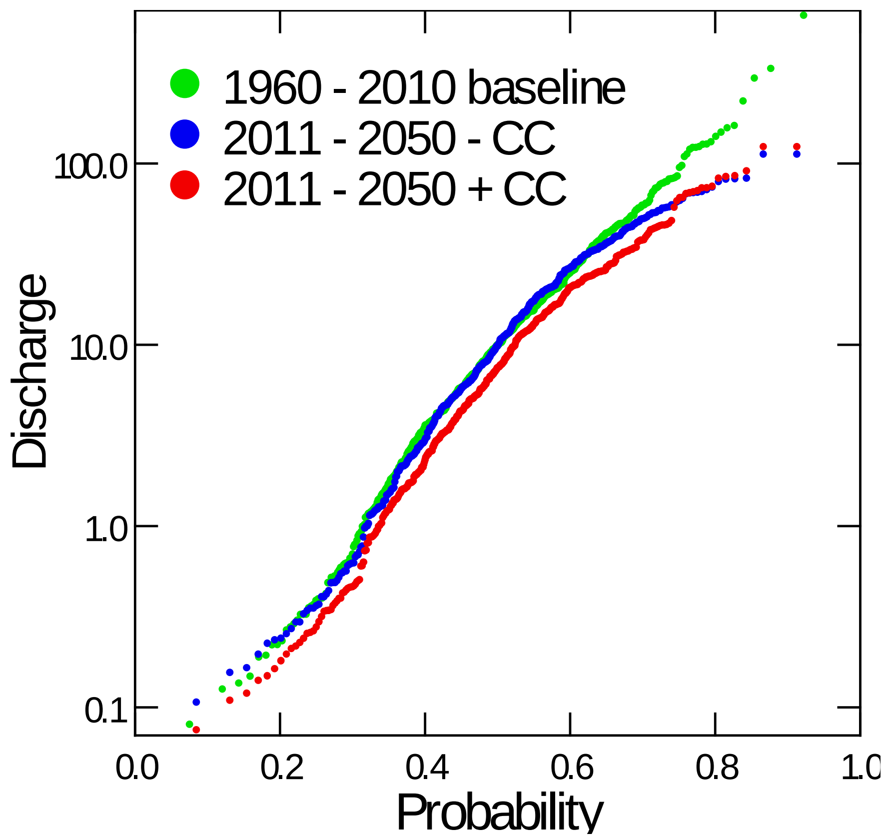

Figure 8.1. Probability of monthly discharge of the Ewaso Ng'iro river for the baseline period 1960 – 2010 (green), a reference scenario for 2011 - 2050 without climate change (blue) and a scenario for 2011 -2050 with climate change (red).

The effects of higher rainfall in the near future are apparently outweighed by the stronger effect of increased temperature. Current global circulation models predict a slight increase in rainfall over eastern Africa. Recent analysis of actual rainfall trends (Williams and Funk 2011) suggest that rainfall may well be declining as a result of warming of the Indian Ocean, an effect not accounted for in current global circulation models. The reduction in discharge under climate change could thus well be more significant than the predictions given above.

It remains difficult, given the above uncertainty, to predict the exact impact of climate change on downstream communities. There is reason for concern however, as the more conservative predictions of the current global circulation models forecast a reduction of the flow of water downstream. Updated global circulation models that do account for the effects of a warming Indian Ocean will result in even more strongly reduced discharge of the Ewaso Ng'iro.

The above indicates that climate change is likely to reduce the flow of water downstream. The debate is to what extent. Abstractions upstream are likely to complicate these effects of climate as they tend to reduce the flow of water during periods of low discharge. A further reduction in water flows during dry periods would without doubt have detrimental effects on the livestock and livestock dependent livelihoods downstream.

One possible solution to consider regulate the period during which abstractions are permissible. At present one is free to use abstractions at the height of a drought, to satisfy demands upstream at the expense of water security to downstream users. The flow of water during dry periods could be sustained when water would be stored upstream for usage during periods of scarcity. This would regulation limiting abstractions during drought and allowing storage during high rainfall periods.

Chapter Nine: Conclusions

This project set out to demonstrate the value of a spatially explicit mapping approach for describing, quantifying and valuing the ecosystems and ecosystem services of Kenya's ASALs. To do this, we chose the Ewaso Ng'iro catchment in Northern Kenya as a case study, for several reasons: the catchment is endowed with very high biodiversity; there is a significant contrast between the upper and lower parts of the catchment in terms of climate, land use and population density; and there are a number of discussions currently underway about the best land use options for the catchment.

In addition to describing and mapping the physical and socio-economic geography of the catchment, we evaluated some of the key ecosystem services provided within the catchment. Ecosystem services are the benefits that humans derive from ecosystems. As described in chapter 2, the ecosystems services approach is a research framework that explicitly links the benefits and services provided by ecosystems to benefit human well-being. Mapping ecosystem services helps decision makers to visualize the impact of land use management and decisions; quantifying the value of ecosystem services makes clear their benefits to human well-being. Kenyan ASAL ecosystems must be managed effectively so that they continue to provide ecosystem services that benefit their human populations. In developing land use plans, decision-makers need to pay attention to the complex linkages between ecosystems, ecosystem services and people, in particular the synergies and trade-offs in terms of supply and demand for land and water.

This project first compiled and mapped existing data regarding key inter-related ASAL ecosystem services (water, biomass, livestock, wildlife, irrigated crops). Based on the quantification of and the demand for these services, we estimated their economic value. Finally, we obtained downscaled climate change projections for Northern Kenya and assessed their possible impact on crop conditions and surface water hydrology. We produced 27 high quality maps describing the geography, supply of ecosystem services, the value of final benefits, and the possible impacts of climate change.

Geography

In terms of the geography of the catchment, the agroclimatatology and topography are the major influences behind much of the vegetation and population distributions, as well as the current land uses. Over 90% catchment is classified as semi-arid to very arid. Furthermore, the seasonal distribution varies along with predictability, and semi-arid to arid zones have very heterogeneous and variable rainfall. We divided the catchment divided into three AC zones (humid to semi-humid A; semi-humid to arid B; arid to very arid C) and found that land cover varies with this classification. In Zone A the main land cover classes are forest (31%), rainfed crop (28%) and scattered rainfed crop (18%). Zone B is dominated by shrub savannah (29%), scattered rainfed crop (19%), shrublands (16%) and rainfed crop (11%). Natural vegetation prevails in Zone C, with dominate land types of shrub savannah (45%), shrublands (26%), grassland (12%), bushlands (7%) and wetlands (7%).

There is significant variation in human population density throughout the catchment, with densities greater than 100 people per km^2 in the highlands, and densities of 10 people per km^2 and below in many parts of the dry lowlands. Poverty rates do not correlate with density, as there are high poverty rates of more than 55% in Isiolo, Garissa and Marsabit, while Laikipia and parts of Samburu have moderate poverty rates of between 35 to 45% (although the overall densities are lower).

Livestock production is the dominant land use (82%), followed by conservancies and mixed crop-livestock production. Again there are differences by agro-climatic zone: wildlife conservation is mostly practiced in zone C, in the arid to very arid land. Conservation forestry is practice in zone A and B where rainfall is high, though we observe some forests in the dry lands. Livestock production, although practiced in all zones, is more widespread in zone C (91%) than in zone B (51%) and A (43%). The combination of livestock production and wildlife conservation occurs in conservancies which are located in zone B (5.3%) and C (4.3%) but the animals are spread throughout the landscape.

Infrastructure mimics population density to some extent, in the case of roads and water infrastructure; this disparity results in downstream more populations have a greater distance to travel to a permanent water source, and travel times to market centres are also much greater.

Supply of services

In this study, we used the framework of intermediate services, final services and benefits to classify ecosystem services. The intermediate services were water and forage, which are inputs into the final benefits of livestock production, wildlife tourism and cropping. In terms of water supply, we estimate that less than 5% of the water in the catchment ends up as blue water, leaving more than 95% of the water balance in the form of green water, which is taken up by vegetation or evapotranspired. The surface water originates upstream and more of it is captured and used there; downstream there is more reliance on groundwater. Forage is produced in 90% of the catchment as it is the dominant land cover. The maps of forage biomass and forage biomass deviations show heterogeneity in terms of forage production and deviations from year to year. Even in a good rainfall year, not all places green up and even in dry years we still see patches of green vegetation.

For both wildlife and livestock, there are differential distributions by species. There are large numbers as well as diversity of species in Laikipia, Samburu, the eastern and northern parts of Isiolo and southern parts of Marsabit. In Garissa and Wajir there are high concentrations of giraffe and oryx. High numbers of cattle are found in Laikipia, Samburu and around Merti in Isiolo. In the high rainfall areas we see more cattle than small stock, while in the drier areas camels contribute almost half of the total animal biomass.

Cropping is concentrated in Laikipia and lower Isiolo, as well as the slopes of Mt. Kenya and the Aberdares, and there is very little elsewhere.

Table 9.1 indicates which final services and benefits are supplied by each land use category. It is immediately obvious that these services are provided as bundles; that is, any given land use provides a number of services.

Use of services

The current use of water is that very little of the total supply in the catchment is used for direct human consumption. Crops use water only in subcatchments 5 and 8. By total number of livestock species, the cattle in the catchment use the most water, with camels a close second, and the population of shoats requiring much less.

We devoted considerable effort to modelling the impact of upstream abstractions on downstream surface water during dry season. These abstractions since 1980 result in a higher probability of water not reaching Merti or the Lorian swamp. This has a potential impact not only on drinking water for people and animals, but also on the greening up of the Lorian swamp, which is a key dry season grazing area. The Lorian swamps have witnessed years of high inflows of one km^3 and above and accordingly high productivity in 2010, 1997 and 1998, 1968, 1961 and 1951. Years with low inflows of below 0.1 km^3, occurred in 2009, 2001 and 2000, and 1991, while the lowest inflow ever occurred in 1952 and 1953. The system is thus exposed to high year-to-year variation in inflow of water from outside. Our analysis suggests that the greenness of the swamps increases at discharge above approximately 10 $m^3.s^{-1}$. In high rainfall or flooding years the biomass produced is sufficient to support 6.3 TLU per hectare. However, more water does not mean more livestock, as forage quality is not very high in the swamps, and data suggest that most livestock are found during intermediate flow years. We postulate that the pattern might be the result of attraction to the swamps at intermediate inflow due to accessibility of drinking water and availability of forage, and expulsion from the swamps at low and high inflows due to lack of drinking water or constrained accessibility at high inflows.

Mobility is critical for both wildlife and livestock as they need to move to find water and forage even in high rainfall years, and particularly in dry years.

Table 9.1: Matrix showing the relationship between land use and ecosystem services

Benefits	Final Services	Conservation Forest	Production forestry	Irrigated crop production	Livestock	Mixed crop-livestock	Livestock/ wildlife	Wildlife
Food	Medicinal plants	+	+	?	+	-	+	+
	Crop	-	-	X	-	+	-	-
	livestock	-	?	+	X	+	X	-
Asset	Livestock	-	+	+	X	+	X	-
Tourism	Wildlife	+	+	-	?	-	+	X
Marketed carbon	Climate regulation	X	+	-	-	+	?	+
Wood +fiber	Trees + woody species	X	X	-	-	+	+	+
Drinking water	Fresh water quality and quantity, water security	X	X	-	+	+	+	-
	Flood regulation, surface+ groundwater	X	+	?	-	?	-	-
Cultural ID	Livestock	X	x	-	+	-	+	-
	Open Land	-	-	-	+	-	+	+

Meaning of symbols: + indicates services supplied, X means significant supply; ? means unknown, and - means not supplied.

Value of final benefits

Only those final benefits that people use directly were valued (livestock, crops and tourism), and we were limited to calculating the market value only. Our results indicate that the market value of those selected ecosystem services is greater in the upstream part of the basin, where cropping is the main activity contributing to the economic value of the sub-catchments located in this area. Sub-catchments located in the downstream part of the basin derive their value principally from livestock assets and in minor part from the selling of livestock products and crops. The high agricultural values are clearly linked to regions of distinctive climatic conditions and also market access and infrastructure. Although the value of agriculture and livestock depend mostly on climatic conditions, market access is also an important determinant to improve these values. We also found that the market value of water for crops is higher than for livestock, not surprising given our methods.

Our calculations suggest that tourism's value is a fraction of that derived from cropping and livestock production. The market value of tourism depends on infrastructure (conservancies, national parks etc), and the number of visitors, which may depend more on organizational and institutional factors, such as operating tours.

The map of distribution of value is can be compared with the map on demography and poverty (map 5), which shows that the percentage of population below the poverty line increases from upstream to downstream. Current and future demographic factors, competition over resources and distribution of ecosystem benefits along the river and across sub catchments are strong factors in future regional development plans.

Impact of climate change

Under the assumptions described in chapter 8, temperatures will increase in the Ewaso Ng'iro by 2050. The impact of climate change on precipitation is more difficult to assess, but current models suggest it will increase slightly, although empirical evidence is beginning to question this. Although the potential maize yield increases, there is no impact of higher rainfall on downstream surface water flow, and it seems likely that downstream flow will decrease.

Next steps

This project represents a first attempt to try to describe and quantify the ecosystem services supplied and used in an ASAL area of Kenya. This effort relied a great deal on accessing data from a range of sources, and ultimately the success of the project was framed by which data we could obtain. In particular, we could improve upon the economic valuation of the ecosystem services with more time and more on tourism revenue and informally traded livestock. A great deal of pastoral livestock trade, especially cross-border, is undocumented. In addition, we did not estimate the subsistence value of livestock production.

Over the next few months, we will be able to evaluate the utility of this approach for decision-making in the ASALs through a series of outreach activities and workshops we have planned with the Ministry of State for Development of Northern Kenya and other Arid Lands and other governmental agencies. This will help us to reflect upon the use of maps and the ecosystem services approach to support land use planning decisions. We will document this process and prepare a presentation and paper describing lessons learned.

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Appendix: List of maps and data sources

Map 1:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000).

Map 2:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000).

Map 3:
Sources: Administrative boundaries (CBS 2001, CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), 1962 population density (Ministry of Finance and Economic Planning 1964), 1989 population density (CBS 1994), 1999 population density (CBS 2002), 2009 population density (KNBS 2010). Note the census data for 1962 was a dot map and was aggregated to sublocation to match the 1989 census boundaries.

Map 4:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), 1979 population density (CBS 1981), 1989 population density (CBS 1994), 1999 population density (CBS 2002), 2009 population density (KNBS 2010). We added the refugee population to Daadab using data from Enghoff et al 2010. Note the urban centres were based on the KNBS classification.

Map 5:
Sources: Administrative boundaries (CBS 2003), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), parks and reserves (IUCN and UNEP/WCMC 2006), 1999 poverty rate and density for rural locations and urban sublocations (CBS 2003). Note for Wajir, Garissa and Tana River districts the poverty rates and density were calculated at the constituency level (CBS 2005).

Map 6:
Sources: Catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), rainfall (Mud Springs Geographers, Inc. 2002. AWhere-ACT Database, Kenya 2002), Agro-climatic zones (KSS, Sombroek 1982).

Map 7:
Sources: Catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), Aridity Index (Mud Springs Geographers, Inc. 2002. AWhere-ACT Database, Kenya 2002).

Map 8:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), Agro-climatic zones (KSS, Sombroek et al. 1982), annual rainfall and potential evapotranspiration (Mud Springs Geographers, Inc. 2002. AWhere-ACT Database, Kenya 2002), rainfall stations (KMD).

Map 9:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), and landcover (FAO 2000). Note the 26 landcover classes were aggregated to 11 major landcover classes. Agro-climatic zones (KSS, Sombroek et al. 1982).

Map 10:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), lithology (KSS, KENSOTER database, ISRIC).

Map 11:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), agro-climatic zones (KSS, Sombroek et al. 1982), landuse (derived from interpretation of landcover, protected area, conservancy and wildlife and livestock distribution and their linkages).

Map 12:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, travel time to major cities (Nelson 2008) Note the map of travel time was estimated based on the combination of different spatial data layers which represent the time required to cross each single point. These dataset include: elevation, slope landcover, urban areas, roads, railways, rivers, borders, major and water bodies.

Map 13:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), airstrips (KAA), hotels, lodges and camps (KWS, SAFARI Map of Kenya, Published by Tourist Maps of Kenya Ltd), parks and reserves (KWS), and conservancies (NRT).

Map 14:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), Airstrips (KAA), hotels, lodges and camps (KWS, SAFARI Map of Kenya, Published by Tourist Maps of Kenya Ltd), parks and reserves (KWS), conservancies (NRT), land parcels (digitized from Thouless 1994).

Map 15:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), boreholes (Rural Focus), Merti aquifer (Gibb Ltd. 2004)

Map 16:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), pans and dams (Rural Focus), surface drainage (KSS, KENSOTER Database).

Map 17:
Sources: Administrative boundaries (CBS 2003, KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), wells and springs (Rural Focus), Merti aquifer (Gibb Ltd. 2004)

Map 18:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), rivers derived from SRTM DEM 90m resolution, water sources (Rural Focus), agro-climatic zones (KSS, Sombroek et al. 1982).

Map 19:
Sources: Administrative boundaries (KNBS 2010), catchment and subcatchment boundaries and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), 1962 population density (Ministry of Finance and Economic Planning 1964), 1979 population density (CBS 1981), 1989 population density (CBS 1994), 1999 population density (CBS 2002), 2009 population density (KNBS 2010). We generated the statistics through spatial allocation of population within the sub-catchments.

Map 20:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, roads and towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), agro-climatic zones (KSS, Sombroek et al. 1982), estimates of forage biomass production (GTZ Range Management Hand Book of Kenya, Volume II, 1, 1991, Nairobi).

Map 21:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), parks and reserves (IUCN and UNEP/WCMC 2006), conservancies (NRT) and wildlife population (DRSRS Aerial censuses).

Map 22:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), parks and reserves (IUCN and UNEP/WCMC 2006), livestock population(DRSRS Aerial censuses).

Map 23:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), water resources (Rural Focus) and livestock movements (FAO 2009).

Map 24:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), rivers derived from SRTM DEM 90m resolution, water bodies (FAO 2000), parks and reserves (IUCN and UNEP/WCMC 2006), conservancies (NRT), elephant population (DRSRS Aerial censuses), elephant movement (Save the Elephant, KWS), landcover (FAO 2000).

Map 25:
Sources: Administrative boundaries (KNBS 2010), catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), parks and reserves (IUCN, UNEP/WCMC 2006 and KWS), conservancies (NRT), livestock asset (DRSRS Aerial censuses) , crop yields and area (Ministry of Agriculture), prices (Market Research and Information department at the Ministry of Agriculture, Kenya), tourism conservancies (Northern Rangelands Trust (http://nrt-kenya.org), visitors to Northern Kenya (Ministry of tourism, Kenya), livestock (KIPPRA, Muthee 2006, Rakotoarisoa et al. 2008)

Map 26:
Sources: Catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), agro-climatic zones (KSS, Sombroek et al. 1982), rainfall and temperature changes (Jones et al, http://futureclim.info).

Map 27:
Sources: Catchment boundary and DEM generated from ASTER DEM 30m resolution, towns (SoK topographic maps scale 1:50,000), water bodies (FAO 2000), agro-climatic zones (KSS, Sombroek et al. 1982), aridity and potential maize yield (Jones et al, http://futureclim.info).