IWMI Working Paper 165

Baseline Review and Ecosystem Services Assessment of the Tana River Basin, Kenya

Tracy Baker, Jeremiah Kiptala, Lydia Olaka, Naomi Oates, Asghar Hussain and Matthew McCartney

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Tracy Baker, Jeremiah Kiptala, Lydia Olaka, Naomi Oates, Asghar Hussain and Matthew McCartney

International Water Management Institute

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Project

This work was undertaken as part of the Water Infrastructure Solutions from Ecosystem Services Underpinning Climate Resilient Policies and Programmes (WISE-UP to Climate) project. The project is generating knowledge on how to implement mixed portfolios of built water infrastructure (e.g., dams, levees, irrigation channels) and 'natural infrastructure' (e.g., wetlands, floodplains, forests) that contribute to poverty reduction; water, energy and food security; biodiversity conservation; and climate resilience at a landscape scale. 'WISE-UP to Climate' aims to demonstrate the application of optimal portfolios of built and natural infrastructure developed through dialogue with stakeholders and decision-makers at multiple levels (local to national) to identify and find consensus on trade-offs. The project also seeks to link ecosystem services to water infrastructural development in the Volta River Basin (Ghana, principally, and also Burkina Faso) as well as the Tana River Basin in Kenya.

The project is led by the International Union for Conservation of Nature (IUCN) and involves the Council for Scientific and Industrial Research - Water Research Institute (CSIR-WRI); African Collaborative Centre for Earth System Science (ACCESS), University of Nairobi; International Water Management Institute (IWMI); Overseas Development Institute (ODI); University of Manchester; and the Basque Centre for Climate Change (BC3). This project is part of the International Climate Initiative. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety), Germany, support this initiative on the basis of a decision adopted by the German Bundestag.

For further details about the project, visit: www.waterandnature.org or www.iucn.org/water_wiseup

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Acronyms

ACCESS	African Collaborative Centre for Earth System Science
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CIESIN	Center for International Earth Science Information Network
DEM	Digital Elevation Model
DHS	Demographic and Health Surveys
ENSO	El Niño / Southern Oscillation
ES	Ecosystem Service
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning Systems Network
GEF	Global Environment Facility
GRW	Gridded Population of the World
ICDP	Integrated Conservation and Development Project
IFAD	International Fund for Agricultural Development
IIASA	International Institute for Applied Systems Analysis
IPP	Independent Power Producers
ISRIC	International Soil Reference and Information Centre (ISRIC – World Soil Information)
ISS-CAS	Institute of Soil Science, Chinese Academy of Sciences
ITCZ	Inter-tropical Convergence Zone
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
JICA	Japan International Cooperation Agency
JRC	Joint Research Centre of the European Commission
KenGen	Kenya Electricity Generating Company
KES	Kenyan Shilling
KNBS	Kenya National Bureau of Statistics
KPLC	Kenya Power and Lighting Company
KWS	Kenya Wildlife Services
MA	Millennium Ecosystem Assessment
MEMR	Ministry of Environment and Mineral Resources
NAAIAP	National Accelerated Agricultural Inputs Access Programme
NCCRS	National Climate Change Response Strategy
NEMA	National Environment Management Authority
NGO	Nongovernmental Organization

NIB	National Irrigation Board
NWCPC	National Water Conservation and Pipeline Corporation
NWMP	National Water Master Plan
ODI	Overseas Development Institute
SEDAC	Socioeconomic Data and Applications Center
SOTER	Soil and Terrain Database
SRTM	Shuttle Radar Topography Mission
TARDA	Tana & Athi Rivers Development Authority
TRDA	Tana River Development Authority
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
WISE	World Inventory of Soil Emission Potentials
WRI	World Resources Institute
WRMA	Water Resource Management Authority
WRUA	Water Resource Users Association

Summary

Ecosystem services are commonly defined as the benefits received by humanity via functioning ecosystems. They can be broadly categorized as provisioning, regulating, cultural, and habitat services; with many services co-occurring and most ecosystems providing a wide range of services across several categories. Water mediates many ecosystem services and is in turn heavily influenced by land management decisions made at different scales from local to basin. Taking a holistic ecosystem services approach that focuses on maintaining healthy ecosystems as primary mechanisms for ensuring sustainable services delivery has been slowly mainstreamed into land management decision making worldwide. In addition, it is now often an important guiding principle in research for development programs.

In many water-rich basins found in less developed countries, efforts are under way to increase energy resources via hydropower production as well as expand irrigation potential to increase food security. However, climate change threatens to undermine these goals – meant to spur development and alleviate poverty – by imposing risks and requiring decision makers to act under significant levels of uncertainty.

Within Kenya, the Tana River Basin serves as an example where there are significant development targets for hydropower, domestic water provision, and irrigation; planned as part of Kenya's 2030 Vision. Currently, the basin supplies Nairobi with hydropower and nearly all of its domestic water resources through a series of water transfers and dams in the Upper Tana Basin. Historically, authorities have struggled to develop sustainable large-scale irrigation projects in the middle and lower basin, while the upper basin continues to be one of the most agriculturally productive regions within the country. Both hydropower production and irrigation expansion have been plagued by controversy with historical efforts leading to relocations and increased conflict. At present, the country is working to balance its need for water, energy, and food security with the preservation of ecosystems and ensuring the sustainability of the services they provide.

The basin is home to two major biodiversity hot spots. At its headwaters, the Kenyan government actively manages the Afromontane forests of the Aberdare Mountain Range, which serves as one of Kenya's five main water towers by ensuring water quantity and quality of the waters supplied to downstream users. At the terminus of the Tana River, lies its rich delta providing numerous livelihood opportunities as well as supporting several endemic and endangered plant and animal species. There are critical concerns regarding how hydropower and irrigation development may affect this rich delta. In addition, alarms have been raised regarding how upstream land management practices may have deleterious effects on current and planned built infrastructure (e.g., hydropower and large-scale irrigation) in the basin.

Under the WISE-UP to Climate project, natural infrastructure is explored as a 'nature-based solution' for climate change adaptation and sustainable development. The project is developing knowledge on how to use portfolios of built water infrastructure (e.g., dams, levees, and irrigation channels) and natural infrastructure (e.g., wetlands, floodplains, and watersheds) in tandem for poverty reduction, water-energy-food security, biodiversity conservation, and climate resilience. This paper presents a basin-scale summary of natural resources within the Tana River Basin and illustrates an overview of how people living within the basin rely on a wide variety of ecosystem services. In addition, the paper puts forth a first approximation of the key role natural infrastructure plays in supporting efforts to ensure water-energy-food security in the Tana River Basin.

INTRODUCTION

The WISE-UP to Climate project within Kenya focuses on identifying optimal configurations of natural and built infrastructure on landscapes in the Tana River Basin (Figure 1). It is, however, important to first define a common set of terminology used in discussions surrounding natural and built infrastructure and the continuum these terms form. Overall, the concept of differentiating among types of infrastructure is rooted in the idea that while humankind may alter natural ecosystems to support their needs and livelihoods, the good health and condition of ecosystems in general is required to sustainably produce the basic services humanity requires for survival (Costanza 1992; Costanza and Daly 1992; Daily 1997). In the 1990s, the United States Environmental Protection Agency began integrating the concept of 'green infrastructure' to guide land use planning and storm water management and soon the concept was promoted as one of the five key strategic areas of sustainable community development (Spitzer 1999). Since this time, the terminology has become widespread worldwide as it evolved, and was expanded to further define and differentiate among different types of infrastructure and the multitude of critical roles they play in sustainable ecosystems (Table 1). Within this review, the focus is on natural and built infrastructure with some discussion surrounding green or semi-natural infrastructure when applicable.

The Overseas Development Institute (ODI) reported that green or natural infrastructure is underutilized in 'fragile states', such as Kenya[1] (Lemma 2012). Key reported messages were that green infrastructure investments, particularly related to climate change mitigation, are often discounted in planning or limited to environmental impact assessments even though such investments may result in many positive co-benefits such as poverty reduction and increased energy security. While the author notes that in some instances poor governance and limited institutional capacity within fragile states is a factor in why green infrastructure receives a low priority, it is also the case that the percentage of international financing available to these states for such undertakings is low. Therefore, while green infrastructure can be a key to poverty reduction and climate change adaptation, it is often absent from the development paradigm.

Concurrent with the mainstream implementation of different types of infrastructure solutions for sustainable land use planning and development, the concept of ecosystem services (Table 2) also began to take root when Daily (1997) edited the work 'Nature's services: Societal dependence on natural ecosystems' and Costanza et al. (1997) put forth "The value of the world's ecosystem services and natural capital" in the journal 'Nature'. Many ecosystem services provided by different types of natural or green infrastructure also produce co-benefits across other services as well as compliment or enhance other types of infrastructure (Tables 2 and 3). For example, many of the grey or built infrastructure have life cycles that can be enhanced by natural or green infrastructure.

As part of the initial project implementation there is a paramount need to identify, describe, and develop a baseline of the biophysical characteristics and ecosystem services within the Tana River Basin. This document provides an overview of natural and water resources as well as linkages to livelihoods within the basin. Understanding the variety and distribution of natural and built infrastructure within the basin plays a critical role in developing a picture of ecosystem services provided by this infrastructure and the appropriate land management and water use strategies to preserve and enhance it.

[1] Fragile states here are defined as "countries where the government cannot or will not deliver core functions to the majority of its people" (DFID 2013) or countries that 'lack political will and/or capacity' to provide the basic functions needed for poverty reduction, development and to safeguard the security and human rights of their population. Kenya is included in the paper's listing of fragile states.

FIGURE 1. Natural infrastructure represents the services that ecosystems provide, which are similar to those provided by built or conventional infrastructure approaches.

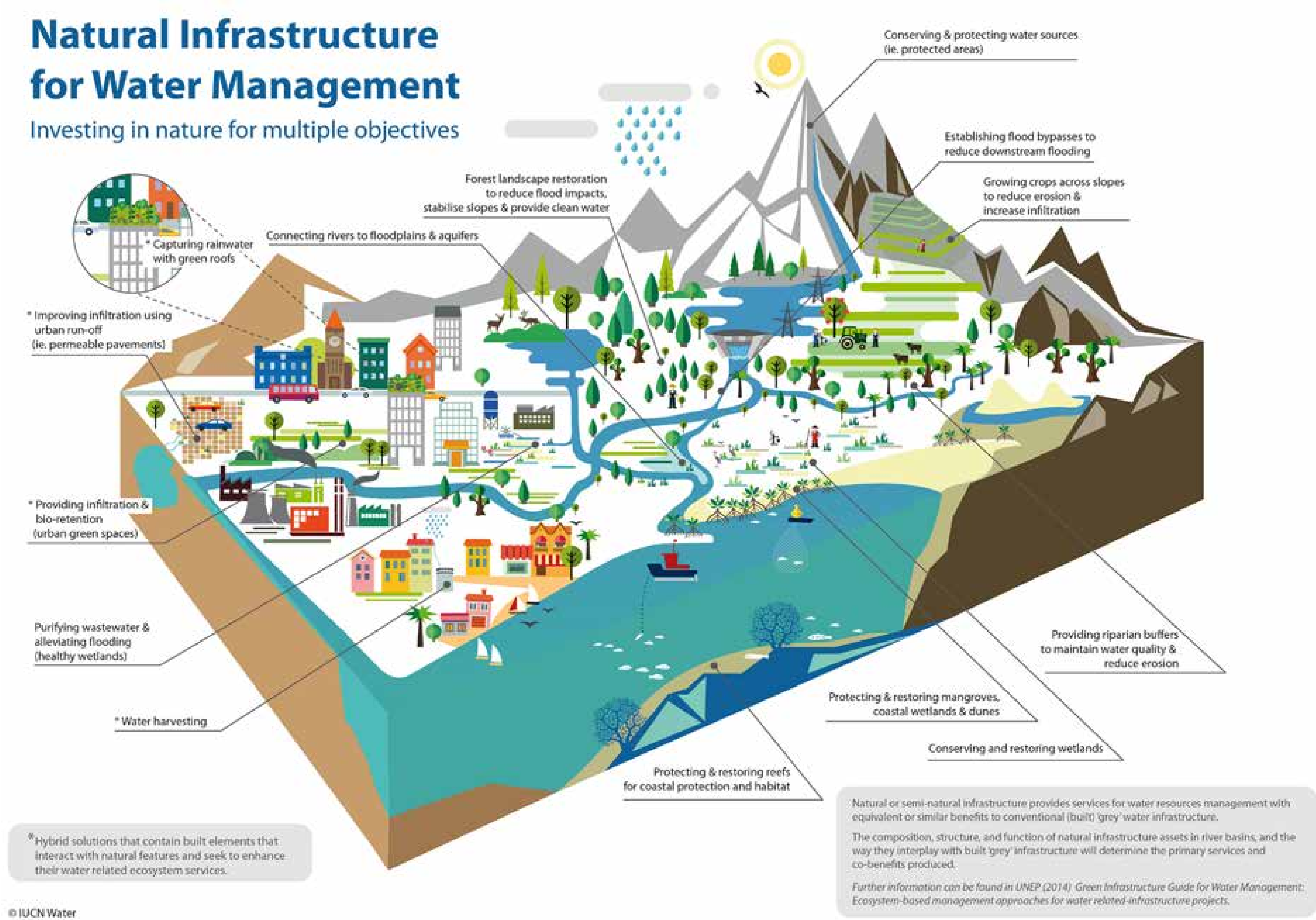

TABLE 1. Types of landscape infrastructure and their benefits to ecosystems.

Type	Definition	Examples
Natural	"[I]nterconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife" (Benedict and McMahon 2002).[1]	Natural forests, floodplains, wetlands, riparian zones, aquifers
Green Semi-natural	Managed or semi-natural land use planning efforts to restore or mimic the natural water cycle using vegetation, soils, and natural processes.	Plantation or managed forests, rain gardens, constructed ponds and wetlands, green spaces, and
Built (Grey)	Engineered water management systems that store, treat, or deliver water.	dams, culverts, irrigation structures, piped drainage systems, levees, water and sewerage treatment, and inter-basin transfer schemes
Blue	Retrofitting existing built infrastructure with high efficiency devices.	improved irrigation, low impact development

Note: [1] While Benedict and McMahon (2002) define green infrastructure as encompassing both unaltered and modified or engineered landscapes, we distinguish here between natural and green infrastructure to bring attention to differences in their biophysical response, in particular for hydrological modeling purposes, while recognizing that the terms are used interchangeably in most contexts. Green infrastructure we define as focusing on restoration and landscape planning efforts with natural infrastructure referring to the conservation and preservation of existing natural, relatively unaltered, landscapes and features. The reasoning here is that depending on the degree of alteration, restoration efforts through the introduction of green infrastructure may not result in a return to an historical ecological of hydrological function of interest. Rather, many ecological restoration efforts fail because many projects are rooted or find themselves trapped in what Hilderbrand et al. (2005) refer to as myths of ecological restoration.

TABLE 2. Ecosystem services categorizations and their evolution since the Millennium Ecosystem Assessment (2005).

MA (2005)	TEEB (2010)	WLE (2014)
Provisioning		
• Food • Fiber • Fuel • Fresh water • Genetic resources • Biochemicals, natural medicines and pharmaceuticals	• Food • Raw materials (timber, fiber, fuel) • Freshwater • Medicinal resources	• Food • Irrigation water • Timber, fuelwood • Medicinal resources • Ornamental resources
Regulating		
• Air quality regulation • Climate regulation • Water regulation • Erosion regulation • Water purification and waste treatment • Disease regulation • Pest regulation • Pollination • Natural hazard regulation	• Local climate and air quality • Carbon sequestration and storage • Moderation of extreme events • Wastewater treatment • Erosion prevention and maintenance of soil • Fertility • Pollination • Biological control	• Air quality regulation • Carbon sequestration • Climate regulation • Extreme event moderation • Water flow regulation • Waste treatment • Erosion prevention • Soil fertility • Pollination

(Continued)

TABLE 2. Ecosystem services categorizations and their evolution since the Millennium Ecosystem Assessment (2005) (continued).

MA (2005)	TEEB (2010)	WLE (2014)
Cultural		
• Cultural diversity • Spiritual and religious values • Knowledge systems • Educational values • Inspiration • Aesthetic values • Social relations • Sense of place • Cultural heritage values • Recreation and ecotourism	• Recreation and mental and physical health • Tourism • Aesthetic appreciation and inspiraton for culture, art and design • Spiritual experience and sense of place	• Aesthetic information • Recreation and tourism opportunities • Inspiration • Spiritual experience • Mental health
Supporting	**Habitat**	**Habitat**
• Soil formation • Primary production • Nutrient cycling • Water cycling	• Habitat for species • Maintenance of genetic diversity	• Maintenance of species life cycles through habitat provision • Genetic diversity

TABLE 3. Examples of water-related ecosystem services and their connection to potential infrastructure solutions based on the TEEB (2010) and WLE (2014) classification systems.

Ecosystem Services	Specific water related service or issue	Natural and Green Infrastructure Solutions	Built Infrastructure Solutions
Provisioning	Domestic water supply Energy	• Reforestation • Forest preservation	• Rainwater harvesting • Water treatment facility • Hydropower dams
Regulating	Flooding Erosion Environmental flows	• Riparian buffer strips • Reforestation • Wetlands conservation or restoration • Floodplain conservation	• Rainwater harvesting • Levees • Compensation release from dams
Cultural	Recreation Aesthetic value Tourism	• Wetlands conservation or restoration • Green spaces	• Reservoirs • Artistic water features
Habitat	Species lifecycle Genetic diversity	• Wetlands conservation or restoration • Riparian forest preservation • Floodplain conservation	• Compensation release from dams • Sewerage treatment facility

This document is divided into the following sections:

- Part I: Review Background
- Part II: Basin Context
- Part III: Physical Geography
- Part IV: Basin Hydrology
- Part V: Ecosystem Services
- Part VI: Management Challenges in the Tana River Basin

PART I: REVIEW BACKGROUND

Assessment Scope

The geographical scope of this assessment is restricted to the Tana River Basin. The technical scope of this assessment focuses on several broad themes: physical geography, water resources, and ecosystem services. Within each theme, several topics are considered in detail where data are available.

Methodology

Desk Study

To address the constraints inherent when working in large basins and with recent significant security threats, an initial desk study was carried out. Findings from the desk study are intended to supplement and support future field assessments, and should be expanded as additional field data are collected during the lifetime of the project. While every effort was made to ensure the veracity of data and statistics presented in this assessment, recent changes in government institutions and varied historical mechanisms for managing biophysical data means that there may be gaps or inconsistencies among agencies in record keeping.

Remote Sensing

Remotely sensed data were used to explore landscape features, such as seasonally inundated areas and wetlands, reservoirs and irrigation structures. We relied principally on SRTM 90m DEM, SRTM 30m DEM, and Google Earth to identify features and verify information acquired from secondary resources when possible.

Spatial Analysis

GIS data were collected from a variety of sources and some were subset from global data sets. New data were digitized from remotely sensed imagery and Google Earth when needed. In some cases, such as in the initial macro level assessment of ecosystem services, spatial analysis methods were employed to generate new information from these data.

PART II: BASIN CONTEXT

The Tana River is Kenya's longest river at approximately 800–900 km and with a roughly 95,000 km^2 contributing source area[2] (Figure 2). Size for the Tana River Basin is widely reported in the scientific literature as well as government and international agency reports as being between 100,000–126,000 km^2; however, in many such instances authors are including the area – or some part thereof – between the Tana River Basin and the Ewaso Ng'iro Basin (contained within the greater Shebelli–Juba Basin). It should be noted that this region is not hydrologically connected to either basin; nonetheless, it is part of the basin management area (Figure 3). Ultimately then, the Tana River discharge is often incorrectly related to a larger area. This is important because accurately knowing the catchment area is a pre-requisite for water resource planning, flood prediction and planning, and understanding sediment discharge (Mosley and McKercher 1993; Dunne and Leopold 1978).

Located wholly within Kenya, the Tana River Basin is bordered by the Ewaso Ng'iro, Rift Valley, and Athi basins to the north, west, and south, respectively. Its headwaters are on Mount Kenya and the Aberdare (or Nyandarua) Range, considered one of Kenya's five 'water towers'[3] (Akotsi et al. 2006). The Tana River winds through a densely forested ecosystem before giving way to agricultural areas and rangelands, ultimately terminating in a large delta at Ungwana Bay in the Indian Ocean. Among perennial rivers in eastern Kenya, only the Tana and the Athi–Galana–Sabaki river systems reach the Indian Ocean year round (FAO 1968).

The Tana River Basin can be considered to have three distinct ecosystems that have influenced its people and development: upland forested regions with high relief and higher rainfall and the drier, flatter middle basin leading into the lower catchment and Tana Delta. The Tana River's delta is considered one of three major floodplains along the East African Coast, with the other being the Rufiji (in Tanzania) and Athi-Sabaki (Pacini et al. 2008).

Historical Background of Development in the Basin

As with many basins where development has been accompanied by the creation of basin authorities, dams, and subsequently irrigation schemes or other similar investments (either national or foreign), many questions arise regarding issues such as labor and resettlement (Cook 1994; Roggeri 1985). Development within the Tana River Basin has been no different in this regard.

It seems that water resource development, including irrigation and hydropower, as elsewhere on the African continent, has taken place on an ad hoc project-by-project basis, largely independent of one another; as though the projects are disconnected both in terms of the greater landscape and hydrologically. Under the African Land Development Programme in the 1950s, several government irrigation schemes were established within the Tana Basin, for example at Hola (1953) and Mwea (1956). These schemes were developed using the labor of Mau Mau detainees (Adams 1992; Migot-Adholla and Ruigu 1989). Later the Bura Irrigation Scheme was created in the lower Tana Basin (1977), only a few years after the establishment of the Tana River Development Authority (TRDA), now TARDA (Tana and Athi Rivers Development Authority). These large irrigation projects were undertaken and operated as independent projects with no overarching authority until TRDA's establishment (Adams 1992).

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[2] Area calculated using a hydrologically correct SRTM 90 m digital elevation model, v4.1 (Jarvis et al. 2008).

[3] Kenya's Five Water Towers are Mount Kenya, the Aberdare Range, the Cherangani Hills, the Mau Forest Complex, and the Mount Elgon forests.

FIGURE 2. Tana River Basin location within Kenya.

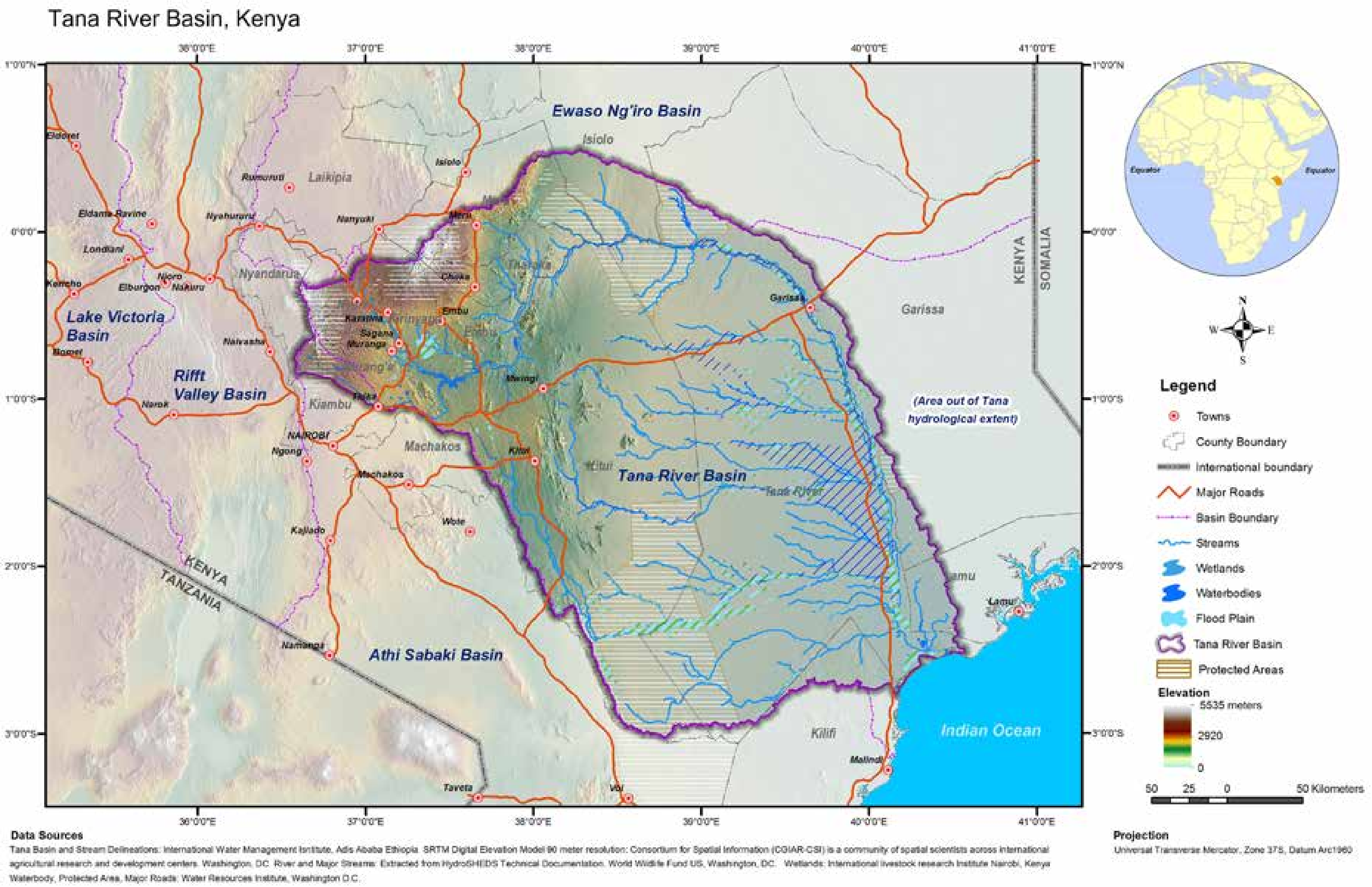


FIGURE 3. Coastal areas between the Shebelli – Juba Basin and the Tana River Basin are hydrologically independent from the two basins[4].

Resettlement and displacement issues have been controversial in the Tana River Basin. For example, in building the Kiambere Dam (1983–1988) it is estimated that around 7,000 people were displaced or resettled, although original estimates were that only around 1,000 would be affected (Horta 1994; World Bank 1993). This was particularly controversial because Kenya's two largest dams, Masinga (1978–1981) and Kamburu (1971–1975) only saw the displacement of 1,000 families in total and a maximum estimate of 4,000–7,000 individuals (Cook 1994). This is primarily because at the time, the upper basin was more sparsely populated (Roggeri 1985). Surveys carried out later reported that families resettled for the Kiambere Dam had only moved on average 14 km from their previous homes, but even so faced numerous challenges in acquiring land and having access to adequate natural resources, such as water and grazing lands, because they were outsiders in their new communities (Cook 1994).

With regard to recent irrigation schemes, the Bura Irrigation Project downstream from the Kiambere Dam has been particularly controversial. As part of this project, 35,000 ha of maize and cotton were to be irrigated; however, only about 6,000 ha came to fruition. Approximately 20,000 farmers were resettled to the area around the scheme in the early 1980s, and they soon became dependent on food aid until the area was finally abandoned (Christensen et al. 2012; Horta 1994). Rehabilitation of the scheme is currently under way, but it is too early to know how successful this will be.

More recently (1990s) and further down in the Tana River Basin, the development of the Tana Irrigation Scheme for rice production has severely impacted local Orma and Boran pastoral communities, and is considered by some to be driving much of the current agro-pastoral violence in the lower Tana River Basin (Jones 2013). The severity of the issue and conflict over natural resource has been widely reported in local and worldwide media outlets (Astariko 2014a, 2014b; Barisa 2014; Gettleman 2013; Jones 2013; Chonghaile 2012; The Economist 2012; BBC 2012; McVeigh 2011; Rice 2008). Between 2012 and 2013, violence intensified between the Orma and Pokomo people leaving more than 50 dead (Nyassy 2013; Los Angeles Times 2012). The Pokomo people are traditionally famers who are settled along the Tana River (Duvail et al. 2012) and with whom the Orma are now competing for water and land resources.

[4] Some of these areas are often grouped into the Tana Basin area calculations in the historical literature, which they should not be. This section is, however, within what is considered the Tana Basin management area.

Resettlement for many pastoralists has in effect meant 'settlement' and the giving up of their traditional nomadic livelihood or being forced into areas where there are agricultural communities vying for the same scarce water resources and where grazing their livestock often results in conflict with agriculturalists (Bennett and McDowell 2012). In addition, the settlement of pastoral peoples from the delta further up into the basin, where there are no flood recession grazing areas, is resulting in increased grazing pressure on landscapes ill-suited for such activities.

Demographics

Fifteen counties cross into the Tana River Basin to some extent with several found wholly within the basin (Table 4). Although some counties, such as Embu, fall entirely within the basin, they comprise a small portion of the overall basin. Within Kenya, the Upper Tana Basin and the Lake Victoria basins are major population growth hotspots (Table 5). An important difference between the two from a water resources perspective is that within the Tana River Basin, growth has occurred in the forested headwaters region around Mount Kenya where there has been roughly a 60% increase in human settlement since 1969 (Table 6). This growing population in the upper Tana River Basin (Figure 4) is leading to potentially increased land degradation, as land shortages result in smaller plot sizes and more intensive agricultural practices (Tanui 2006). Based on estimated and predicted gridded population densities since 1990, population within the basin boundary has risen 27% overall, from 4.9 million to more than 6.5 million people in 2010 (CIESIN-FAO-CIAT 2005; Balk and Yetman 2004). These data represent disaggregated human population information that allow for a more realistic spatial representation of potential human population within natural boundaries – such as a basin in this case – as opposed to assuming an even distribution of human population within arbitrary political boundaries such as those used for census (Deichmann et al. 2001).

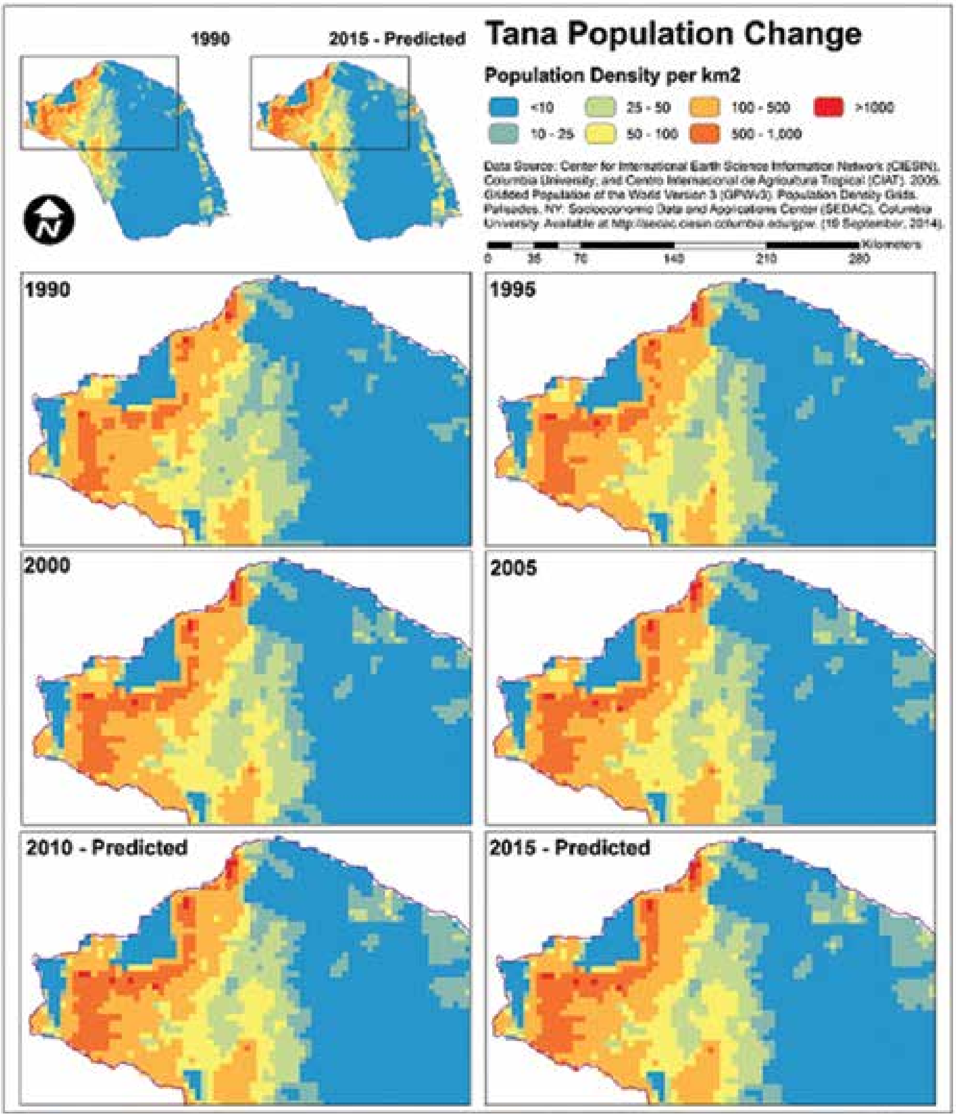
Forested headwater regions of catchments are critical natural infrastructure features insofar as they control the amount and timing of flows within a catchment (Bonell 1993). Furthering the challenges posed by a loss of this natural infrastructure within the headwaters is that there are increased water abstractions and land use changes associated with agricultural production that contribute to erosion and sedimentation. Pastoralists dominate areas between the Masinga Dam and the Tana Delta, and little change has occurred in population density.

TABLE 4. Current counties, as of 2010, intersecting or falling wholly within the Tana River Basin boundary.

County	Area within Basin (km^2)	% of Total Basin	% of Total County Area	County	Area within basin (km^2)	% of Total Basin	% of Total County Area
Embu	2,824	3	100	Lamu	1,528	2	25
Garissa	4,382	5	10	Machakos	2,072	2	33
Isiolo	2,725	3	11	Meru	3,643	4	53
Kiambu	51	0.1	2	Murang'a	2,005	2	79
Kilifi	2,028	2	16	Nyeri	2,419	3	73
Kirinyaga	1,474	2	100	Tana River	37,484	40	99
Kitui	29,179	31	96	Tharaka	2,667	3	100
Laikipia	246	0.3	3				

Source: KNBS 2009.

FIGURE 4. Population growth areas within Kenya are most prominent along the shores of Lake Victoria and within the upper reaches of the Tana River Basin.



Source: CIESIN-FAO-CIAT 2005.

The Japan International Cooperation Agency (JICA), as part of a study carried out during the development of the National Water Master Plan 2030 (Ministry of Environment, Water and Natural Resources 2013), projects that population within the basin will reach 8.4 million by 2030. Of these, at least 4.7 million people across urban and rural areas are proposed to have access to improved piped water systems by 2030.

For counties where 95% or more of the area is located within the Tana River Basin, 41% of households use streams as their primary water source, with 24% of households using springs, wells, or boreholes as well as another 24% using piped water (not into their home) as a primary water source (KNBS 2009; Table 7). On the other hand, as reported by Moselleo et al. (Forthcoming), Nairobi receives as much as 80% of its domestic water supply from within the Tana Basin via transfers from Thika (also known as Ndakaini) Dam.

Within the basin, at least 3% of the population still relies on wood for its primary source of cooking fuel and light, with only 11% of the population using electricity.

TABLE 5. 2009 Census population by district. In 2010, Kenya reorganized administrative boundaries, combining several districts. This resulted in 69 districts being reduced to 47 counties.

District	2009 Population	Current County	District	2009 Population	Current County
Embu	296,922	Embu	Mbeere	219,220	Embu
Garissa	190,062	Garissa	Meru Central[1]	141,768	Meru
Isiolo	100,176	Isiolo	Meru South	128,107	Tharaka
Kiambu	384,883	Kiambu	Murang'a[2]	778,984	Murang'a
Kirinyaga	528,054	Kirinyaga	Mwingi	244,981	Kitui
Kitui	447,613	Kitui	Nyeri	693,558	Nyeri
Laikipia	399,227	Laikipia	Tana River	143,411	Tana River
Lamu	101,539	Lamu	Tharaka	130,098	Tharaka
Machakos	442,930	Machakos	Thika	295,617	Split: Kiambu and Murang'a
Malindi	400,514	Kilifi			

Source: KNBS 2009.
Notes: [1] Meru Central includes the formerly Meru North District. Meru North was not counted as a separate census in 2009.
[2] Previously included Murang'a District as well; however, during the 2009 census the data were all included in Murang'a. In addition, this county now includes part of the former Thika District.

TABLE 6. Population estimates in the Mount Kenya regions have shown a rapid increase in human habitation.

District	Area (km^2)	1969	1979	1988	1998	2009
Meru*	9,922	596,506	830,179	1,214,950	1,409,373	1,356,301
Nyeri	3,284	360,845	486,417	695,901	661,156	693,558
Laikipia	9,723	66,506	134,524	229,126	322,187	399,227
Embu*	2,714	178,912	263,173	394,820	449,149	516,212
Kirinyaga	1,437	216,988	291,431	416,140	457,105	528,054
Total	27,080	1,419,757	2,005,724	2,950,937	3,298,970	3,493,352

Source: Modified from Tanui 2006 to include information from the KNBS 2009.

The vast majority of people rely on lanterns and tin lamps as primary light sources (KNBS 2009; Table 8).

When considering earning potential and opportunity, educational level is critical. Within the Tana River Basin, anywhere from 11–64% of people from counties with greater than 95% of their area in the basin have only up to pre-primary of basic literacy (KNBS 2009; Table 9). In the Tana River District, which lies almost wholly within the basin and encompasses 40% of the basin area (Table 4), 45% of men and 57% of women have no education. Women are disproportionately impacted through this lack of education coupled with social and traditional societal rules and, therefore, less likely to have access to higher earning potential. According to the Kenya Integrated Household Budget Survey (carried out in 2005–2006), a high proportion of people living in counties within the basin live below the overall poverty line (KES 1,562 [USD 17] for rural households and KES 2,913 [USD 32] for urban households; Table 10; KNBS 2007).

TABLE 7. Main water source per household by district during 2009. Bold districts are entirely within the basin.

District	Pond/Dam	Lake	Stream	Spring/Well/Borehole	Piped into dwelling	Piped	Jabia/Rain/Harvested	Water Vendor	Other
EMBU	377	18	22,153	12,798	10,888	32,386	323	1,122	73
GARISSA	574	94	5,416	4,838	2,447	16,993	81	1,329	346
ISIOLO	40	3	2,098	7,179	1,887	10,153	24	999	80
KIAMBU EAST	1,109	63	5,825	37,751	7,805	15,890	502	6,358	39
KIAMBU WEST	212	18	1,206	6,289	4,628	15,598	881	7,704	6
KIRINYAGA	318	28	63,242	24,356	10,975	51,515	756	2,951	79
KITUI	3,294	149	48,012	36,512	899	3,678	196	2,024	16
LAIKIPIA	7,847	40	26,873	32,560	8,753	21,809	1,580	3,604	48
LAMU	1,396	146	532	11,402	1,732	5,030	1,652	265	29
MACHAKOS	5,720	37	9,126	53,256	7,836	18,987	1,081	21,797	33
MALINDI	4,978	286	5,762	12,154	8,663	34,360	1,224	5,750	153
MBEERE	4,285	81	18,669	19,329	922	4,902	284	3,000	73
MERU CENTRAL	132	-	7,680	2,885	2,929	20,700	109	2,710	64
MERU SOUTH	199	4	16,124	7,867	1,831	6,952	36	236	10
MURANG'A NORTH	155	52	48,914	13,781	6,032	22,681	5,366	671	49
MURANG'A SOUTH	1,378	38	54,655	36,773	3,220	13,050	2,503	2,934	27
MWINGI	2,536	50	18,296	18,069	1,003	6,907	312	3,781	13
NYERI NORTH	695	21	29,022	11,166	9,452	39,716	2,764	2,676	96
NYERI SOUTH	416	35	26,772	7,535	15,082	48,616	5,442	2,155	42
TANA RIVER	2,972	35	8,724	9,813	691	3,570	37	1,302	1,480
THARAKA	21	28	16,084	7,828	328	2,895	23	179	7
THIKA EAST	969	39	5,130	6,723	1,172	5,411	116	879	2
THIKA WEST	430	1	2,929	8,042	15,263	37,972	154	7,247	13
TOTAL	40,053	1,266	443,244	388,906	124,438	439,771	25,446	81,673	2,778
TOTAL FROM DISTRICTS WITHIN BASIN (>95%)	6,982	258	158,215	91,307	23,781	94,044	1,335	7,578	1,655
PERCENTAGE w/in TANA	2%	0%	41%	24%	6%	24%	0%	2%	0%

Source: KNBS 2009.

TABLE 8. Main fuel and light source per household by district during 2009.

District	Electricity	Pressure Lamp	Lantern	Tin Lamp	Gas Lamp	Fuelwood	Solar	Other
EMBU	17,057	699	26,819	32,305	455	425	2,179	199
GARISSA	10,956	121	5,558	7,182	3,784	2,745	68	1,704
ISIOLO	5,738	102	5,623	4,936	602	4,769	296	397
KIAMBU EAST	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
KIAMBU WEST	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
KIRINYAGA	25,353	1,028	51,589	69,116	1,005	413	5,349	367
KITUI	5,989	594	49,385	32,103	618	2,801	2,953	337
LAIKIPIA	18,222	542	36,366	35,413	740	5,276	6,127	428
LAMU	3,767	135	7,211	8,752	158	560	1,173	428
MACHAKOS	34,003	1,095	56,610	22,613	428	168	2,253	703
MALINDI	14,220	731	15,531	39,925	311	1,925	399	288
MBEERE	2,554	293	19,693	25,230	323	689	2,336	427
MERU CENTRAL	5,386	242	13,967	13,360	227	332	3,615	80
MERU SOUTH	3,829	136	12,032	14,344	222	737	1,765	194
MURANG'A NORTH	15,574	437	37,904	40,292	549	259	2,518	168
MURANG'A SOUTH	12,508	713	42,813	55,207	530	244	2,390	173
MWINGI	3,271	257	28,974	13,662	344	2,091	1,949	419
NYERI NORTH	19,954	855	36,954	30,340	557	714	6,011	223
NYERI SOUTH	33,132	786	32,563	35,965	481	290	2,615	263
TANA RIVER	778	51	6,443	17,443	539	2,109	257	1,004
THARAKA	826	93	3,801	18,194	154	1,652	2,307	366
THIKA EAST	2,853	181	8,491	8,254	104	44	440	74
THIKA WEST	40,462	712	19,165	10,568	130	71	384	559
TOTAL	276,432	9,803	517,492	535,204	12,261	28,314	47,384	8,801
TOTAL FROM DISTRICTS WITHIN BASIN (>95%)	24,650	1,437	86,448	100,045	1,766	6,987	7,696	1,906
PERCENTAGE w/in TANA	11%	1%	37%	43%	1%	3%	3%	1%

Source: KNBS 2009.

TABLE 9. 2009 educational statistics for districts with greater than 95% of their total area within the Tana River Basin.

	Gender	Never Attended	Pre-Primary	Primary	Secondary	Tertiary	University	Youth Polytechnic	Basic Literacy	Madrassa	Total	% less than Primary Education
KIRINYAGA	Male	15,450	11,300	144,858	57,408	7,927	3,021	1,143	606	69	241,782	11%
	Female	29,583	10,683	143,713	55,248	7,578	1,685	548	1,021	49	250,108	17%
TANA RIVER	Male	27,506	4,600	22,807	4,139	584	160	162	61	1,354	61,373	52%
	Female	36,294	4,104	19,486	2,112	329	38	27	120	815	63,325	64%
THARAKA	Male	8,442	3,359	36,290	5,921	1,248	365	744	54	2	56,425	21%
	Female	12,821	3,160	37,836	5,227	1,042	157	738	91	5	61,077	26%
EMBU	Male	11,557	4,726	79,344	30,183	5,740	2,325	897	265	21	135,058	12%
	Female	17,897	4,470	76,750	32,031	7,009	1,515	587	465	19	140,743	16%
KITUI	Male	24,994	13,193	119,574	26,275	4,522	1,561	2,454	387	36	192,996	20%
	Female	40,608	12,142	125,883	25,348	4,638	881	3,279	728	21	213,528	25%

Source: KNBS 2009.

TABLE 10. Percentage of people within a given county who live below the overall poverty line.

County	% Overall Poverty	County	% Overall Poverty	County	% Overall Poverty
Embu	41%	Kirinyaga	26%	Meru	28%
Garissa	55%	Kitui	63%	Murang’a	31%
Isolio	63%	Laikipia	48%	Nyeri	32%
Kiambu	25%	Lamu	31%	Tana River	75%
Kilifi	67%	Machakos	57%	Tharaka	37%

Source: KDHS 2007.

Prior to 2013, Kenya had an administrative system of provinces in place. These were reorganized into 47 counties under the new constitution. Three former provinces cross into the Tana River Basin: Central, Eastern, and Coast and correspond to the upper, middle and lower portions of the basin (Figure 5). While none of the provinces are contained wholly within the basin, basic household information characteristics collected under the USAID Demographic and Health Surveys Program (KDHS 2008) provide additional insights into reliance on natural resources within the basin and surrounding areas. For example, across the three provinces, firewood and straw are widely used for cooking in the home with as many as 61%, 41%, and 83% of households in the Central, Coast, and Eastern provinces doing so, respectively. In addition, across the three provinces, more than 40% of people surveyed identified agriculture as their primary occupation.

What these statistics indicate is a high reliance on the natural environment in people’s day-to-day lives, either through their employment or in meeting their daily basic needs. In addition, due to low education levels, few people are likely to have opportunities to engage in higher earning occupations. Finally, it is clear that at present the hydro-electric dams are benefiting those who live outside the basin in urban centers such as Nairobi, while those living within the basin receive few benefits in terms of electricity.

FIGURE 5. Former Kenya provinces and the Tana River Basin.

Source: KDHS 2008.

Tribes of the Tana River Basin

Within the Tana River Basin, tribal populations vary from upstream to downstream and among various agricultural and pastoral peoples. While the Kenya census statistics do not provide detailed information on tribal composition at the district level, numerous studies have documented dominant tribes within the basin. Several tribes are dispersed across zones, such as agricultural people who are found within the lower portion of the Upper Tana and upper portion of the Middle Tana, or pastoralists who seasonally migrate from the Tana Delta to further upstream areas within the lower portion of the Middle Tana.

In the area surrounding Mount Kenya and stretching down toward the Middle Tana, several agricultural tribes are found, principally the Kikuyu, Embu, and Kamba (also called, Wakamba) as well as Meru and Mbeere. Archeological and historical evidence suggests the various peoples are all closely related and that substantial intermarriage occurs among these groups. As a result, they all share many common customs (Mwakikagile 2007). Most importantly, the areas surrounding Mount Kenya, including the mountain itself, hold am important place culturally to the people of the region as 'the place of God, *Ngai*' (Emerton 1999).

Kikuyu make up the largest ethnic group in Kenya and Mount Kenya plays an important role in their cultural identity and customs, but the onset of the colonial era saw a breakdown of traditional land tenure systems giving way to a more commercial agricultural system that heavily increased pressure on the landscape (Kenyatta 1961). This has had long-term negative consequences for the Upper Tana in general, and has heavily influenced human settlement since independence. Nevertheless, while various aspects of foreign cultures can be seen in their current way of life, there is a strong commitment to traditional values and customs (Mwakikagile 2007).

The Embu people are related to the Kikuyu and have had strong historical ties, particularly with regard to achieving independence from British colonial rule (Mwakikagile 2007). Like the Kikuyu, the Embu are traditionally agriculturalists but also engage in apiculture (beekeeping) and honey production in the forests and highland areas of the Upper Tana (Tanui 2006).

Other tribes of the Upper Tana, such as the Kamba, Mbeere, and Tharaka are widely distributed though more commonly found in lowland areas and hills (Ngari 2013). While traditionally they are mixed agriculturalists and hunter-gatherers, Kamba people can be found in urban centers and towns throughout the basin (Irungu 2000). Ngari (2013) reports that these linguistically-related peoples migrated into the resource-rich and favorable climate of the Upper Tana from areas around Mount Kilimanjaro in Tanzania. Here, their populations increased and became more widespread throughout the basin under favorable environmental conditions, which as Ngari (2013) suggests, illustrates a clear strong and early linkage among people and the environment of the Upper Tana.

Further down in the Lower Tana, the Pokomo and Orma tribes are dominant, with the Pokomo being a sedentary agricultural people while the Orma are pastoralists. Pokomo communities traditionally farm within the Tana River floodplains and rarely use land more than 3 km from the floodplain area (Townsend 1978). Pokomo people also engage in other activities such as fishing, though less frequently.

Townsend (1978) argued that historically the Pokomo and Orma had what might be called a symbiotic relationship with one another and with the Tana River, whereby the Orma brought their cattle to water during the dry season at authorized points along the river that cross Pokomo farms. In these former times, there were no disputes as to who 'owned' the land adjacent to the river (Pokomo). This, however, changed drastically in recent years, as access to land and water resources has been restricted. While current violence among the Orma and Pokomo is often cited as an 'historical feud', anthropological evidence suggests otherwise and one ethnographer citing that "(n)owhere in this part of Africa were farmers and pastoralists ever united in any statelike political structure; the reasons for this… may be in large part ecological" (Townsend 1978). In other words, changes driven by natural resources availability and more recent political and population pressures have caused a change in this historical relationship rather than it being a long-standing feud as is often depicted in the popular press.

Similar to the Orma are the Wardei people. Ethnically, the Wardei are Orma people who were enslaved by Somalis during the nineteenth century, but in the 1930s they returned to the Tana River region where they are referred to as Wardei now rather than Orma. That said, they identify themselves as ethnically Orma. The distinction comes in that as part of their enslavement, these formerly Orma people adopted many aspects of Somali language and culture. It is important to note that all of the pastoralist tribes found within the Tana River region are descended from the Oromo people in Ethiopia (Irungu 2000).

Along the coastal region, the Mijikenda (also known as the 'Nine Tribes') are found. The term Mijikenda reflects the brief coming together in the early 1940s of nine separate but related tribes: Digo, Duruma, Giriama, Rabai, Ribe, Kambe, Jubana, Choni, and Kauma (Allen et al. 1983). While the 'union' of these nine tribes had nearly collapsed by the late 1940s, the union was not formally dissolved until 1980 (Willis and Gona 2013). By this time, nevertheless, the term was well integrated into common usage and now widely refers to a group of people in the coastal Kenya region who share a common identity. For example, the groups share common origin mythology known as Shungwaya, which asserts that their peoples all migrated from areas further north of the Tana River, possibly around the Juba-Shebelle River area (Morton 1977; Figure 3). In addition, while the individual groups have unique customs, they also share a common tradition: preservation of space known as *kaya*. *Kaya* (pl. *makaya*) are intact forest spaces, which represent formerly fortified villages that were deliberately preserved and now considered to be focal points for preserving important cultural traditions as well as biodiversity. In 2008, UNESCO declared 11 of these sacred forests to be World Heritage Sites, though none are located within the Tana River Basin (http://whc.unesco.org/en/list/1231/).

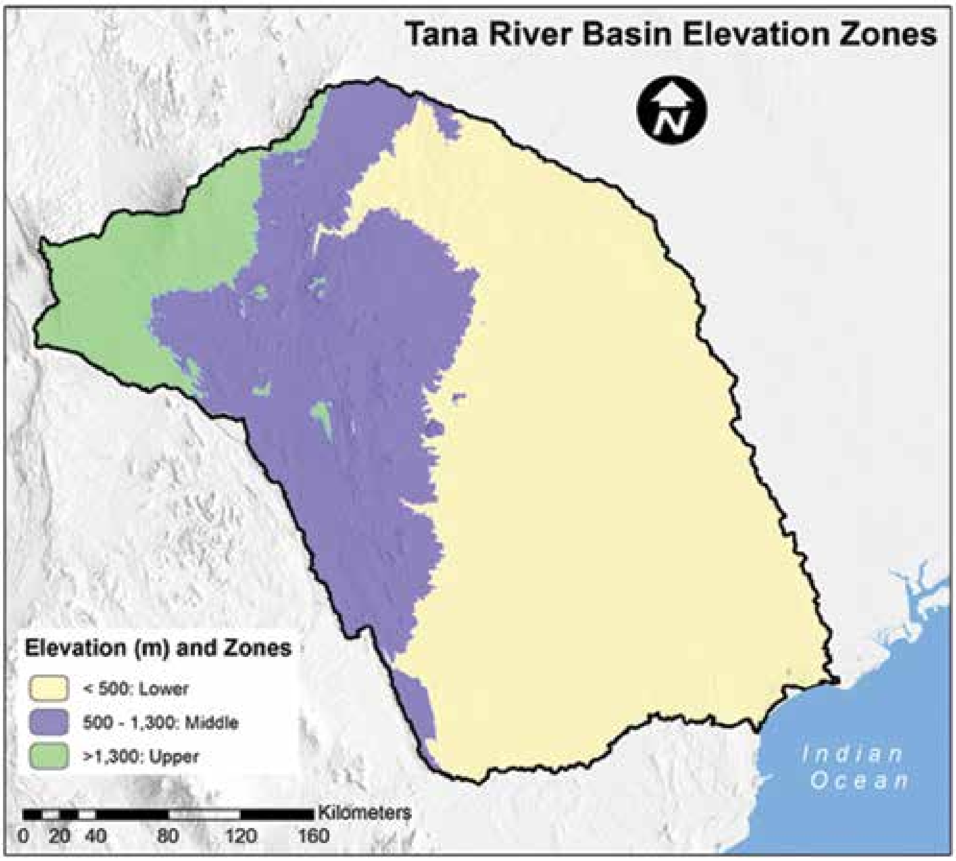
The rich history of the people in the Tana River Basin illustrates clear evidence of people's reliance on ecosystem services to flourish in the past. Today, however, the people in the basin are living at the nexus of development and increased pressure on land and water resources. This is exacerbated by increased population density, often caused by involuntary migration or relocation, as well as through migration into areas where irrigation schemes were planned, such as the Bura. This has led to an increase in tribal conflict within the basin, in general, and in the delta, in particular.

Land Cover and Use within the Tana River Basin

Within the Tana River Basin, livelihoods are clearly and inextricably linked to the natural environment in a co-evolving way such that people influence and are influenced by land cover. Principal land uses within the Tana River Basin can be subdivided along elevational (Figure 6) and precipitation zones (Table 11), and these in turn play a significant role in defining livelihood zones (Figure 7). A broad land cover assessment within the upper basin indicates that it is dominated by agriculture with some forested (natural and plantation) regions, and that bushland covers the mid to lower basin comprising more than 60% of the overall land cover (Figure 8).

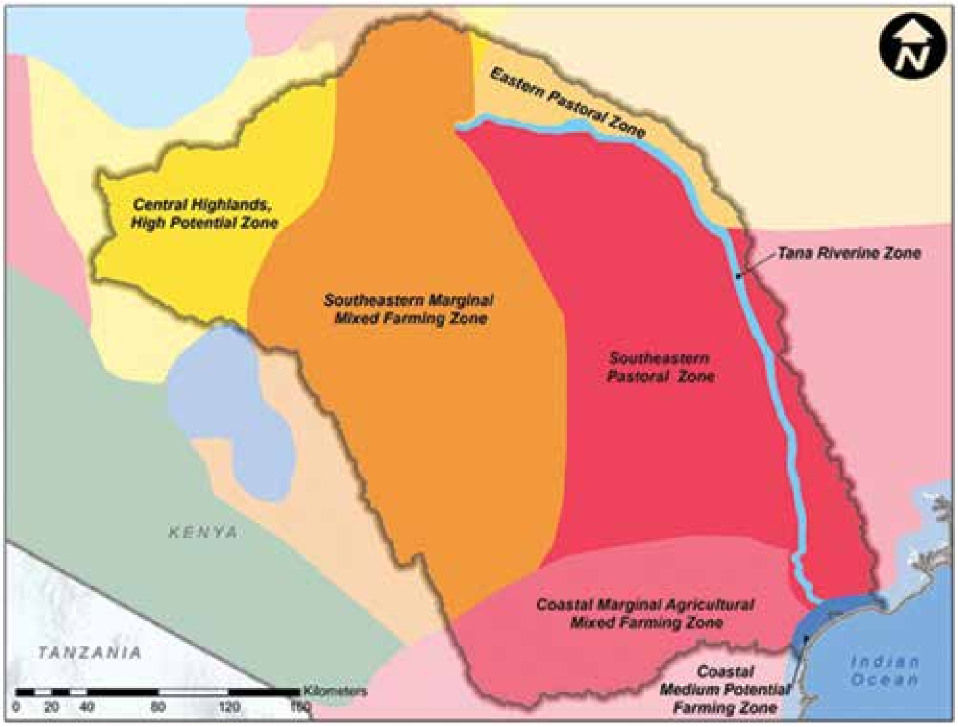
Emerton (1999) and Tanui (2006) identify major shifts in upland forest management that heavily influenced the modern day challenges faced in managing land and water resources in the area around Mount Kenya and, therefore, the Tana River Basin (Table 12). This illustrates a clear example of how complex historical land management shifts from customary practices in areas with historically low population densities have changed through colonial times and into the present.

FIGURE 6. Elevation zones within the Tana River Basin illustrate that much of the basin lies within the lower agro-pastoral and pastoral areas.



DEM Source: Jarvis et al. 2008.

FIGURE 7. Livelihood zones intersecting the Tana River Basin.



Source: Famine Early Warning Systems Network (http://www.fews.net/).

During and since colonization; relocations, resettlements, and land exclusions combined to increase pressure on landscapes, and many modern solutions, such as protected areas and buffers zones, have done little to promote biodiversity or protect landscapes from either an ecological or a social perspective. Within the upper basin in particular, agricultural plots are small (<1 ha; Figure 9) to accommodate the burgeoning population and the region is intensely cultivated (Figure 10).

TABLE 11. Precipitation, altitude, and land use in the Tana River Basin.

Zone/Original Vegetation		Elevation	Annual Rainfall	Present Land-use
Upper	Afro Alpine	>3,350 masl	800–1,200 mm	National Park
	Forest Zone	2,400–3,350 masl	1,600–3,000 mm	Upper Montane, National Reserve
Middle	Woodland	1,500–2,400 masl	1,400–2,400 mm	Tea zone
		1,300–1,800 masl	1,400–2,000 mm	Coffee and banana zone
		800–1,750 masl	800–1,600 mm	Tobacco/maize/millet/cotton
	Bushland	600–900 masl	500–900 mm	Semi-arid pastoralist zone (ASAL)
Lower	Bushland, Coastal	Below 600 masl	Below 800 mm	Pastoralism and agro-pastoralism

Source: Modified from IFAD-UNEP-GEF (2006).

FIGURE 8. Generalized land cover within the Tana River Basin.

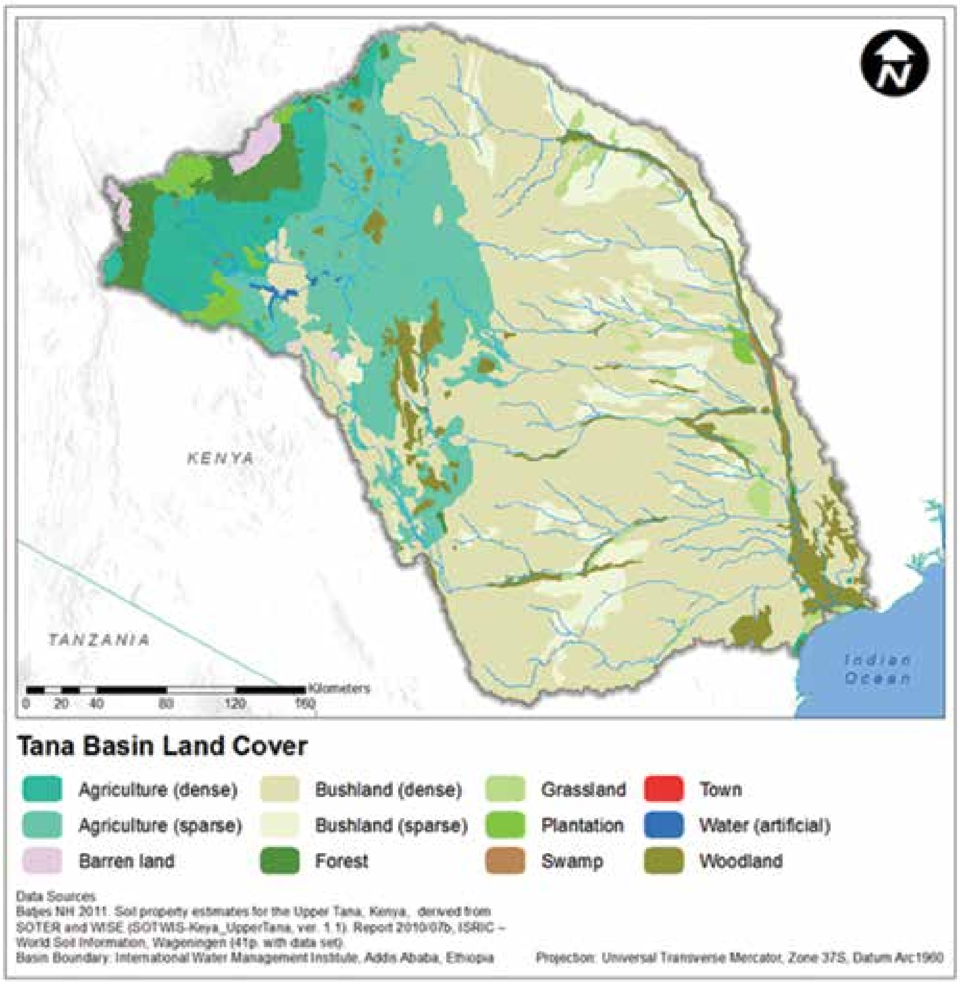


TABLE 12. Management shifts in the Mount Kenya region between 1900 and the 1990s.

Years	Management Shifts
1900–1930	During the initial phase of the colonial era, forest exploitation was extreme. Mount Kenya was declared “Crown Land” and commercial harvesting of indigenous species. Initially this was done freely, but then in the 1920s plantations of indigenous and exotic species were developed.
1930–1980	In 1932, the Mount Kenya Forest Reserve was declared a protected area. The Forest Act of 1942 and the Forestry Policy of 1957 permitted local communities to access the forests for tribal ceremonies and honey collection. During the 1950s and 1960s, commercial logging in plantations began. After 1963, commercial logging continued in earnest and local communities began to be resettled into the area, increasing the demand for agricultural land.
1980s	Bans and prohibitions on forest resources were put in place; however, during this period, illegal extractive activity continued at both a commercial and subsistence level. There was a high demand at a national and international level for indigenous hardwood products from the region.
1990–2000s	A movement toward community-based forest conservation efforts got under way once it was realized that implementing wholly exclusionary tactics was unsuccessful in the 1980s. Under some of these programs limited forest grazing was permitted and the shamba system was reinstated in former plantation areas as the government degazetted land for landless people, but then banned the practice again in 2004.

Source: Tanui 2006.

FIGURE 9. Other than large-scale irrigation schemes and plantations, plot size in the Tana Basin is generally less than 1 ha.

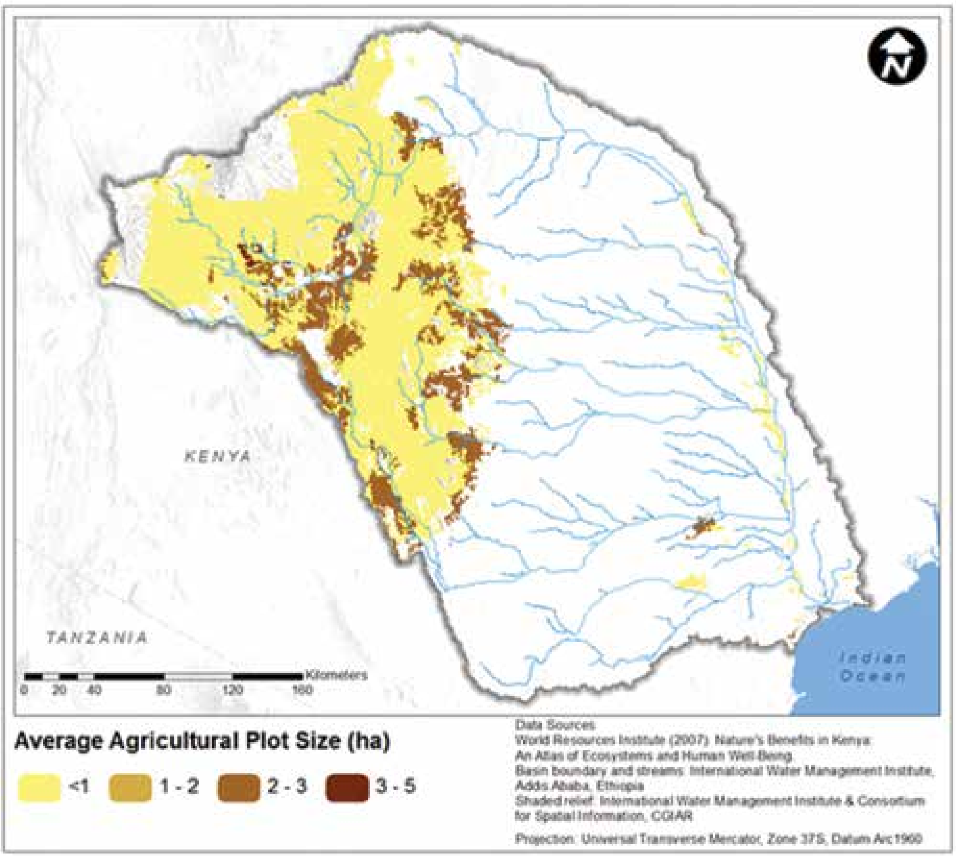
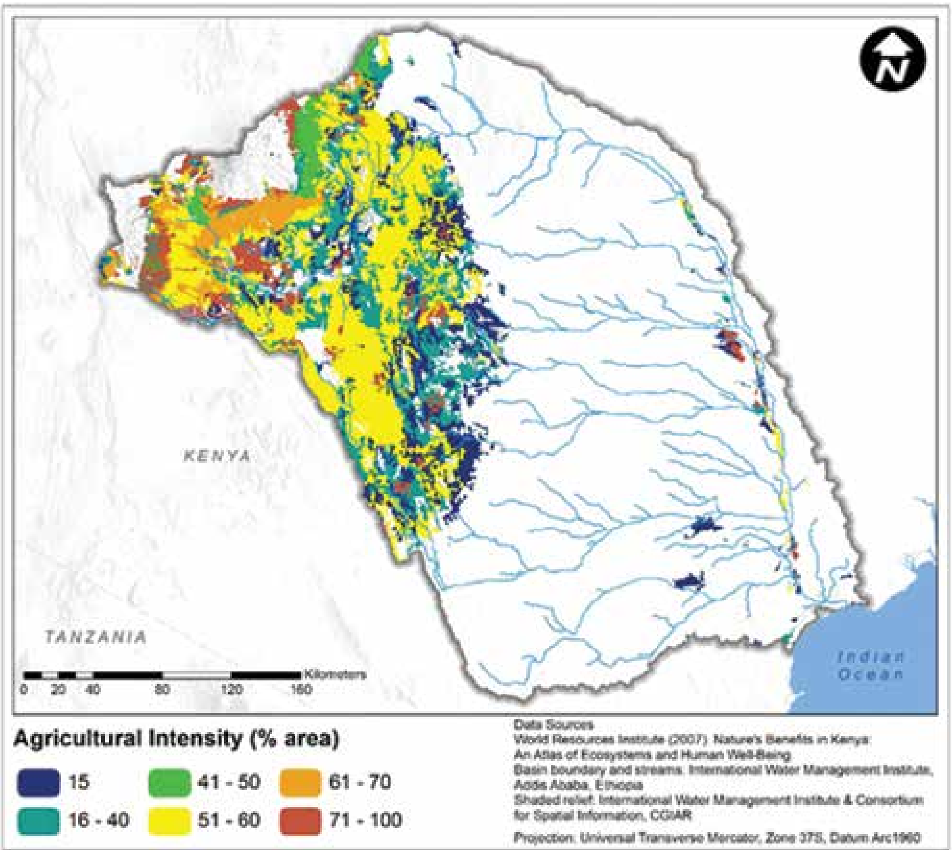


FIGURE 10. Agricultural intensification is greatest in the upper basin where, in most instances, more than 50% of an area is under some form of cultivation.



Protected Lands

Approximately 8% of Kenya's overall land is considered protected to varying degrees. Within the Tana River Basin, this area is much greater with approximately 27% (25,000 km^2) of the basin area designated as protected lands (Figure 11; Table 13). These areas comprise national parks, national reserves, and forest reserves, and are not entirely free from human habitation or impact. They also represent complex and challenging points along the social and ecological nexus.

A particular ecological challenge faced in managing protected areas is that management of surrounding areas can heavily influence the managed space (DeFries et al. 2007; DeFreis et al. 2004). Transitional areas nearest to the protected boundaries are particularly at risk and when not managed properly, may exacerbate issues. This is especially true when such areas serve as ecological flow corridors. These areas are perhaps more heavily relied upon when boundaries are put in that push local people out. There have been numerous criticisms of protected areas and buffer zones worldwide, in general, and in Africa, in particular.

Okello and Kiringe (2004) report findings that agricultural encroachment and migratory corridor losses pose a significant threat to biodiversity in and around Kenya's protected areas. From an ecological standpoint, Western et al. (2009) similarly found that Tsavo East, Tsavo West, and Mount Meru suffer disproportional losses (greater than 60% wildlife declines) within the actual park boundaries as well as surrounding areas compared to other protected parks within Kenya. They did not find that these losses were necessarily due to poaching, which Kenya Wildlife Services is more aggressively controlling, but instead they suggest that agricultural expansion into areas surrounding parks is a greater issue. In more recent years, however, there has been some evidence that poaching is again increasing. That said, Western et al. (2009) argue that a major challenge is that the conservation system of creating exclusionary sites (i.e., using fences or other similar methods) is highly flawed, in that it does nothing to protect migratory areas and generally causes spatial segregation of the landscape. Hansen and DeFries (2007) assert that it is, in fact, the ecological function of regions surrounding protected areas that requires more management focus.

Within the Aberdare Range, a 400 km electric fence enclosing Aberdare Conservation Area was completed after 20 years in 2009 (Kiogora et al. 2011). This project was spearheaded by the conservation NGO Rhino Ark as a way to protect the dwindling Black Rhino population through habitat preservation and poaching reduction as well as curtail human-wildlife conflict. And while many of these benefits have been realized in several regards (KWS-UNEP-KFWG 2003), Kiogora et al. (2011) also recognize that there is increased pressure along the fence buffer zone that needs to be addressed.

Finally, from a cultural perspective, protected areas have been criticized as a form of neo-colonialism in African countries, merely hiding behind the auspices of conservation. Neumann (1997) argues that the now common integrated conservation- development projects (ICDPs) are, to some degree, complicit in increasing land insecurity issues and conflict in rural Africa because they ignore social and cultural complexities. Such projects often take on contradictory practices such as purporting to preserve traditional lifestyles (often poorly defined or understood from the outset), while also modernizing these same societies by increasing market access or facilitating more equitable access to resources. Consequently, ICDPs facilitate the exertion of greater control over local livelihoods by the state or other outsiders, which further social inequities.

FIGURE 11. Protected areas designated within the Tana River Basin as of 2007. Major protected areas are highlighted here, but there are also numerous small, protected areas in the Upper Tana between Mount Kenya and Meru.

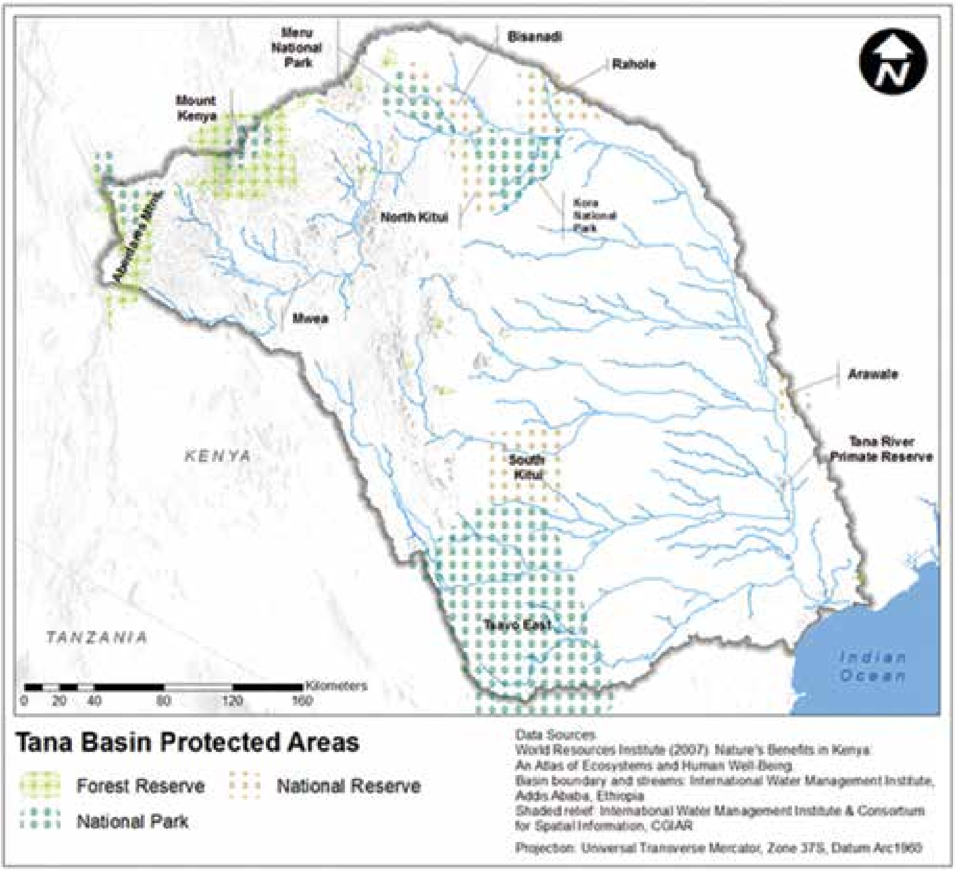


TABLE 13. Forest reserves, national parks, national reserves located wholly or partially within the Tana River Basin.

Name	Designate	Year Established	Area (km^2)
Aberdare	Forest Reserve	1943	802
Imenti	Forest Reserve	1938	123
Kiagu	Forest Reserve	1959	7
Kieiga	Forest Reserve	1959	6
Kierera	Forest Reserve	1959	5
Kijege	Forest Reserve	1959	20
Kikingo	Forest Reserve	1959	9
Kikuyu Escarpment	Forest Reserve	1943	415
Lusoi	Forest Reserve	1984	4
Makongo-kitui	Forest Reserve	1961	32
Mataa	Forest Reserve	1960	9
Mount Kenya	Forest Reserve	1943	2,019
Munguni	Forest Reserve	1959	5
Mutejwa	Forest Reserve	1959	9
Mutharanga	Forest Reserve	1959	6
Mutito	Forest Reserve	1962	31
Ngaia	Forest Reserve	1959	83
Ngamba	Forest Reserve	1961	9
Njuguni	Forest Reserve	1959	18
Nuu	Forest Reserve	1961	45
Nyambeni	Forest Reserve	1959	52
Nyeri	Forest Reserve	1932	12
Thunguru Hill	Forest Reserve	1959	9
Thuuri	Forest Reserve	1959	7
Witu	Forest Reserve	1962	23
Aberdare	National Park	1950	721
Kora	National Park	1989	1,654
Meru	National Park	1966	853
Mount Kenya	National Park	1949	592
Tsavo East	National Park	1948	13,052
Arawale	National Reserve	1974	452
Bisanadi	National Reserve	1979	705
Mwea	National Reserve	1976	65
North Kitui	National Reserve	1979	672
Rahole	National Reserve	1976	1,231
South Kitui	National Reserve	1979	1,955
Tana River Primate	National Reserve	1976	111

Source: WRI-DRSRS-MENR-CBS-ILRI 2007.

Wilshusen et al. (2002) review the position seen often in conservation literature, that community conservation efforts and programs do little to preserve biodiversity and that more top-down authoritarian approaches are needed to overcome the ineffective policies and management systems in place in less developed countries. They argue that the greater challenge faced is that past (typically colonial) policies put in place land tenure and management systems that are at the root of the challenge. They are quick to point out, however, that they reject the concept of a 'noble savage' whereby it is assumed that indigenous practices have a greater respect for – or live in harmony with – natural resources. Furthermore, they argue that numerous studies have already shown this to be a mythology based on conditions such as low human population density, which no longer exist in the modern word (*for further discussion see* Brandon 1997; Redford et al. 1998; Redford and Mansour 1996; Redford and Richter 1999; Robinson 1993). In addition, they assert that these two extremes are unproductive in protecting natural resources and livelihoods and that instead there is a need to rigorously pursue a middle ground that asks the right questions and seeks solutions that are 'ecologically sound, politically feasible, and socially just' and that can be 'legitimately enforced based on strong agreements with all affected parties'.

Livelihoods

Within the Tana River Basin, peoples' livelihoods comprise a wide spectrum of activities: fishing, agriculture (subsistence, rain-fed, and irrigated), livestock, and pastoralism, as well as work related to national parks and conservation or protected areas and employment within urban or industrial centers. Industrial livelihoods commonly found within the basin are typical of urban areas: food processing, beverage production, leather making, steel, textiles, printing, and tea and coffee processing (Ministry of Environment, Water and Natural Resources 2013).

Livelihoods and Land Use

The FEWS NET (Famine Early Warning Systems Network) identifies seven major livelihood zones within the basin that are summarized below (Figure 7; *see* http://www.fews.net/ for full detailed zone descriptions). Of these zones, the greatest proportion of area within the Tana Basin is located within two marginal zones – Southeastern Marginal Mixed Farming and Southeastern Pastoral – where rains are unreliable and access to markets is often poor or in constant flux. Further and supplementary land use assessments, within each livelihood zone, present a more revealing picture of the critical role that ecosystem services play in the livelihoods of Kenyans living in the Tana River Basin.

Within these zones, human population pressure has increased steadily and is expected to continue doing so (Table 14). Population pressure within the Central Highlands has largely decreased, quite likely due to the lack of available land for agriculture. Since 1990, areas with the most significant population increases are the Tana Riverine Zone and the Eastern Pastoral Zone, which abuts the Tana River above Garissa, at 60% and 65% increases, respectively. These areas also have large numbers of internally displaced persons due to natural disasters (e.g., flooding and drought) and ethnic violence. Many of these affected people, especially pastoralists, relocate to villages closer to the river (NRC-IDMC 2014). That said, less than 4% of the total basin population lives within the aforementioned two zones.

Central Highlands, High Potential Zone

This region comprises only 11% of the basin but around 60% of the total basin population lives here (Table 14). The area is considered to be food secure, having reliable rainfall for agricultural production (Table 15). Common food crops in this zone are maize, Irish potato, and beans.

TABLE 14. Modeled populations within livelihood zones from 1990–2015. Counts for 1990–2005 are corrected using census data, while 2010 and 2015 are predicted estimates based on current and historical patterns.

Zone	1990	1995	2000	2005	2010	2015
Central Highlands	3,051,550	3,374,825	3,609,350	3,773,775	3,919,125	4,015,525
Southeastern Marginal Mixed Farming	1,629,425	1,819,425	1,964,500	2,073,600	2,173,925	2,248,475
Coastal Marginal Agricultural Mixed Farming	17,425	20,475	23,250	25,800	28,450	30,950
Coastal Medium Potential Farming	6,675	7,850	8,900	9,900	10,900	11,875
Tana Riverine	69,975	87,475	106,000	125,800	148,575	173,450
Eastern Pastoral	21,375	27,500	34,250	41,750	50,500	60,325
Southeastern Pastoral	126,125	149,200	170,800	191,275	212,925	234,025

Source: CIESIN-FAO-CIAT 2005.

TABLE 15. Annual activity patterns in the Central Highlands region indicate diversity among agricultural and livestock activities that are possible throughout the year. This region is highly productive and has the highest population density within the basin as a result.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***		***Long Rains***									***Dry***
Crops												
Legend	Land Preparation				Planting			Harvesting				
Maize + Beans												
Coffee												
Tea												
Irish Potato												
Cabbage												
Pyrethrum	**Include pruning**											
Others*	**Grown and harvested at different times throughout the year**											
Milk Availability	**Thtroughout the year due to dairy farming**											
Livestock	**Livestock husbandry, vaccinations and general management throughout the year (intensive)**											
Food Prices				**High**								
Market Access			**Poor**							**Poor**		
Labor		**Peak**										

* Permanent crops including avocado, passion fruit, mangos, macadamia nuts, bananas, and pineapple

Source: Adapted from FEWS NET (http://www.fews.net/).

While agricultural productivity is high, many households produce crops for cash sales such as coffee, tea, and pyrethrum, and then purchase much of the food needed to meet household requirements. There is a well-developed road network in the region, facilitating access to numerous markets where food and cash crops are bought and sold. This is the only region within the basin that does not experience a lean season where food insecurity peaks. A major development constraint, however, in this high population density area is small farm size. In addition to crop production, households will typically have animals such as dairy cattle, chickens, goats, and sheep, which contribute to income via dairy and poultry production and sales.

Cash crop production areas within the Tana River Basin are found predominantly in upper and western portions of the catchment as well as in riverine areas. Major crops found are banana, potato, cotton, beans, and maize, with coffee and tea grown in the Mount Kenya region (Ministry of Environment, Water and Natural Resources 2013). Coffee and tea zones are clearly depicted in Figure 12 and they comprise a large portion of agricultural production, with overall land use area estimates by type are indicated in Table 16.

FIGURE 12. The Central Highlands region within the Upper Tana River Basin is the most productive area and has the highest population and population density.

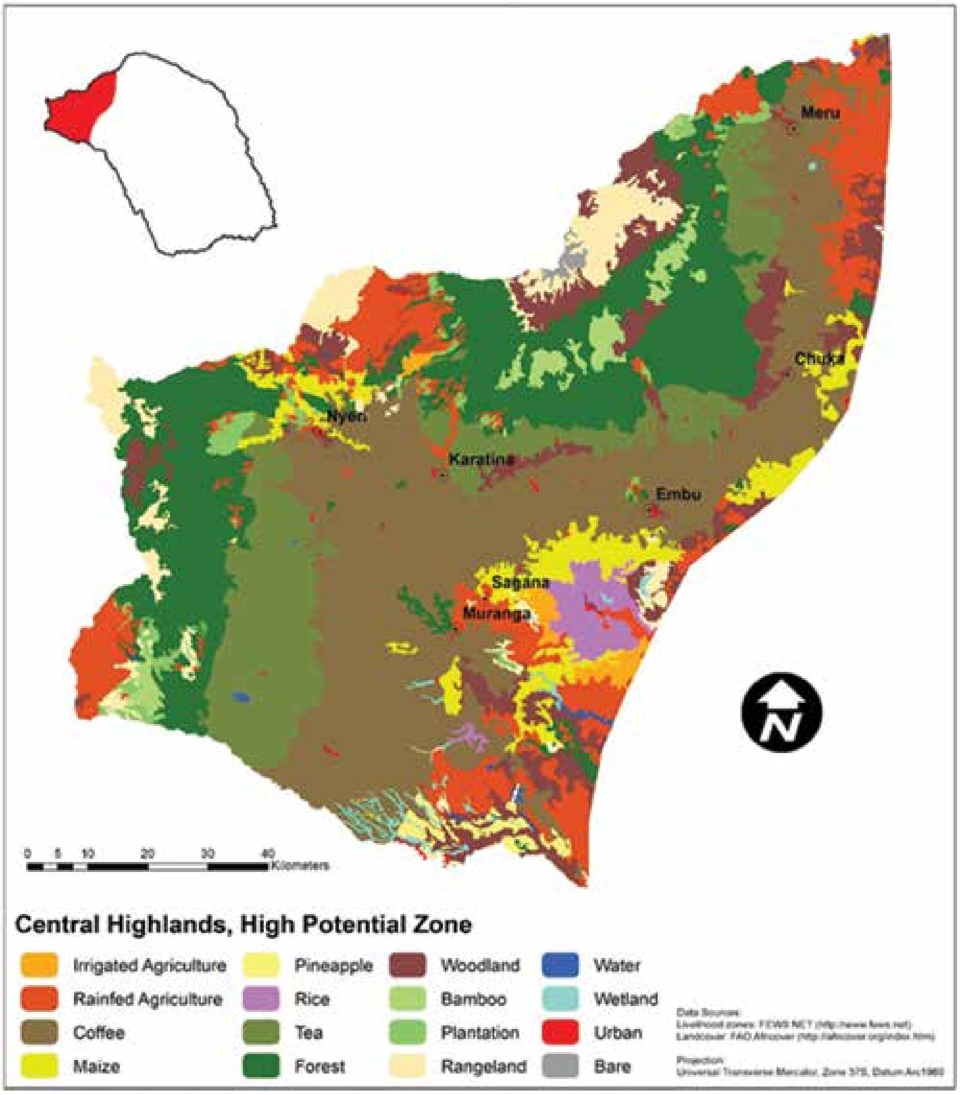


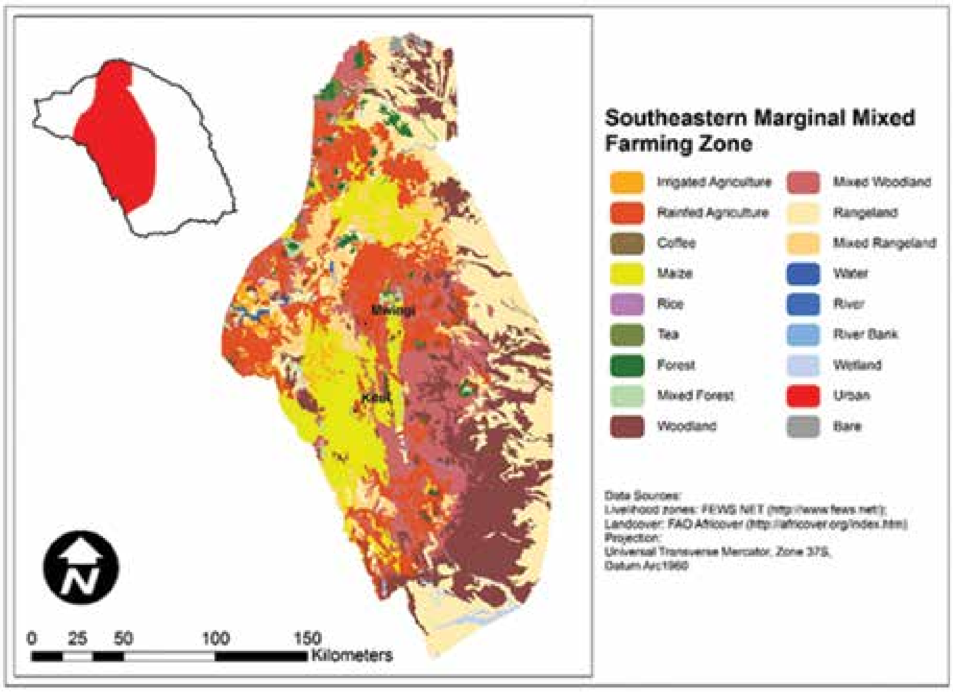
TABLE 16. Land use by approximate areal coverage in the Central Highlands. Irrigated and rain-fed agriculture are small-scale mixed crop areas.

Land use	Area (km²)	Land use	Area (km²)	Land use	Area (km²)
Bamboo	175	Pineapple	78	Tea	1,211
Bare	22	Plantation	168	Urban	21
Coffee	3,087	Rain-fed Agriculture	1,195	Water	19
Forest	2,129	Rangeland	499	Wetland	57
Irrigated Agriculture	89	Rice	174	Woodland	886
Maize	506				

Southeastern Marginal Mixed Farming Zone

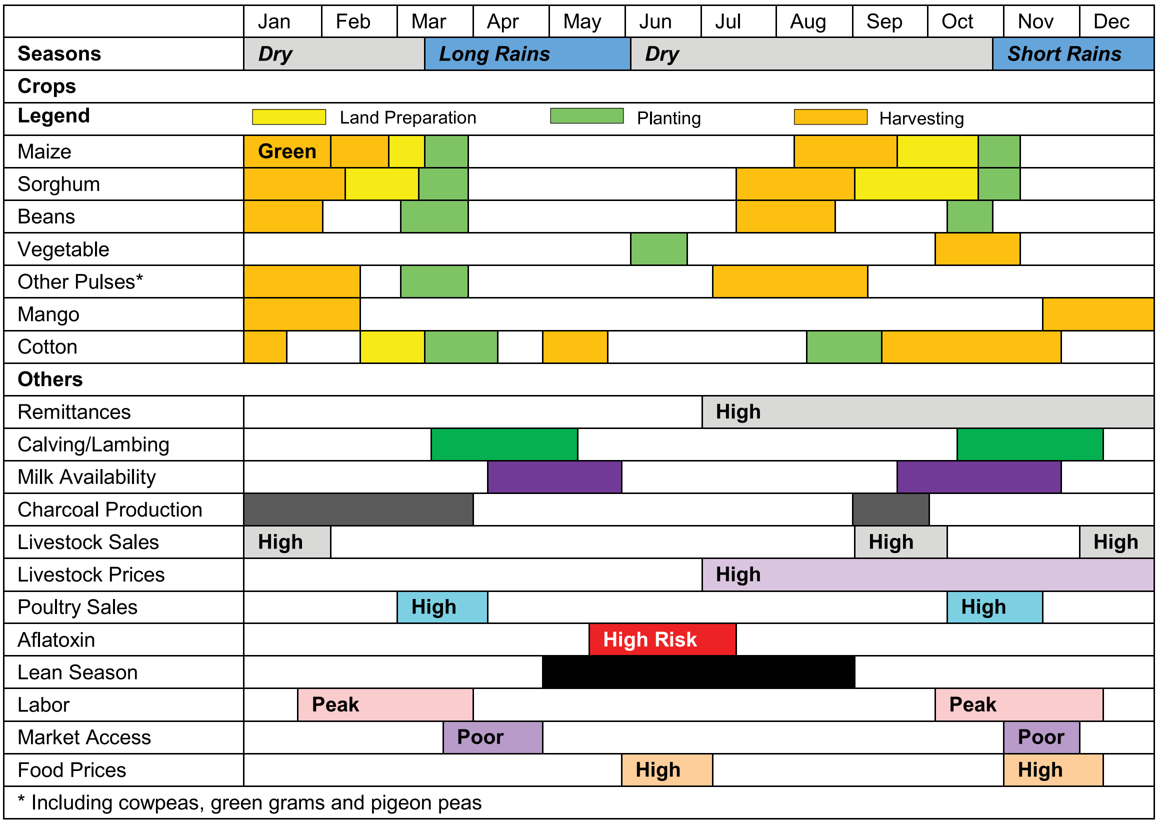
This zone (Figure 13) is located in a semi-arid region of the basin and comprises the largest livelihood zone at 38% of the Tana's total area and 33% of its population (Table 14). Rainfall within this zone is low and unreliable in some years, though crops are grown under rain-fed conditions (Table 17). Food crops consist principally of maize, sorghum, and pulses, while common cash crops are cotton, tobacco, and *khat* (*miraa*). Land use areas by type are indicated in Table 18 and highlight a diverse landscape in this zone. In addition to livestock (cattle, goats, and sheep) and poultry, many households also keep beehives, producing honey for sale. For many people living in this zone, remittances play a significant role in household income. Economic conditions are challenging and food security is considered poor. In part this is due to factors such as lack of food storage capacity and market gluts that occur during good rainfall years when everyone must take

FIGURE 13. Small-scale rain-fed agriculture dominates this zone, with maize being a dominant crop. In this area, many small plots are interspersed among woodlands, forests and rangelands, and are therefore indicated as mixed land use types. Rangelands here include shrublands and areas with sparse tree cover.



their harvests to market. Unreliable water supplies and high agricultural input costs also contribute to poor food security here.

TABLE 17. While there is a clear diversity of activities across agricultural and livestock within the Southeastern Marginal Mixed Farming Zone, engagement almost exclusively in rain-fed agriculture coupled with unreliable rainfall patterns means that during about one third of the year people here experience food insecurity, though typically earlier in the year than other regions within the basin.



Source: Adapted from FEWS NET (http://www.fews.net/).

TABLE 18. Land use by approximate areal coverage in the Southeastern Marginal Mixed Farming Zone. Irrigated and rain-fed agriculture are small-scale mixed crop areas.

Land use	Area (km^2)	Land use	Area (km^2)	Land use	Area (km^2)
Bare	111	Mixed Rangeland	3,221	River Bank	32
Coffee	55	Mixed Woodland	5,359	Tea	70
Forest	498	Rain-fed Agriculture	6,052	Urban	5
Irrigated Agriculture	420	Rangeland	7,911	Water	80
Maize	4,597	Rice	7	Wetland	290
Mixed Forest	296	River	17	Woodland	7,070

Coastal Marginal Agricultural Mixed Farming Zone

From the mouth of the Tana River and southwards toward Tanzania, this zone covers an expansive area within Kenya and comprises 13% of the basin and less than 1% of the basin's population; however, it has seen a 44% increase in population since 1990 (Table 14). The area receives low and unevenly distributed rainfall, with the long rains (April–July) less reliable than the short rains (October–December). Livestock and crop production are dominant livelihood activities (Table 19), while the vast woodland and rangeland areas (Figure 14; Table 20) provide opportunities for firewood sales as another important income generating activity. Both rain-fed and irrigated agricultural practices are employed in this zone with maize and cassava being principal food crops, and coconuts and mangos representing primary cash crops. Livestock also play a large role in household income for many. Most food, aside from maize and cassava, is purchased rather than produced by households in this zone, and people are highly reliant on food production and distribution from up-country. A major contributor to environmental degradation in this zone is charcoal production. Historically, charcoal production was only used as a coping strategy during shocks, but it has now become a livelihood strategy for some households. Market access in this zone is generally poor and human-wildlife conflict poses a threat to crop production.

TABLE 19. Within this zone, rainfall is low, erratic, and unreliable and crop diversity is lower. People within this zone are reliant on markets to purchase food produced in others areas. Due to the propensity for flooding, crop and property losses can pose additional challenges.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***			***Long Rains***				***Dry***		***Short Rains***		
Crops												
Legend		Land Preparation			Planting			Harvesting				
Maize*												
Cassava**												
Vegetable				**Local**								
Cotton												
Pineapple												
Others												
Key Ceremonies												
Milk Availability												
Livestock Sales	**High**			**High**				**High**				**High**
Livestock Prices						**High**						**High**
Malaria												
Flooding												
Lean Season												
Labor		**Peak**						**Peak**				
Market Access				**Poor**								**Poor**
Cross Border Trade Inflows					**Peak**							
Food Prices				**High**						**High**		
* Intercropped with pigeon peas and cow peas ** Cassava and sweet potatoes planted together												

Source: Adapted from FEWS NET (http://www.fews.net/).

FIGURE 14. Rangelands, which include shrublands and areas with sparse trees, dominate the landscape in this zone. It is also where Tsavo East is located. Woodlands are also common and small-scale agriculture is mixed throughout.

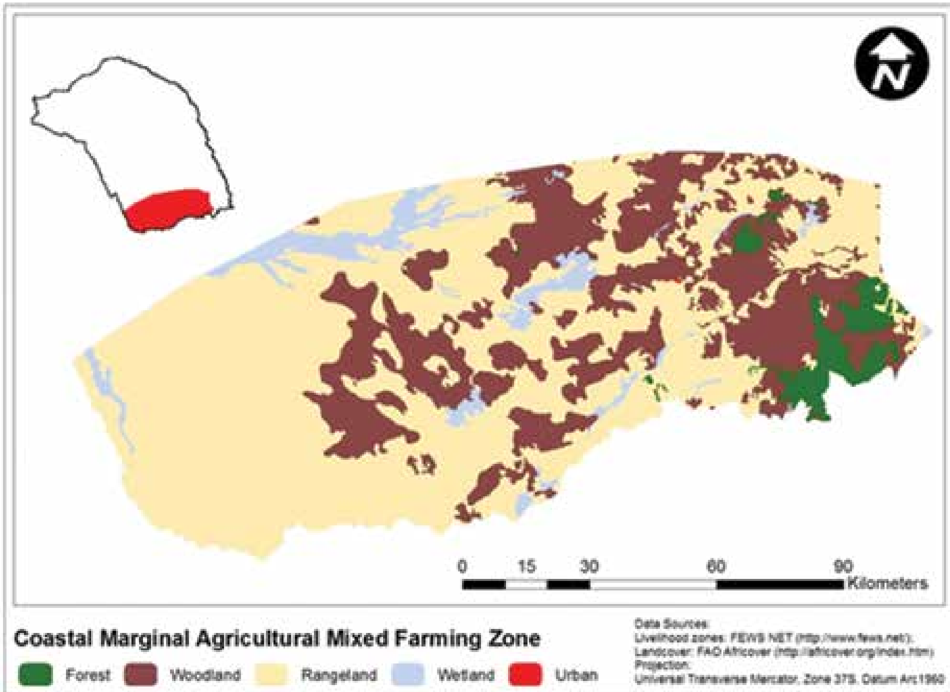


TABLE 20. Land use by approximate areal coverage in the Coastal Marginal Agricultural Mixed Farming Zone.

Land use	Area (km^2)	Land use	Area (km^2)
Forest	424	Wetland	634
Rangeland	7,890	Woodland	3,408
Urban	2		

Coastal Medium Potential Farming Zone

This zone comprises a narrow (approximately 15 km wide) strip along Kenya's coast, and less than 0.5% of the Tana River Basin falls within this area; however, it is home to the highly productive Tana Delta (Figure 15; Table 21). Only around 0.2% of the total basin population is found here; however, similar to the Coastal Marginal Agricultural Mixed Farming Zone, there has been a 44% population increase since 1990. The area is dominated by a monsoonal climate pattern and receives high rainfall. People living within this zone practice a diverse set of livelihood activities such as fishing, mixed farming, mangrove harvesting, and tourism-related work (Table 22). Mosello et al. (Forthcoming) report that while there are informal resource sharing agreements in place among the various wetland resources users, during times of scarcity there are often conflicts among groups. Fishing is the main income source, though livestock comprise a significant portion of many households' income. Food crops in this zone may be rain-fed or irrigated, and consist principally of maize, pulses, and cassava. Common cash crops are coconuts, sesame, cashews (a high-value crop), and mangos. Most household food requirements are met through market purchases, except for maize. Tourism-related activities are also common livelihood strategies; however, they are fraught with several challenges in that jobs are limited, wages are typically low, and there is a high prevalence of HIV/AIDS associated with the industry.

FIGURE 15. The Tana Delta begins in this region. Crop production is generally small-scale and distributed throughout the forests, woodlands, and rangelands. It may be only rain-fed or also make use of rudimentary irrigation mechanisms.

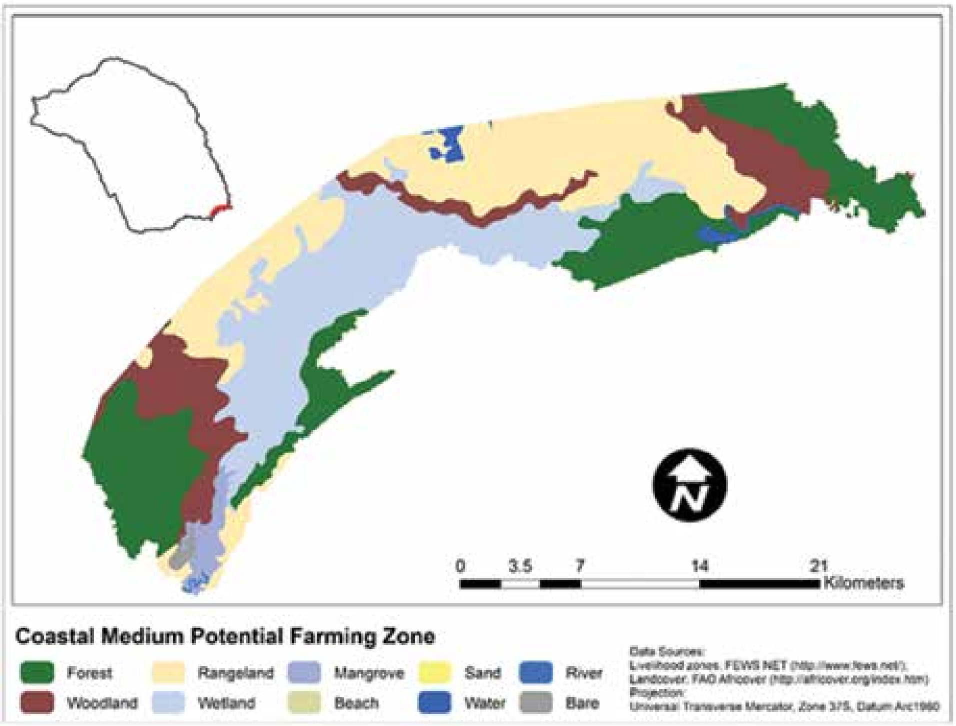


TABLE 21. Land use by approximate areal coverage in the Coastal Medium Potential Farming Zone.

Land use	Area (km^2)	Land use	Area (km^2)	Land use	Area (km^2)
Bare	2	Rangeland	136	Water	4
Beach	trace	River	1	Wetland	118
Forest	129	Sand	trace	Woodland	69
Mangrove	9				

TABLE 22. This region experiences a great degree of diversity in livelihood activities besides agricultural and livestock related activities. Tourism and fishing activities play a significant role in many livelihoods here. Flooding late in the year, following on the heels of the lean season, can jeopardize crop production.

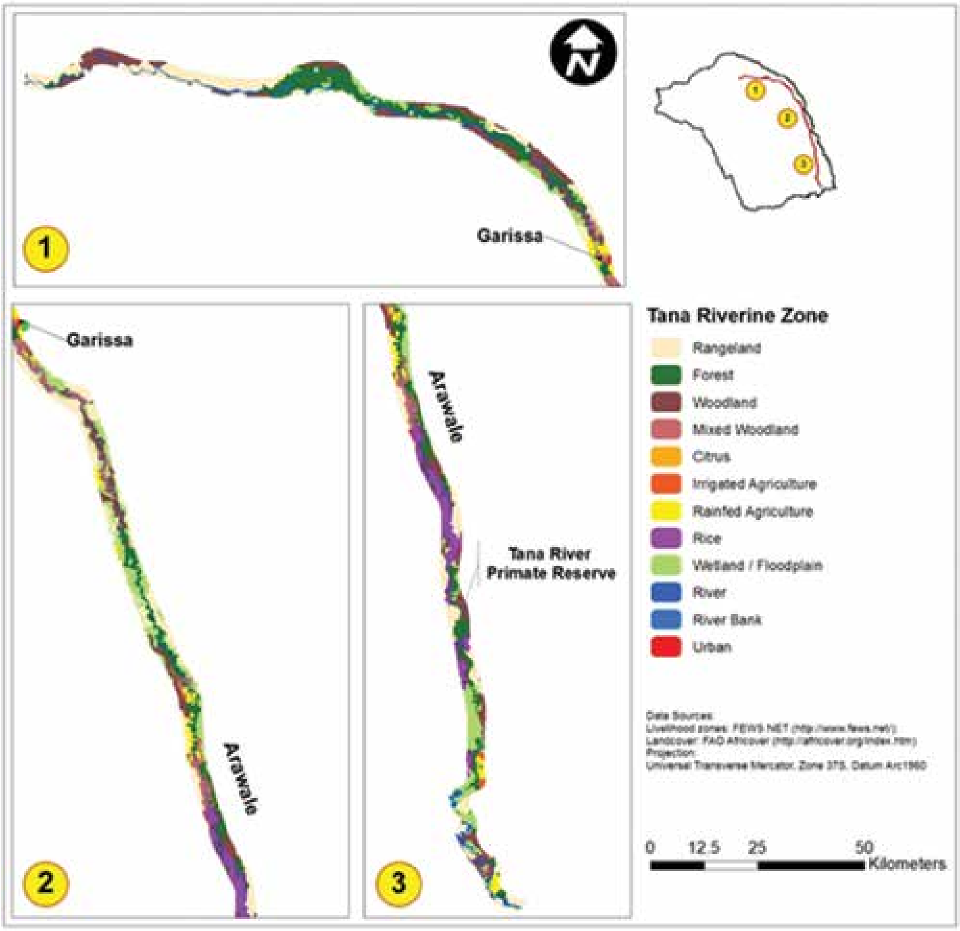
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***		***Long Rains***			***Dry***				***Short Rains***		
Crops												
Legend		Land Preparation				Planting			Harvesting			
Maize*												
Cassava**												
Vegetable				**Local**								
Coconut	**For the fruit and to make wine: harvested all year**											
Mango												
Cotton												
Other crops***												
Others												
Key Ceremonies												
Fishing												
Tourism Peak												
Kidding/Lambing												
Milk Availability												
Charcoal Production												
Livestock Sales	**High**			**High**				**High**				**High**
Livestock Prices						**High**						**High**
Flooding												
Malaria												
Lean Season												
Labor		**Peak**						**Peak**				
Market Access			**Poor**									**Poor**
Cross Border Inflows						**Peak**						
Food Prices				**High**						**High**		
*Intercropped with beans and cowpeas **Cassava and sweet potatoes planted together ***Cashews and pineapples												

Source: Adapted from FEWS NET (http://www.fews.net/).

Tana Riverine Zone

Comprising only 2% of the basin, the long and narrow Tana Riverine Zone (Figure 16) is a challenging place for people to make their livelihoods. Close to 3% of the basin's population is found within this zone (Table 14). Temperatures are high along the river, rainfall is erratic and unreliable, and the area is prone to flooding. Unlike the previous zones, where the majority of people are settled (>80%), only about 45% of people are settled here with another 30% being semi-nomadic and reliant on the river during the dry season for livestock watering. In addition, around 15% of the zone's inhabitants are internally displaced persons. Maize and beans are most commonly grown crops in this zone (Table 23). Other food crops are sorghum, maize, pulses, and millet, while cash crops are mostly tomatoes, bananas, and melons; however, the zone is primarily dominated by non-agricultural land uses (Table 24). Livestock make large contributions to household income as well. Many poor households in this zone are reliant on cash remittances, gifts from other households, and firewood collection. Poorly developed irrigation and unreliable water sources constitute a major constraint to increasing crop production and improving household income.

FIGURE 16. The main stem of the Tana River and its immediate vicinity (~5 km strip) make up this highly impacted zone. Agriculture is practiced right up to the river and in the floodplains.



Riverine forest only extends 0.5–3.0 km beyond the river's edge and drops off quickly indicating that the water table also drops (Maingi and Marsh 2002). This riverine forest is home to two endemic primate species: Tana River Red Colobus (*Colobus badius rufomitratus*) and the Tana River mangabey (*Cercocebus galeritus galeritus*). The riverine forest is one land use that is highly dependent on the river's flood response, which has been altered by upstream dams. The influence of the upstream dams has result in decreased season peak flows during April and May, with increased flows from January – March. These changes have affected many ecosystem services, such as flood recession agriculture and grazing to name a few, in the lower portion of this zone in particular (Hamerlynck et al. 2010).

TABLE 23. There is little diversity in livelihood activities within the Tana Riverine Zone. While fishing is a common activity, fisheries are not as prominent and productive as they are in the delta. This region bisects the Southeastern Pastoral Zone and results in conflict among groups vying for use of the river's resources during the dry season, which poses a high threat to security.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***		***Long Rains***			***Dry***				***Short Rains***		
Crops												
Legend	Land Preparation			Planting			Harvesting					
Maize and Beans	Harvesting	Land Preparation	Planting	Planting			Harvesting	Harvesting	Land Preparation	Land Preparation / Planting	Planting	
Livestock Production												
Calving										Peak	Peak	
Kidding/Lambing			Peak	Peak						Peak	Peak	
Disease Outbreaks						Highly Likely	Highly Likely					
Prices				Peak	Peak						Peak	Peak
Milk Availability	High	High		High	High						High	High
Livestock Sales									High	High		
Others												
Fishing				Peak	Peak	Peak					Peak	Peak
Risk of Insecurity					High	High						High
Malnutrition								High	High	High	High	
Lean Season								Lean	Lean	Lean	Lean	
Labor Availability		Peak	Peak	Peak						Peak		
Market Access				Poor	Poor						Poor	Poor
Food Prices					High	High		High	High			

Source: Adapted from FEWS NET (http://www.fews.net/).

TABLE 24. Land use by approximate areal coverage in the Tana Riverine Zone. Irrigated and rain-fed agriculture are small-scale mixed crop areas.

Land use	Area (km^2)	Land use	Area (km^2)	Land use	Area (km^2)
Citrus	trace	Rain-fed Agriculture	65	River Bank	9
Forest	335	Rangeland	466	Urban	2
Irrigated Agriculture	5	Rice	92	Wetland	304
Mixed Woodland	91	River	139	Woodland	323

Eastern Pastoral Zone

This zone is partly within a large shrubland plain that extends from the upper section of the Tana River near Garissa to the Somalia border (Figure 17), and comprises 4% of the basin and less than 1% of the basin's population (Table 14). That said, this area has seen the greatest percentage increase in population (65% since 1990). Many factors could be driving this development, such as increasing pressure to settle for pastoralists due to exacerbating climate conditions, numerous food aid programs in the region, and increasing Somali refugees in and around the Dabaab refugee camp, which is just outside the basin boundary. Rainfall here is low and animal husbandry is the dominant livelihood activity. Around half of the residents in this zone are nomadic with another 20% being semi-nomadic. Livestock numbers per household are more than four times those in previously described zones, and inhabitants do not engage in crop production (Table 25). The overwhelming majority of the landscape is comprised of non-agricultural land uses (Table 26). Poor households may adopt livelihood activities such as selling firewood, poles, and gum. School meals are an important food source for many children in this zone and food aid is also a household food source, covering up to 50% of household food requirements. Social support from community members is often needed for the poorest households.

FIGURE 17. This sparsely populated zone has seen dramatic increases in population since 1990. Lands here are used primarily for livestock production, though some patches of small-scale agriculture can be found within the woodlands and rangelands near Garissa.

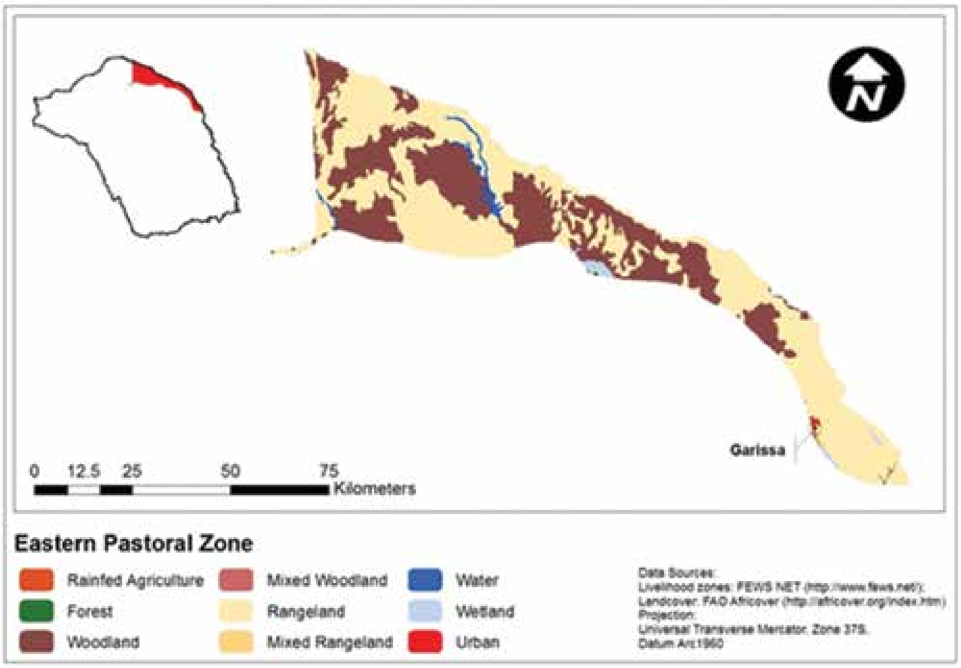


TABLE 25. Inhabitants in the Eastern Pastoral Zone do not have diversified livelihoods but are reliant almost exclusively on livestock production. Food insecurity is high in this area and food aid is commonly needed for households to meet basic food requirements. Water stress peaks after the short rains during the longer of two dry seasons.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***			***Gu***		***Dry***				***Deyr***		
Livestock Production												
Calving										Peak		
Kidding/Lambing				Peak						Peak		
Disease Outbreaks						Highly Likely						
Prices				Peak							Peak	
Milk Availability	Shoats			Shoats							Cattle	
Migration		Dry		Wet			Dry				Wet	
Others												
Livestock Sales	High					High			High			High
Risk of Insecurity				High			High					High
Malnutrition								High				
Lean Season												
Labor Availability		Peak							Peak			
Market Access				Poor							Poor	
Water Stress												
Cross Border Inflows						Peak						
Food Prices					High			High				

Source: Adapted from FEWS NET (http://www.fews.net/).

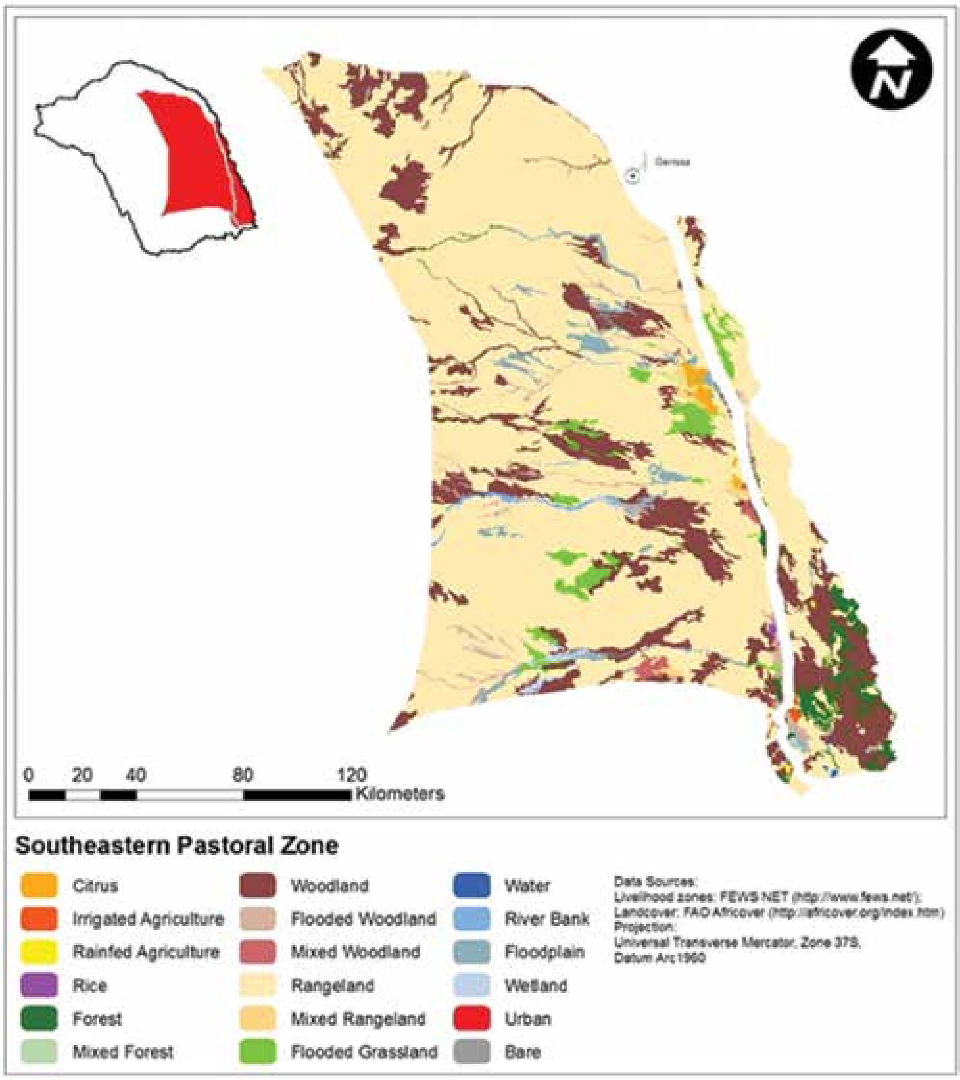
TABLE 26. Land use by approximate areal coverage in the Eastern Pastoral Zone. Rain-fed agriculture refers to small-scale mixed crop areas.

Land use	Area (km^2)	Land use	Area (km^2)	Land use	Area (km^2)
Forest	2	Rain-fed Agriculture	6	Water	44
Mixed Rangeland	3	Rangeland	2,233	Wetland	34
Mixed Woodland	1	Urban	2	Woodland	1,341

Southeastern Pastoral Zone

This is the second largest zone within the Tana River Basin, covering 32% of the total area, but is sparsely populated with only 3.5% of the total basin population (Table 14). The zone is dominated by non-agricultural land uses, with the primary use being rangelands (Figure 18; Table 27). This area receives low and unreliable rainfall and is cut through by the Tana Riverine Zone.

FIGURE 18. Flood recession grazing is common in this part of the basin owing to the numerous ephemeral streams and floodplains. Agricultural areas are found toward the Tana River, which runs through this zone as well as near the coastal zones. When present, small-scale agriculture is generally mixed within forested, woodland, and rangeland (including shrublands) areas.



Residents here are mostly nomadic and semi-nomadic and livestock production is the primary income source (Table 28). Households hold large numbers of livestock with few other livelihood activities, making them particularly vulnerable to livestock diseases and cattle raids, which are a constant threat experienced by those living in this zone. When needed and possible, other important income sources in this zone are firewood collection, charcoal production, and bush products. Most food is purchased, as residents here do not engage in crop production (cash or food). Livelihoods diversification in this zone is challenging due to the lack of reliable water resources.

TABLE 27. Land use by approximate areal coverage in the Southeastern Pastoral Zone. Irrigated and rain-fed agriculture are small-scale mixed crop areas.

Land use	Area (km^2)	Land use	Area (km^2)	Land use	Area (km^2)
Bare	5	Irrigated Agriculture	21	Rice	16
Citrus	110	Mixed Forest	21	Riverbank	90
Flooded Grassland	630	Mixed Rangeland	145	Urban	4
Flooded Woodland	505	Mixed Woodland	123	Water	13
Floodplain	638	Rain-fed Agriculture	11	Wetland	119
Forest	556	Rangeland	22,435	Woodland	4,878

TABLE 28. Like the Eastern Pastoral Zone, people living in the Southeastern Pastoral Zone are engaged in limited livelihood activities related to livestock production. Rainfall is low and unreliable; hence, rain-fed agriculture is not possible. Water stress here peaks in the second dry season before the onset of the short rains.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasons	***Dry***		***Long Rains***			***Dry***				***Short Rains***		
Livestock Production												
Camel Calving			Some							Peak		
Cattle Calving										Peak		
Kidding/Lambing			Peak							Peak		
Disease Outbreaks						Highly Likely						
Prices				Peak							Peak	
Milk Availability	Shoats			Shoats							Cattle	
Camel Milk												
Migration		Dry		Wet			Dry			Wet		
Others												
Livestock Sales	High					High			High			High
Risk of Insecurity				High			High					High
Malnutrition								High				
Lean Season												
Labor Availability		Peak							Peak			
Market Access				Poor						Poor		
Water Stress												
Cross Border Inflows						Peak						
Food Prices					High			High				

Source: Adapted from FEWS NET (http://www.fews.net/).

Biodiversity

Biodiversity can be defined in its simplest terms as the number and variety of plants and animals living in a given location. Generally, higher levels of biodiversity support healthy ecosystem services and contribute to overall system resilience and ability to respond to and recover from shocks or extreme perturbations (MA 2005). The Tana Delta is recognized both regionally and internationally as a critical biodiversity hotspot. Others that come under this category of hotspots are the Afromontane forests of Mount Kenya and the Aberdare Range (Myers et al. 2000; NEMA 2009).

As reported by Hamerlynck et al. (2010), riverine forests in the lower basin are considered a biodiversity hot spot and contain a plethora of endemic and restricted range species. The area is also home to a complex socio-ecological landscape dependent on flood-related ecosystem, services (*for detailed discussions see* Luke et al. 2005 on plants; De Jong and Butynski 2009 on primates; Owino et al. 2008 on birds; Malonza et al. 2006 on reptiles and amphibians; and Seegers et al. 2003 on fishes). As reported by Moinde-Fockler et al. (2007) and Hughes (1984, 1990) the Tana riverine forests are highly dependent on sustained floods for their health and productivity. In turn, local people and several endemic animals are reliant on the health of these forests. As pointed out by Leauthaud et al. (2013), Hamerlynck et al. (2010, 2012), Maingi and Marsh (2002), and Hughes (1984, 1990), the changes in flood regimes caused by upstream water resources development coupled with intensive land use, increased human pressure, and unsustainable land use practices have resulted in severe degradation of these important forests.

Medley (1993) and Hamerlynck et al. (2010) report on the extensive ecosystem services provided by the Tana riverine forests and their importance to the local population. Medley (1993), for example, identified 93 plant species within the Tana River National Primate Reserve used by local people (resident Pokomo agriculturalists as well as pastoral Orma and Wardei people) for food, construction, medicinal, and other purposes. Both studies note that depositional riverbanks are important for agriculture and the Pokomo people residing within the Tana Riverine Zone. Hamerlynck et al. (2010) further note that riverine forests in the lower basin provide a wide array of ecosystem services:

- Provisioning: flood recession agriculture, fisheries, timber for canoes, roof thatch products, clay for bricks, medicinal products, and water
- Regulating: carbon fixing, erosion protection, climate and flood regulation, water purification
- Cultural: complimentary livelihood strategies, walks across the landscape, rituals regarding access to resources, cultural heritage, and sense of place (ancestral)
- Supporting: soil formation, primary production, water cycling

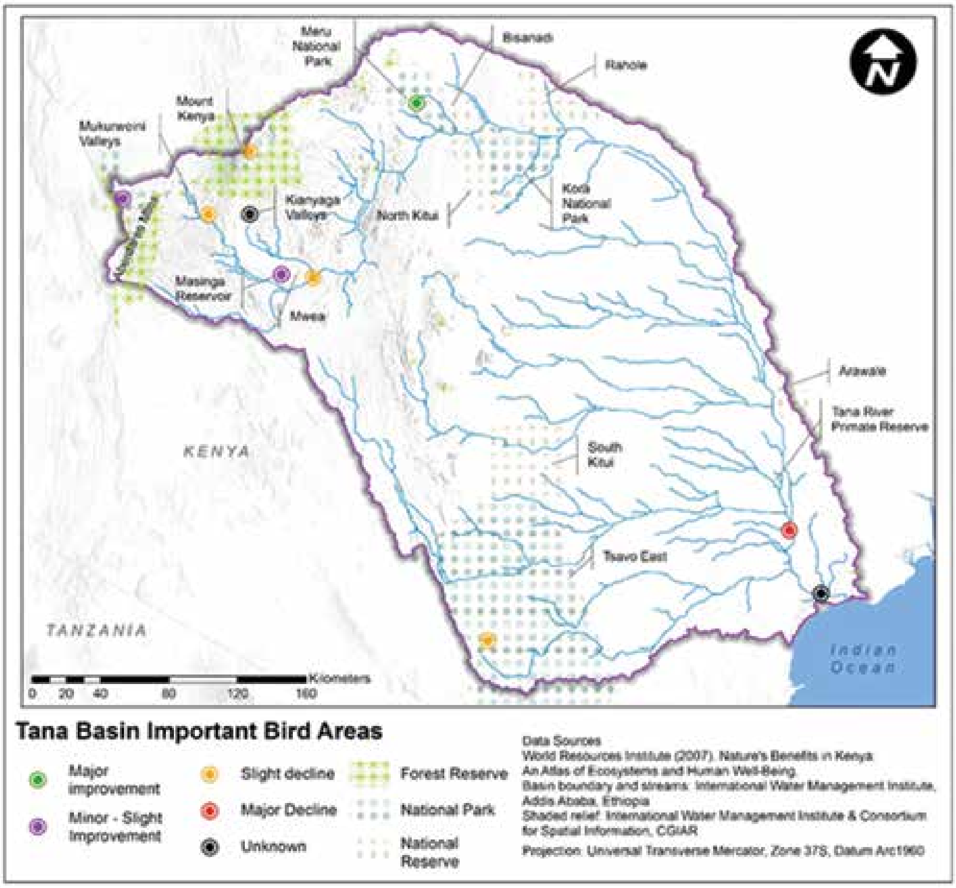
The lower basin riverine forest is also home to the Tana River National Primate Reserve where the Tana River Red Colobus (*Colobus badius rufomitratus*) and Tana River mangabey (*Cercocebus galeritus galeritus*) are endangered and endemic (Mittermeier et al. 2012; Luke et al. 2005). Census numbers in 1994 and 2004 indicate a significant decline in the Tana River Red Colobus population, though the Tana River mangabey population has remained stable (De Jong and Butynski 2009; Luke et al. 2005). Luke et al. 2005 also report a relationship between forest patch size and numbers of primate groups, suggesting that activities that increase forest fragmentation may negatively affect populations. De Jong and Butynski (2009), and Moinde-Fockler et al. (2007) further detail the severe threats caused to this habitat via poor forest management mechanisms, charcoal production, and agricultural expansion. In addition, Hamerlynck et al. (2012) noted that several primate groups have now relocated lower in the basin, in the Tana Delta region. They assert that this behavior suggest that as habitat destruction continues in and around the primate reserve, the animals are moving into completely unprotected areas where threats are even greater. Maingi and Marsh (2002) also found that forest regeneration was severely impacted since the building of upstream dams has altered the flooding and sedimentation regimes in the lower basin.

Throughout the basin, there are ten designated Important Bird Areas concentrated within the forested upper basin and the delta (Figure 19). Areas within the upper basin have fared better than those lower in the basin, despite the intensely managed landscape and higher human population density. This may in part be to the integration of wood lots into croplands and increased efforts by the government to preserve remaining forest areas.

As compared to the Tana Delta, fewer biodiversity studies have been undertaken or received as much attention in the Mount Kenya and Aberdare Range. Eastern Afromontane ecosystems are considered hot spots due to the large numbers of endemic and restricted range species found within them (Myers et al. 2000). In a heavily impacted landscape such as the upper Tana River Basin, a key to preserving biodiversity could potentially be in promoting agrobiodiversity given that basin development is a priority.

It is all too easy to assume that expanding agriculture has a wholly negative impact on the region's biodiversity. It is well considered that replacing native vegetation with agricultural vegetation, which is domesticated and necessarily lacks genetic diversity, can in fact be equated to an overall loss in biodiversity (Gepts 2012). There are ways to combat this total loss, however,

FIGURE 19. Areas within the Tana Basin designated as 'Important Bird Areas' by Birdlife International.



when land is managed under the paradigm of agrobiodiversity where the emphasis is on supporting ecosystems in conjunction with agricultural production based on ecological principles (Brussaard et al. 2010; Jackson et al. 2007; DeFries et al. 2004).

Such approaches advocate for landscape diversification as opposed to intensification strategies, which more often promote landscape specialization. Within much of the basin, crop diversification varies with the uppermost regions having the greatest diversity (Figure 20). Diversified approaches serve two important functions in that they increase resilience to system shocks as well as promote biodiversity. As such, the ecosystem services upon which agricultural production is based upon are also supported and sustained. In other words, such approaches look at landscapes with a systems based perspective.

Already, it is common in the upper basin for farmers to engage crop production in forest remnants or to have woodlots present in cultivated areas (Figure 21). While the percentage of agricultural land and the amount of area set aside with woodlots is small, it does represent an example of a more diversified landscape where many benefits are found: wildlife habitat, fuel, building supplies, and forage. WRI-DRSRS-MENR-CBS-ILRI (2007) found some evidence that diversifying cultivated areas in the upper basin to include woodlots has some benefits: reducing poverty as well as preserving native forest habitats given the high demand for wood products.

FIGURE 20. In addition to small plot sizes and intensive cultivation, the most upper reaches of the basin indicate the highest level of crop diversity (number of crops grown by a farmer simultaneously), but this quickly gives way to areas with low crop diversity that are intensively cultivated on small plots.

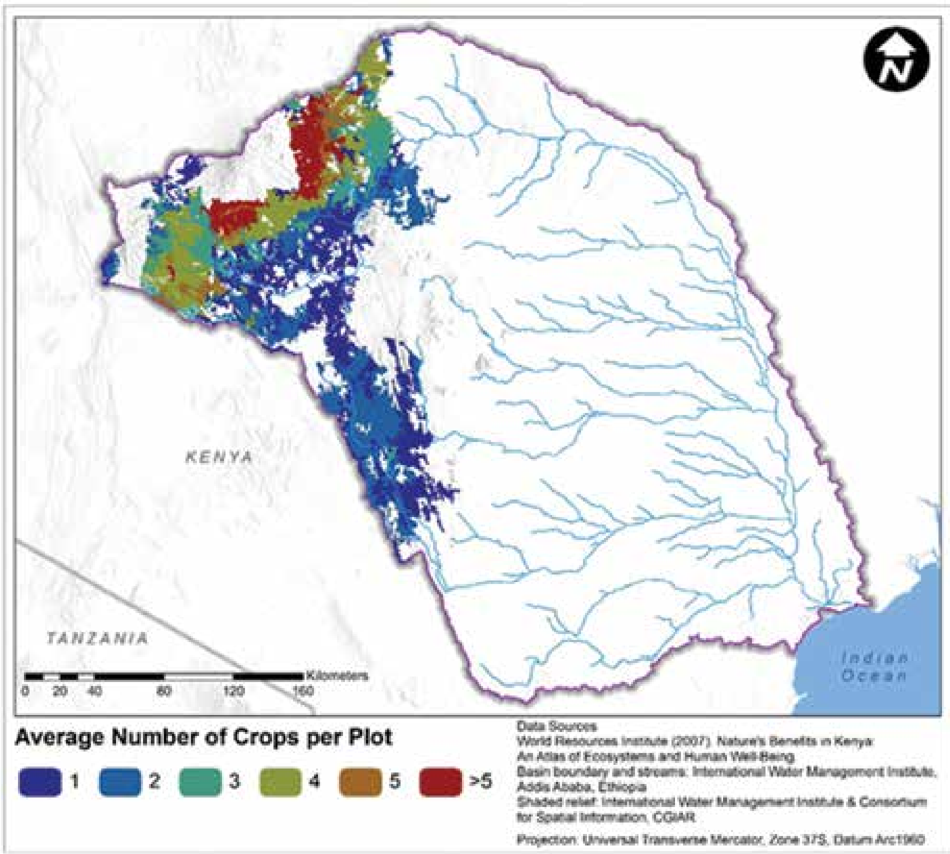
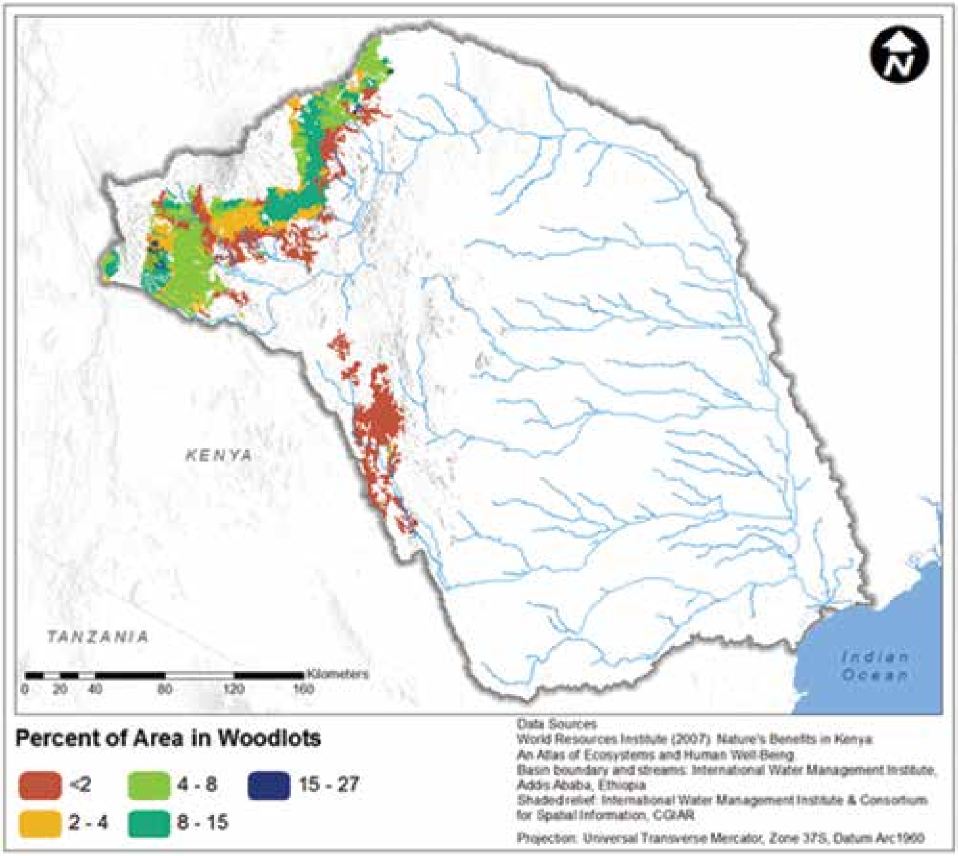


FIGURE 21. Woodlot integration into cropping areas provides fuel wood as well as supports bird habitat.



PART III: PHYSICAL GEOGRAPHY

The Tana River Basin spans an altitudinal range from the Tana Delta at 0 masl up to over 5,000 masl at its upper boundary on Mount Kenya (Figure 22). As such, the basin has a diverse physical geography, spanning upland forests and agricultural lands through the vast Tana Plains, which begin soon after the dissected plain where Masinga Dam is located, and finally into the coastal delta (Figure 23). Greater than 45% of the Tana Basin's contributing source area lies below 350 masl and approximately 80% of the basin area lies below 1,000 masl (Figure 6). This steep relief in the upper basin makes the Tana River an ideal location for hydropower potential.

Agro-ecological zones of the Tana Basin (Figures 24 and 25) range from Coastal to Alpine and represent within them all of Kenya's seven agro-climatic zones, with the majority of land area classified along the continuum of semi-humid to semi-arid.

FIGURE 22. Below the steep slopes of Mount Kenya, the Tana River finds its headwaters in forest areas above Kabaru and winds its way down through the Masinga Reservoir to the delta.

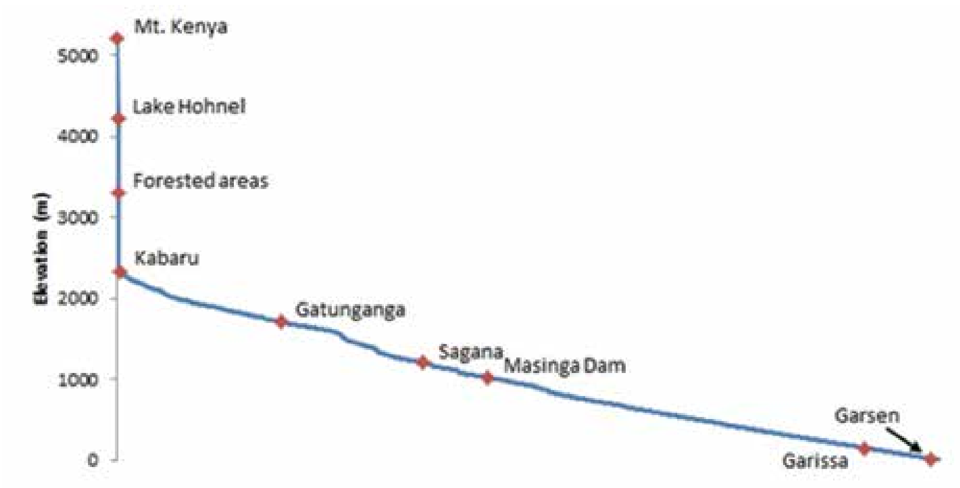


FIGURE 23. Landforms of the Tana Basin illustrate that the basin is dominated by a large plain.

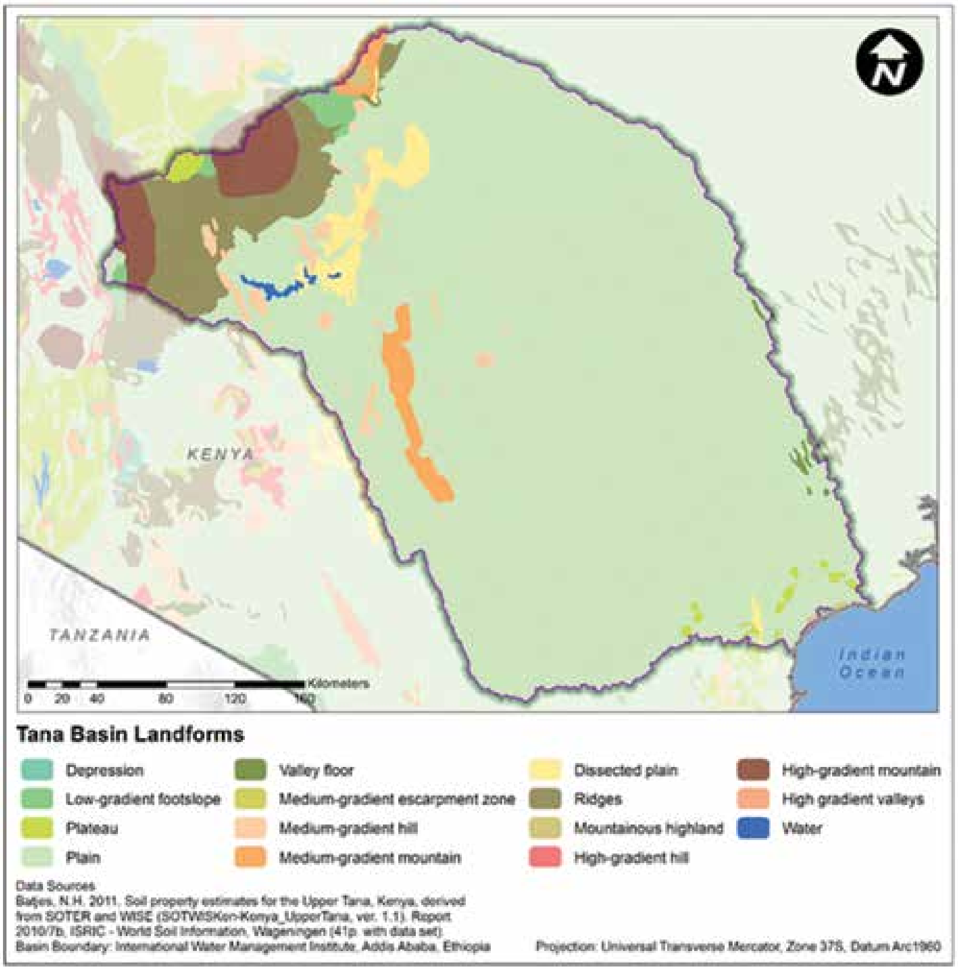


FIGURE 24. Agro-ecological zones of the Tana River Basin.

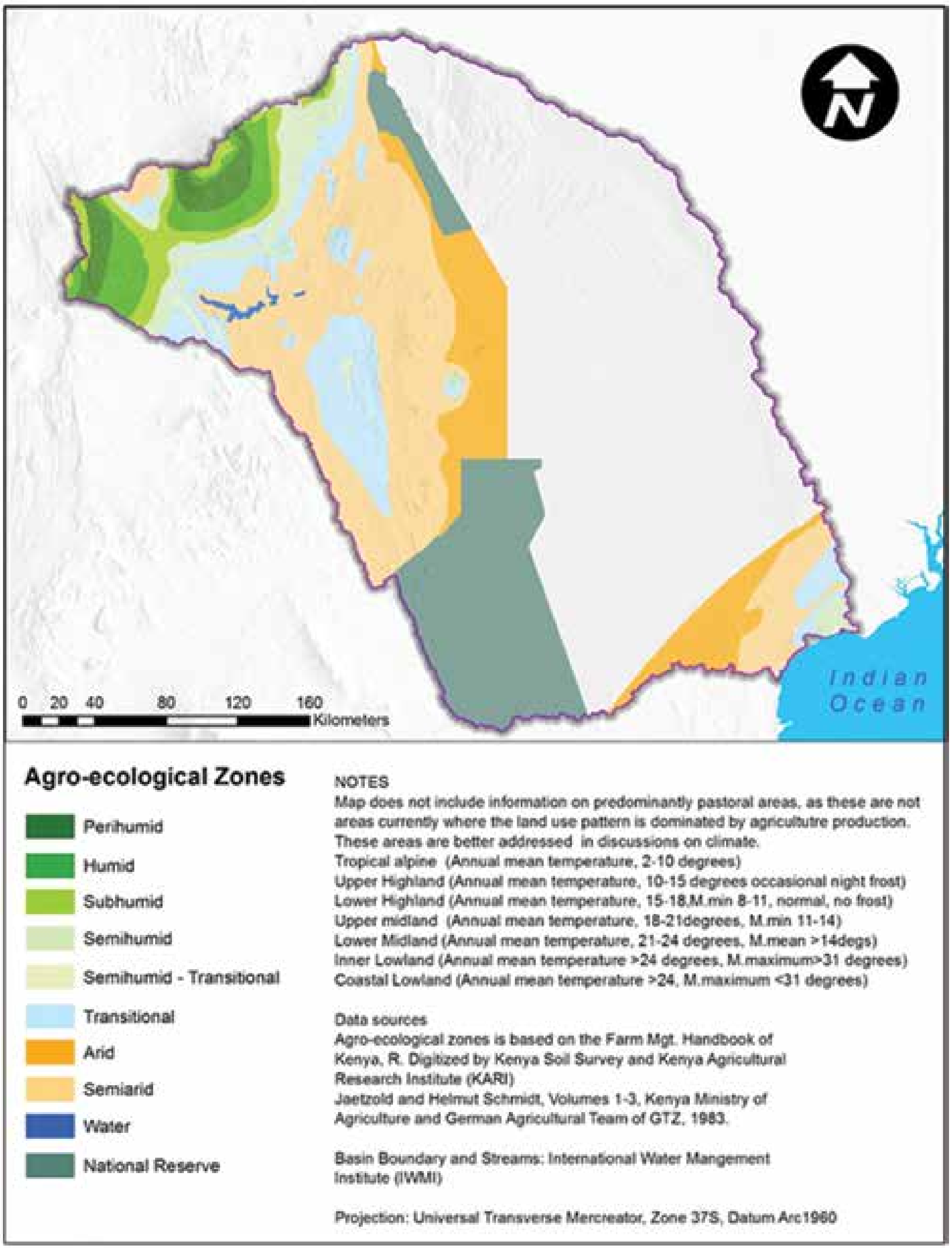
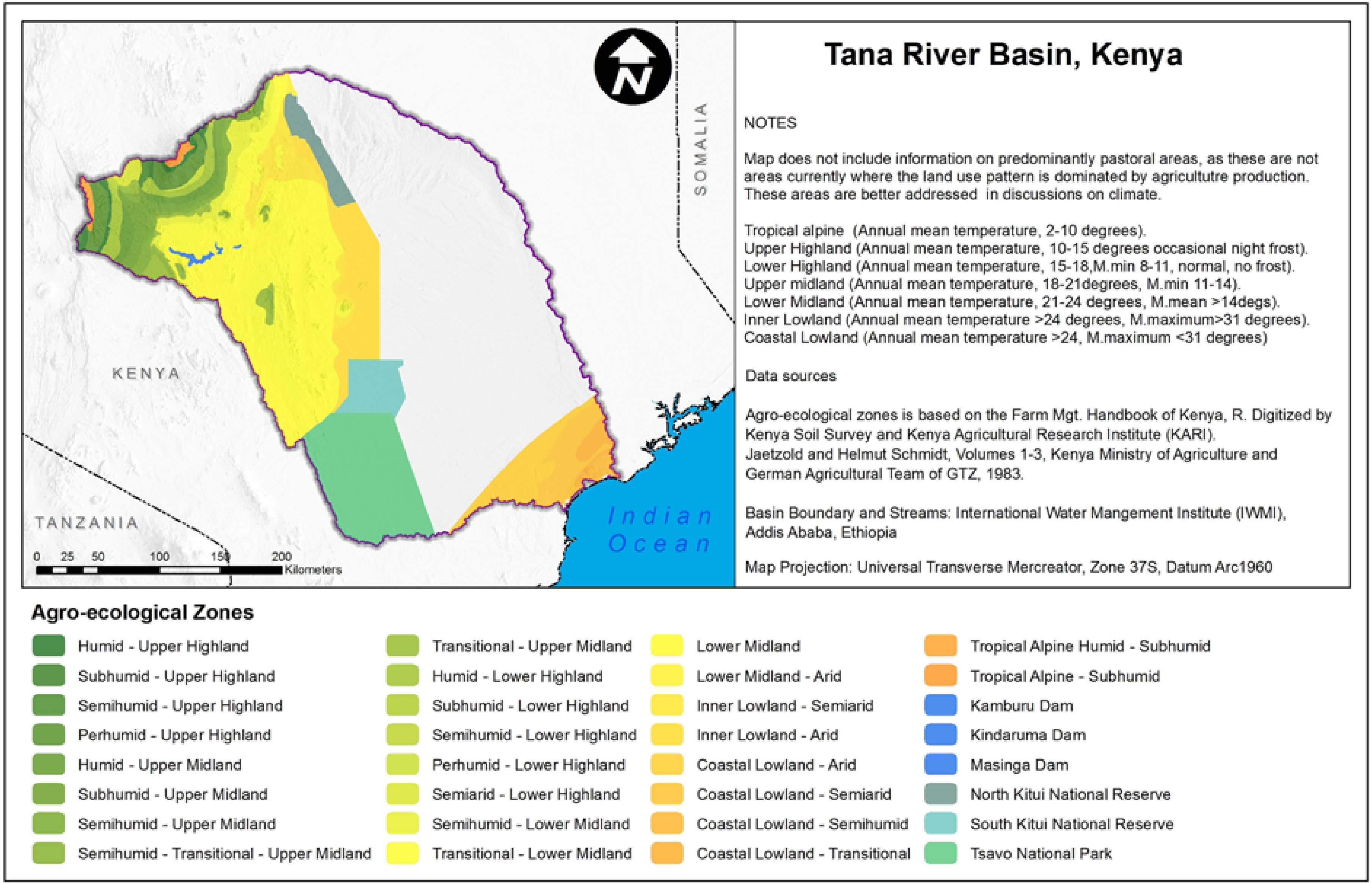


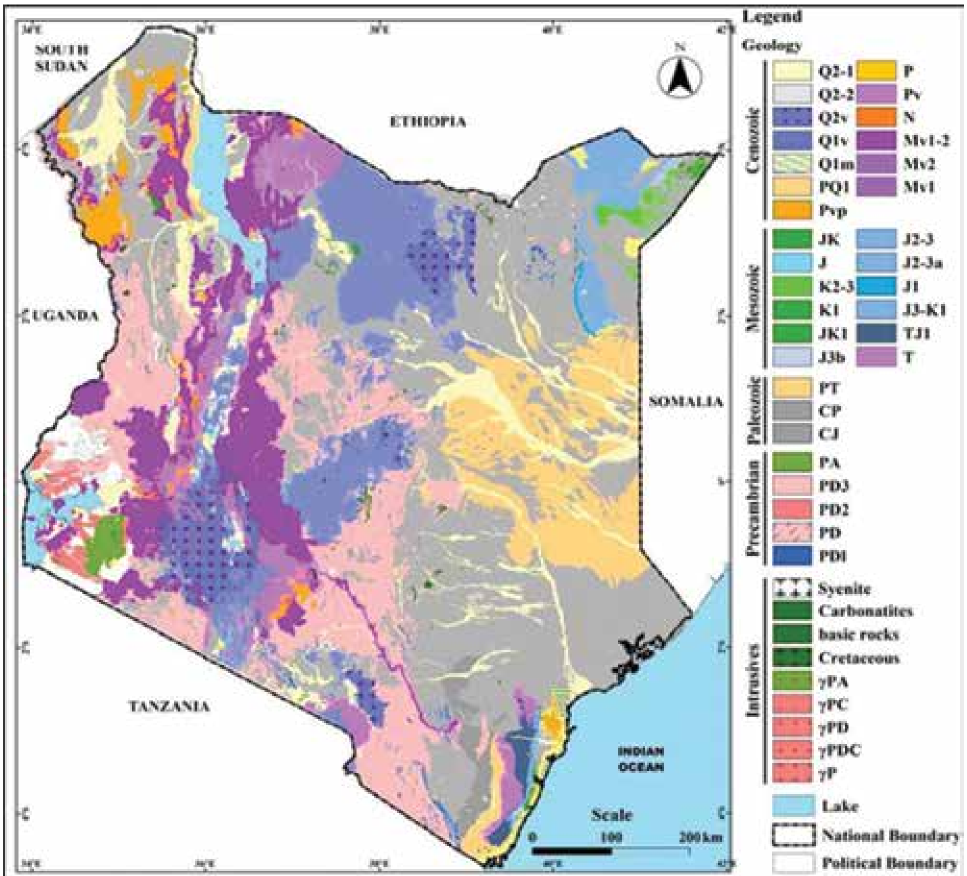
FIGURE 25. Detailed agro-ecological zones of the Tana River Basin.



Geology

Kenya has four major geological series: Precambrian, Paleozoic, Mesozoic, and Cenozoic (Figure 26). Principal geological formations represented in the Tana River Basin are igneous, metamorphic, sedimentary, and unconsolidated rocks in the Tana Delta (Figure 27). Geology of the Tana Basin is partially underlain by the metamorphic rocks of the Mozambique Belt (Schlüter 2008). Quaternary and Tertiary sediments are found within the coastal region and Quaternary Volcanics in its upper reaches around Mount Kenya (Veldkamp et al. 2007). Cenozoic Alluvials occupy the middle and lower stream areas, covering about two thirds of the basin, with some pockets of Marine and Lacustrine sediments. The igneous rock around Mount Kenya was formed as a result of volcanic

FIGURE 26. Geology formations of Kenya.



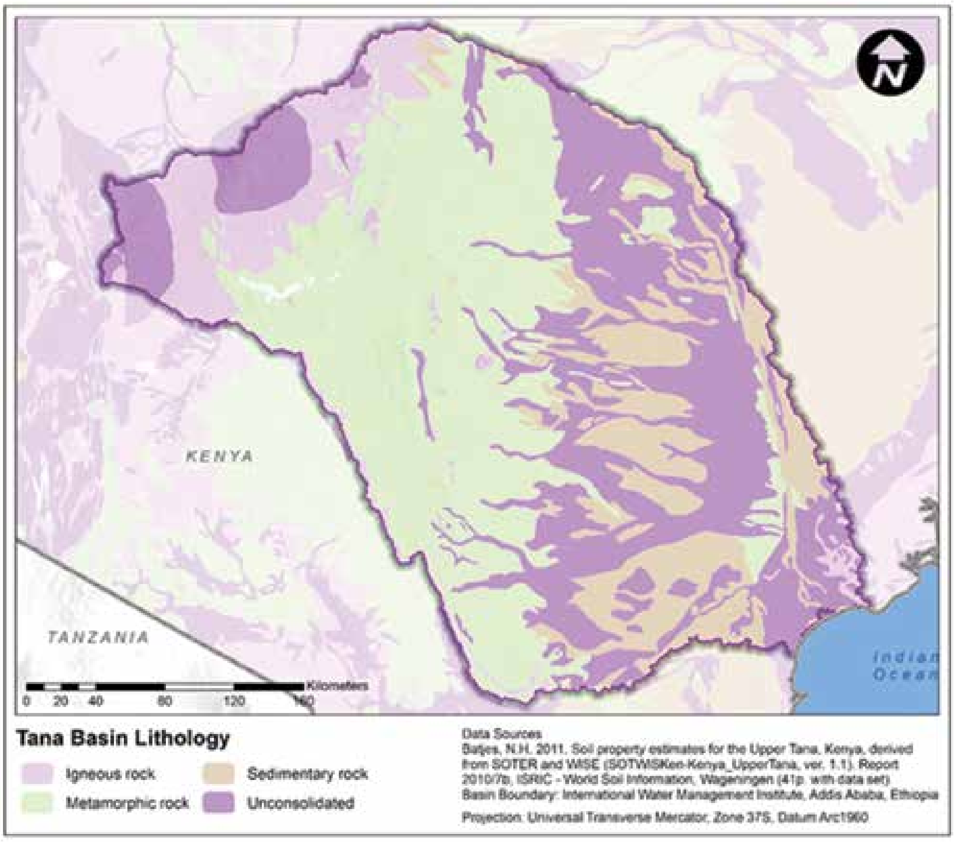
Period	Geology	Description
Cenozoic	$Q_{2\text{-}1}$	Holocene. Alluvium
	$Q_{2\text{-}2}$	Holocene. Colluvial deposits, pebble sheets and red soils
	Q_{2v}	Holocene. Basalt flows, pyroclastics, volcanic soils
	Q_{1v}	Pleistocene. Trachytes, basalts and pyroclastics
	Q_{1m}	Pleistocene. Sands, marine deposits
	PQ_1	Plio-Pleistocene. Sediments of Turkana area
	Pvp	Pliocene. Trachytes, phonolites, basalts, rhyorites
	P	Pliocene. Sandstones, sands
	Pv	Pliocene. Trachyte, phonolite, basalts
	N	Neogene. Undifferentiated sediments, interbedded in volcanic: sands, shales, tuffs
	M_{v1}, M_{v2}	Miocene Phonolites, trachytes and olivine basalts
Mesozoic	JK	Jurassic-Cretaceous. Turkana Grits
	J	Jurassic. Condensate undifferentiated sequence of sandstones, limestones
	$K_{2\text{-}3}$	Cenomanian to Maastrichtian. Marehan series. Sandstones, shales with marine limestones
	K_1	Neocomian. Shales and limestone
	JK_1	Tithonian to Neocomian. Mandera Series. Dolomites, shales, sandstones
	J_{3b}	Kimmeridgian-Tithonian. Dense limestone with an intermediate shale member
	$J_{2\text{-}3}$	Bajocian-Upper Jurassic. Posidonia shales and Kambe oolitic limestone

Period	Geology	Description
Mesozoic	$J_{2\text{-}3a}$	Bajocian to Oxfordian. Mainly limestones oolitic or not with shale sans sandstones
	J_1	Toarcian. Didimtu. Non oolitic limestone
	TJ_1	Upper Triassic-Lower Lias. Coarse grained sandstones
	T	Triassic. Mariakani. Sandstones, shales
Paleozoic	PT	Permian-Lower Triassic. Maji-ya-Chumvi. Shales, siltstones
	CP	Upper Carboniferous-Lower Permian. Taru Grits. Tillites, grits, shales
	CJ	Duruma Series of undifferentiated Karoo
Precambrian	PA	Precambrian A. Bukoban. Quartzites and volcanics
	PD_3	Precambrian D_3 Kavirondian. Emba. Grits and mudstones
	PD_2	Precambrian D_2 Nyanzian. Rhyolites, andesites, basalts and greywackes
	PD	Precambrian D. Mozambique belt. Quartzites, micaschists, biotite and hornblende gneiss, granitoid gneiss, amphibilolites, migmatites, syntetonic granites
	PD_1	Crystalline limestones, intercalations in PD
Intrusive	γPA	Precambrian A
	γPC	Precambrian C
	γPD	Precambrian D
	γPDC	Precambrian DC
	γP	Undifferentiated Precambrian

Map source: Ministry of Environment, Water and Natural Resources 2013.

activity in the mountain. However, it is now extinct having erupted last 1.3 - 1.6 million years ago (Baker 1967). The lower slope of the mountain has never been glaciated. The area is comprised of unconsolidated soils or rocks from volcanic deposits and these loose soil particles are prone to weathering and erosion.

FIGURE 27. Major rock groups of the Tana River Basin.



Phonolites, trachyphonolites, basalts, ignimbrites, and trachytes of different phases of volcanism (Hughes et al. 2012) represent volcanics upstream in the Tana River Basin. The middle Tana flows through metamorphic rocks such as gneisses, schists, migmatites, quartzites, and calc-silicate rocks, which are associated with marble (Bear 1952). Middle and lower areas of the Tana Valley run through Plio-Pleistocene sediments of the Lamu embayment. There are several terrace remnants of at least three higher fluvial levels occurring. At the transition from the Precambrian metamorphic area to the sedimentary area, the stream pattern changes to meandering and as a result, a broad alluvial valley has been formed (Oosterom 1988; Schlüter 2008). At the mouth of Tana River, there is a broad floodplain connected by widespread deltaic environments dominated by silt/clay environments (Thompson 1956).

Soils

While numerous soils make up the Tana Basin (Figure 28), Solonetz, Ferralsols, and Planosols comprise approximately 56% of the total area (Table 29). Solonetz soils are alkaline or sodic and have high clay content in the surface horizon. Within the Tana Basin, these soils dominate the riparian areas and floodplains, and are commonly associated with coastal areas (Figure 29). These soils are slow to drain due to their high clay content, which is another difficulty faced in both rain-fed and irrigated agriculture, as these soils are easily inundated.

Ferralsols are another soil that dominates the middle catchments of the Tana Basin (Figure 29; FAO-IIASA-ISRIC-ISS-CAS-JRC 2008), and are generally old and highly weathered. While these soils are deep and have clay materials and micro-aggregates diffused throughout their profile, giving them a good physical structure, but they have low fertility. In addition to their low fertility, they exhibit poor hydrological function in that their high clay content results in water retention, while the presence of micro-aggregates decreases the soil's ability to hold available water.

FIGURE 28. FAO soil groups found within the Tana Basin.

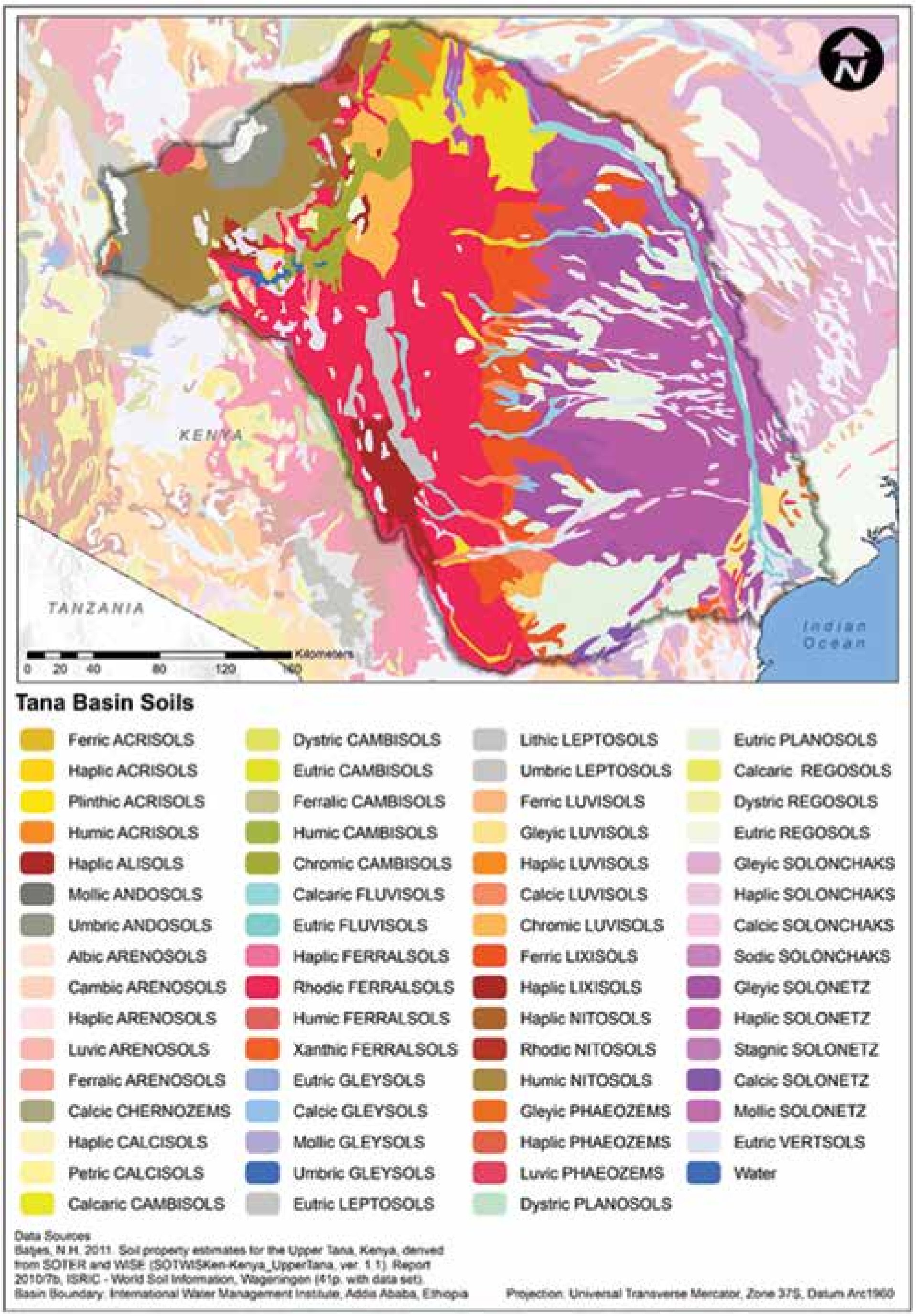


FIGURE 29. Solonetz and Ferralsols soils dominate the Tana Basin.

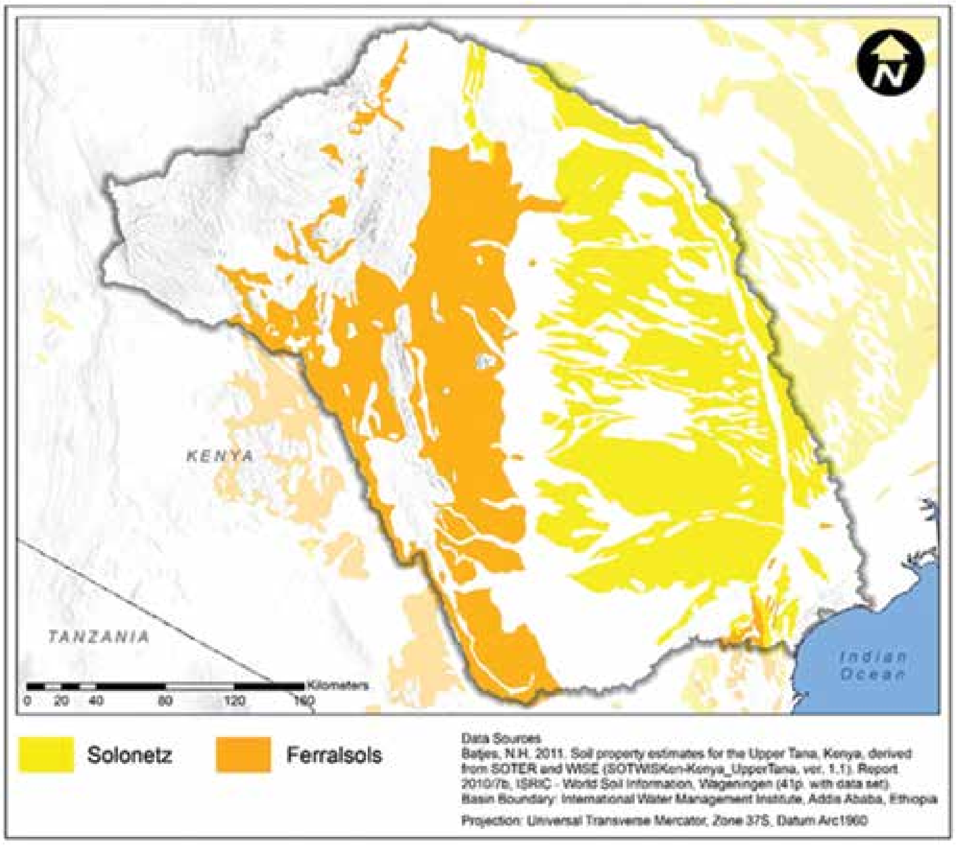


TABLE 29. Soil coverage of the Tana Basin.

Soil Type	Area (km^2)	% of Basin	Soil Type	Area (km^2)	% of Basin
Solonetz	23,459	25	Leptosols	1,688	2
Ferralsols	19,930	21	Regosols	886	1
Planosols	9,849	10	Phaeozems	641	1
Lixisols	7,665	8	Histosols	559	1
Cambisols	7,211	7	Arenosolsl	558	1
Nitisols	6,920	6	Gleysols	498	1
Luvisols	5,290	5	Solonchaks	260	<1
Vertisols	4,606	4	Acrisols	108	<1
Fluvisols	2,447	3	Chernozems	32	<1
Andosols	2,214	2	Calcisols	19	<1

Source: Derived from the Soil and Terrain Database (SOTER) of East Africa, and Batjes 2011.

In the mid-slopes of the Aberdare Range and Mount Kenya in the upper catchments, Humic Nitisols are the dominant soil type. These soils are formed on volcanic deposits and are strongly weathered, but far more productive than most other red tropical soils (ISRIC 2008; NAAIAP 2014). Humic Nitisols are well-drained, deep, dark friable red soils and are commonly referred to as *Kikuyu* red soils (Kapkiyai et al. 1999; UNESCO 1977). They are generally good for agriculture and are mainly cultivated with tea or coffee and food crops such as maize in smallholdings. The soils are highly resistant to soil erosion, but poor land management practices in these areas that receive ample precipitation, can degrade the soils leading to excessive soil loss (Geertsma et al. 2009, 2010; ISRIC 2008).

Climate

Kenya's climate is strongly influenced by the inter-tropical convergence zone (ITCZ), resulting in a bimodal precipitation pattern (McSweeney et al. 2010a). An assessment of monthly records for the Tana Basin region indicates a bimodal precipitation pattern throughout, with long rains generally occurring from March – May and shorter rains from October – November. There are two dry seasons from June – September and December – February. The exception to this rainfall pattern is in the uppermost basin, where there is continuous rainfall from March – November with peaks in March – May and October – November and a short dry season from November – February. The average annual temperatures in the Tana Basin range from -5 ◦C to 25 ◦C in the uplands and 22 ◦C to 30 ◦C in the coastal areas (Figure 30). Within the Tana Riverine and Pastoral zones (Figure 7), average annual maximum temperatures can reach 35 ◦C to 38 ◦C (FEWS NET 2011). Similarly, rainfall varies from 300 mm in low-lying regions to 2,400 mm around Mount Kenya annually (Figure 31), though some coastal and pastoral regions may receive only 200–250 mm (FEWS NET 2011). Within the Tana Basin there are 228 stations currently maintained or archived by the Kenya Meteorological Department, which present a variety of climate variables, though with varying degrees of completeness (Figure 32).

FIGURE 30. Average annual minimum and maximum temperature in the Tana Basin.

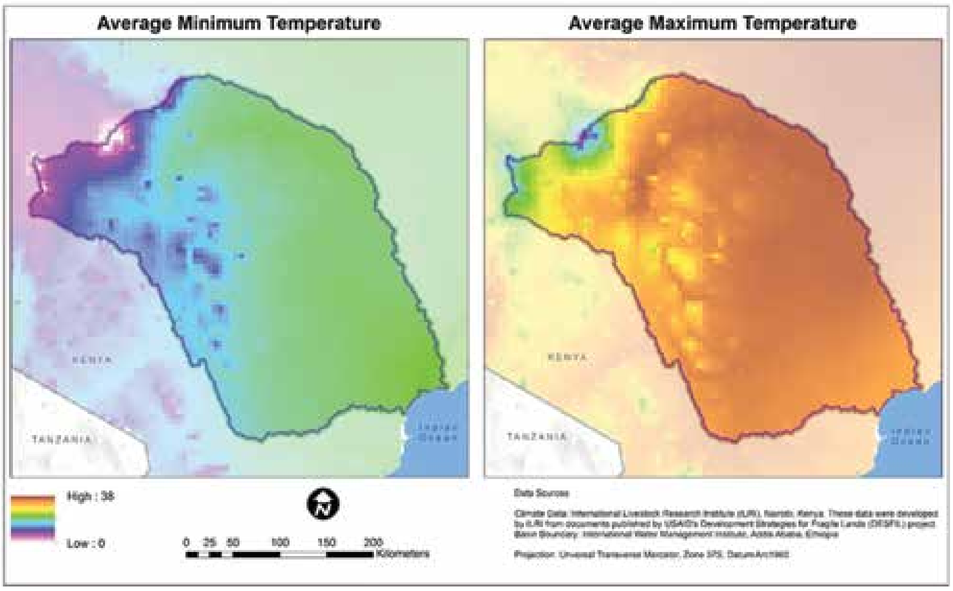
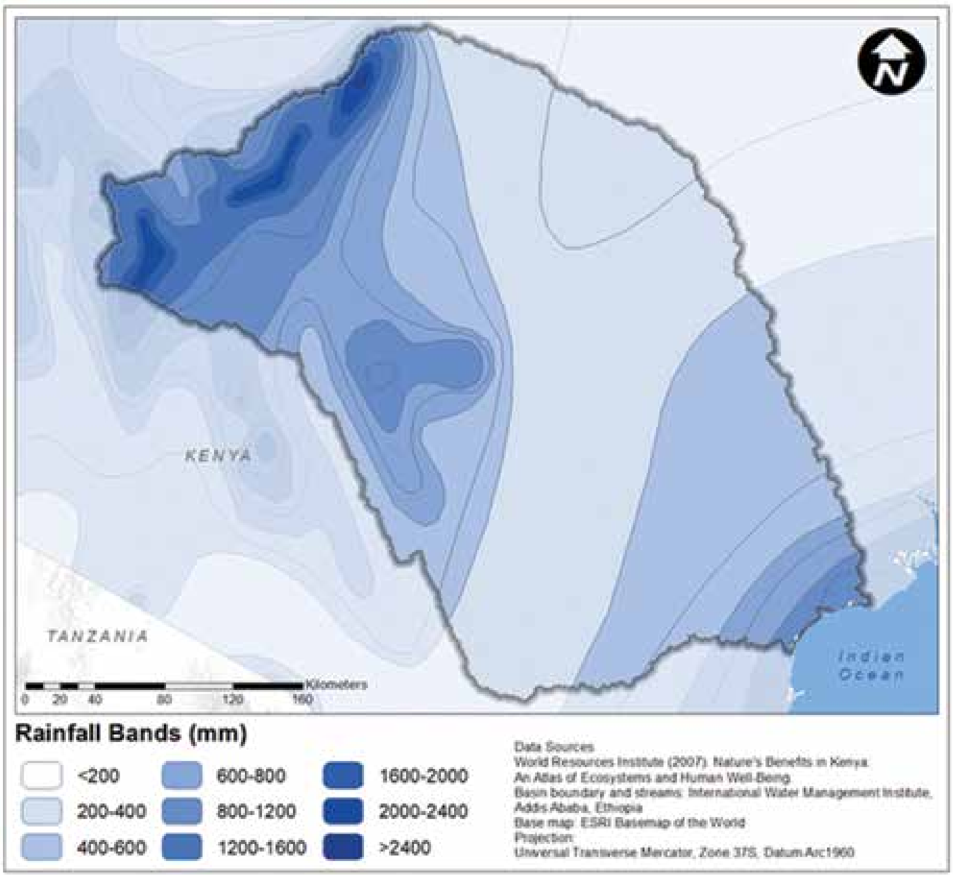


FIGURE 31. Rainfall bands within the Tana Basin indicate low rainfall amounts in pastoral dominated areas with higher rainfall along the coast and in the upper reaches of the basin.



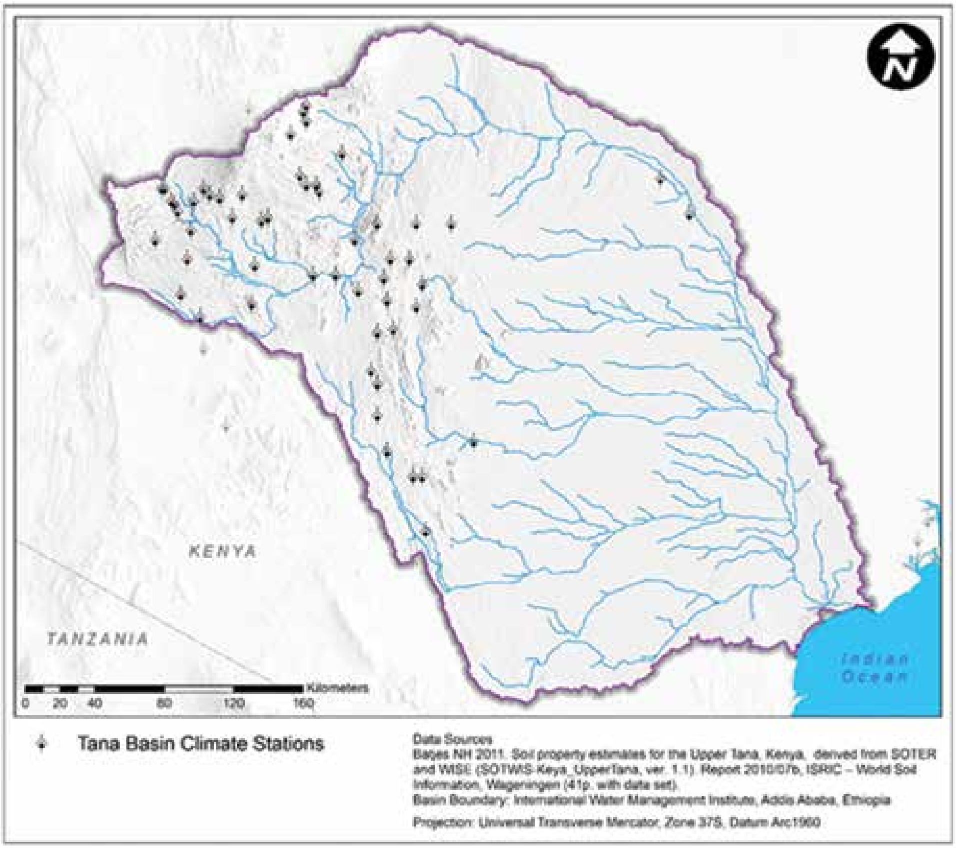
High inter- and intra-annual variability in precipitation has important implications for stream flow, patterns of water availability and use, and for ecosystem services within the Tana Basin. Volume, timing and duration of precipitation patterns vary considerably from year to year, especially during extreme El Niño/Southern Oscillation (ENSO) events. During such times, precipitation is greater than average, resulting in increased flood risk. Conversely and following El Niño events are La Niña events that bring drier than average conditions and drought (McSweeney et al. 2010b).

Kenya experienced particularly challenging circumstances during the El Niño (1997/98) and La Niña (1999/2000) events. Around 300,000 people were displaced and there were striking increases in water-related diseases (cholera, typhoid, amoeba, and bilharzia), disruptions in food supplies due to flooded roadways, and severe social disruption that compelled women and children to walk greater distances to draw water (Mogaka et al. 2006).

Climate Change

Evidence suggests that mean average temperatures in Kenya have risen by 1°C since the 1960s, and while there are no statistically significant rainfall trends (McSweeney et al. 2010a, 2010b), there is direct evidence that overall rainfall amounts during the long rains have declined by as much as 100 mm (Funk et al. 2010). Models as far ahead as the 2090s project further increases in both temperature and annual rainfall at the national level, and more intense rainfall events, but

FIGURE 32. Sample of the distribution of climate stations within the Tana Basin. Not all locations are presently functioning, but contain historical records only.



there is no consensus on future ENSO patterns (McSweeney et al. 2010a, 2010b). Downing et al. (2009) reported that most climate change models, generally, show a potential additional increase in temperature in Kenya by as much as 1°C by 2030.

An increased number of intense rainfall events is likely to lead to increased runoff and heightened flood risk. Nevertheless, the impacts in a specific location depend on many other (non-climatic) bio-physical and socioeconomic factors contributing to hydrological change, in addition to the uncertainties inherent when downscaling climate models (Conway 2011; Taylor et al. 2013; Oates et al. 2014). Climate change is perhaps best understood as a 'threat multiplier' – exacerbating risks to natural resources and social systems, already posed by Kenya's variable rainfall patterns, coupled with population growth, land use change, and other natural or anthropogenic pressures on water resources (Brown et al. 2007).

Rainfall variability and future changes are thought to pose significant risks for Kenya's socioeconomic development, as many key sectors are climate-sensitive (NCCRS 2010). For example, a 2010 assessment of historical climate trends toward drying, indicate a threat to crop surplus regions in Central Kenya, and specifically in the upper Tana River Basin (Funk et al. 2010). Mogaka et al. (2006) estimate that extreme climate events, such as floods and droughts, are already costing the Kenyan economy 2.4% of GDP (KES 16 billion) per annum due to crop losses, livestock deaths, reduced hydropower generation, and declines in industrial production. Droughts on the other hand, such as the 1999/2000 La Niña drought reduced output in every major sector of the economy (Mogaka et al. 2006) and left approximately 4.7 million Kenyans facing starvation (Government of Kenya 2010). In short, within the Tana River Basin the existent high level of uncertainty in potential future climates means that planning for a range of possibilities is critical across the entire water-energy-food nexus.

PART IV: BASIN HYDROLOGY

Surface Water Hydrology

Mount Kenya and the Aberdare Range together form the headwaters for the Tana River Basin. From a management perspective, the basin is divided into 35 management areas located within the basin boundary and managed by the Water Resources Management Authority of Kenya (WRMA; http://www.wrma.or.ke/; Figure 33). These management areas, in general, follow the boundaries of major hydrological subcatchments and features within the basin. The Tana River system consists of several tributaries, including several perennial tributaries: Chania, Thika, Maragua, Saba Saba, Thiba, Nyamihidi, Ena, Nithi, Mutonga, Thanantu, Bisanadi, and El Lurt. In the uppermost reaches of the Tana River, the Chania and Thika rivers have their waters diverted to Nairobi Metropolitan Area through Sasumua and Thika dams in the Upper Tana Basin. In the middle to lower reaches of the Tana River, several tributaries such as Tula, Herimani, Thua, and Tiva *lagas* join the main stem of the Tana River; however, they are all seasonal (Figure 34). Adjacent to the eastern lower basin is Ijara-Lamu with rivers flowing to Somali (13,281 km^2) or into the Indian Ocean (17,253 km^2) (Ministry of Environment, Water and Natural Resources 2013). As previously indicated, this region accounts for 24.2% of the Tana River Basin management area, though it is not hydrologically connected. Average annual flows measured at Garissa are

FIGURE 33. Management areas within the Tana River Basin.

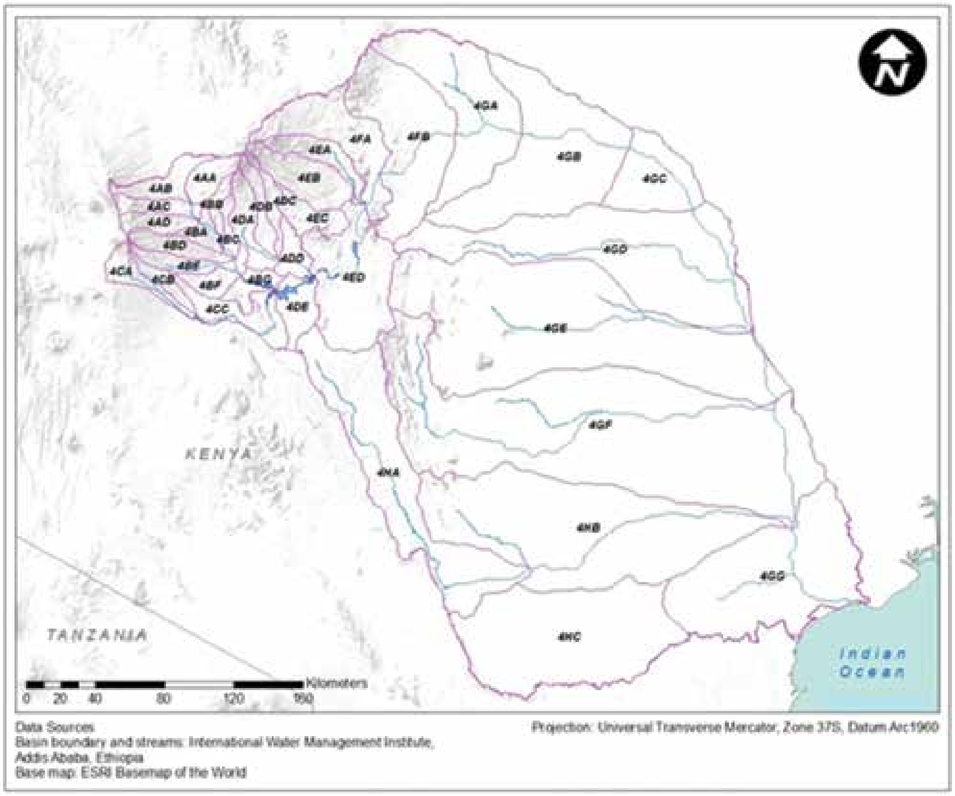
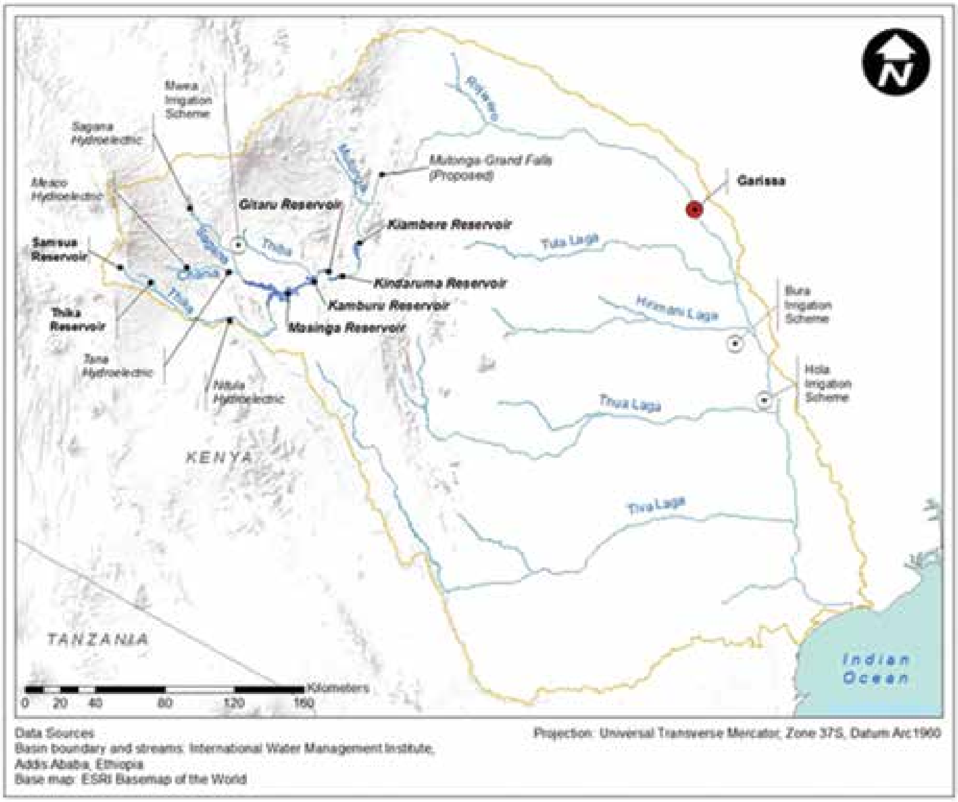


FIGURE 34. Major built infrastructure of the Tana River Basin. As illustrated here, most infrastructure is confined to the upper basin.



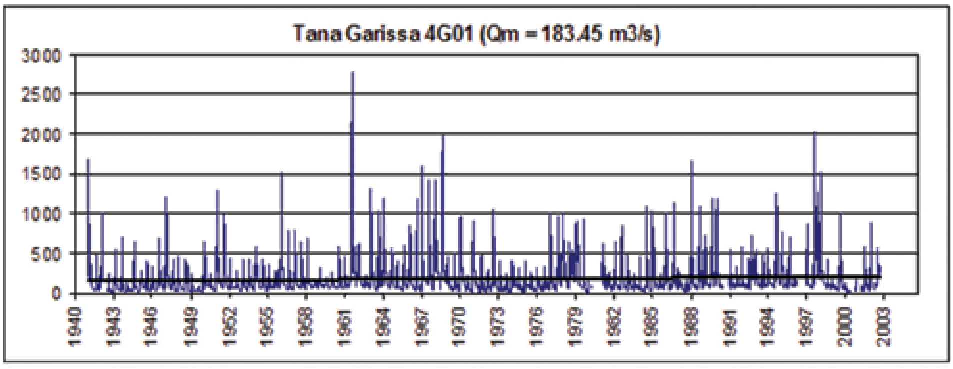
156 m^3s^{-1} (Duvail et al. 2012) or 5.02 km^3yr^{-1} (Leauthaud et al. 2013), with a peak discharge of 3,568 m^3s^{-1} recorded on November 21, 1961 (Maingi and Marsh 2002). Further downstream at Garsen, Leauthaud et al. (2013) report a discharge of 3.12 km^2yr^{-1}.

Following its bimodal precipitation pattern, the Tana River experiences annual peak flows during the long rains (March through May) and the short rains (October through December). The river discharges in the Tana Basin range between 60–750 m^3s^{-1} and has a marked seasonal signal (Geertsma et al. 2009, 2010). Flow regulation along the main stem by the Upper Tana reservoirs can be low at times, which is due to significantly high inflows relative to reservoir capacity, though spillage events are now becoming more frequent. This is illustrated in the discharge hydrograph of a downstream gauge station (Station 4G01) in Garissa (Figure 35).

Surface water and groundwater resources within the Tana Basin are used to meet water demand needs throughout the basin. It is estimated that annual surface runoff of 5,853 Mm^3 can be harnessed alongside an annual sustainable groundwater yield of 585 Mm^3 in the Tana Basin (Ministry of Environment, Water and Natural Resources 2013). Sustainable groundwater yields were calculated as 10% of the groundwater recharge excluding river courses and riparian areas with a width of 1 km, where groundwater abstraction is restricted in the catchment area. Present water demands (2010) are estimated to be 14% of the available water resources. That said, the water demand is expected to increase drastically to 105% by 2030, making the Tana, a river basin under severe stress (Ministry of Environment, Water and Natural Resources 2013).

Kenya's Water Resources Management Authority (WRMA) has its regional office for the Tana Basin in Embu and is the agency responsible managing hydrological data.Currently, throughout

FIGURE 35. Discharge hydrograph of Tana River at Garissa.



Source: WRMA 2008.
Note: Average annual discharge over the period of record is indicated by the black line.

the entire Tana River Basin, there are 35 river gauging stations, of which only 5 have installed automatic data loggers. At the time of this writing, WRMA (at Embu) has only one observation borehole dedicated for groundwater monitoring. In addition, there are 44 water abstraction boreholes also used to monitor groundwater by the agency. The agency plans to add 18 additional dedicated groundwater-monitoring boreholes in the catchment.

Flooding

Flooding supports ecosystem services, such as delta building and forest regeneration, but can also result in disservices, such as loss of life, property, and livelihoods, to the people, flora, and fauna of the Tana River Basin. Over the past 50 years, the Upper Tana catchments above the Masinga Dam has undergone rapid and major large-scale land cover changes, as previously discussed. Forest losses from conversion to small-scale agriculture and timber harvest activities, particularly in the headwater regions, have caused a general trend in increased surface runoff (e.g. flow flashiness) and flooding during the rainy seasons coupled with drastically decreasing dry season flows. It is asserted that the increased flooding directly caused by upstream changes have been controlled by the Seven Forks Dams (Figures 34 and 36). This was evident during the 1997–98 El Niño events because there was a decreased flood impact coming from upstream versus direct rainfall (Gadain et al. 2006). In the lower vast semi-arid and arid areas of the Tana Basin, flash floods are also experienced in the seasonal tributaries (*lagas*) during extreme rain events.

Maingi and Marsh (2002), Hughes (1990), and Medley (1990) have suggested that that the flood regime within the Tana Basin is critical to downstream habitats, especially riverine forests. Periodic flooding causes changes in stream meandering with some meanders being cut off, often forming oxbow lakes, and the result is a complex and diverse floodplain where transitional or pioneer forests are found. These floodplains have traditionally received sediment-laden floodwaters via two mechanisms: from upstream through the main stem and through occasional flooding of the *lagas*. Since the building of the Seven Forks Dams upstream, however, changes have been noted in the flood regime, with as much as a 20% reduction in peak flows (Leauthaud et al. 2013; Maingi and Marsh 2002).

When dams are built, downstream flood regimes are altered with potentially negative impacts to ecosystem services (Maingi and Marsh 2002). Changes upstream in the Tana Basin are leading to flashier flows with increased volumes of water reaching the reservoir. Flashier flows are also associated with heavier sediment loads entering the reservoir. When the reservoir overflows, as

FIGURE 36. Seven Forks Dams in the Upper Tana River Basin.

Note: Average annual discharge over the period of record is indicated by the black line.

it did during the 1997-98 El Niño events, there can be heavy damage to downstream riverine ecosystems. In Garissa, which was severely affected by the 1997-98 El Niño floods, houses in the built-up areas from 600 m to 700 m away from the left bank of the river were inundated to a depth of more than 1.0 m (Ministry of Environment, Water and Natural Resources 2013). As reported in Leauthaud et al. (2013), after Garissa, floods are attenuated and so reservoir overflow events are felt less downstream. Significant flood damage experienced during the 2010 enhanced long rains in the Tana Delta were more likely the result of *lagas* flooding and direct rainfall.

In normal non-extreme rainfall conditions, the reduced flooding within the Tana River has led to the reduction of riverine forest along the floodplains (Hamerlynck et al. 2010, 2012; Maingi and Marsh 2002; Hughes 1984, 1990; Medley 1990). Riverine forest decline is exacerbated by expansion of large-scale irrigation and forest over-exploitation for charcoal and fire wood in the floodplains (Moinde-Fockler et al. 2007; Hamerlynck et al. 2012). Flood-based farming along with the high and unique biodiversity supported by the riverine habitat along the floodplains, have been negatively affected (Hamerlynck et al. 2012). Groundwater recharge on the local and semi-regional aquifers found within the Tertiary sediments and Quaternary alluvium deposition, which relies on periodic flooding within the floodplains, has also reduced in the lower eastern part of the Tana Basin (Knoop et al. 2012).

High Grand-Falls Dam, the sixth dam in the Seven Forks Project, has a planned flood control space of 1,458 Mm^3 above its live storage and is expected to significantly reduce flood-related damages downstream. However, there is a fear that the large dam and the river flow diversions for irrigation will cease completely the natural flood regime that has sustained the riverine forest and biodiversity along the floodplain and the Tana Delta (Hamerlynck et al. 2012). Other soil and water conservation interventions are planned in the upstream catchments, to slow surface runoff and reduce the negative effects of the flooding and sediment delivery on the Seven Forks Project (WRMA 2008).

Flood monitoring in the Tana Basin is carried out by TARDA and WRMA. TARDA's flood forecasting and warnings are derived by monitoring storage levels at the Masinga Dam. TARDA is also expected to monitor and control flood discharge for the High Grand-Falls Dam upon completion. Downstream of the Seven Forks Project, there are two river gauging stations at Garissa and Garsen for flood monitoring. These gaging stations have three water levels: alert, alarm, flood; and are monitored by WRMA (Embu). Flood monitoring information is relayed to the national and county administration in the Lower Tana catchments. There are also plans to build flood protection infrastructure in Garissa Township (Ministry of Environment, Water and Natural Resources 2013).

Sedimentation

Within the Tana Basin, an important component of flooding is sediment delivery. Poorly maintained agricultural lands and cultivation of unsuitable lands such as stream banks and steep slopes, has caused considerable soil loss in the Upper Tana Basin, in particular, and is a major land management challenge with maize and coffee production areas being particularly prone to erosion during high rainfall (Knoop et al. 2012; Mogaka et al. 2006). Growing rural populations in the upper catchments – along with an associated rise in demand for agricultural land – have contributed to conversion of forested areas into small-scale agricultural plots. In many instances, farmers are engaged in unsustainable agricultural practices such as continuous tillage, which leads to an increase in runoff volume (WRMA 2008; Kitheka and Ongwenyi 2002). Soil loss is more pronounced during the short rains (October – November) than during the long rains (March – May) due to lack of vegetation on the landscape (Brown et al. 1996; Hughes 1984). Knoop et al. (2012) reports that within the upper basin there is a direct relationship between stream flows and sediment loads, with low flows of 0.10 m^3s^{-1} producing 2–5 mg/l loads and higher flows of 100 m^3s^{-1} producing as much as 100 mg/l of sediment.

It is estimated that the sediment load in the Tana River varies from 2,796 tonnes per day during dry season to about 24,322 tonnes per day during the rainy season (Kitheka et al. 2005). This sediment load translates to between 1 and 8 million tonnes per year. These current estimates are far greater than earlier estimates of sediment flow through the Tana Basin, which amounted to an average 0.25 million tonnes per year in 1965 and 2.5 million tonnes per year in 1986 (IFAD-UNEP-GEF 2004). Dunne and Leopold (1978) as reported by Hughes (1984) have suggested, however, that sediment transport rates at Garissa may be as high as 8.5 million tonnes per year.

Downstream from Garissa, no perennial tributaries enter the Tana River; however, several ephemeral streams provide a substantial contribution to flow and sediment discharges into the riverine system during major flooding events, such as the El Niño (Hughes 1984, 1990). As Brakel (1984) asserts, large sediment loads are predictable from the Tana River given its well-developed delta. From this perspective, sedimentation provides an ecosystem service, as rich nutrients are transported and deposited downstream. It is a delicate balance, however, because when sediment plumes increase substantially, they can have negative consequences offshore when light is blocked leading to, for example, coral reef die offs (Mogaka et al. 2006).

Hughes (1984) points out that floodplains developed through sediment deposition have given rise to the best floodplain forest. Maingi and Marsh (2002) stress that sediment trapping overall has been high in dams along the Tana River, and they give the example of Ongwenyi et al. (1993) in which the authors reported that 12.6 Mm^3 of sediment were deposited in the Kinaruma Reservoir from 1968–1970. Bunyasi et al. (2013) further estimates that sediment trap rates for the Masinga Dam are as much as 100% for sand, 99% for silt, and 2% for clay, and that no spillage years are becoming more common. This poses a challenge for the delta as well as for hydropower production.

For the delta and riverine forests, without sediment deposition, they necessarily erode. Tamooh et al. (2012) report that analyses of suspended sediment loads in the Tana River reveal that lower basin sediments are now derived predominantly from riverbank erosion and occasional pulses from the *lagas*, confirming concerns that other researchers have raised that the dams are trapping most sediment. Such degradation has the potential to negatively affect livelihoods in communities that have become reliant on the nutrient-rich sediment-laden floodplains.

A major mechanical challenge in dam infrastructure for hydropower production can be high sediment loads from the upstream catchments. Bunyasi et al. (2013) report this as a concern for the Seven Forks Project, in that captured sediments have an abrasive effect on power generating mechanisms adding to energy losses and maintenance costs. This makes controlling sediment delivery through improved upstream land management practices a critical priority for the life of dams downstream.

The main upstream reservoir in the Tana Basin is the Masinga Dam; however, it was designed based on a siltation rate of 3 million tonnes per year of sediment (Mogaka et al. 2006). By 1988, the siltation rate had increased to 10 million tonnes per year, reducing the water storage by 6% over 8 years (Mogaka et al. 2006). Increased upstream water use for irrigation, especially at the Mwea Rice Irrigation Scheme, and the increasing water supply transfers to Nairobi are also reducing the water inflows to the reservoirs.

Mogaka et al. (2006) conducted a study between February 2001 and November 2003 along the Tana River system to the estuary. According to this study, most of the sediment flows are associated with poor land use activities and land use change in the upper catchments. Sediment flow regulation afforded by the Seven Forks reservoirs is minimal due to large inflows as compared to current storage capacity, resulting in low sediment trap efficiency for the dams. Masinga, the uppermost reservoir, has already lost significant live storage due to high sediment inflows far above the initial design estimates.

Future sediment flow dynamics downstream may change with the construction of the High Grand Falls Dam, which will have a live storage of 6.5 Bm^3. The dam will be further downstream in the Seven Forks cascade and includes the Mutonga tributary, which also carries significant water (and sediment) flows downstream (Pacini et al. 2008). This higher reservoir capacity will result in increased sediment trapping efficiency (Brune 1953; Siyam et al. 2001). Therefore, dam construction is predicted to affect riverbank farming that is dependent on both floodwater to irrigate crops as well as fertile sediment deposits. It is envisaged that with the construction of the dam, floodplain agriculture will diminish and cropping by local communities will be limited to the riverbanks (Quan 1994; IUCN 2003), thereby further increasing the conflict over resources in the lower basin. The dam may also influence other natural ecosystem services provided by the floodplains in the coastal delta such as biodiversity, fuel wood, riverbank stability, fishing, and flood recession agriculture and grazing (Duvail et al. 2014; Knoop et al. 2012; Hughes 1984).

Groundwater

Due to changes in land cover through intensive agricultural practices and high population growth, reduced groundwater recharge is becoming an often cited and growing concern in the Tana River Basin, particularly in the middle and lower basins. Currently, according to Knoop et al. (2012), groundwater resources are not widely used in the basin, but in the near future this is likely to change as the climate changes and pressure on water resources increases to meet the growing demand for livestock and agriculture. Of the national total of 57.21 Mm^3yr^{-1} of groundwater abstractions, only 4.79 Mm^3yr^1 are abstracted in the Tana Basin, though Mogaka et al. (2006) indicated that as much as 6.85 Mm^3yr^{-1} could be safely withdrawn from groundwater resources. Knoop et al. (2012), however, assert that there are severe localized issues with groundwater over abstraction in the upper basin. A major challenge facing the basin is that because groundwater is presently underutilized, little effort has gone into maintaining or enhancing recharge. For example, Knoop et al. (2012) has noted that uncontrolled sand mining and quarrying in the middle basin has reduced the buffering and water storage capacity of the *lagas,* thereby limiting their ability to act as recharge zones for local aquifers during flood events.

Geology inherently influences characteristics that determine the water yield, chemical composition, and the depth of the aquifers. The upper basin is dominated by volcanic rock formations (Figure 27), which tend to be higher yielding, though Knoop et al. (2012) caution that in many areas fractured rocks are exposed, thereby increasing the potential for groundwater pollution. The middle portion of the basin is dominated by poor yielding metamorphic rock. In locations where groundwater is utilized, there are highly localized issues with poorly understood seasonal variation, salinity, fluoride, iron, and manganese (Knoop et al. 2012). Sedimentary and unconsolidated rock formations dominate the lower basin and are considered an important irrigation water supply, and the coastal zone is entirely dependent on groundwater (Knoop et al. 2012). However, similar to the middle region, fluoride and salinity are challenges often faced.

WRMA, to determine aquifer recharge and abstraction levels, monitors groundwater resources within the Tana River Basin. This task is carried out using fully developed production wells. Unfortunately, this potentially misrepresents groundwater distribution, as the boreholes used are not strategically located to capture the range of groundwater variation in monitoring individual aquifers that span the basin. WRMA, through its catchment management strategy, however, has indicated plans to drill additional dedicated boreholes to enhance the monitoring of groundwater resources in various aquifers (WRMA 2014).

PART V: ECOSYSTEM SERVICES

Decision makers are always faced with how to approach society's multiple and competing interests and objectives regarding natural resources and their development (DeFries et al. 2004). How they respond to this challenge is influenced by their access to information.

People derive a whole host of benefits from the natural environment, known as ecosystem services. Ecosystem services (ESs) are people-focused and defined across landscapes at multiple scales, and they also serve as an indication of human well-being. In the simplest terms, ecosystem services may be defined as "the benefits that people obtain from ecosystems" (MA 2005). System assessment using an ecosystems framework necessarily aims to identify linkages among human well-being and the natural environment. As highlighted by this paper, people living within Kenya's Tana River Basin derive a significant amount of their livelihoods either directly or indirectly through a host of ecosystem services.

Ecosystem services within the Tana River Basin support and are supported by natural and built infrastructure, and with pressure to further develop the latter, finding a balance among the two is key. Examples of ESs found within the Tana Basin are detailed in Table 30, though these are not intended to be a complete or exhaustive list. Built infrastructure in the Tana River Basin context most commonly refers to dams, which may vary in terms of size and purpose, and consequently effect potential impacts – negative and positive – on ESs. When properly built and managed, dams can provide sediment capture, reduce flooding, help maintain environmental flows, and increase food production. Because dams necessarily change downstream flows, they can nonetheless have deleterious consequences on ecosystems that require a flood pulse or sediment to maintain productivity. Moreover, it is well understood and accepted that the creation of large dams, often for hydropower, will result in the loss of land as the reservoir fills. If not properly considered and addressed ex ante, dams can result in community relocations or lead to increased conflict over already scarce resources. Similarly, natural infrastructure, such as wetlands, when managed and maintained can enhance ES benefits through mechanisms of sediment trapping and flood control. Their high levels of biodiversity tend to lead to greater resilience within systems to absorb shocks.

TABLE 30. Examples of major natural, green, and built infrastructure features within the Tana River Basin and their relationship to selected ecosystem services. This chart is not intended to be exhaustive but provide examples only.

	Provisioning Services						**Regulating Services**					**Cultural Services**				**Habitat Services**		
Landscape Feature	Water Supply	Food Production	Fuel Production	Medicinal Plants	Grazing	Energy Production	Carbon Sequestration	Water Purification	Erosion Control	Regulate Extreme Events	Nutrient Cycling	Tourism	Recreation	Spiritual	Social Systems	Biodiversity Hotspot	Endemic Species	Important Bird Areas
Mount Kenya	■											■		■	■			■
Tana River and tributaries	■					■									■	■	■	
Agricultural Lands		■							■		■				■			
Forest Reserves	■	■	■	■			■		■	■	■			■		■	■	■
Grasslands					■		■		■		■				■			
Rangelands					■		■		■		■				■			
Woodlands			■				■		■		■					■		■
Wetlands							■	■	■		■						■	■
Seven Forks Dams and reservoirs	■					■												
Sasumua and Ndakaini dams	■									■								
Other Hydroelectric Dams						■				■								
National Parks and Reserves												■	■	■		■	■	■
Lower Tana Riverine Forest				■			■		■	■	■	■				■	■	■
Large Irrigation Schemes	■	■																
Floodplains					■			■	■		■				■			
Tana Delta		■			■							■	■		■	■	■	■
Mangrove Forest										■	■							

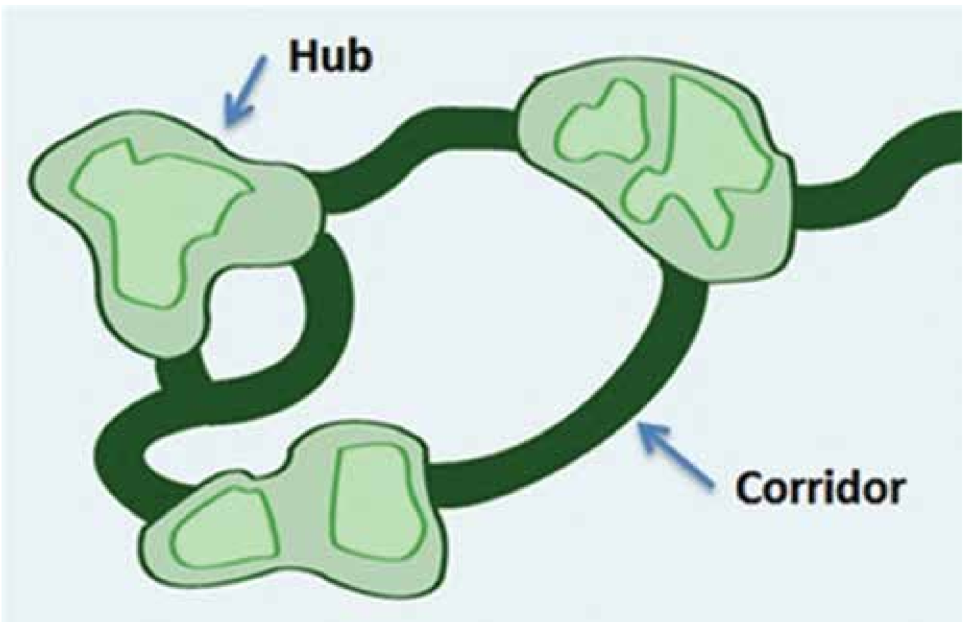
Ecosystem services are commonly recognized across four categories:

- Provisioning services – products obtained directly from ecosystems such as food, fresh water, fuel, wood, fiber, and medicine. Within the Tana River Basin, this includes services such as flood recession grazing, flood recession farming.
- Regulating services – benefits obtained by regulating ecosystem processes such as climate, floods, disease, and water quality. Within the Tana River Basin, important regulating services include flood attenuation, sediment trapping, and groundwater storage.
- Cultural services – material and nonmaterial benefits derived from ecosystems such as aesthetic, spiritual, educational, and recreational. Within the Tana River Basin, cultural services include traditional ceremonies, sacred space (e.g., Mount Kenta and Mount Meru), indigenous knowledge, social systems based on natural resources, and tourism.
- Habitat services – species life cycle maintenance, genetic diversity. As a designated biodiversity hotspot, the Tana Basin region is rich in habitat services, for endemic and endangered species such as the Tana River Red Colobus and the Basra Warbler.

Natural and Built Infrastructure in Support of Ecosystem Services

Natural (or Green) infrastructure represents places on the landscape, such as interconnected networks of natural areas or open spaces ('hubs') that serve as anchors between networks of ecosystem services connected via corridors (Figure 37); Benedict and McMahon 2002). These areas are working landscapes and may consist of features such as forests, floodplains, wetlands, riparian zones, and aquifers. Built infrastructure, on the other hand, refers to human-built or engineered structures for water resources management and may include features such as dams or irrigation schemes. These markedly different types of infrastructure can provide similar services: sediment capture, flood control, and environmental flows maintenance, as well as support economic development. The two do not have to be viewed in

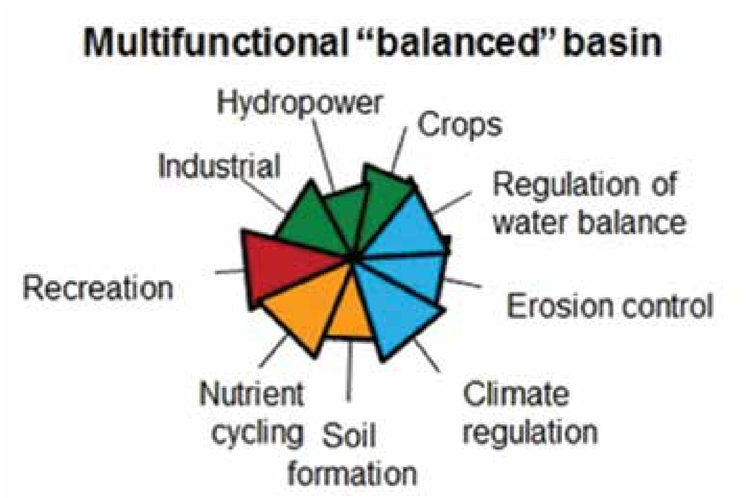
FIGURE 37. Potential conceptualization of ecosystem services on a landscape as modified from USEPA on Natural Infrastructure.



Source: http://www.epa.gov/region3/green/infrastructure.html.

opposition to one another, and natural infrastructure should be seen as a valuable and necessary part of enhancing or improving the performance of built infrastructure as one component of an integrated and multifunctional system that supports human well-being by preserving ecosystem process and function (Figure 38). In an agricultural system managed using ecological principles, built infrastructure such as irrigation or reservoirs and ponds may even serve important habitat functions. To address challenges faced within the Tana River Basin, combinations of natural and built infrastructure can be considered with regard to how they maintain or enhance ecosystem services.

FIGURE 38. Landscapes provide multiple ecosystem services, and balancing these demands requires the support of healthy and functional ecosystems.



Source: Boelee 2011.

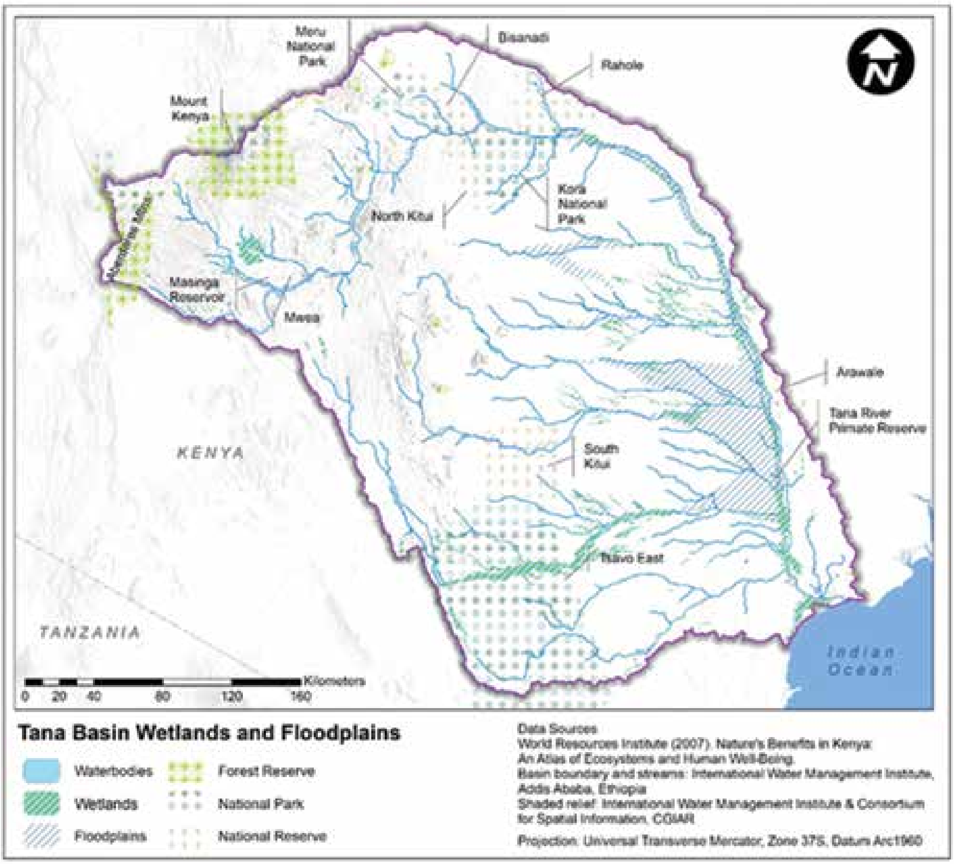
Wetlands and Floodplains

Wetlands are places on landscapes that are seasonally or continually inundated by water. They are considered some of the most biologically diverse spaces on landscapes and perform valuable functions such as attenuate floods by storing water, filter toxins from water, capture sediment, sustain dry season flows, and provide important habitat for birds, amphibians, fish, and other fauna. There is a diversity of wetlands types, covering more than 3,000 km^2, found in the Tana Basin including swamps, marshes, estuaries, the delta, seasonally flooded grasslands and woodlands, and riparian zones (Figure 39). These represent the largest and richest wetland diversity in Kenya.

Major wetlands include the Tana River floodplains, areas adjacent to the Seven Forks hydropower dams, and the coastal swamps in the Tana Delta. The Tana River floodplain consisting of wetlands from the middle to lower catchments are critical in supporting local livelihoods and biodiversity. The Seven Forks hydropower project in the middle catchments supplies a large share of Kenya's hydropower and also supports diverse habitats. Downstream, the Tana Delta (130,000 ha) consists of several rich and diverse habitats, including savannah grasslands, riverine forests, and rangelands. It also provides habitat to over 320 plant taxa; 58 of these are tree species, 2 of which are critically endangered and 7 are on the IUCN red list, while overall the status of 21% of the plants are of concern (MEMR 2012).

Hamerlynck et al. (2010) give an overview of the critical ecosystem services provided by floodplains and wetlands in the lower basin. These services range from riverbanks and floodplains

FIGURE 39. Major wetland and floodplain areas found within the Tana Basin.



serving as valuable locations for farming, fisheries, livestock, wildlife and tourism, as well as providing local communities with construction materials, medicines, flood protection, water supply, and food. Within the delta, flood recession grazing has historically been and continues to be an important way of life for the Orma people, as previously discussed, and the delta's mangroves provide protection for coastline infrastructure.

Forests

Two principal types of forested lands serve as a source of natural infrastructure in the Tana Basin: Afromontane forest reserves in the upper basin and riparian forests along the main stem of the Tana River, especially in the lower basin.

As previously discussed, Tana Riverine forests are highly dependent on flooding (Hamerlynck et al. 2012; Maingi and Marsh 2002; Hughes 1984, 1990). As part of the flooding process, they depend on water table depth (i.e., recharge), which drops off sharply away from the Tana River's edge. The riverine forest extends 0.5–3.0 km from the river's edge (Maingi and Marsh 2002; Medley 1990).

Medley (1990) asserted that extractive forest resources utilized by the Pokomo people along the Tana River, in particular, can serve as an incentive for resources conservation and forest protection by local people. The Pokomo people, for example, rely on numerous plant species within the Tana Riverine forests for food, construction materials, medicines, and other purposes. Throughout the basin, apiculture (beekeeping) is an important livelihood activity – as well as providing critical pollination services for agriculture – and is reliant upon healthy forests throughout.

Within the upper basin, the Afromontane forests serve as one of Kenya's principal water towers, receiving ample rainfall and acting as a major recharge zone for groundwater as well as an important source of drinking water for Kenya's capital, Nairobi. Protection of these water resources is critical from both a quantity and quality perspective. The well-known East Africa Catchments hydrological studies in the 1950s – 1970s and established in the Aberdare Range (Blackie et al. 1979), concluded that within the upper basin converting from bamboo forest to *Pinus patula* and *Pinus radiate* plantations showed no significant difference in water yield and only slight increases in sediment loss during the establishment phase of the forests. Unfortunately, these studies were halted prior to widespread conversion of forests to small-scale agriculture. Hence, less is known about the small-scale (i.e., small catchment) impact that such changes have had on the water balance in the upper basin. However, evidence has pointed strongly towards increased sediment loss in the upper basin (v.s., *Sedimentation* section). Baker and Miller (2013) found that in the Mau Forest that removal of plantation forests had a rapid and significant impact on hydrological response within the River Njoro, local groundwater resources, and ultimately Lake Nakuru National Park.

Diverse and seemingly contradictory responses to forests caused Bruijnzeel (2004) to assert that tropical forest hydrology is clearly much more complex than the commonly held notion that forests act as sponges on the landscape and their removal automatically results in decreased water yields in the long term. In fact, Bruijnzeel (2004) points out that some tree species or crops may have a drying effect on streams, and that plant growth stages are also critical because they impact evapotranspiration processes. Another factor in many tropical forest areas is the variable rainfall, which makes understanding of hydrological processes and scaling of calibrated models challenging in the absence of long-term data.

Hydrologically, there is little doubt that forests serve a critical, albeit complex, role on landscapes. During rainfall events, they attenuate raindrop impact, reduce potential erosion, and in many instances increase soil infiltration thereby potentially enhancing groundwater recharge and allowing for a slower release of rainfall over time into the system. When forests are converted to small-scale agriculture or removed for fuelwood purposes, soil is left exposed and susceptible to erosion, thereby altering evapotranspiration processes. The result is often an increase in baseflow, though timing of forest conversion plays a critical role in this process (Smakhtin 2001). Forest removal followed by poor land management practices or poor choice of replacement vegetation can cause severe reductions in groundwater recharge (Bonell et al. 2010; Bruijnzeel 2004).

In addition, wood lots and plantation forests across the basin serve important functions on the landscape, especially within the upper reaches of the basin, though they might more properly be considered green rather than natural infrastructure, as they include some level of planning and they may tend toward lower biodiversity and resilience (e.g., pineapple or eucalyptus monoculture plantations). As noted in the Blackie et al. (1979) studies, such infrastructure helps preserve or mimic a natural state on the landscape as well.

Dams

Hydroelectric power currently accounts for 49% of Kenya's total energy production (Ministry of Energy and Petroleum 2014). Most of the current and planned hydropower resources are concentrated in the Tana River system. As part of its Vision 2030 Plan, however, the Kenyan government also plans to expand alternative energy sources through geothermal and coal resources (Kenya Vision2030 2014). If carried out, these plans combined will significantly reduce Kenya's dependency on hydropower by 2030.

The Seven Forks Project is the largest hydropower project within the basin. This project consists of five major currently operating plants: Masinga, Kamburu, Gitaru, Kindaruma, Kiambere (Table 31), but also includes the planned High Grand Falls Multipurpose Dam. The five presently operating plants provide roughly 70% of Kenya's hydropower energy. Masinga, Kamburu, and Kiambere plants have sizable storage reservoirs while Gitaru and Kindaruma are run-of-river plants (Figure 34). Several other small run-of-river mini hydropower plants also exist in the Tana River system upstream of the main Seven Forks Project. Such dams include the Sagana (1.5 MW), Tana (14.5 MW), Mesco (0.35 MW), and Ndula (2 MW).

TABLE 31. Principal features of the reservoir and hydropower facility – Seven Forks Project.

Reservoir		Masinga	Kamburu	Gitaru	Kindaruma	Kiambere
Commissioning	Year	1981	1974	1978	1968	1988
Catchment area	km^2	7,335	9,520	9,520	9,807	11,975
Average lateral	m^3/s	111.48	27.24	0	0.88	6.63
Average Flow	m^3/s	111.48	138.72	138.72	139.60	146.24
Dead storage	Mm^3	150.0	27.0	7.5	8.5	100.0
Live storage	Mm^3	1,410.0	123.0	12.5	7.5	485.0
Total storage	Mm^3	1,560.0	150.0	20.0	16.0	585.0
Gross Head	M	50	82	144	37	145
Net Head	M	49	77	136	32	134
Turbine Type	-	Kaplan	Francis	Francis	Kaplan	Francis
Installed capacity	MW	40.0	94.2	225.0	44.0	144.0
Max. Discharge	m^3/s	100.4	154.5	177.9	161.1	125.9

Source: KenGen 2014; Table sourced from Kiptala 2008.

Kenya Electricity Generating Company (KenGen) is solely responsible for energy generation in the Tana River Basin. It is the leading energy producer, generating about 76% of Kenya's energy annually (4,279 GWh yr^{-1}) with seven independent power producers (IPP) accounting for the balance (Ministry of Energy and Petroleum 2014). The electricity transmission company, Kenya Power and Lighting Company (KPLC), purchases energy produced in bulk. Because of high reliance on cheap hydro sources, KenGen provides the lowest-cost power to KPLC and ranks highest in its order of dispatch (Kiptala 2008).

The High Grand Falls Multipurpose Dam (500 MW) is currently being implemented by the Kenyan government under TARDA and the Ministry of Devolution and Planning. The project is one of the flagship projects in the government's ambitious Kenya Vision 2030 strategic plan to increase hydropower production and irrigation-based agriculture. Its construction is funded through a public-private partnership with Chinese firms, and financial backing is provided by Exim Bank, China. The project has drawn some criticism from studies that indicate negative impacts on the Tana Delta ecosystem (Duvail et al. 2012; IUCN 2003).

KenGen has also completed the feasibility study for the Karura Hydropower Plant. The hydropower plant is expected to utilize the remnant head between Kindaruma Hydropower Station and the Kiambere Reservoir. The Karura Hydropower Plant is expected to have an installed potential capacity of 40-60 MW. The detailed design for the project is currently ongoing and the construction is expected to start in 2018 (KenGen 2014).

Beyond hydropower production, dams serve other important purposes in the upper basin. For drinking water supplies, Nairobi receives much of its water from the Tana River Basin by way of water transfers from the Sasumua and Thika (Ndakiani) reservoirs (Table 32; Droogers et al. 2011). WRMA (2008) indicates that within the upper basin, above the Masinga Reservoir, up to 96 small-scale water storage structures (averaging 6 Mm^3 each), as many as 1,400 check dams, and an unknown number of sand dams are planned. Most of these structures are planned with the intent to reduce sedimentation in the main reservoirs, but could potentially provide additional benefits such as groundwater recharge or water supplies for irrigation or livestock.

TABLE 32. Existing hydroelectric dams within the Tana River Basin, but off the main stem of the river.

Dam Name	Year Built	River	Catchment Area (ha)	Gross Storage (Mm^3)	Purpose
Sasumua	1956	Chania	30,000	13.3	Water supply to Nairobi
Ndakaini-Thika	1994	Thika	85,000	70	Water supply to Nairobi

Source: Derived from Droogers et al. 2011.

Irrigation

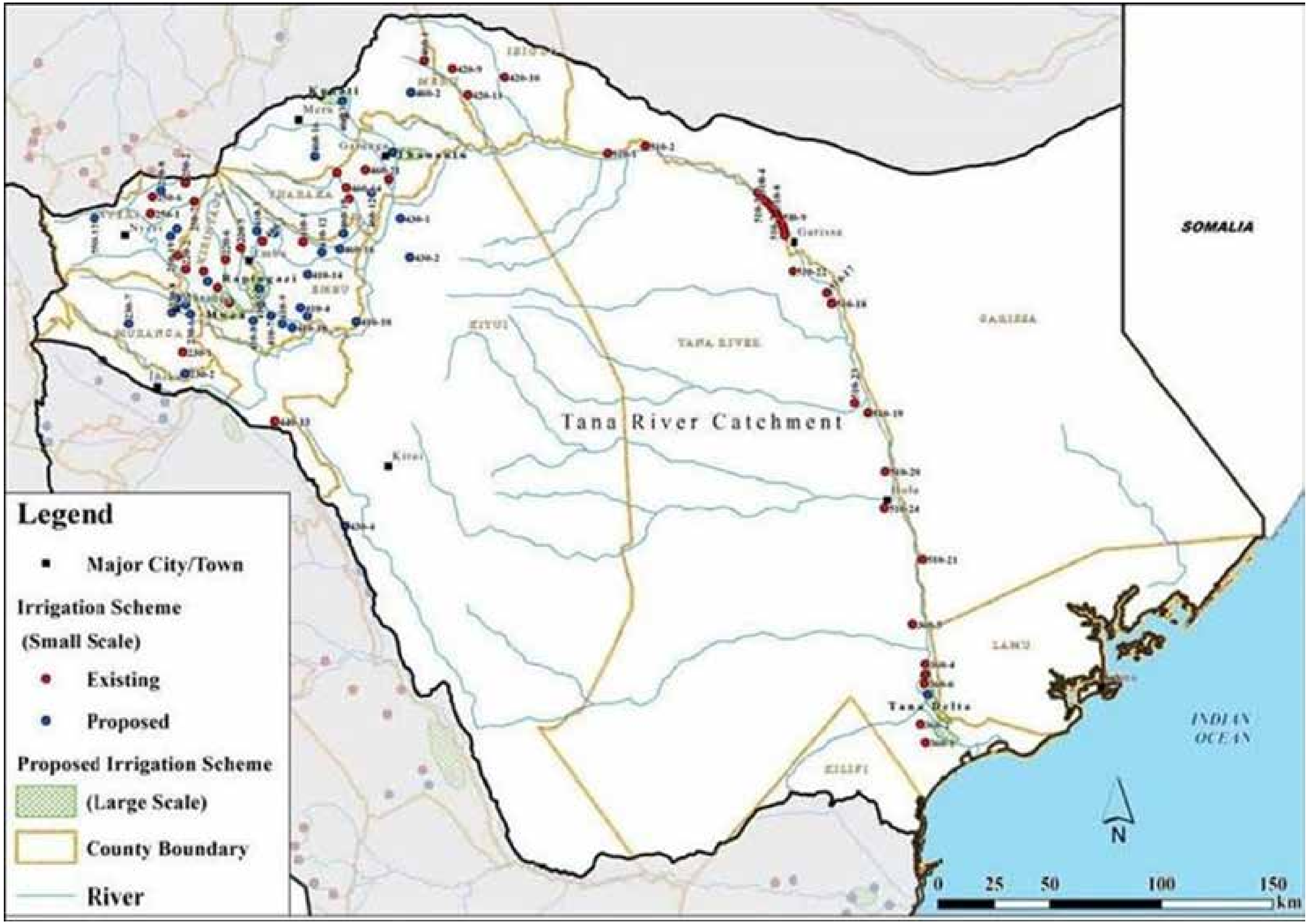
Irrigation accounts for 75% of water demand in the Tana Basin (Geertsma et al. 2009, 2010), and while there are only a few large-scale irrigation schemes, there are numerous small-scale existing and planned schemes (Figure 40) that when combined have the potential to significantly influence water demand. The Tana Delta has been identified as underutilized for irrigation. Two irrigation schemes, Hola and Bura (4,654 ha of potential 16,500 ha) already exist in the Lower Tana Basin.

As one of its flagship projects, the Kenyan government has proposed the Galana-Kulalu Food Security Project, which is currently being implemented by the National Irrigation Board. This project proposes to irrigate 1 million acres between the Tana and Galana rivers, which spans the Tana and Athi river basins. Although it remains to be seen whether the project will entirely come on line due to a variety of challenges stemming from security, poor road infrastructure, and inadequate financing; a pre-suitability study has been completed that recommends that the Galana River (Athi Basin) should be made the priority river for irrigation (NIB 2014).

Currently, irrigation development is concentrated in the Tana Basin's upstream catchments and along the river floodplains (Figure 40). The upstream catchments receive ample precipitation and are dominated by rain-fed agriculture with supplementary irrigation. These areas, as previously mentioned, have high population densities and, are therefore dominated by smallholder irrigation, though its extent is unclear. The lower catchment consists of more sparsely populated drylands with a semi-arid climate and large flat land areas dominated by pastoralists. These areas are considered to have a high potential for large-scale irrigation, but are constrained by available water resources (Figure 41).

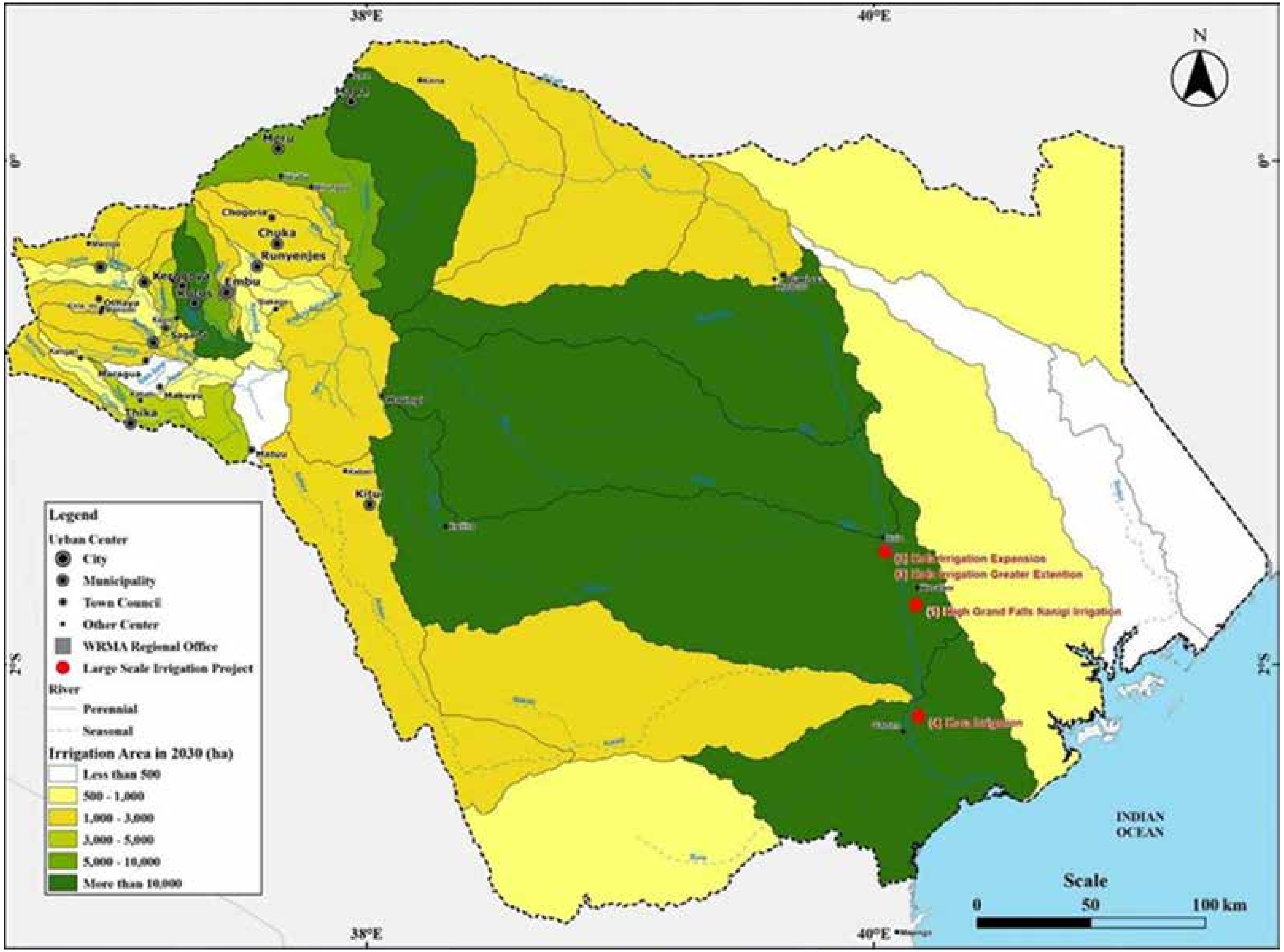
Total existing irrigation is estimated to cover 64,425 ha, consisting of 11,200 ha of large-scale schemes, 14,823 ha of small-scale schemes and 38,402 ha of private irrigation schemes (Ministry of Environment, Water and Natural Resources 2013). Large-scale schemes mainly consist of public

FIGURE 40. Existing and proposed irrigation schemes in the Tana River Basin management area.



Map Source: Ministry of Environment, Water and Natural Resources 2013.

FIGURE 41. Potential irrigation development in the Tana Catchment by the year 2030.



Map Source: Ministry of Environment, Water and Natural Resources 2013.

irrigation schemes that are operated by the National Irrigation Board (NIB), a state agency. Public schemes include Mwea Irrigation Scheme (7,400 ha rice), Hola Irrigation Scheme (900 ha, cotton and maize), and Bura Irrigation Scheme (2,500 ha rice).

The Kenyan government has prioritized significant increases in large-scale irrigation in the Tana Basin (Table 33). An estimated 292,100 ha of large-scale irrigation is planned to be implemented by the year 2030 through various state agencies, including the National Irrigation Board (NIB), the Tana River Development Authority (TARDA), and Ministry of Water and Irrigation (MWI). Small-scale and private irrigation schemes are also expected to expand through increased investment in water harvesting structures such as water pans, small dams by other government agencies, and with NGOs or private developers operating within the basin.

TABLE 33. Proposed large-scale irrigation projects in the Tana River Basin.

Project	County	Irrigation Area (Ha)	Develop Type	Water Source	Agency
Rahole/Lorian swamp	Garissa	10,000	New	Weir	MWI
Kagaari-Gaturu-Kieni	Embu	6,600	New	Dam	NIB
Mwea (Thiba Dam)	Kirinyaga	10,000	Extension	Dam	NIB
Mitunguu	Meru	10,000	Rehab & Extension	Dam	NIB
Bura West	Tana River	5,500	Rehab & Extension	Weir	NIB
Bura East	Garissa	12,000	New	Weir	NIB
Kibwezi[1]	Kitui	30,000	New	Dam	NIB
Kunati	Meru	2,500	New	Weir	NIB / TARDA
Thanantu	Meru	5,000	New	Weir	NIB / TARDA
Thiba-Yatta-Mwstastabi	Kitui	5,000	New	Weir	TARDA
Tana Delta	Tana River	12,000	Rehab and Extension	Weir	TARDA
High Grand Fall Multipurpose Dam	Garissa/Tana River	180,000	New	Dam	TARDA
TOTAL		288,600			

Source: Ministry of Environment, Water and Natural Resources 2013.
Note: [1] It is questionable whether this scheme is within the Tana Basin boundary. It is more likely within the Athi River Basin, but near the boundary with the Tana.

Natural and Built Infrastructure Linkages

As previously described, Tana River is Kenya's longest river and one of the country's principal basins covering over 95,000 km^2 and numerous agro-climatic zones. Due to the large areal coverage and diverse landscapes of the Tana River Basin, it is impractical to carry out highly detailed analysis of the interactions among natural and built infrastructure and the ecosystem services they support throughout the basin. However, selected locations on the landscape can be identified and assessed to better understand the key integrated role that natural and built infrastructure play in the basin, and facilitate a pathway forward in planning efforts. Figures 42 and 43, in combination with Table 34, provide a preliminary overview of the relationships between natural and built infrastructure in the basin.

FIGURE 42. Outlets and subbasins in the Tana River Basin.

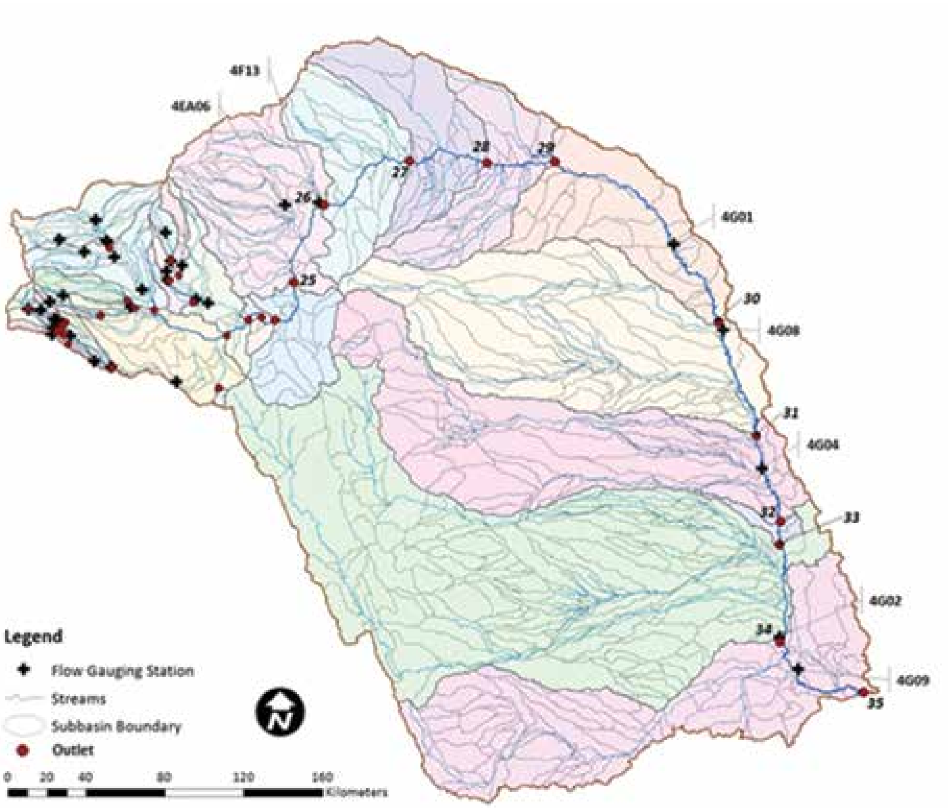


FIGURE 43. Inset of Upper Tana River Basin outlets.

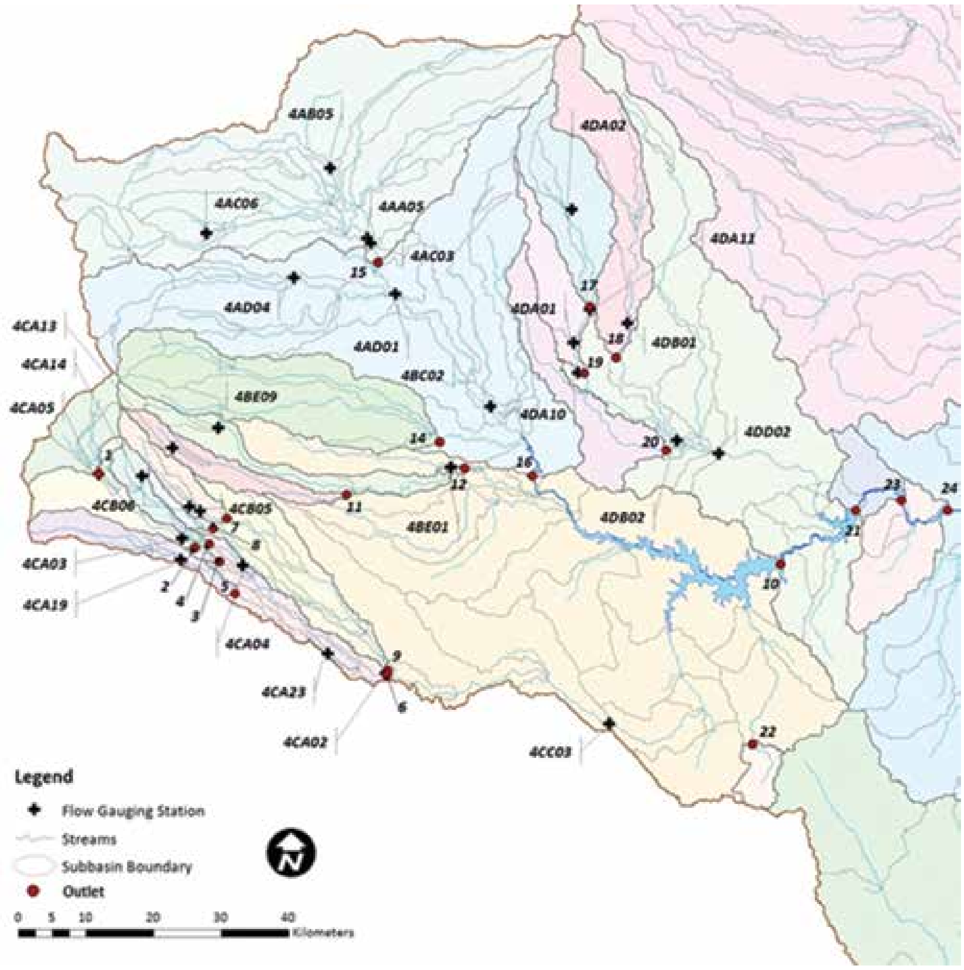


TABLE 34. Overview of key natural and built infrastructure within the Tana River Basin and a cursory look at their relationships.

ID	Main local river name	Natural infrastructure	Built infrastructure	Comments
1	Sasumua	Chania River headwaters in northeastern subcactchments; western edge of Aberdare	Sasumua Dam	Built in 1956; Supplies water to Nairobi; 15.9 Mm^3 gross storage; ~128 km^2 catchment.
2	Chania	Forested from discharge gauge 4CA05 downstream to discharge gauge 4CA03. Part of Aberdare.	Mataara Hydropower Dam (under construction)	1 MW expected; will use waterfall occurring on Chania River near Mataara Tea Factory; construction under way.
3	Chania	Downstream from edge of Aberdare Forest.	Mwagu Intake	End of transmission tunnel for supplying water to Nairobi from Ndakaini Dam via Kiama and Kimakia rivers; enters Chania River.
4	Kimakia	Almost wholly within the Aberdare Forest and protected area.	Kimakia Intake	Receives water through the transmission tunnel from Ndakaini Dam via Kiama River; compensation flow provided to Kimakia.
5	Karimenu	Aberdare Forest edge is near gauge.	Karimenu II Dam (proposed)	
6	Chania	Chania WRUA has done much work to protect the riparian zones within Chania, including exclusion of *eucalypt* species planting.	Thika Water and Sewerage System	Intake from Chania to supply Thika.
7	Thika	The catchment area above the dam is within the Aberdare Forest.	Ndakaini Dam	Completed in 1994; Supplies water to Nairobi; 70 Mm^3 gross storage; ~850 km^2 catchment;
8	Kiama	Almost wholly within the Aberdare Forest and protected area.	Kiama Intake	Receives water through the transmission tunnel from Ndakaini (Thika) Dam; compensation flow provided to Kimakia.
9	Thika	Nothing significant within subcatchment; however, it is immediately downstream from Aberdare Forest.	Del Monte Intake	
10	Tana Thika	Significant wetland areas have formed around edges of the reservoir.	Masinga Dam	Commissioned in 1981; Hydropower reservoir with 40 MW capacity and a total storage of 1,560 Mm^3; ~7,335 km^2 catchment; numerous small dams can be found throughout the subcatchment.
11	Irati	Headwaters area is within the Aberdare Forest.	Mesco Dam	Commissioned in 1930; 0.35 MW capacity; run of river hydropower
12	Maragua	Headwaters area is within the Aberdare Forest.	Maragua Dam	
13	Maragua	Nothing significant within subcatchment area.	Wanjii Power Plant	Verify gauge (4BE01) location; run of river hydropower with 7.4 MW; commissioned in 1954.
14	Mathioya	Headwaters area is within the Aberdare Forest.	Ndula Dam	2 MW capacity; run of river hydropower; commissioned in 1954.

(Continued)

TABLE 34. Overview of key natural and built infrastructure within the Tana River Basin and a cursory look at their relationships (Continued).

ID	Main local river name	Natural infrastructure	Built infrastructure	Comments
15	Sagana	Headwaters areas for several main tributaries (Nairobi, Amboni, and Mweiga) are found with the Aberdare or Mount Kenya forest reserves, as well as part of Aberdare National Park. In addition, there are other protected forest areas within the subcatchment: Lusoi and Nyeri.	Sagana Falls Power Plant	1.5 MW capacity; run of river; commissioned in 1956.
16	Tana	Headwaters for Gura and Gikira rivers are in Aberdare Forest and Aberdare National Park. Headwaters for Ragati River are in Mount Kenya Forest Reserve.	Tana Hydroelectric Dam	14.4 MW capacity; run of river; some parts of Mwea Irrigation Scheme are within this subcatchment on the southeastern side.
17	Thiba	Area above discharge gauge 4DA02 is wholly within the Mount Kenya Forest Reserve.	Thiba Dam (under construction)	Will be used to supply supplemental water to Mwea Irrigation Scheme during low flows or the dry season.
18	Niyamindi	Headwaters and upper half are within the Mount Kenya Forest Reserve.	Mwea irrigation intake	Gravity fed intake weir here connects via canal to Thiba River to supply Mwea Irrigation Scheme.
19	Thiba	Small area of headwaters within the Mount Kenya Forest Reserve.	Mwea irrigation intake	Water from Thiba River combined with water from Niyamindi River enters canal system for Mwea here. Scheme started in 1956 with 30,350 ha gazetted and 9,000 ha under paddy production but with planned expansions. Kenya's largest irrigation scheme.
20	Thiba		Mwea Irrigation Scheme	End of Mwea Irrigation Scheme. See ID 19 for description of Mwea Irrigation Scheme.
21	Thiba Tana	Headwaters are within the Mount Kenya Forest Reserve and on north side of reserve is the Mwea National Reserve. Significant wetland areas have formed around edges of the reservoir.	Kamburu Dam	Hydroelectric dam with 94.2 MW capacity; completed in 1975; 150 Mm^3 total storage; ~9,520 km^2 catchment area.
22	Thika		Yatta Furrow Irrigation Scheme	This irrigation scheme appears to be in two distinct areas, one of which has an intake on the Thika River and the other (larger of the two areas) on a tributary that goes into Masinga Reservoir.
23	Tana		Gitaru Dam	Hydroelectric dam with 225 MW capacity; commissioned in 1978; 150 Mm^3 total storage.
24	Tana	Significant wetland areas have formed around edges of the reservoir.	Kindaruma Dam	Hydroelectric dam commissioned in 1968 with 40 MW capacity; ~9,807 km^2 catchment area; 16 Mm^3 total storage.

(Continued)

TABLE 34. Overview of key natural and built infrastructure within the Tana River Basin and a cursory look at their relationships (Continued).

ID	Main local river name	Natural infrastructure	Built infrastructure	Comments
25	Tana		Kimbere Dam	Hydroelectric dam commissioned in 1988 with 144 MW capacity; 11,975 km^2 catchment area; 585 Mm^3 total storage.
26	Tana	Several rivers here have their headwaters in the Mount Kenya Forest Reserve: Kathita, Thingithu, Muthonga, Mara, and Ena. There are several additional small forest reserves in the subcatchment: Kierera, Kijege, Mutharanga, Munguni, Njuguni, Kiagu, Kiega, and Imenti.	High Grand Falls Dam (proposed)	Multipurpose dam with 500 MW planned capacity; reservoir will also irrigate 30,000 ha, and supply water to Lamu Port for domestic use as part of the LAPSSET (Lamu Port–South Sudan–Ethiopia Transport Corridor) Program.
27	Tana	Ngaya Forest Reserve covers the uppermost region of this subcatchment. There are numerous protected forest reserves as well: Nyambeni, Thuuri, Kikingo, Mataa, and Mutejwa. Meru National Park is also located within this subcatchment and parts of Bisanadi National Reserve are as well.	Adamson Falls Dam	
28	Tana	Several protected areas are located here: Kitui National Reserve, Kora National Park, and Bisanadi National Reserve. In this area, there are some floodplains along the river and wetlands on the southern side of the Tana along the Machungwa Monune rivers.	Kora Dam	
29	Tana	Kora National Park and Rahole National Reserve cover most of this subcatchment. Along the Tana River, the riparian flood zone is well vegetated.	Rahole Irrigation Scheme (Proposed)	Some sources (WRI-DRSRS-MENR-CBS-ILRI 2007) have indicated a reservoir to be built on the Rahole River. At present, the irrigation scheme is small and being clearly supplied by the Tana River with plans to build a 50 km canal and supply 8,000 ha; however, it is unclear if this will divert water from Tana or Rahole River.
30	Tana	Main natural infrastructures here are the floodplains and wetlands along the main Tana River.	Bura Irrigation Scheme Nanighi Barrage (LAPSSET)	It is expected that Bura may cover 6,500 ha; part of the High Grand Falls Irrigation Project; parts of this will be rehabilitation of the old scheme.
31	Tana	Ngamba Trust Forest Reserve (~1,100 ha) is located here. Other main natural infrastructures are the floodplains and wetlands along the main Tana River. There are also important seasonal wetlands along many of the lagas (Tula and Matia), connecting these seasonal rivers at various times during the year.	Hola Irrigation Scheme	The fate of Hola Irrigation Scheme is uncertain, though anticipated to cover 3,500 ha; part of the High Grand Falls Irrigation Project; parts of this will be rehabilitation of the old scheme. There are ongoing discussions about reviving the scheme, which was abandoned.

(Continued)

TABLE 34. Overview of key natural and built infrastructure within the Tana River Basin and a cursory look at their relationships (Continued).

ID	Main local river name	Natural infrastructure	Built infrastructure	Comments
32	Tana	Arawale National Reserve, Nuu Forest Reserve, and Makongo Forest Reserve are all located here. Other main natural infrastructures are the floodplains and wetlands along the main Tana River. There are also important seasonal wetlands along many of the lagas, connecting these seasonal rivers at various times during the year. The floodplains in this area become quite expansive and are important for livestock grazing. The outlet of this area serves as the inlet of the Primate Reserve.	Masilana Irrigation Scheme	Borders the Tana River Primate Reserve with a 20,000 ha command area.
33	Tana	Main natural infrastructure are the floodplains and wetlands along the main Tana River that become quite expansive and are important for livestock grazing during the year as the lagas flood. This entire subcatchment floods.	Tana River Primate Reserve	
34	Tana	Largest of the subcatchments. Main natural infrastructure are the floodplains and wetlands along the main Tana River that become quite expansive and are important for livestock grazing during the year as the lagas flood. South Kitui, Tsavo East, and parts of the Tana River Primate Reserve are all located within this subcatchment.	Delta	
35	Tana	Tsavo East and the Tana Delta Biodiversity Hot Spot are all located in this subcatchment.	Basin Outlet	Within the Tana Delta it is expected that in 2015, the Tana Delta Irrigated Sugar Project will begin development with a 20,000 ha command area planned along the Matomba Branch of the lower Tana River.

PART VI: MANAGEMENT CHALLENGES IN THE TANA RIVER BASIN

With its growing population, the Tana River Basin faces numerous challenges in managing multiple interests and objectives, some of which have already been discussed in the preceding pages. Along with others, these need to be considered from both a biophysical and social context. The upper reaches of the basin are home to some of Kenya's most fertile and productive agricultural areas as well as the environmentally and economically valuable Mount Kenya Forest Reserve (Emerton 1999). Within the basin, there is fierce competition for water resources among many different activities and actors: irrigation, fishing, horticulture, rice production, hydropower, domestic water use, factories (i.e., Del Monte and Kakuzi) and drinking water for Nairobi as well as major towns such as Thika, Nyeri, and Karatina. Several factors detailed below impose additional challenges to managing water resources due to their direct impact on water availability.

Shamba System

As previously noted, settlement within the Upper Tana Basin has been heavily influenced by changes that came about during the colonial era and in direct opposition to traditional land tenure systems. Tanui (2006) asserts that a particularly critical point to note was the change from traditional land tenure systems to large -scale commercial agriculture, which resulted in a clear need for soil and water conservation measures to combat erosion and overall land degradation. Such measures, however, were enforced through coercive measures by the colonial government and so such measures over time – and for a long time after independence – came to be identified as "tools of colonization and dominion" (Tanui 2006).

Another historical remnant of the colonial era is the *shamba* system, which was introduced around 1910 from the *Taungya* practice used in Burma to manage teak (Oduol 1986). Under this land management system, seedlings are intercropped for some period (3–4 years) with food crops. Once the trees in a plot reach a size that shade begins to limit crop growth potential, the crops are phased out and the farmer will move to a new plot (Tanui 2006). This is how the practice works in theory, but often farmers decide to continue farming a plot rather than allow seedlings to take hold. Due to its misuse and damage to forested areas, and consequently to downstream communities, this system was discontinued by a Presidential order in 1988. It was then reinstated in 1994 but later banned in 2003 (Imo 2009), and while the ban was lifted in 2012, the practice is still banned in some locations. During the ban, the practice continued illegally in many locations. Kenya Wildlife Services carried out an aerial survey in 1999 to assess the extent of illegal *shamba* system practices and found that a majority of plantations slated for *shamba* system practices at that time were not being properly utilized (KWS-UNEP-KFWG 2003; Table 35). The system is at present being actively employed in the Aberdare forests under the watch of KFS in areas that are being managed for timber production.

Eucalyptus Production

Wood is required for tea plantations in the Upper Tana Basin and, as a consequence, fast growing Eucalyptus *spp.* are in demand. Additionally, throughout the basin, there is a demand for fuelwood. Large-scale planting of Eucalyptus *spp.* worldwide have been met with controversy due to impacts they may have on water availability, as well as their negative allelopathic effects and potential to increase soil erosion. At the same time, famers favor these trees for their high value and because they are harvestable in as little as five years (Pohjonen and Pukkala 1990).

TABLE 35. KWS assessment of shamba system practices around Mount Kenya.

Status	Number of Forest Plantation Areas	%
Not planted with tree seedlings	73	57
Partially planted with tree seedlings	14	11
Planted with tree seedlings	16	13
Not planted and encroaching into natural forest	24	19
Total	127	100

This trade-off between a quick investment return and potential environmental degradation has even been favored in some circles of development economics (Jagger and Pender 2003). A primary source of controversy in the eucalyptus debate is that, within the scientific literature, watershed response to eucalyptus appears to be highly localized and a result of complex interactions among species selection, slope, climate, ground litter, and adherence to appropriate management strategies.

Studies over multiple spatial scales and with afforestation over varying spatial distributions have shown that within a few years (<5) of tree planting, there is a significant reduction in peak flows (Sikka et al. 2003; Sahin and Hall 1996; Poore and Fries 1985). For areas prone to flooding, this may at first seem a favorable solution to deal with excess water and such solutions have been used in swampy areas (Poore and Fries 1985). Nevertheless, eucalyptus has also been shown in some instances to increase peak flows by increasing hydrophobicity of soils and decreasing available ground litter (Coelho et al. 2005; Poore and Fries 1985). Eucalyptus may, therefore, be a shortsighted solution because low flows can be negatively impacted such that within a decade, streams will stop flowing (Sikka et al. 2003; Scott and Lesch 1997). Baker and Miller (2013), for example, found in Kenya's Mau Forest that afforestation efforts with eucalyptus plantations followed by their widespread removal resulted in flashier flows and severe flooding, and within 10 years of tree removal there was flow cessation in the once perennial River Njoro during the dry season. This further resulted in disappearance of fishes from the river and increased sedimentation to Lake Nakuru due to increased streambank erosion during flashy flows. Engel et al. (2005) discovered that to meet water demand, Eucalyptus *spp.* are able to draw extensively (up to 67% in their study site) from groundwater when other sources, such as streams, are unavailable. This is unsurprising given it is a tree evolved to survive in the more arid Australian environment and, as Johansson and Tuomela (1996) report, several species are easily adaptable to semi-arid regions such as the Tana River Basin, especially when irrigated. In addition, these impacts and drying up may continue for several years after clear felling has taken place. It is most likely attributable to severe soil desiccation and aquifer drawdown (Engel et al. 2005).

Eucalyptus is an allelopathic plant, in that its leaves and roots have chemicals that alter soil chemical composition in ways that can suppress understory growth. These changes in soil chemical composition have been shown to negatively affect crops due to impacts on germination, seedling length, and vigor; thereby lowering potential crop yields (Sasikumar et al. 2001; May and Ash 1990). Babu and Kandasamy (1997) have suggested many species are suitable as natural herbicides. A major factor in allelopathic severity seems to be timing, distribution, and intensity of rainfall events. This is because allelopathic properties can quickly degrade or be flushed through the system before affecting crops (Kidanu 2004; May and Ash 1990).

While the potential negative impacts on water availability are frequently cited, eucalyptus has also been cited as a potential benefit to severely degraded lands in helping control soil erosion (Jagger and Pender 2003). However, other soil and water conservation measures such as terraces have been shown to be more effective (Inbar and Llerena 2000). In lands that are not highly degraded, however, there is clear evidence that *Eucalyptus spp.* contribute substantially to increasing erosion for many reasons. For example, in areas where it negatively impacts understory growth, either through shading or allelopathic tendencies, soils are left exposed to overland flow processes and rainfall kinetic energy (Valentin et al. 2005). Inbar and Llerena (2000) found that mature eucalyptus plots produced higher sediment yield than any other vegetated plot in their study site. Zhou et al. (2002) found that kinetic energy from rainfall is the most important factor to consider in whether eucalyptus can have an influence on soil erosion. In instances where rainfall is less than 5 mm during a rainfall event or intensities are greater than 40 mm^{-h}, then eucalyptus may help reduce erosion due to its tall canopy. Otherwise, the authors found that erosion increases unless there is understory protection present. Under such low rainfall circumstances, however, there is an increased likelihood in alleleopathic impacts. Similarly, Cinnirella et al. (1998) found that when coppiced, eucalyptus can afford some protection if there is also some understory coverage. In more arid regions where eucalyptus may deplete soil water or tap into groundwater resources, soils will dry out and be left more exposed to erosion by wind. A bigger issue concerning eucalyptus is that it has clearly shown a propensity to thrive in East Africa and, as such, people have been keen to undertake large-scale conversions from native vegetation with which tropical soils co-evolved and supported one another. Often the result is that the tree is not managed appropriately as an agroforestry crop with the aforementioned complex environmental implications or adaptations in mind.

Finally, conversion of indigenous riparian forests to other land uses such as agriculture and eucalyptus is considered to have a negative impact on Tana River Red Colobus through native habitat destruction within the riverine zone (Mittermeier et al. 2012). At issue here is that while planting various *Eucalyptus spp.* should in theory provide a source of fast-growing fuelwood and help preserve indigenous tree species, its popularity and demand has led to widespread expansion and undermined Colobus habitat and social behavior (Wasserman et al. 2012).

Stone Quarrying and Sand Harvesting

Notable challenges to controlling erosion and sedimentation within the Tana River Basin are relatively widespread sand harvesting and quarrying activities. Both sand and gravel are important ecosystem services within the basin (Knoop et al. 2012; Terer et al. 2004); however, these activities are also considered one of the leading causes of erosion and sedimentation in the basin (Kizito et al. 2014). Knoop et al. (2012) point out that the industry, if well-regulated, could be managed to enhance ecosystem services by ensuring various mining activities consider timing, location, and types of materials extracted. Currently, these activities – when occurring in the upper basin, in particular, – can negatively affect the Seven Forks Dams system and the hydropower production it provides.

Quarrying takes place primarily in the upper basin (Figure 44). These activities supply stone for the construction and building materials that are in high demand throughout Kenya. Many of these activities are unregulated and when abandoned are left open, which as reported by Kizito et al. (2014) can lead to increased sediment loads. Wells and Wall (2001) report that technical developments since that 1980s that make stone extraction easier, coupled with high cement costs and demand have driven the market and, therefore, has resulted in expansion of informal quarries. They also report that quarrying activities have expanded through extension into new areas and hiring more workers, as opposed to intensifying operations. Wells and Wall (2001) further cite

FIGURE 44. Example of a quarry area alongside the Amboni River in the upper basin.

a report by Mjaria (1997), which indicated that around 200,000 workers were employed in the quarrying industry.

Sand harvesting takes place primarily in the middle and lower basin (Knoop et al. 2012) and several areas are considered hot spots for this activity because many of the streambeds dry out during the year making them accessible. Significant negative environmental consequences result when sand is harvested from dry streambeds. As reported by Knoop et al. (2012), such rivers not only become more prone to erosion but also lose their ability to hold excess water and provide a water buffer to local communities during dry times of the year. Terer et al. (2004) assert that sand harvesting is an important livelihood activity and is considered a highly valued ecosystem service in several communities within the lower Tana Basin.

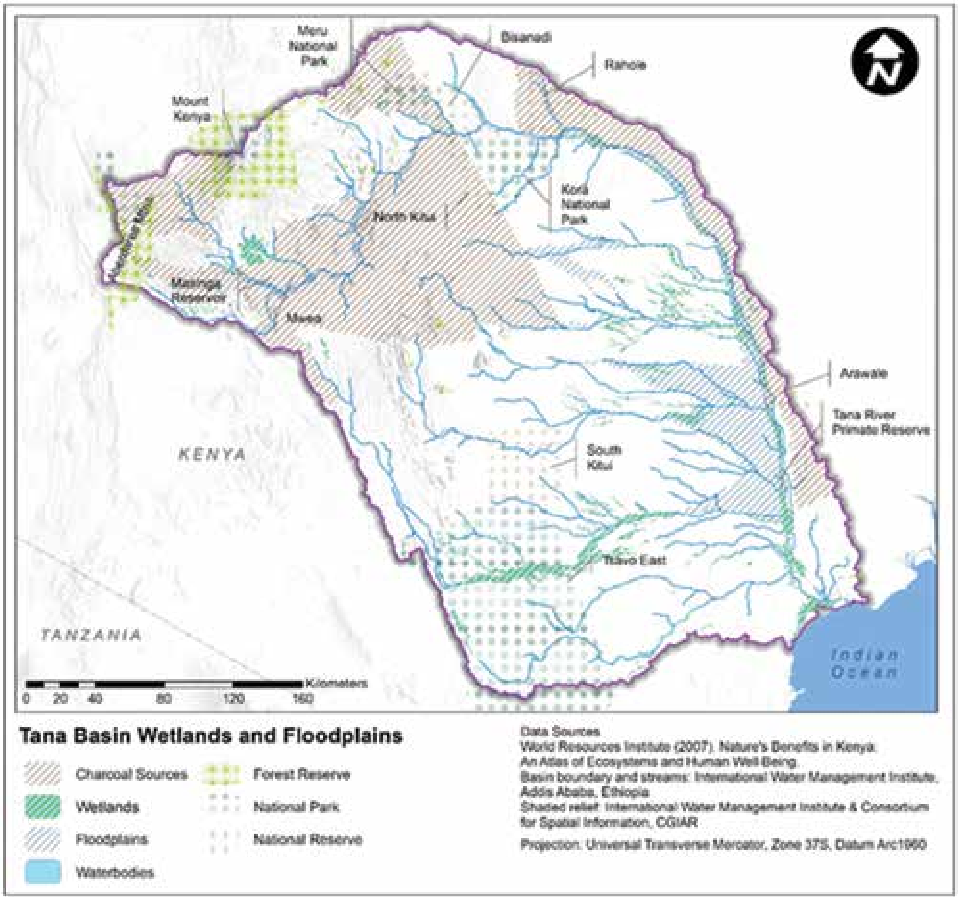
In addition to environmental consequences, there are also social consequences. For example, Masese et al. (2012) report that opportunities to earn money through sand harvesting activities are a cause for primary school absenteeism or school drop out in poor communities. Ontiri and Robinson (2015) give an example of the Kaiti River (Figure 45), where unsustainable resource extraction such as uncontrolled sand harvesting is leading to significant levels of natural resource degradation. In turn, the community cites such severe degradation as the root of numerous negative social consequences such as increased stress and decreased mental wellbeing, causing youth in particular to resort to drug use in the face of dwindling livelihood opportunities.

Charcoal Production

Kenya's population is still heavily reliant on charcoal as a major energy source, with 80% of the urban population depending on it (Iiyama et al. 2014). According to WRI-DRSRS-MENR-CBS-ILRI (2007), approximately 500,000 Kenyans rely on the charcoal value chain for their livelihoods, with around 200,000 on the production side and 300,000 on the transport and vending side. Charcoal production within and around the Tana River Basin (Figure 46) poses a significant threat to biodiversity and water resources through land degradation. Within the Tana Basin, KWS-UNEP-KFWG (2003) identifies several key charcoal production hot spots: Nyeri, Garissa, Embu, and Meru.

FIGURE 45. During the dry season, the Kaiti River in the Middle Tana Basin, is a sand harvesting source relied upon by local communities.

FIGURE 46. Major charcoal production areas within and around the basin. Many of these areas cross beyond the basin boundary and are encroaching at its edges.



Although there is a government ban on logging in Kenya, illegal tree poaching still occurs within the Upper Tana Basin targeting particularly vulnerable tress species: cedar (*Juniperus procera*), wild olive (*Olea europaea*), East African Rosewood (*Hagenia abyssinica*), camphor (*Ocotea usambarensis*) (KWS-UNEP-KFWG 2003). Tree poaching and illegal logging in the upper basin is for charcoal production in addition to firewood, poles, and timber.

Lower in the basin where pastoralists have lost access to tradition grazing areas, they will often engage in opportunistic charcoal making as a survival mechanism, though it is not a preferred livelihood activity and has a host of negative social connotations within their communities (Bennett and McDowell 2012). Due to increasing challenges posed by increased drought frequency and severity and loss of grazing areas, pastoralists have begun engaging in more frequent charcoal production. The highest levels of charcoal production in Kenya are in arid and semi-arid areas dominated by pastoralists. A major challenge, however, is that inefficient and unsustainable practices are utilized for its production (KFS 2013). It is important to note, however, that most charcoal production (90%) within Tana County, in particular, is from legal sources such as private and trust lands. This form of charcoal production typically utilizes *Prosobis juliflora* and *Prosobis chilensis* species, which are invasive and have damaging impacts on biodiversity and the hydrology of riverine systems (Shackleton et al. 2014; KWS-UNEP-KFWG 2003). Finally, it has been suggested that, if the charcoal industry became legalized and regulated, there are areas within the Tana Basin (i.e., Kwale and Kilifi) where charcoal production would be sustainable and provide government tax revenues as high as KES 5.1 billion per year (WRI-DRSRS-MENR-CBS-ILRI 2007).

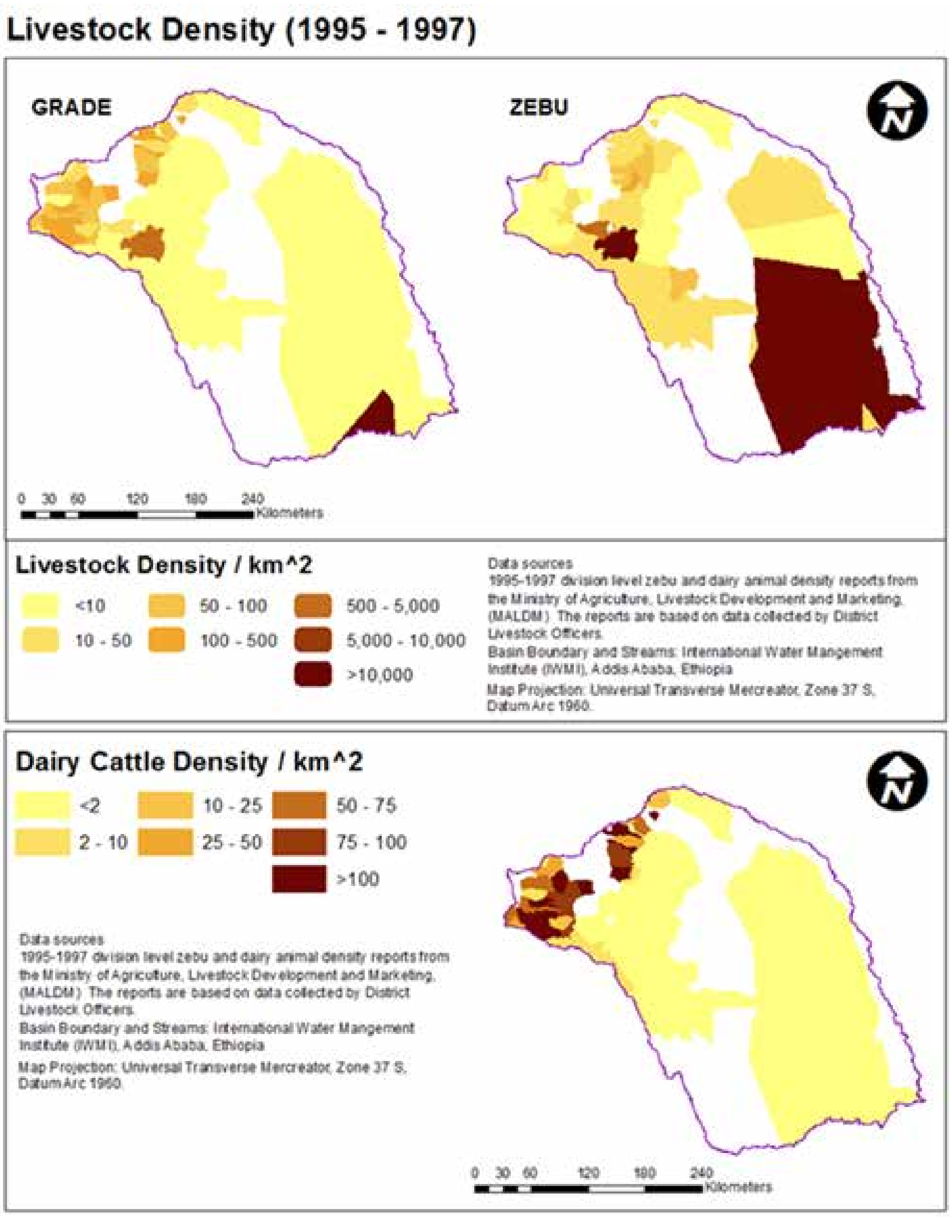
Livestock Grazing

Intensive livestock grazing has led to the expansion of woodland vegetation in rangeland areas worldwide that were once grasslands. This has taken place with attendant potentially negative consequences on a host of ecosystem services, such as climate regulation and landscape hydrological function (Asner et al. 2003; Wu et al. 2000; Archer et al. 1995). Livestock grazing is often cited as a challenge in East Africa, where overgrazing is considered a source of serious land degradation. In the Tana River Basin too, it is often cited as a significant issue that urgently needs to be addressed. That said, particularly in the upper basin, practices such as zero grazing have been implemented. Within the Upper Tana Basin, dairy cattle are more commonly kept, while in the lower part of the basin Zebu and Grade cattle are preferred (Figure 47). In addition, other types of livestock are commonly kept in the basin and are important in providing food security (Figure 48; Table 36).

In addition to issues surrounding land degradation, WRI-DRSRS-MENR-CBS-ILRI (2007) suggested that livestock water demand in Kenya might be as high as 15% of all water demands. This is often coming at the expense of large grazing wildlife, whose numbers have decreased by as much as 67% since the late 1970s. This decline in grazing wildlife is attributed to land and water resources competition coupled with poaching (WRI-DRSRS-MENR-CBS-ILRI 2007).

Similar to the spatially differentiated threats posed by charcoal production, livestock grazing is considered problematic in the Tana River Basin, as it is generally uncontrolled (Knoop et al. 2012). Within the upper basin, livestock pose threats to indigenous forest regeneration. Due to limited land available for agricultural production in the upper basin, many farmers allow their livestock to graze in forested areas, which can lead to difficulties in forest regeneration as grazing animals selectively consume saplings when available. In these upper reaches of the Tana Basin, livestock are integrated into cropping systems and so aerial censuses are more challenging and may be less accurate.

FIGURE 47. Dairy cattle density by district in the Tana Basin during a 1995–1997 survey carried out by ILRI indicates that dairy cattle are concentrated in the upper most part of the basin.



Downstream within the basin, while some of the Orma pastoralists are seemingly settling into a more sedentary agricultural lifestyle, it is coming at a great social cost. Bennett and McDowell (2012) detail the social difficulties being faced by the Orma as they must adapt to a new way of life after having been displaced from their traditional recession grazing lands along the floodplains of the Tana River in the 1990s, to make way for a large-scale rice irrigation schemes. While the armed conflict that has ensued among the Pokomo and Orma people since this time has been publicized in popular media outlets worldwide (Astariko 2014a, 2014b, September 16; Barisa 2014, August 29; Jones 2013, March 2; Gettleman 2013, February 21; Nyassy 2013, January 10; The Economist 2012, September 20; BBC 2012, September 18; Chonghaile 2012, September 13; Los Angeles Times 2012, August 22; McVeigh 2011, July 2; Rice 2008, June 24), far less discussion has been had regarding what leads to these conflicts. For example, aside from being relocated to

FIGURE 48. Various types of livestock kept within the Tana Basin according to 2009 surveys.

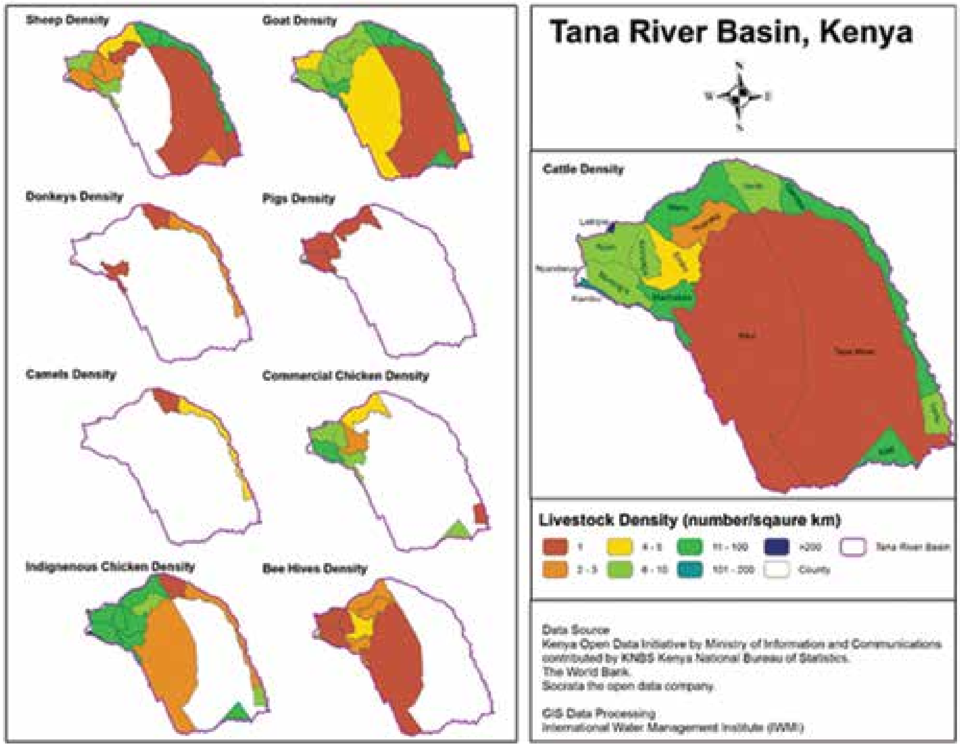


TABLE 36. County level census information regarding the number of animals in 2009.

County	Cattle	Sheep	Goats	Camels	Donkeys	Pigs	Indigenous Chicken	Chicken Commercial	Beehives
Embu	150,700	47,550	220,795	13	7,813	6,368	436,899	67,892	100,976
Garissa	903,678	1,224,448	2,090,613	236,423	75,178	59	82,127	22,168	4,415
Isiolo	198,424	361,836	398,903	39,084	22,189	115	35,137	6,652	1,444
Kiambu	284,216	147,801	115,900	127	13,716	43,378	801,072	1,686,565	23,965
Kilifi	186,963	46,949	472,108	16	3,980	2,445	655,266	176,740	6,005
Kirinyaga	144,112	27,642	101,596	7	3,990	10,606	465,455	82,458	10,227
Kitui	340,341	65,504	1,057,390	2,123	136,621	1,152	711,182	44,238	389,061
Laikipia	189,685	340,914	282,734	2,803	13,475	2,707	318,125	41,847	25,633
Lamu	81,200	15,626	68,178	47	2,572	55	87,951	7,636	1,219
Machakos	339,891	126,608	629,974	20	21,336	4,026	862,592	182,952	46,370
Meru	471,719	197,923	402,317	4,040	14,901	29,211	1,117,305	186,977	139,627
Murang'a	243,248	54,319	187,147	4	3,298	22,284	682,752	515,090	33,494
Nyeri	222,246	168,809	102,926	88	3,283	13,584	513,,637	152,380	15,999
Tana River	269,894	272,852	484,220	48,882	17,590	35	109,105	11,606	15,527
Tharaka	63,444	31,961	142,813	12	5,444	980	135,417	5,692	77,383

Source: KNBS 2009.

places where water resources for livestock (the mainstay of pastoral peoples) were quite scarce, many people felt compelled to engage in agricultural activities or charcoal production (Bennett and McDowell 2012). As such, they become outcasts among their own communities because 'turning the soil' is viewed as something associated with death and engaging in fire- dependent activities (e.g., charcoal production) is viewed as particularly shameful (Bennett and McDowell 2012). Those who make these difficult choices are then cast out from their communities and families. In turn, this exacerbates the conflict over water and land resources as the Orma begin encroaching on the traditional farming areas of the Pokomo. The need to address this challenge to land and water resources for livestock is paramount within the delta, in particular.

CONCLUSION

It is clear that the Tana River Basin is rich in natural resources and its unique ecosystems have supported a diversity of livelihoods and people for centuries. For Kenya to achieve its Vision 2030 water-energy-food security goals, decision makers will be confronted with doing so under the veil of uncertainty imposed by climate change. Decisions they make stand to bring about significant positive changes within the basin and the country as a whole, but these decisions need to be weighed against multiple competing interests. Without proper planning and accounting for climate and human population change, there is a potential for short-term gains coupled with long-term losses resulting from changes in ecosystems and the current services they provide.

At present, 49% of Kenya's total energy needs are met by hydropower production – with 70% of that amount being met by the Seven Forks Project in the Upper Tana Basin – and the completion of the Grand High Falls Dam is already under way. When viewed alongside plans to add additional hydropower dams (in the Tana Basin and elsewhere) and increase both coal and thermal energy extraction, Kenya stands to not only provide energy security for its people, but also to become a major supplier of energy in the region.

By integrating the impending impacts of climate change with the potential and currently planned trajectories of change into multi-scale and multi-disciplinary assessments, it is possible to make evidence-based decisions regarding hydropower production and irrigation expansion within the Tana River Basin. By developing a baseline understanding of the basin's resources and coupling this with field studies and modeling efforts, an increased understanding of the relationship between natural and built infrastructure will come into greater focus. These efforts can facilitate the development and exploration of a portfolio of scenarios that balance natural and built infrastructure to support development as well as preserve key ecosystem services for future generations.

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