The Economics of Ecosystem Services of the Tana River Basin

Assessment of the impact of large infrastructural interventions

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Executive Summary

Tana River is Kenya's longest river and originates from two of Kenya's major water towers: Mt. Kenya and the Aberdares. The Tana River Basin covers 22% of the country's total land mass and is home to 18% of the country's population. It contributes over 50% of Kenya's river discharge to the Western Indian Ocean. Ecosystems in the Tana River Basin including forests, arid and semiarid lands, mountain vegetation, freshwaters and wetlands, marine and coastal areas and agro systems provide a range of ecosystem services vital for human wellbeing such as drinking water, hydro-electric power, fisheries, agriculture and biodiversity.

The river basin is facing a number of challenges potentially undermining the continuous provision of ecosystem services. The upper catchment is threatened as more land is allocated to farming while poor farming practices have also led to soil erosion and pollution of the rivers. Water resources are planned to be used for water supply to Nairobi and Lamu port/city and this is envisaged to lead to an over-abstraction of water in the Basin. A proposal for the expansion of irrigated agriculture and energy through additional dams has also raised concerns.

The study

Against this background, the Water Resources Management Authority-Tana Catchment Area (WRMA-TCA) with the support of UNEP and Wetlands International (representing the Ecosystem Alliance) and The Netherlands Ministry of Economic Affairs are working towards determination of **the value of the ecosystem services of the Tana River basin and their economic significance to the Kenyan economy**, with a view to providing evidence for development planning and water resources allocation, so as to safeguard its hydrological, ecological and socio-economic benefits. The main objective of this study is to assess the economic value of the positive and negative externalities of different water-flows regimes, both upstream and downstream in the Tana River basin. In order to achieve this objective, the multidisciplinary study includes the following specific sub-objectives:

- Create baseline information on the **state of ecosystems** in the Tana Basin for planning, management and monitoring of ecosystems;
- Undertake an assessment of the **hydrological status** of the Tana River Basin under different water and climate regimes;
- Determine **economic values** of ecosystem services for use in decision making in development planning and water resources allocation in the Tana River Basin;
- Design a **stakeholders map** revealing the level of influence of various entities in managing the Tana River Basin as well as the level of impact of various water and climate regimes;
- Establish a basis for transparent **choices and trade-offs** for sustainable management of the Tana River Basin;
- Increase **awareness** on the significance of ecosystems and ecosystems services of the Tana to the economy of the country and its growth.

The **integrated assessment** of the Tana River Basin evolves around an extended cost benefit analysis taking into account the environmental and societal changes in river basin regimes. In valuing ecosystem services provided by the Tana River Basin, various aspects are taken into account such as the large *diversity of ecosystem services* affected throughout the river basin, the *spatial variation* in changes in ecosystem services with the main differences between upstream and downstream effects, and the temporal dynamics of the changes varying between short time and long term effect, as well as season fluctuations.

The study builds around four scenarios which resemble the most important developments that are currently planned in the Tana River Basin. These include:

- **Scenario 0 – No Dams**: The naturalized state of the river, without any interventions. Although this scenario does not serve as a realistic alternative for the current development of the Tana River Basin, it does provide useful comparative context for reflecting on the question whether past decisions to build dams and irrigation schemes has increased welfare in the basin.
- **Scenario 1 – Masinga+ dams**: This baseline scenario represents the current situation. In total five hydropower dams (Masinga, Kamburu, Kindaruma, Gitaru and Kiambere) have been constructed in the Tana River (upper basin), providing almost three quarters of the national energy demand. Additionally, two dams have been constructed in the Chania (Sasumua) and Thika (Thika) rivers, which supply water to Nairobi (Nippon Koei, 2013).
- **Scenario 2a - HGFD:** This policy scenario represents a future situation in which the High Grand Falls Dam (HGFD) is completed and additional irrigation in Bura, Hola and the Delta is established. The HGFD is a flagship project for the Kenyan government within the National Water Master Plan 2030 (Nippon Koei, 2013). The HGFD will be used for – in order of priority – flood management, power generation and supply of irrigation, drinking and industrial water (Republic of Kenya, 2011a).
- **Scenario 2b – Million Acres**: This additional policy scenario is similar to scenario 2a, with the addition of one million acres (~400.000 ha) of irrigated land for which water is extracted from the HGFD reservoir.

Hydrology

The hydrological research contributes to the overall study by undertaking an assessment of different hydrological scenarios and boundary conditions for the provisioning of ecosystem services in the Tana River Basin. A GIS based rainfall runoff model, called STREAM, was set up to simulate river discharges for each scenario. The translation from discharge to flood formed the link between the hydrological model and the ecosystem services.

The results reveal that the interventions of the HGFD, and its related large-scale irrigation schemes, have the potential to change the hydrological system dramatically. The proposed dam alone will be responsible for a significant decrease in flood events in the middle of the catchment area (65% in Garissa), while the construction of the High Grand Falls Irrigation schemes alone will diminish a vast amount of flood events in the lower catchment area. The combined effects of these interventions, that is the complete HGFD project, impacts the amount of flood events the most, with a decline of 65% in the middle catchment area in Garissa, with 12-19% in the lower catchment area in Nanigi and Garsen and with 8% at the river outlet in Kipini. Overall, it can be concluded that the magnitude of the dampening effect on discharge of Masinga and the HGFD, significantly reduce the seasonal signal. The hydrological analysis also shows that with the large extraction of water due to the million acres irrigation, overall water resources at Garissa are greatly reduced, almost to a constant level of natural minimum flow with hardly a flood peak left.

Ecology

The Tana River Basin is ecologically endowed with rich ecosystem services of which some of them are dwindling due to increasing human pressure. For example, flooding of Tana River has profound influence on the ecology of the flood plain as well as the formation and distribution of wetlands in the reserve. Ideally, Tana River floods twice a year in November -December and May -June, depositing a fertile layer of silt on the plain and oxbow lakes. The lower sections of Tana River support unique wetland ecosystems such as riverine forests, oxbow lakes, floodplain grasslands, mangrove forest, sand dunes, and coastal waters. Besides having a huge local significance, the Tana River Basin is of international importance due to its richness in biodiversity which include several IUCN Red-listed species, endemic or regional endemic species and CITES listed species.

In the ecosystem assessment, the major issues affecting the Tana River Basin will be explored within the framework of DPSIR (Drivers-Pressures-State-Impact-Response) model. The model is used as a convenient organizing framework tool for systematically structuring environmental information. The ecosystems in the Tana Basin are broadly classified into the following categories: Montane/Highland Forests; Agro-ecosystems (Cropland); Grasslands; Tana Delta; Coastal Forests; Mangroves; Small Wetlands (Lakes and Rivers); and Settlements.

The upper catchment is the most degraded as indicated by very high scores. There is moderate degradation in the middle catchment while the lower catchment scored mostly very low degradation levels. Areas with the most impact appear to closely overlap with the distribution of cropland thereby confirming that poor agricultural practices are the main causes of land degradation. The main factors that may contribute to degradation in the middle catchment (classified in this assessment as moderate) are wildlife and livestock grazing. This area is mostly covered by rangelands for pastoralists, game parks and wildlife dispersal corridors. Although the lower catchment is least degraded, this region is likely to be affected the most as a result of changes in the water flow regime.

Economy

The main purpose of the hydro-economic model is to conduct a cost-benefit analysis of large interventions such as reflected in the scenarios. The economic research contributes to the model by providing dose-response functions which relate hydrological input in terms of river discharge and flooding, to ecosystem service output such as crop yields and fish catch. The dose response functions were obtained by statistical analysis of time-series data. Significant results were obtained for rice production, beef cattle population and health in Tana River County and Garissa County, which are all strongly correlated to changes in water flow. In literature and from interviews it was found that the Tana River, while vital for the health of the people living in the Basin, can cause lethal floods in extremely wet years. Supporting the literature study, a clear statistical relation was established between the average discharge in Garissa during the rainy seasons and the mortality rate in the Lower Tana (Garissa and Tana River counties). Mortality rates tend to increase both when the water flow is low and when it is high.

Additionally, the benefits of irrigation schemes and hydropower were calculated. Irrigated agriculture currently has the potential to produce 64,000 tons of rice and maize per year. The benefits of hydropower total an annual US$ 25-43 when compared to an alternative of natural gas and geothermal generation, yet the cost of generating hydropower is also significant, as shown in the cost benefit analysis below.

Household survey among Delta communities

To determine potential changes in the economic value of the mangrove ecosystem goods and services in the Tana River Delta as a result variations in the hydrological conditions, a field study has been conducted in the Kipini division of the Tana Delta Sub County. The research employs novel valuation techniques (i.e. choice modelling). A total of 530 questionnaires have been collected from three sub locations namely, Kipini, Matangeni and Kau. This sub-study reveals the value of various ecosystem services that are likely to be affected because of changes in the Tana River regimes, such as the breeding and nursery function of the mangroves, the potential of developing touristic and recreational activities, the function of shoreline protection of the coastal ecosystems, the value of preventing floods in the coastal region.

This sub-study concludes that the mangroves in the Tana Delta contribute significantly to the well-being of the people by providing a number of products such as fuelwood and building poles, and indirect use values such as nursery and breeding ground for fish, flood control, tourism and recreation and shoreline protection. The mangroves ecosystem services play a key economic role in the livelihoods of the people of Kipini division and as such should be safeguarded, enhanced and accounted for during planning for the development of the delta and indeed the Tana basin. Contrary to the popular notion that the flooding havoc in the delta is caused by excess rainfall upstream, local communities believe that before the dams on the Tana River were constructed, they used to cope well with natural flood events. Moreover, public awareness of future plans for the Tana River Basin proved to be limited. More than half of the respondents have no knowledge of the proposed one million acre scheme and the High Grand Falls dam.

Stakeholders

The stakeholders of the Tana River Basin which are affecting or effected by the HGF dam project are truly diverse, varying from highly powerful politicians to large-scale farmers and tourism operators, to small-scale semi-subsistence farmers and fishermen that depend on the Tana River for their livelihoods. This stakeholder analysis is a descriptive qualitative study and was conducted by a participatory research approach employing the following data gathering instruments. First, structured in-depth interviews were carried out with systematically selected individual stakeholders representing local communities and institutions. In total 43 stakeholders were interviewed which are either potentially affected by hydrological changes in the Tana River Basin caused by the HGF dam project or stakeholders that are in a position to influence these changes themselves. Second, focus group discussions (FGD) were conducted with 2-5 representatives of the farming and fishing community groups, affected by the HGF dam project in different ways.

The SA reveals a number of insights. First, it finds that the general degree of awareness and knowledge regarding the HGF dam project is low. This lack of awareness and knowledge especially affects the primary stakeholders who have the greatest dependency on the Tana River. Despite their primary stake, it turned out that these stakeholders have no opportunity to influence the HGF dam project. Second, it reveals that the number of water-related conflicts is likely to increase due to the HGF dam project and this may lead to further instability in the basin. These problems can be tackled by increasing the awareness and knowledge of the HGF dam project by improving public consultation by the decision-makers at the primary stakeholders. Stakeholder participation and involvement in an early stage encourages 'ownership' of the plan and can engender trust among all partners and reduce conflicts. Third, the SA shows that there is a lack of harmonisation of interests amongst the relevant Ministries. The risk of a lack of harmonisation of interests is that one Ministry obtains a disproportionate amount of influence instead of all Ministries influencing the HGF dam project from their respective fields of interest. The Ministry of Environment, Water and Natural Resources is the Ministry that is best positioned to harmonize the interests of all relevant Ministries through the allocation of water due to the many economic purposes that water serves. Finally, the SA shows that the HGF dam project involves many costs that the decision-makers do not seem to take into account. The distribution of costs and benefits of this infrastructural project are likely to be unequally distributed: the majority of the population downstream of the HGF dam incur costs without being able to exert influence on this decision. The ultimate decision-makers consider this unequal distribution as inevitable in the process of increasing economic growth in Kenya.

Extended cost benefit analysis

The extended cost benefit analysis (CBA) combines the costs side (i.e. the financial inputs resulting from the interventions) and the benefits side (i.e. the socio-economic consequences that result from these interventions). Combining information generated in the previous sub-studies, predictions of costs and benefits were made for a period of 25 years for the three scenarios (1, 2a and 2b) relative to the baseline scenario (0) of the naturalised state of the Tana River without dams. A sensitivity analysis of the CBA results was carried out for varying climate change scenarios.

The extended CBA draws a number of conclusions. First, the construction of the existing dams (i.e. Masinga and others) has generated abundant welfare for the upstream region in terms of electricity, potable water and agricultural outputs. The downstream region lost slightly more benefits than it gained. This loss mainly resulted from reduced agricultural productivity and increased health issues. The benefits of scenario 1 for downstream counties come from an increase in power supply and flood prevention. Second, the positive change that occurs as a result of the HGF dam compared is especially the increase in electricity supply. The downstream positive and negative effects show a similar but less pronounced pattern as occurred with the Masinga dam addressed in Scenario 1. Third, the million acres scenario seems to create significant agricultural benefits in the downstream region (i.e. Tana River County) yet the large water demand of the irrigation schemes is likely to cause serious water shortages in this same region which will lead to substantial declines in health, potable water availability, fisheries and livestock.

When looking at the distribution of costs and benefits at the county level, the winners and losers of the three interventions are more specifically revealed. Clearly, upstream counties such as Nairobi and Kirinyaga benefit most from the interventions. For each dollar invested in the current dams, eight dollars were returned in terms of electricity and water benefits within the county. These positive effects in the upstream counties are less pronounced in scenario 2a and 2b, yet the benefits still outweigh the costs (measured proportional to the population share in the Tana Basin). The "losers" of the current dams are the counties Kitui, Tana River and Isiolo. All downstream counties suffer from the million acres project, except for the Tana River county where most of the planned irrigation is scheduled to take place.

Policy recommendations and suggestions for further research

This study aimed at clarifying the different values and perspective of the ecosystem services of the Tana River basin and their significance to the Kenyan economy, with a view to providing evidence for development planning and water resources allocation, so as to safeguard its hydrological, ecological and socio-economic benefits. In doing so, strict research boundaries had to be set, which also implies that the study has limitations in terms of the extent to which concrete policy recommendations can be formulated. In other words, the study clearly shows that current development plans in the Tana River Basin have positive but also serious negative effects for various stakeholder groups in the basin. It is beyond the scope of this study to determine whether these negative effects can be mitigated in a cost-effective manner. Although these research boundaries limit the direct use of this study for policy implementation in the Tana River Basin, it also helps to identify a number of critical areas that deserve further attention before the proposed development projects are implemented.

First, the study shows that the negative downstream effects of the HGF dam often outweigh the positive effects of the dam upstream. This outcome does not imply that the HGF dam should not be developed, but instead calls for further investigations to what extent alternative dam management regimes could mitigate the negative effects of the HGF dam downstream. A next study could use the basic information collected in this research to optimize water allocation across the various uses.

Second, although the study shows that several planned development projects fall short in terms of economic efficiency, it does not provide an immediate alternative for the basic economic services provided by these interventions, since this is beyond the scope of the current study. We think these questions are excellent topics for future research. For example, the study shows that the million acres project is difficult to achieve with the present water resources available and that the external costs of this project are significant. Next studies could elaborate on alternative, more water efficient methods of food production.

In summary, the current study is a first step towards a truly integrated analysis which aims at optimising water use within the Tana River Basin, taking into account the development goals of the Kenyan government, the limits to the hydrological system, as well as the capability of stakeholders to adapt to new conditions. For that ambitious goal, this study provides an excellent starting point.

Acronyms and Abbreviations

CANCO	-	Community Action for Nature Conservation
DR	-	Dose-response
FGD	-	Focus Group Discussion
GDP	-	Gross Domestic Product
GWh	-	Gigawatt hour
HGF	-	High Grand Falls
HQ	-	Headquarters
IUCN	-	The International Union for Conservation of Nature
kgs	-	kilograms
KMFRI	-	Kenya Marina and Fisheries Research Institute
kWh	-	kilowatt hour
KWS	-	Kenya Wildlife Services
KWTA	-	Kenya Water Towers Agency
LAPSSET	-	Lamu Port Southern Sudan –Ethiopia Transport
MP	-	Multipurpose
MSD	-	Medium speed diesel
MW	-	megawatt
NEMA	-	National Environment Management Authority
NGO	-	Non-Governmental Organization
NIB	-	National Irrigation Board
NRM	-	Natural Resource Management
O&M	-	Operation and maintenance
RAP	-	Resettlement Action Plan
SA	-	Stakeholder Analysis
SFD	-	Seven Forks Dam
TARDA	-	Tana and Athi River Development Authority
TEEB	-	The Economics of Ecosystems and Biodiversity
TNC	-	The Nature Conservancy
TR	-	Tana River
TWSC	-	Tana Water & Sewerage Company
UNEP	-	United Nations Environment Programme
US$	-	United States Dollars
WRMA	-	Water Resources Management Authority
WRUA	-	Water Resources Users Association
WWF	-	World Wide Fund for Nature

1 Introduction

Pieter van Beukering

The Tana River is Kenya's longest river and originates from two of Kenya's major water towers: Mt. Kenya and the Aberdares. The Tana River Basin covers 21% of the country's total land mass and is home to 18% of the country's population. It contributes over 50% of Kenya's river discharge to the Western Indian Ocean. Ecosystems in the Tana River Basin including forests, arid and semiarid lands, mountain vegetation, freshwaters and wetlands, marine and coastal areas and agro systems provide a range of **ecosystem services** vital for human wellbeing. For example, the basin supplies 80% of the *drinking water* for Kenya's capital, Nairobi. The Tana River is also the country's primary source of *hydro-electric power* through the river's many dams (i.e. 70% of Kenya's hydroelectric power and 38% of Kenya power supply). *Fisheries* and *agriculture* in the basin provide a major source of food and employment for the estimated 7 million residents that live in the greater basin area and in other parts of the country. One of the basin's important ecosystems is the Tana Delta at the coast. This *biodiversity* hotspot is home to several endangered species and was designated as a Ramsar site in 2012.

Today, the river basin is facing a number of **challenges** potentially undermining the continuous provision of ecosystem services. The upper catchment is threatened as *more land is allocated* to farming while poor farming practices have also led to soil erosion and pollution of the rivers by agro-chemicals. Tana Basin Water resources are planned to be used for drinking water purposes for the city of Nairobi and Lamu port/city (under development) and this is envisaged to lead to an *over-abstraction of water* in the Basin. Various forms of *mining* are other key environmental challenges in the basin. A proposal for the expansion of intensive and irrigated agriculture (for bio-fuels and food crops) in the basin and energy through *additional dams* has also raised concerns about impacts on the provision of ecosystem services.

Assessment of the status of these ecosystem services and subsequent determination of the related socio-economic benefits they provide is critical for decision makers in Kenya to make well-informed decision making, in development planning, water resources allocation and in directing investments for the management of these ecosystems and their services. It is against this background, that the Water Resources Management Authority-Tana Catchment Area (WRMA-TCA) with the support of UNEP and Wetlands International (representing the Ecosystem Alliance) and The Netherlands Ministry of Economic Affairs are working towards an analysis of **the societal costs and benefits of future scenarios in the Tana River Basin taking into account the value of the ecosystem services.** The main purpose of this analysis is to provide evidence for development planning and water resources allocation, so as to safeguard its hydrological, ecological and socio-economic benefits. The findings of this study are expected to create awareness on the importance and value of these ecosystems to the government, private sector and donor community thereby is catalysing investment in the rehabilitation and protection of these ecosystems. This work reflects on what is envisaged in Kenya's National Water Master Plan and the Tana Catchment Management Strategy, all contributing to Kenya's Vision 2030. The results of the proposed assessment are also expected to benefit the current ongoing Strategic Environmental Assessment (SEA) for the Tana Basin.

The main objective of this study is to assess the societal costs and benefits of the of different water-flows regimes, both upstream and downstream in the Tana River basin. In order to achieve this objective, the multidisciplinary study includes the following specific sub-objectives:

- Create baseline information on the **state of ecosystems** in the Tana Basin for planning, management and monitoring of ecosystems;

- Undertake an assessment of the **hydrological status** of the Tana River Basin under different water and climate regimes;
- Determine **economic values** of ecosystem services for use in decision making in development planning and water resources allocation in the Tana River Basin;
- Design a **stakeholders map** revealing the level of influence of various entities in managing the Tana River Basin as well as the level of impact of various water and climate regimes;
- Establish an extended costs-benefit framework basis for transparent **choices and trade-offs** for sustainable management of the Tana River Basin;
- Increase **awareness** on the significance of ecosystems and ecosystems services of the Tana to the economy of the country and its growth.

To meet the above objectives, the study adopted a **multidisciplinary and transdisciplinary approach.** A team of Kenyan and Dutch researchers was established consisting of ecologists, hydrologists, economists, and political scientists. Research organizations that are involved include The University of Nairobi, National Museums of Kenya, and the VU University, Amsterdam. A hydrological study conducted at the Utrecht University in the Netherlands also contributed to this project. At various stages of the research process, including scoping, data sharing, reviewing, outreach and dissemination, workshops and field visits were organised with the aim to engage policy makers, practitioners and local communities maximising incorporation of their knowledge and visions. This process was facilitated by UNEP, Wetlands International and the Netherlands Ministry of Economic Affairs. In order to build capacity in conducting ecosystem services studies, Kenyan and Dutch students were selected to take part in the research. The study commenced in January 2014 and was scheduled to be completed in July 2015.

The team contributes to an **integrated assessment** of the Tana River Basin which is schematically represented in Figure 1. The study evolves around an extended cost benefit analysis taking into account the environmental and societal changes in river basin regimes. In valuating ecosystem services provided by the Tana River Basin, a multitude of aspects are taken into account. First, the *diversity of ecosystem services* affected throughout the river basin may be large, involving a wide range of economic sectors. Second, the relevant ecosystem services will not change in total isolation of each other, thereby calling for a comprehensive analysis accounting for *mutual dependencies*. Third, there is an obvious *spatial variation* in changes in ecosystem services, with the main distinction between upstream and downstream effects. Fourth, changes in ecosystem services are *not constant over time*. Therefore, the analysis accounts for dynamics of the river basin regimes distinguishing between short time and long term effect, as well as season fluctuations.

While on the one hand the study's main objective is to conduct an integrated assessment by linking ecological, hydrological, economic and governance dimensions, the study's added value, on the other hand, is also to provide more **indebt knowledge within these individual components**. Therefore, each sub-study also provides relevant insights that may not necessarily be directly relevant for the extended cost-benefit analysis, but which does generate useful knowledge for policy makers, practitioners and local communities that operate in the Tana River Basin in alternative ways. Also, the sub-studies presented in the respective Chapters of this report should be seen as an effort to archive information that is highly scattered and often hard to access. In this manner, the study hopes to leave a report for future teams to make a head start for follow-up research, which systematic and rich in information. At the same, the team acknowledges that despite the major efforts put into collecting all relevant information, given the huge area and multidisciplinary nature of the study, no doubt relevant studies or reports may have been missed.

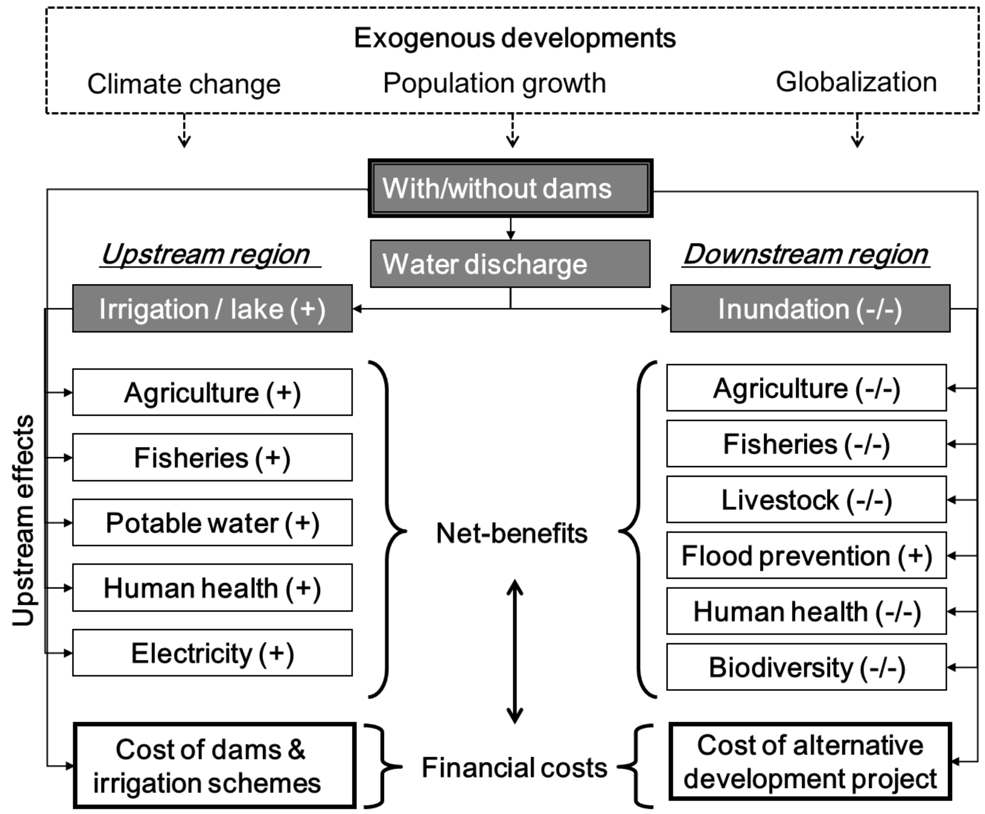

Figure 1 General economic analytical framework for river basins (example application for dams in the Tana River Basin)

The remainder of this report will elaborate further on the various sub-components of the research, as listed in the sub-objectives above. Chapter 2 explains the background of the Tana River Basin and the policy context in which it is managed. Chapter 3 presents the hydrological analysis in which various infrastructural interventions such as additional dams and irrigation schemes drive three main scenarios. In Chapter 4, an ecosystem assessment is conducted which the current status of seven main ecosystems in the Tana River Basin are described. Chapter 5 presents the estimation of various value functions of Tana related ecosystem services. Chapter 6 addresses the household survey and choice experiment conducted among residents in the Tana Delta. Chapter 7 assesses the governance domain of the Tana River Basin aiming to identify the winners and losers of the various scenarios. Chapter 8 combines the above sub-components into an integrated ecosystem services analysis, calculating the societal costs and benefits of the various infrastructural interventions in the Tana River Basin. As shown in the visualisation of the structure of the report in Figure 1, Chapters are, on the one hand, stand-alone studies which add value to the knowledge base of the Tana River Basin, while on the other hand, contain elements that feed other components of the study, ultimately combined in the cost benefit analysis presented in Chapter 8. Yet, in principle, each Chapter can also be considered as an independent individual research effort.

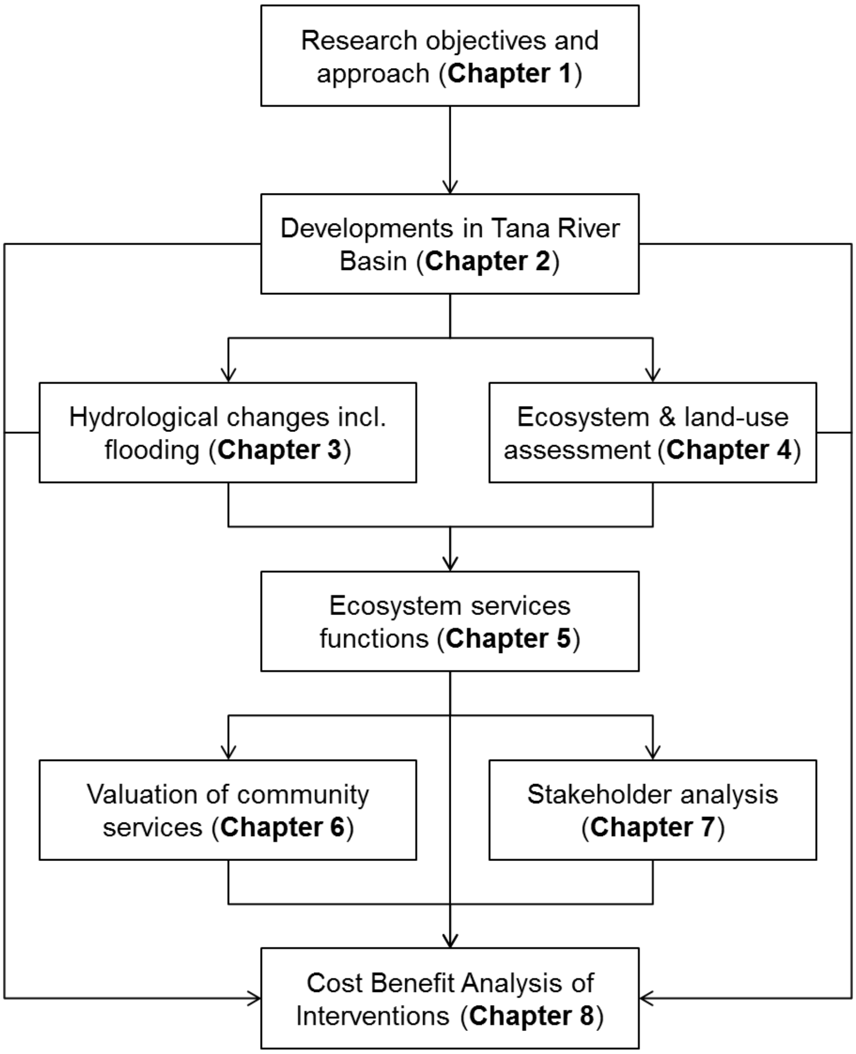

Figure 2 Structure of the report and the overall study

2 Background & Approach of Integrated Assessment

Pieter van Beukering & Maxime Eiselin

2.1 Introduction

This Chapter describes the general characteristics of the Tana River Basin. This information provides an important context, in which the study is conducted. After describing the biophysical characteristics of the Tana River Basin, going into more depth for the three sub-basins (i.e. upper, middle, and lower), attention will be given to the threats, drivers, ecosystem services and interventions in the various zones.

2.2 Tana Catchment Area

The Tana Catchment Area is located in the south-eastern part of Kenya (Figure 3). It neighbours the Ewaso Ng’iro North Catchment in the north, Somalia and the Indian Ocean in the west and the Rift Valley Catchment in the west. The Tana watershed is situated approximately between lat. $0^0$0’53” and $2^0$0’41’’ South, and lon. $38^0$25’43” and $40^0$15’ East, covering an area of 126.026 km^2, corresponding with 21.9% of the countries territory. The drainage area of the Tana River is 95.884 km^2, or 76.1% of the Tana Catchment Area. Based on the 2009 census, the Kenyan population was estimated to be about 7 million people in 2010 (Nippon Koei, 2013a).

Figure 3 Location map of the Tana Catchment Area (Nippon Koei, 2013a)

The Tana Catchment Area is home to Kenya's largest river: the Tana River. It discharges over a length of 1,012 km and it is estimated to contribute to 50% of Kenya's total river discharge (5 billion m^3/annum) (Agwata, 2005; Kitheka et al., 2004). The river springs in the western edge of the drainage area, below the summits of Mount Kenya (5,119 m a.m.s.l.) and the Aberdare Range (3,999 m a.m.s.l.), and ends at the eastern edge at the Indian Ocean.

The Tana River springs between the alpine landscapes of Mount Kenya and the Nyandarua Ranges and then follows its path towards the northeast. After reaching the Grand Falls dam site, the Tana River flows down for about 100 km in easterly direction from an elevation of 450 m to 200 m through moorlands, tropical forests and savannah grassland to the Kora Rapids. In the next 700 km downstream, the river gradually changes its direction towards the south, flowing through semi-arid lands as the only perennial stream around. At this point the river has a cross-section of 100 m while discharging through a 3 to 4 km wide alluvial floodplain, until the river passes mangrove forests near the coast and finally pours into the Indian Ocean (Republic of Kenya, 2011c).

The Tana River follows its path across various physiographical and climatic conditions. Therefore, the catchment area is roughly divided in three major sub-catchments, namely the upper, middle and lower catchments (Figure 4). The upper catchment area has a size of 15,000 km^2 at an altitude of more than 1000 m a.m.s.l.; the middle catchment area covers an area of 15,700 km^2 at altitudes between 300 m to 1000 m a.m.s.l.; the lower catchment area measures 95,300 km^2 at altitudes below 300 m a.m.s.l. (Hirji et al., 1996; Nippon Koei, 2013a).

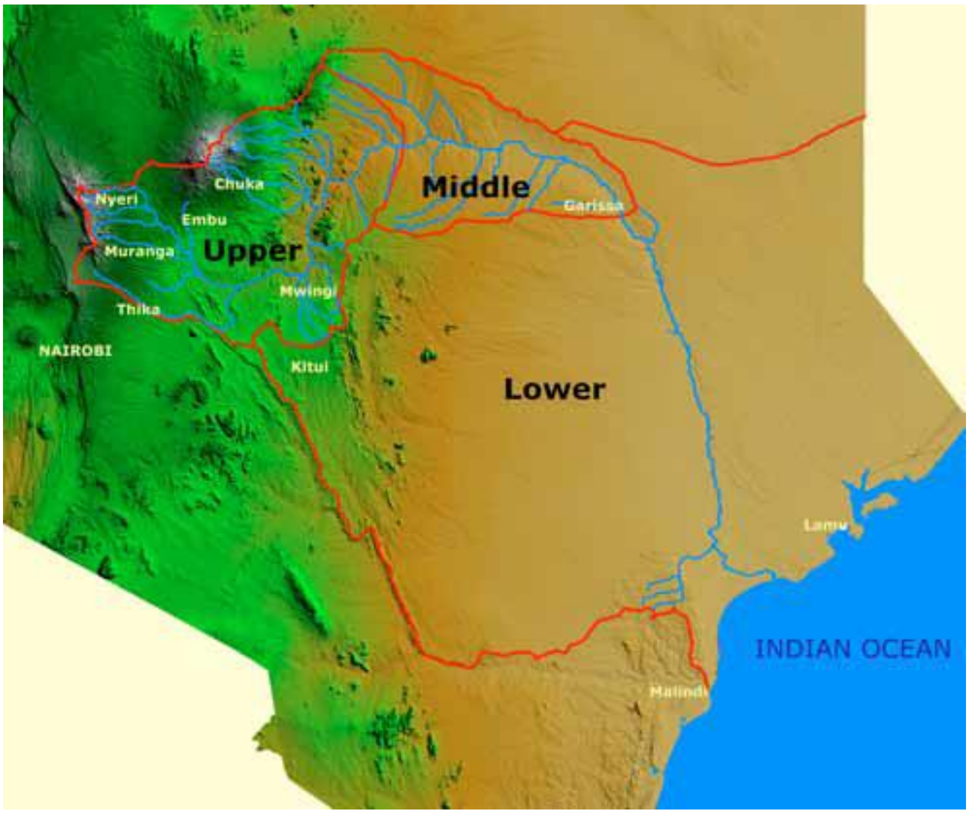

Figure 4 Map of the Tana River Basin with division in sub-Basins (Knoop et al., 2012)

Kenya is divided into 47 counties. The counties are geographical units for administrative purposes, established by the Kenyan government in 2010. Figure 2.3 shows that the Tana River traverses the whole area of the Muranga, Kirinyaga, Embu, Tharaka, Kitui, Tana River, Lamu county, as well as parts of Nyeri, Garissa, Kiambu, Machakos and Nyandarua counties (Figure 5).

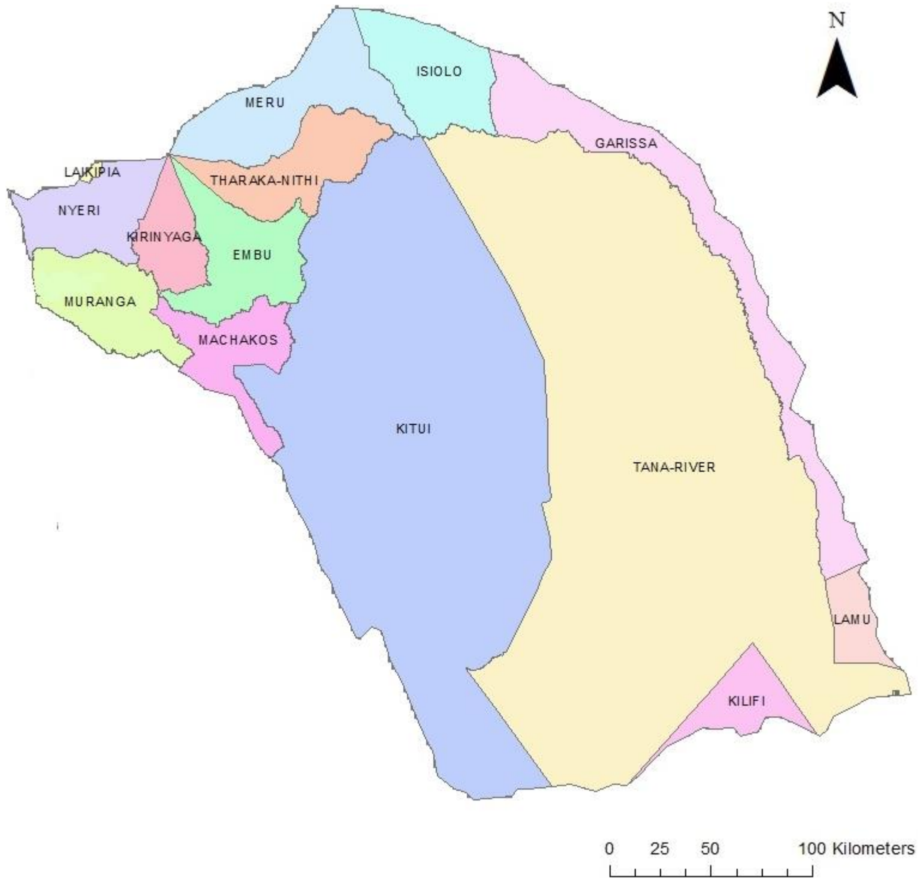

Figure 5 Map of the Tana Catchment Area and their related counties

The climate of Kenya is influenced by the equatorial location and the monsoon rains, which is regulated by the north-south movement of the Inter-Tropical Convergence Zone (ITCZ). It causes two dry seasons and two rain seasons annually (Table 1). At a catchment scale, the climate is further controlled further by regional factors, such as the topography of the steep mountains on the highland plateau and by local factors, including vegetation covers and sea breezes from the ocean.

Table 1 Seasons in Kenya

Month	Season
December – February	Dry season
March – May	Rain season, called as Long Rains
June – August	Dry season
September – November	Rain season, called as Short Rains

Average annual rainfall in the Tana River Basin differs spatially, having a trend of increasing precipitation towards the north-west. Figure 6shows that most of the basin's territory is characterized by semi-arid and arid conditions. It ranges from less than 300 mm in the lower catchment area, to 400 - 700 mm in the middle catchment area, to around 1,600 mm around Mount Kenya. Close to the Indian Ocean, a tropical strip along the coastline once again causes higher amounts of rainfall. Figure 7 clearly visualizes the spatial attenuation for the upstream to downstream rainfall stations at Nyeri, Meru, Garissa and Garsen. Observing at the catchment area as a whole, the average mean annual rainfall is 840 mm, of which approximately 90% is supplied by the two rain seasons (Nippon Koei, 2013b; Republic of Kenya, 2011c).

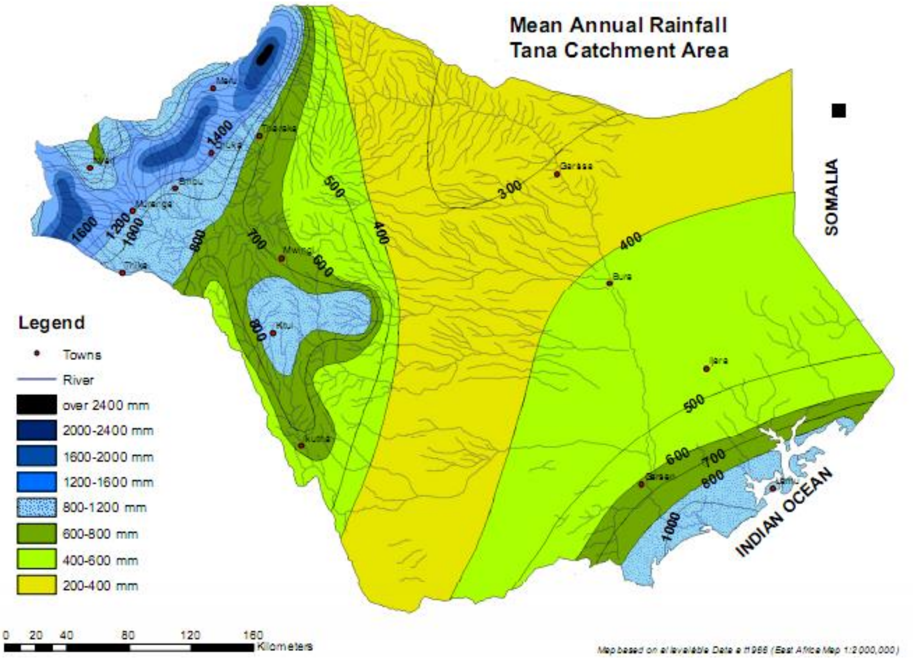

Figure 6 Mean annual rainfall in the Tana River Basin (Dickens et al., 2012)

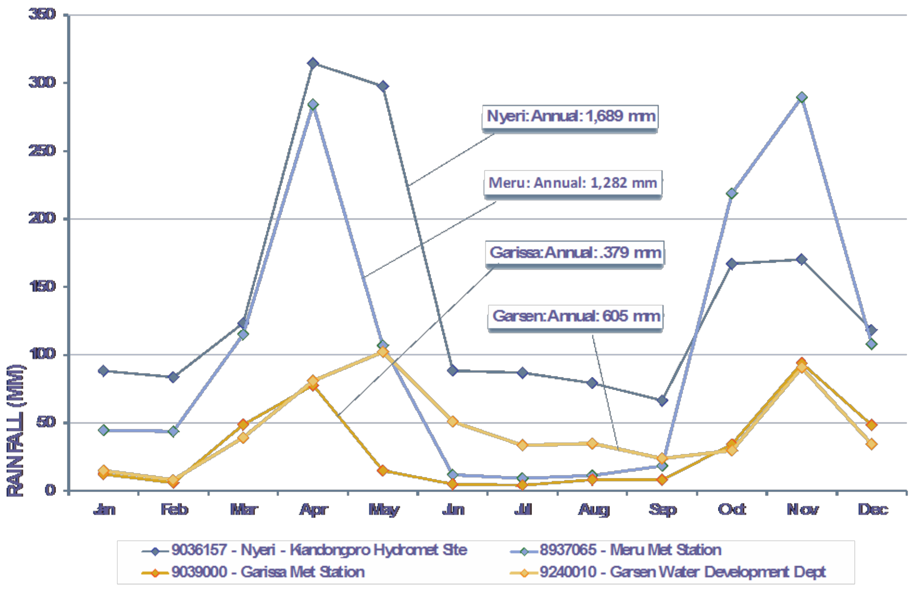

Figure 7 Mean rainfall at the selected rain gauges (Republic of Kenya, 2011c)

Average annual temperatures are closely related to altitude. It varies from 10 – 30 ^{0}C, with a range of less than 5 ^{0}C per season (Odhengo et al., 2012). The number of sunshine hours differs spatially, with an increase from the north-western upper catchment area towards the south-eastern lower catchment area. Similarly, water vapour pressure increases towards the south-east. The free water evaporation peaks during March and October and reaches a minimum during June and July; it has a spatial range from about 1,400 mm per year in the highlands to more than 2,600 mm per year in the upper parts of the lower Basin (Royal Haskoning, 1982).

The upper Tana

Knoop et al. (2012) highlight the importance of the upper Tana. Starting from the morphological reasons, this part of the catchment area has a high number of perennial and seasonal tributaries. These include among others, the rivers Thika, Sagana, Thiba, Mutonga and Chania. They are considered the most relevant ones as they have historically provided the Tana River with enough water to sustain agriculture and hydropower among other activities. The upper Tana is also the part of the catchment which shows the highest average annual precipitation rate, at around 1,000 mm. The average altitude of the area is about 1,000 m above the sea level and the climatic conditions are typically humid or semi-humid during the whole year.

In this part of the catchment, the soil is mainly volcanic, rich in nutrients and it is therefore possible for cultivating coffee, rice, wheat, tea and maize. Dairy production, poultry and sheep farming are also widely practiced (Agwata, 2005). Overall, water resources in the upper Tana are mainly used for agriculture, irrigation and hydropower.

Energy production is a key area as it is estimated that three quarters of the overall electricity demand of Kenya is supplied by the energy produced out of the five hydropower stations – the Seven Forks scheme built between 1968 and 1988 – located in this part of the Tana catchment area (IUCN, 2003). Maingi et al., (2002) argue that the first three dams created rather small reservoirs that did not directly impact the flow of the Tana River. The case was different for the two other dams, the Masinga Dam and the Kiambere dam, built in 1981 and 1988, which have an installed generation capacity of 40 MW and 144 MW respectively (WRMA, 2009). It is argued that these two dams have reduced the flow, the transportation of sediments downstream as well as the magnitude and incidence of floods in the Middle and Lower Tana.

As the Government of Kenya (GoK) plans to further boost hydropower to meet the increasing electricity demand of Kenya, the upper part of the Tana basin has been proposed as an ideal place where to build additional hydropower stations like the High Grand Falls (HGF) dam, which is projected to have a rated power output between 500 MW and 700 MW. These dams are essential for producing electricity as well as creating additional reservoirs to supply the increasing water demand within the catchment area.

The increase of population, anthropogenic activities and demand for water encouraged the GoK to take measures aimed at ensuring water availability. Building another dam in the upper part of the Tana River basin is aimed at providing the lower part of the catchment area – especially the region of Lamu – with water and at boosting the energy supplied by the national grid. However, as highlighted by Snoussi et al. (2004), the impact of new dams in the upper part of the Tana catchment area might have additional repercussions on the flow, sediments transportation and flood frequency and magnitude which will impact the livelihood of the downstream communities as well as the ecosystem services. In fact, the Tana River used to flood the banks of the middle and lower basins twice a year, hence sustaining all ecosystems such as riverine forests, lakes and grasslands.

IUCN (2003) reported that after the construction of the last dam in 1988, the floods have drastically reduced with a consequent impact on the agricultural activities of the downstream communities. The presence of new dams along the upper part of the catchment area would not only mean the total control of Tana River's waters but it might also contribute to the end of natural floods in the middle and lower Tana.

The middle Tana

The middle Tana registers humid to semi-arid conditions as the altitude rapidly decreases from 1,000 m to 200 m above sea level. The Tana is the most important of the few water bodies that permanently flow through this part of the catchment and therefore constitutes a major source of livelihood for the population (IUCN, 2003). In the middle Tana, the soil is mainly composed of cambisols and alkaline rocks and can therefore sustain the cultivation of cotton, tobacco, beans as well as dryland farming (Agwata, 2005; Knoop et al., 2012).

The number of anthropogenic activities is drastically lower in this part of the catchment area compared to the upstream and downstream territories. The reason is that the population density in the middle Tana is low and the generally dry conditions of the area are a limit for development. This part of the Tana catchment is home of three national reserves, namely the Meru National Park, Kora National Park and Rahole National Reserve which border the Tana River.

The lower Tana

The lower Tana is the part that covers most of the Tana catchment area with approximately 95,000 km^2. This territory is mainly semi-arid or arid with local geography under 200 m whereas there is a difference in the agro-climatic situation of the Tana delta and the coastal region which register higher rainfalls and humidity (Knoop et al., 2012; Agwata, 2005). Despite the presence of seasonal tributaries called lagas crossing the lower part of the catchment area, the Tana River remains among the main sources of livelihood for the population living in the lower basin.

Along the banks of the river, between the municipalities of Mbalambala and the Tana River delta, there is a unique riverine forest which is, according to the International Union for the Conservation of Nature (IUCN), home to rare and endangered species such as the Tana River Red Colobus and the Tana River Mangabey, both belonging to the primate family. Recent studies revealed the scarce regeneration capacity of the forest due to the lack of peak flows (Maingi et al., 2002). On the one hand, this is argued to be the consequence of climate change. On the other hand, studies have demonstrated that the construction of dams in the upper Tana have significantly impacted on the discharge of the river and on the transportation of sediments and nutrients downstream. Similarly to the middle basin, the lower Tana is scarce in water resources mainly because of high evapotranspiration rates and use for irrigated agriculture. Planning the use of water resources in the lower Tana is crucial as the given the expected increased water claims in the near future (e.g. the Lamu Port and LAPSSET corridor project).

2.3 Economic interests

The scenarios in this study are based a number of large scale interventions that are planned in the Tana River Basin which are born out of the need to support the rapidly growing economy of Kenya. To get a better understanding of the underlying economic developments driving the planned interventions, a more indebt description of these economic interests is presented in the following.

Hydro-power

The upper Tana Catchment Area is home to the largest dam and reservoir capacity in Kenya (Nippon Koei, 2013b). The region has a total installed capacity of 567 MW and the total gross storage of the reservoirs amounts 2,331 million m^3 (Nippon Koei, 2013a). This is enough to deliver about 70% of Kenya’s total hydropower generation and 40 to 60% of the total energy production in the country (Odhengo et al., 2012). As shown in Figure 8, the installed capacity of the Tana hydropower stations can deliver up to 13 GWh/day (about 567 MW) during rainy season, but only 7 GWh/day (about 300 MW) during dry season (Republic of Kenya, 2011a).

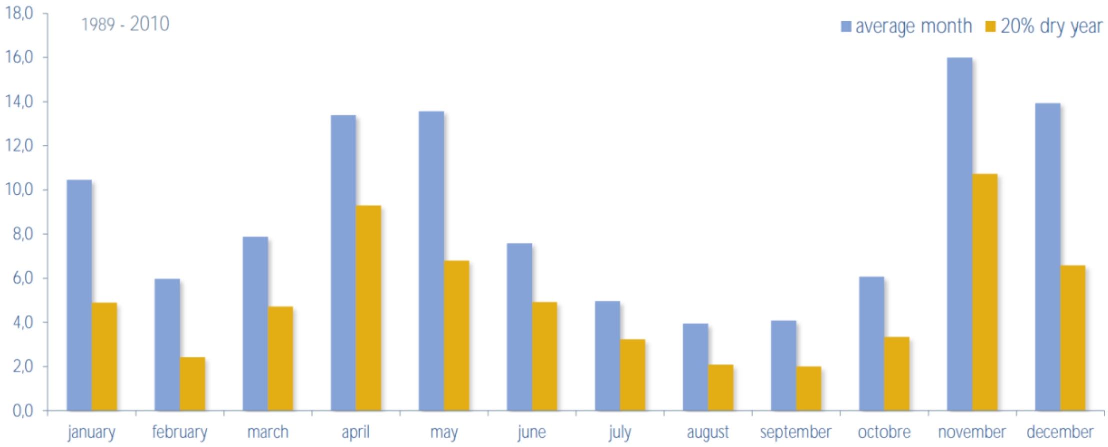

Figure 8 Mean monthly hydropower production, GWh/day (Republic of Kenya, 2011a)

The hydropower potential of the upper reaches of the Tana River originate from the relatively high average annual precipitation rates and the numerous perennial and seasonal tributaries, e.g. the Thika, Sagana, Thiba, Mutonga and Chania rivers, that are vital for fuelling the Tana River with water (Knoop et al., 2012).

In total five major hydropower stations have been installed on the Tana River, which together form a cascade of power plants. From upstream to downstream these dams include the Masinga, Kamburu, Gitaru, Kindaruma, and Kiambere dams. These dams are also called the Seven Forks Dams. The dam sites are shown in Figure 9 and Figure 10 and the dam characteristics are summarized in Table 2.

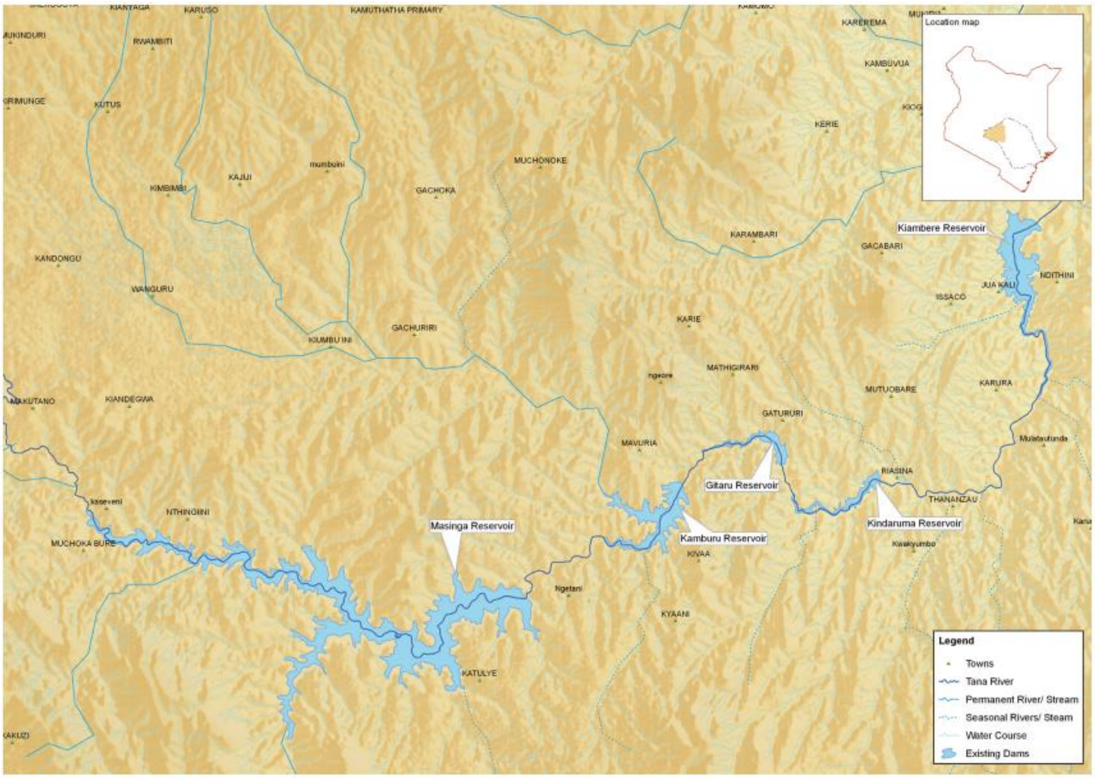

Figure 9 The Tana power cascade in detail (Republic of Kenya, 2011a).

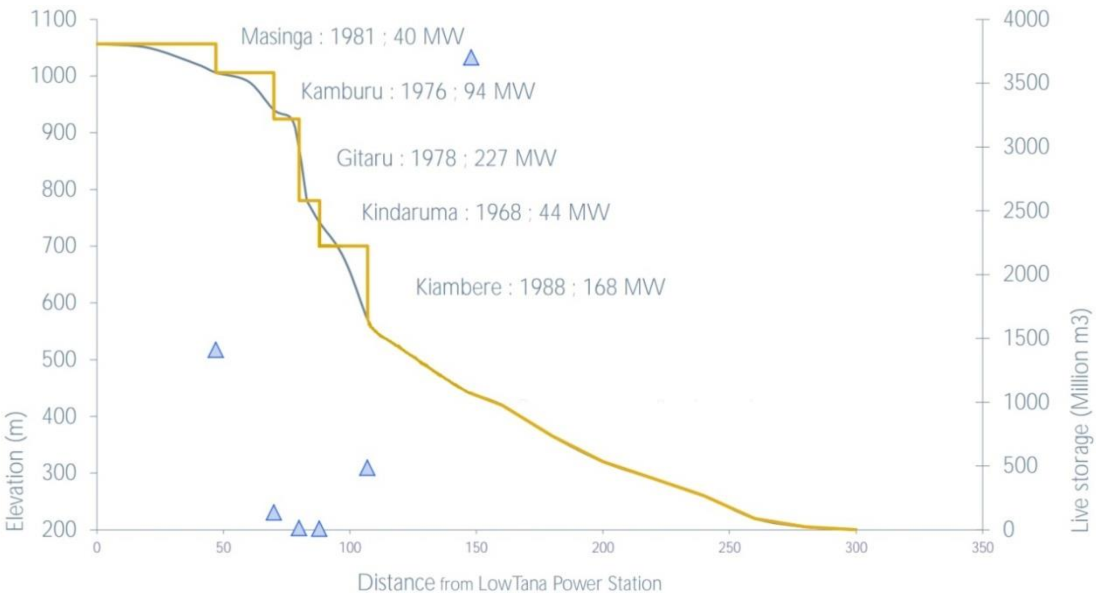

Figure 10 The Tana cascade power plants (based on Republic of Kenya, 2011a)

Table 2 Main data on the Seven Forks Dams (Republic of Kenya, 2011a)

Dam characteristics	Masinga	Kamburu	Gitaru	Kindaruma	Kiambere
Catchment area (km^2)	7,335	9,520	9,667	9,807	11,975
Reservoir capacity (million m^3)	1,560	150	20	7	485
Average discharge (m^3/s)	75	97	98	99	112
Power plant capacity (MW)	40	94	226	44	168
Head (m)	50	82	144	37	150

Drinking water

Further upstream of the Seven Forks Dams, the flow of the Chania and Thika tributaries is blocked by the Sasumua (1968) and Thika (1993) dams (Nippon Koei, 2013a). These dam reservoirs are utilized to divert water for domestic purposes to Nairobi and satellite towns, located in the neighbouring Athi Catchment Area. It delivers more than 80% of the water consumed in the (peri-) urban regions of Nairobi (Odhengo et al., 2012). Other water transfer schemes are in place from the Masinga reservoir to Kitui and from the Kiambere reservoir to Mwingi, both supplying water for domestic purposes as well. The main data on the water transfer schemes is shown in Table 3.

Table 3 Main characteristics on the water transfer schemes

Water source	Sasumua reservoir	Thika reservoir	Masinga reservoir	Kiambere reservoir
Demand centre	Nairobi & satellite towns	Nairobi and satellite towns	Kitui	Mwingi
River	Chania	Thika	Tana	Tana
Year of commissioning	1968	1993	1981	1998
Transfer volume (m^3/day)	56,200	414,700	7,296	1,390
Inter/intra Basin water transfer	Inter	Inter	Intra	Intra
Transfer distance (km)	60	50	60	70

Crops

According to the Republic of Kenya (2011b), the total cropping area in the Tana watershed in 2011 was about 1.0 million ha. However, irrigation-based farming is still a limited practice in the basin. The irrigation potential is estimated to be around 132,000 ha, of which 64,425 ha is irrigated already (Agwata, 2006). The irrigated land is divided into 11,200 ha (17%) large-scale schemes, 14,823 ha (23%) small-scale schemes, and 38,402 ha (60%) private schemes. They are managed by several governmental authorities, such as TARDA or the NIB, or by private organizations (Republic of Kenya, 2011b).

Since the Tana River traverses a diverse range of climate zones and soil types, it is subjected to various agricultural potentials and productions. For the comprehensibility of the targeted audience, only the large-scale irrigation schemes (>500 ha) were studied in this report.

The upper catchment area has rich volcanic soils and abundant water resources that give potential for the production of rice, bananas and horticultural crops (Agwata, 2005). These crops are respectively farmed at the Mwea (7,860 ha), Kaggari-Gaturi-Kieni (700 ha), and Mitunguu (600 ha) irrigation schemes. Agricultural areas in the volcanic and alkaline middle catchment area are largely occupied by rain fed agriculture and have not been opened for large-scale irrigated agriculture yet (Agwata, 2005; Knoop et al., 2012). The low land area, with its alkaline soil and an (semi-) arid climate, has been marked as underdeveloped by the Kenyan government although efforts have been made to implement public large-scale irrigation schemes in several parts of the huge unused flat lands (Agwata, 2005).

Several areas have been opened up for large-scale irrigation practices, but have deteriorated because of financial shortages for rehabilitation and maintenance. The large-scale irrigated areas currently in use, represent just a fraction of the land that was initially proposed for irrigation. These schemes include the Bura Irrigation Project (maize), Hola Irrigation Project (maize) and Tana Delta Irrigation Project (rice), currently areas under irrigation of 3,000 ha, 1,000 ha, and 2,000 ha, respectively. By contrast, the initial plans were to cover 11,700 ha in Bura, 4,800 ha in Hola and 4,000 ha in the Delta. Table 4 illustrates the key characteristics of the existing large-scale irrigation schemes in the Tana Catchment Area.

Table 4 Key characteristics of the existing large-scale irrigation schemes

Irrigation scheme	Mwea	Kaggari-Gaturi-Kieni	Mitunguu	Bura	Hola	Tana Delta	Delmonte
Irrigated area (ha)	7,860	700	600	3,000	1,000	2,000	8,000
Water source	Thiba & Nyamindi	River Thuchi	River Thingithu	Nanighi pumping station	Makere pumping station	Tana River, 13 km north of Garsen	Thika River, Makindi, Samuru
Average water abstraction (1000 m^3/month)	43,034	555	485	2,379	793	1,095	11,718
Dominant crop	Rice	Bananas	Horti-culture	Maize	Maize	Rice	Pineapple
Year of commissioning	1956	Unknown	2013	1982	1953	1997	Unknown
Executing agency	NIB	NIB	NIB	NIB	NIB	TARDA	Delmonte K Ltd

Figure 11 gives an overview of the locations where existing dam, irrigation and water transfer interventions interact with the Tana River. To summarize this section, Table 5 gives an overview of the Tana Catchment Area key characteristics and their sub-catchments, based on the findings above.

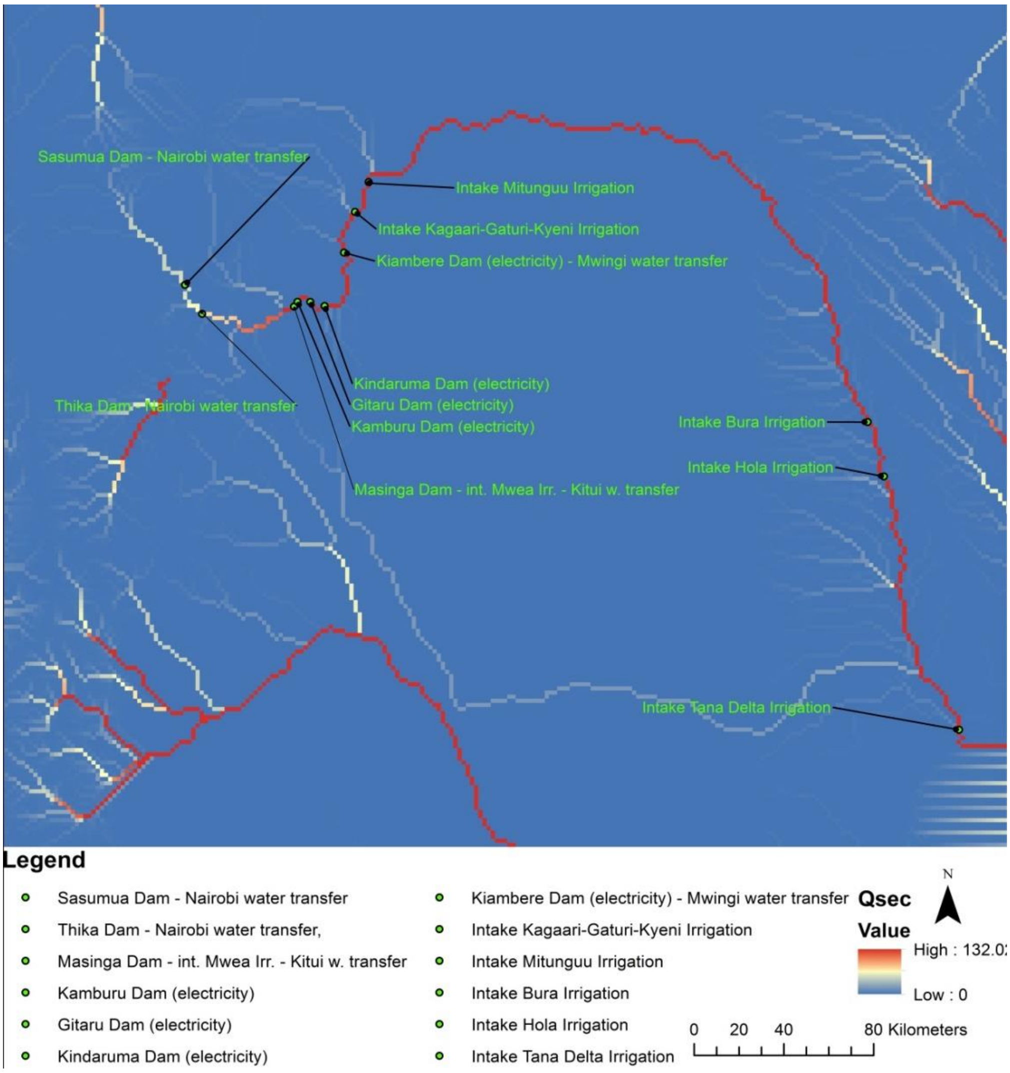

Figure 11 *Overview of the locations where existing dam, irrigation and water transfer interventions interact with the Tana River*

Table 5 *Key characteristics of the Tana Catchment Area*

Sub-catchment	Upper Tana	Middle Tana	Lower Tana
Average altitude (m)	> 1,000	100 – 300	< 300
Sub-catchment area (km^2)	15,000	15,700	95,300
Dominant climate	Humid	(Semi-) arid	(Semi-) arid; humid along the coast
Average annual precipitation (mm)	> 700	400 – 700	< 400
River gauge coverage	Abundant	Moderate	Sparse
Major river interventions	- Large-scale irrigation schemes; - Seven Fork Dams; - Water transfer for domestic uses	None	- Large-scale irrigation schemes; - Highest flow ever measured in Garissa
Soil type	Mainly volcanic	Volcanic and alkaline	Mainly alkaline

2.4 Ecosystem services and integrated river basin management

Lack of effective water resource planning that ensures a sustainable water use remains one of the biggest challenges of our time (SIWI, 2010). This challenge also accounts for the Tana River Basin, where a complex problem setting of water resource exploitation affects the socio-economic and natural environment. It requires a fully integrated approach covering the relevant societal and environmental components and their inter-linkages. This study applies the ecosystem services approach which finds its origin in the Millennium Ecosystem Assessment (MEA 2005) and which has been further developed by a large group of scholars such as Daily et al. 2009 (see Figure 12). The ecosystem services approach set-up is such that the outcomes of the present work can be used by environmental economists to assess the ecosystem changes in monetary units, or in alternative indicators, such as health. In this way, there can be a more comprehensible translation towards policy-makers and institutions that want to mitigate the effects of the threats in the Tana River Basin.

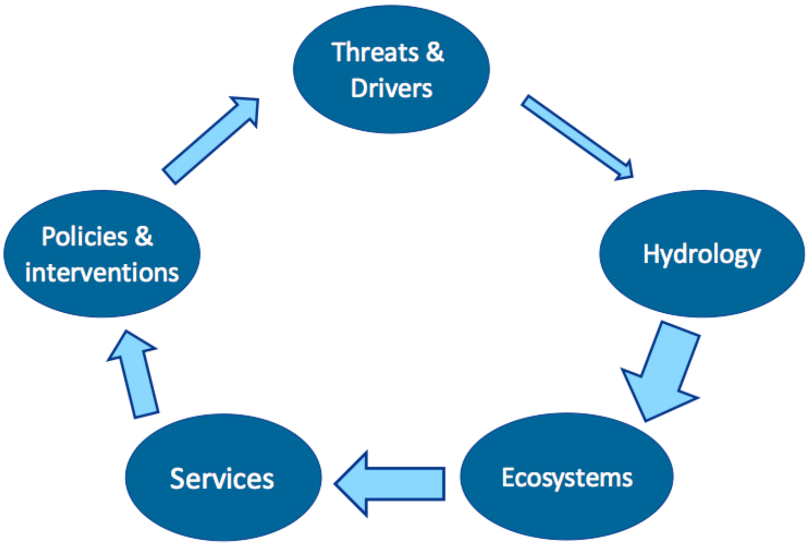

Figure 12 Ecosystem Services approach for the Tana River Basin (Based on Daily et al., 2009)

To evaluate the complex changes that take place in the Tana River Basin, this study is subdivided in different components that address the causal relationship between (1) socio-economic drivers and threats that likely change the hydrological status of the Tana River Basin; (2) the physical alterations of the hydrological regime that result from these drivers and threats; (3) the impacts from these hydrological changes on the ecosystems along with (4) the societal changes in ecosystem services that follow from the modified eco-hydrological system; as well as (5) an assessment on governance involving a stakeholder analysis to map the influence every party has on the developments in the Basin.

Threats and drivers

The government of Kenya aims to transform the country into a newly middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment (Kenya Vision 2030). Obviously, enough energy, food and drinking water for the population forms a key-part of this vision. To fulfil this objective, several socio-economic activities have been proposed for the Tana River Basin. These activities will likely change the performance dynamics of the Tana River watershed.

Securing the increasing human needs for the future requires more and larger hydrological interventions in the Tana River than there are today and represent the driving forces of environmental change. This forward-looking study includes the major policy-driven interventions that were proposed in the Vision 2030 and in the National Water Master Plan 2030, namely: the construction of additional dams, large-scale irrigation schemes and water transfer schemes for domestic purposes. This study also takes into account the more diffuse and indirect driver climate change, which makes the situation even more complicated (see Table 6).

Note that for the comprehensibility for the target audiences, the scenarios in this study will not address the whole list of threats and drivers, but will put its focus on the most important drivers and threats of change, as listed in the table below. The relevant threats and drivers are more thoroughly addressed in the upcoming Chapters.

Bear in mind that the Tables in the sections below distinguish between the upper, middle and lower Tana Catchment Area. This characterization functions as a rough indicator for the spatial variability of the different components.

Table 6 Threats and drivers of change in the Tana River Basin

Changes	Upper	Middle	Lower
Policy-driven changes			
Additional dams	X		
Land-use change	X	X	X
Irrigation schemes	X	X	X
Harbour development			X
Exogenous changes			
Climate change	X	X	X
Population growth	X		X

Hydrology and ecology

The socio-economic activities and population growth trigger an excessive use of water resources and pressures from climate change might cause even more intense periods of droughts and floods. It is likely that the future demand for water will increasingly exceed the regional supply, resulting in eminent hydrological and ecological changes in the Tana River watershed.

The physical state of the hydrological regime of the Tana watershed will most likely change in terms of water quantity and flooding area (table 1.2). However, there is still a knowledge gap about the spatial quantification of these state changes. This study aims to fill this gap through hydrological modelling (see next Chapter).

After quantifying the changes in available water resources, a direct or indirect link can be made to changes in the different ecosystems and their ability to provide services; the ecological conditions are closely related to water availability and the occurrence of flooding, both upstream and downstream of the Basin. Changing the hydrological parameters will likely change the state of savannah, mangroves, biodiversity and wildlife, lakes, rivers and reservoirs that are dependent on the Tana River (Table 7); which in turn affects the ecosystem services from the modified eco-hydrological system.

Table 7 Hydrological and ecological elements relevant for the Tana River Basin

Effects	Upper	Middle	Lower
Hydrology			
Water quantity	X	X	X
Flooding area		X	X
Ecology			
Savannah		X	X
Mangroves			X
Biodiversity/wildlife			X
Lakes/rivers/reservoirs	X	X	X

Ecosystem services

The Tana River provides a range of ecosystem services that are critical for the functioning of the Basin and the wider Basin. Due to the upcoming developments in the different parts of the catchment area, the spatial distribution of the ecosystem services is likely to change. Hence, upstream water abstraction practices might enhance provisioning services in the upper Basin and likely to have a negative impact on the services downstream. Table 8 shows an intuitive interpretation of the positive (+) and negative (-) changes in the ecosystem services; yet, the outcome of this study aims to address these spatial service changes as quantitatively as possible.

Table 8 Ecosystem services relevant for the Tana River Basin

Services	Upper	Middle	Lower
Drinking water	+ +	- -	-+
Electricity	+ +	+	+
Fisheries	+	- -	- - -
Livestock	0	- - -	-- -
Flood damage			
Crops	+	- -	- +
Human health	+	- -	- -

Governance

Figure 42 provides a visualisation of the main stakeholders that are affected and/or affecting the developments in the Tana River Basin. For example, the marginalised and vulnerable local communities in the lower parts of Tana River Basin are likely to have the least amount of influence while being most affected by the construction of new dams upstream. Similarly, several ministries of the GOK are highly influential in determining the future of the Tana River Basin while probably not facing direct negative consequences of large infrastructural interventions. These influences and impacts are explicitly addressed in the stakeholder analysis in Chapter 7.

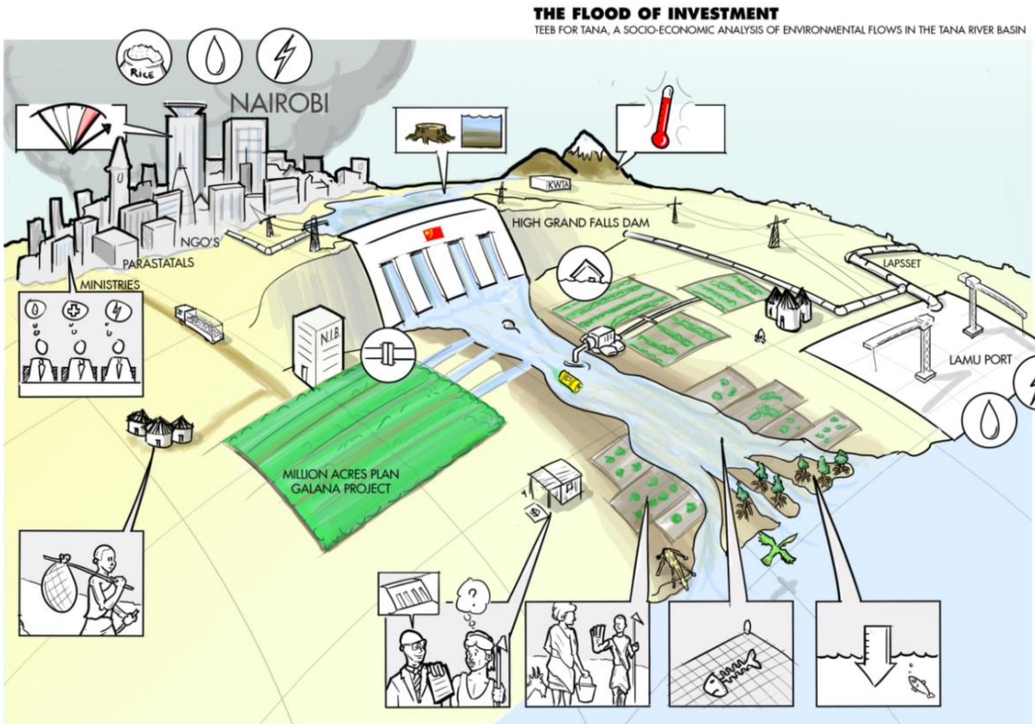

Figure 13 *Visualisation of the various stakeholder interests in the Tana River Basin in relation to the HGF dam project*

2.5 Scenarios

Various developments are planned in the Tana River Basin, focused on increasing food, energy and water productivity and economic growth. Planned land use, water use, and infrastructural interventions are assumed to provide several benefits, of which the most important are generation of electricity and stable provision of water in (semi-)arid regions (reservoirs) (Nippon Koei 2013). However, the interventions also contain the risk of adversely affecting the ecological and economic systems, and in turn people's livelihoods (Hamerlynck et al. 2010). Often, the costs and benefits of large infrastructural works in the river basin are not equally distributed in space and time. The potential adverse effects of the planned interventions may therefore result in a degradation of the services provided by the Tana River to a point where it can have direct and indirect adverse effects on people living in the downstream regions (Temper, 2010; Martin, 2012; Duvail et al., 2012). To evaluate the societal impact of the main developments in the Tana River Basin, the interventions with the presumed largest impact are included in this cost benefit analysis. These include:

- **Scenario 0 – No Dams**: The naturalized state of the river, without any interventions. Although this scenario does not serve as a realistic alternative for the current development of the Tana River Basin, it does provide useful comparative context for reflecting on the question whether past decisions to build dams and irrigation schemes has increased welfare in the basin. Moreover, this parameterization has also been used to calibrate the model.
- **Scenario 1 – Masinga+ dams***:* This baseline scenario represents the current situation. In total five hydropower dams (Masinga, Kamburu, Kindaruma, Gitaru and Kiambere) have been constructed in the Tana River (upper basin), providing almost three quarters of the national energy demand. Additionally, two dams have been constructed in the Chania (Sasumua) and

Thika (Thika) rivers, which supply water to Nairobi (Nippon Koei, 2013). Flooding volume and frequency have greatly decreased since the last dam was constructed in 1989 (Dickens et al., 2012). The five dams have resulted in less variability in discharge, with a 20% decrease in peak flows in May and a roughly 70% increase in low flows in February and March (Maingi & Marsh, 2002).

- **Scenario 2a - HGFD:** This policy scenario represents a future situation in which the High Grand Falls Dam (HGFD) is completed and additional irrigation in Bura, Hola and the Delta is established. The HGFD is a flagship project for the Kenyan government within the National Water Master Plan 2030 (Nippon Koei, 2013). The HGFD will be used for – in order of priority – flood management, power generation and supply of irrigation, drinking and industrial water (Republic of Kenya, 2011a). Its hydropower generation capacity will exceed that of the five existing dams combined (Nippon Koei, 2012; Government of Kenya, 2013). A feasibility study has been conducted on the HGFD, which forms the most comprehensive document with respect to the HGFD project (Republic of Kenya, 2011a).
- **Scenario 2b – Million Acres**: This additional policy scenario is similar to scenario 2a, with the addition of one million acres (~400.000 ha) of irrigated land for which water is extracted from the HGFD reservoir. Within the Kenya Vision 2030 agriculture has been identified as one of the key sectors to help reach the envisaged annual economic growth rate of 10%. In order to increase the agricultural productivity, irrigation has to be further developed (Government of Kenya, 2007). Irrigation is by far the biggest consumer of water in Kenya. It is expected to contribute to roughly 91% of the total water demand in 2030, of which 94% will be extracted from surface water (Nippon Koei, 2012). With irrigation being the largest water consumer, its effect on the water balance is expected to be significant. Along the entire Tana River there are plans for new irrigation schemes. There is a multitude of plans but only the large-scale irrigation schemes are included in this study.

Note that the construction of the Lamu Port has been excluded from this analysis given the limited information available on this major investment.

Since the scenarios used in this study are based on governmental development plans that cover a land-use planning till 2030, a limitation of this study is that the timescale is focused on short to medium term outcomes, till about the year 2080 maximum in the hydrological analysis. The cost benefit analysis is based on a time frame of 25 years. Using a longer time horizon is out of the scope of this study because the study area is developing at such a high speed that it is not possible to make reliable assumptions on the long-term hydrological and economic system. In addition, the uncertainties in the available climate models increase rapidly when looking further into the future.

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3 Hydrological Assessment of the Tana River

Hans de Moel, Maxime Eiselin, Frank van Weert, Kasper de Lange & Silas Mogoi

3.1 Introduction

In this sub-study, a hydrological model has been set up for the Tana River basin to be able estimate the impact of anthropogenic interventions and climatic change in the river basin. With this model, the impact of the High Grand Falls Dam and various irrigation and water transfer schemes on the overall water resources can be established. Hydrological indicators (like river discharge, water level, frequency of flooding) estimated from this will be linked to the provisioning of ecosystem services in order to assess the impacts of such anthropogenic interventions on those services.

For this purpose, the STREAM model has been used and further developed. STREAM is a transparent rainfall-runoff model that has been applied in numerous river basins all over the world to estimate water resources (Aerts et al., 2007; Kuma et al., 2010; Maina et al., 2013), including studies on water resources in Ethiopia and the Kitui district in Kenya (Aerts et al., 2007; Lasage et al., 2015).

Extensive field work has been performed (Eiselin, 2014; Lange, 2014) in order to provide input for this modelling framework related to anthropogenic interventions (existing and planned dams, irrigation and water transfers) and hydrological baseline information (discharge time series and water level relationships). This has been supplemented by globally available spatial datasets to serve as input for the modelling framework.

3.2 Methodology

STREAM model

For this study, the STREAM model - Spatial Tools for River Basins and Environment and Analysis of Management Options – has been used (Aerts et al. 1999). STREAM is a conceptual GIS-based rainfall runoff model which calculates the water balance in each grid cell of the catchment and then routes overland flow and ground water flow (see Figure 14). The water balance is estimated for every individual grid cell using the Thornthwaite-Mather equation (Thornthwaite and Mather, 1957). The equation approaches the hydrological cycle as multiple compartments in order to simulate runoff, ground-water storage and soil moisture reservoir for the movement of water throughout the basin. Hence, a distinction can be made between fast and slow hydrological processes. Fast processes include runoff and the soil reservoir, both acting as linear components. Potential evapotranspiration is steered by the surface temperature. Actual evapotranspiration is dependent on land-use and the soil water holding capacity (Figure 15).

STREAM has been set up with daily time-steps for this study, calculating the water balance and routing the runoff downstream every day. It has been assumed that water flows an average of about 80 km/day, or roughly 0.9-1 m/s; only stopped by reservoirs. STREAM has been operationalized in Matlab, making use of some Topo-toolbox functions for topographic analysis (Schwanghart & Kuhn, 2010; Schwanghart & Scherler, 2014).

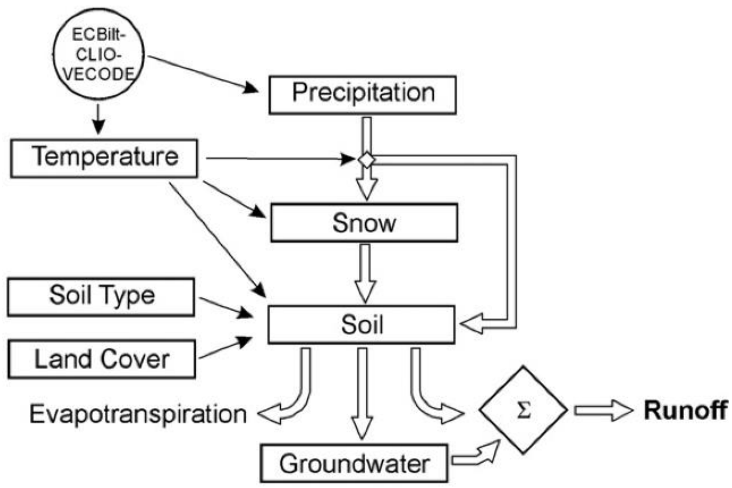

Figure 14 The operational concept of the STREAM tool (Aerts et al. 1999)

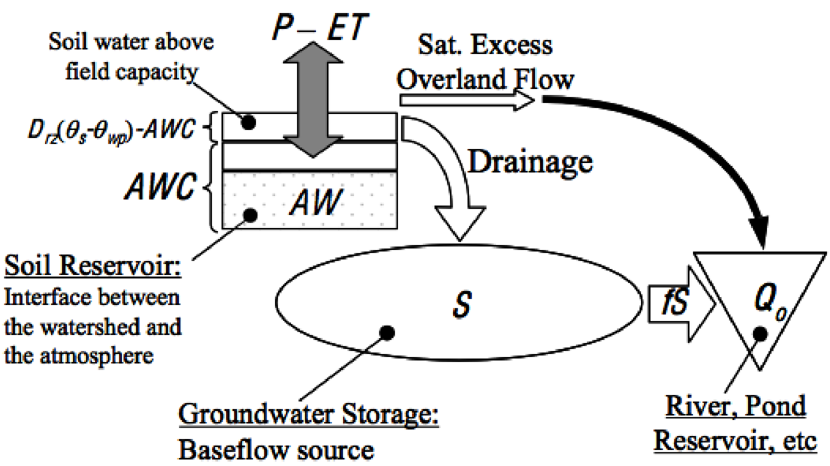

Figure 15 Illustration of a daily soil-water and watershed budget (Thornthwaite and Mather, 1957)

Input data

STREAM requires several spatial maps as input data. All input maps have been resampled to a resolution of 1 arc-minute (roughly 1850 by 1850 m) at which the computations were performed. Input maps include:

- Daily maps of *precipitation* and *temperature*. These have been taken from the dataset of Adam and Lettenmaier (2003) which was further corrected by Maurer et al. (2009), which covers the period of 1950-1999 for the entire globe at an original resolution of 0.5° by 0.5°(~55 km) (see Figure 6 in previous Chapter). This dataset was found to produce much better results as compared to the ERA-interim dataset that is also available at a daily temporal resolution.
- Information on soil characteristics have been used to derive the *water holding capacity* of the soil. For this, the ISRIC-WISE database has been used (Batjes, 2006), which derived various soil properties at a global scale from the Digital Soil Map of the World (DSMW; FAO, 2003), including the available water capacity of the soil (TAWC).

- *Elevation* information was used to derive flow directions. For this the SRTM dataset was used, which has an original resolution of 3 arc-seconds (~90 m).
- For the calculation of evapotranspiration, information on *land cover* is needed. This has been taken from the Africover database. This has been recalculated to crop factors based on Doorenbos and Pruitt (1977), which can be found in the STREAM manual (Aerts and Bouwer, 2003).

Besides these input spatial data layers, discharge time-series and rating curves have been used for model validation and flood analyses. These were provided for various gauging stations by the Water Resources Management Authority (WRMA).

Model calibration

The STREAM model has been set up for the entire Tana River basin and calibrated using the discharge time series for Garissa, which has the longest record (1941-2013). This station is located in the middle of the Tana River, downstream from the main source of Tana River water (Mt. Kenya and the Aberdares) and has the longest record. From this dataset, the time series 1957 till 1981 was chosen for calibration to simulate the naturalized flow, i.e. before the major river flow regulation by the Masinga Dam (1981) and the Kiambere Dam (1988).

Note that the first three constructed hydropower dams, Kindaruma (1968), Kamburu (1975) and Gitaru (1978), have relatively small water reservoir sizes - 16, 150, and 20 million m^3 respectively. Consequently, they did not heavily impact the downstream flow regime. The situation changed after the construction of the Masinga Dam (1981), which contained by far the biggest reservoir, 1,560 million m^3, which is equivalent to six months of mean Tana River discharge storage. This reservoir has been functioning as water storage since for providing a constant flow so as to optimize power production downstream. The construction of the Kiambere Dam (1988) further controlled the flow of the Tana River, as it is the last major hydropower dam that controls the river stream. This also makes the Kiambere Dam responsible for the delivering the environmental flow downstream.

Calibration was carried out by adjusting model parameters within their physical ranges. Firstly, the annual water balance was corrected by the crop factor to obtain the same area under the simulated hydrograph and the measured hydrograph. Secondly, it was required to do a visual control to check the base flow, flood peaks and timing. This was done by adjusting a factor for the slope, and a factor determining the contribution of ground water to the base flow. The resulting hydrograph for the calibration period is shown in Figure 16.

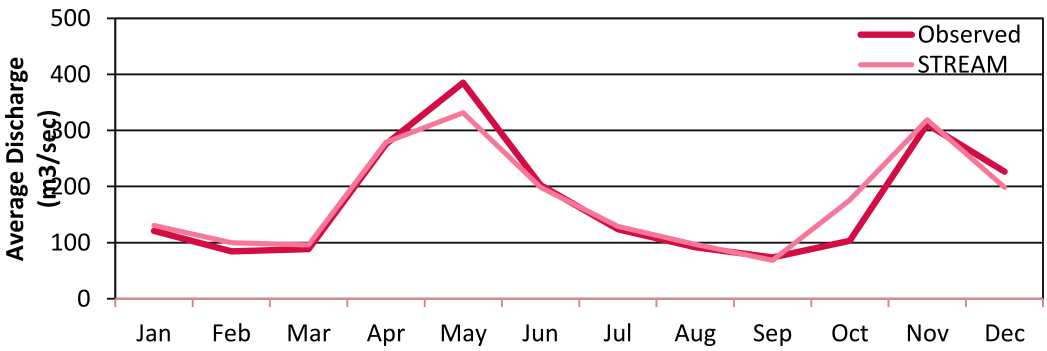

Figure 16 Model calibration for average monthly discharge in Garissa (1957 - 1981)

Flooding

Flooding is an important process in the Tana basin, with both recession agriculture and ecosystems dependant on annual flooding. Therefore, besides discharge also water levels have been computed for Garissa. However, too high floods can also have destructive consequences. For this purpose, small/medium floods and large floods have been differentiated. Small/medium floods have been defined as water levels reaching 3m gauge height, and large floods reaching 4m gauge height. For Garissa, various rating curves exist for different time periods, which have been used to estimate water levels for the observed time series. For the simulated time series (scenarios of anthropogenic interventions), gauge heights have been calculated using a single rating curve, namely the most recent one (1985 to date).

Anthropogenic intervention scenarios

Water resources of the Tana River basin are heavily used. Therefore, the STREAM model was further developed in order to integrate the effect of reservoirs direct extraction from the river. This way, the influence of dams, irrigation and water transfers could be incorporated. A large amount of interventions have been identified and incorporated in the model framework. As explained in more detail in Chapter 2, this has resulted in the following set of scenarios.

- **Scenario 0 – No Dams**: The naturalized state of the river, without any interventions. This parameterization has also been used to calibrate the model (see section on calibration);
- **Scenario 1 – Masinga+ dams***:* This baseline scenario represents the current situation, including the Sasumua, Thika and Masinga reservoirs. Evaporation from these and some other smaller dams, water transfers from Thika and Kiambere and intake for irrigation for several areas (Mitunguu, Kaggari, Bura, Hola, etc.) are accounted for;
- **Scenario 2a - HGFD**: This policy scenario represents a future situation in which the High Grand Falls Dam (HGFD) is completed and additional irrigation in Bura, Hola and the Delta is established, as well as the Nanigi – Lamu water transfer;
- **Scenario 2b – Million Acres**: This policy scenario is the same as 2a, but with the addition of one million acres (~400.000 ha) of irrigated land for which water is extracted from the HGFD reservoir.

In Appendix B the exact water extractions and parameterisations can be found of the above scenarios. The parameterization of the dams has been done using a so-called s-shaped curve, where more water is released when the reservoir is very full, but less water is released with low levels in order to simulate operations aimed at keeping the reservoir as full as possible for energy generation.

Climate change scenarios

The effect of climate change on Tana River discharge has been assessed based on six GCMs and three SRES emission scenarios (B1, A1b and A2). As two GCMs did not have A2 emission scenario information this resulted in 16 combinations. The GCMs were taken from the IPCC fourth assessment simulations (IPCC, 2007) and include: CCCMA-CGCM3.1, CNRM-CM3, GISS-AOM, MPI-ECHAM5, NCAR-CCSM3 and Miroc3.2hires. GISS-AOM and Miroc3.2hires did not have result for the A2 scenario.

Climate change effects have been calculated using the delta change method (see e.g. Diaz-Nieto and Wilby, 2005; Choi et al., 2009). The changes in monthly GCM data between a climatic reference period (1975-2005) and future periods around 2050 (2035-2065) and 2080 (2065-2095) were calculated for each month (i) using the following equations:

$$\Delta TMP = \bar{T}_{future,i} - \bar{T}_{ref,i}$$

$$\Delta PRE = \frac{\bar{P}_{future,i}}{\bar{P}_{ref,i}}$$

Given the large size of GCM grid cells as opposed to the Tana river catchment, from each GCM model a representative grid cell has been taken for which these delta factors were calculated. These change factors were then used to perturb the time-series of observed precipitation and temperature in order to simulate the effect of these climatic changes on river discharge.

3.3 Results intervention scenarios

The scenario analysis shows that anthropogenic intervention has a profound effect on the hydrology in the Tana River basin. Table 9 shows for Garissa the average mean, minimum and maximum monthly discharge (m^3/sec) over the 50 years of simulated discharge (i.e. the number for Min relates to the average of 50 years where for each year the monthly discharge for the month with the lowest discharge – usually March or September – is taken). The influence of the Masinga dam is very clear in the comparison between Scenario 0 and Scenario 1. This shows a decrease of about 9% in mean discharge, associated with a marked increase of minimum discharge (increasing with about a third) and a marked lowering of maximum discharge (decreasing by about a quarter). The potential construction of the HGFD will enhances this effect even more, as is seen from the changes from Scenario 1 to Scenario 2a. In case indeed a million acre of extra irrigation land is developed using water from the HGFD, mean discharge will drop considerable (by about a third when compared to the current situation). The increase in minimum discharge as a result of the buffering effect of the dams will also for a large part be nullified.

Table 9 Overview of hydrological changes for Garissa

	Monthly discharge (m^3/sec)			Average days per year with flood level	
	Mean	Min	Max	Small/Med	Large
Scenario 0 – naturalized	128	27	405	16	15
Scenario 1 – current	116	37	303	13	10
Scenario 2a – HGFD	110	66	203	7	6
Scenario 2b – million acre	77	42	151	4	3
Scen 0 to 1	91%	137%	75%	84%	66%
Scen 1 to 2a	95%	178%	67%	53%	56%
Scen 1 to 2b	66%	114%	50%	26%	32%

Figure 17 illustrates that magnitude of the dampening effect of Masinga (Scenario 1) and the additional effect the HGFD may have on discharge, reducing the seasonal signal considerably. These hydrographs also illustrate that with the large extraction of water due to the million acres irrigation in Scenario 2b, overall water resources at Garissa are greatly reduced, almost to a constant level of natural minimum flow with hardly a flood peak left.

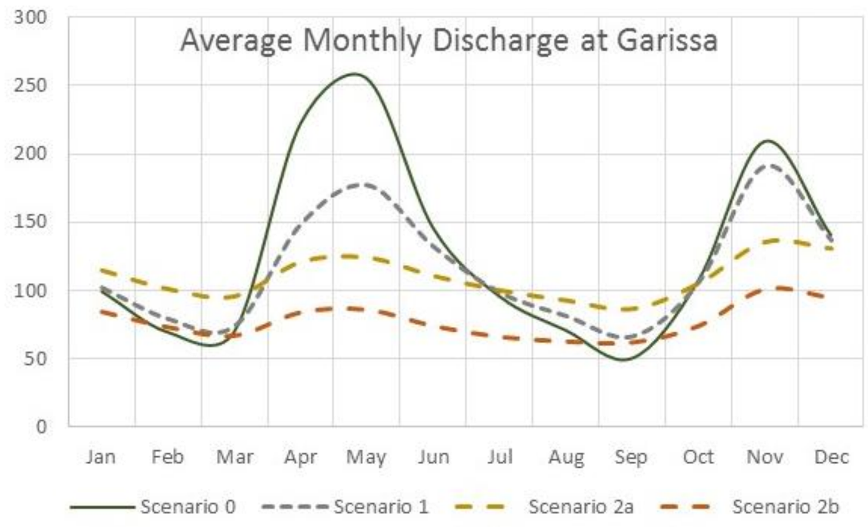

Figure 17 Hydrographs giving the average discharge (m^3/sec) for the different scenarios at Garissa

The effect on flooding is further illustrated by the average amount of days that flood levels are reached in the basin. For Garissa, about 16 days of small/medium flood conditions occur in the naturalized situation on average per year (Scenario 0) (Table 9). This decreases considerably though for the various intervention scenarios (Figure 18). The amount of floods dropped about 15% with respect to the naturalized situation after the inclusion of the Masinga dam in the simulations (Scenario 0 to 1). The addition of the HGFD will almost half the amount of flooding as opposed to the current situation (Scenario 1 to 2a) and subsequent addition of extraction of irrigation water for the million acre project will reduce small/medium flooding at Garissa to about one-fifth of the naturalized situation, or one-third of the current situation (Figure 16).

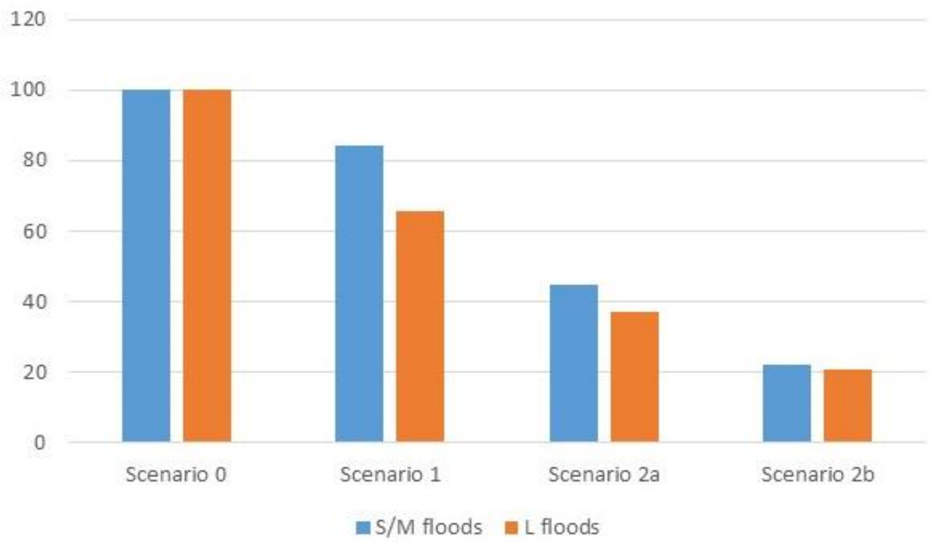

Figure 18 Relative amount (in percentage with respect to scenario 0) of small/medium and large floods at Garissa under the different scenarios

3.4 Results climate change

Climate change can have pronounced effects on water resources availability due to changes in precipitation patterns and increased temperature (and evapotranspiration). There is, however, considerable uncertainty in the projections of water resources as there may be opposite effects (e.g. more precipitation, but also more evapotranspiration). Therefore, it is important to use multiple GCMs and multiple scenarios. Generally, the uncertainty between GCMs is larger as compared to the uncertainty resulting from different emission scenarios. Figure 19 illustrates this uncertainty for the Tana River. Depending on the GCM, an increase or decrease in river discharge over the years is calculated. For cases where an increase in discharge is estimated, particularly an increase in discharge in the first rainy season is estimated. When looking at higher emission scenarios (A1b and A2), it becomes apparent that more of the GCMs estimate increased discharges, also for the second rainy season and during the dry period. When looking at the results for 2080, we see this pattern continues, although discharge during the dry season doesn't always increase as much (Figure 20).

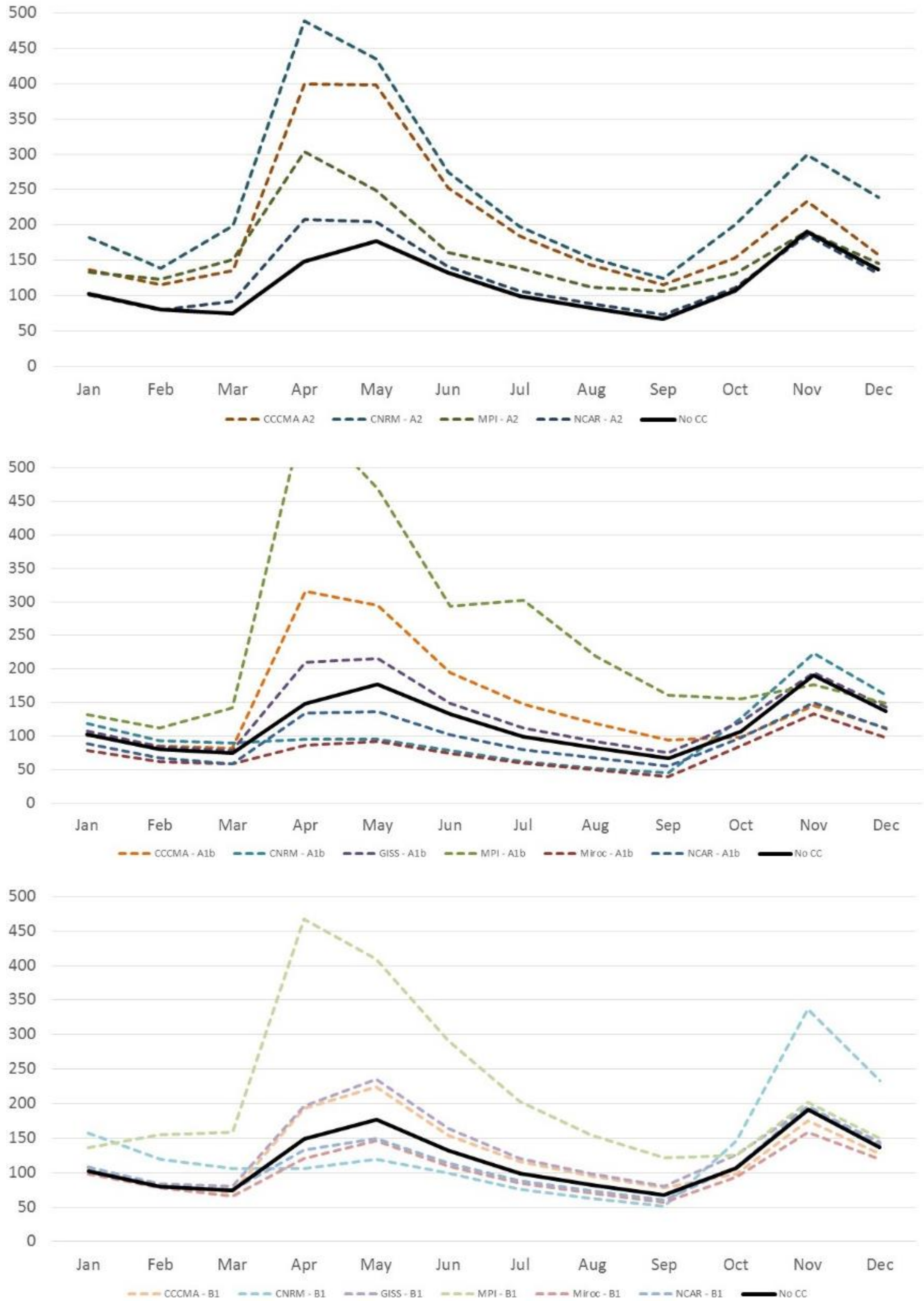

Figure 19 Hydrographs for discharge (m^3/sec) at Garissa under three emissions scenarios for 2050 (B1, upper panel; A1b, middle panel; A2, lower panel)

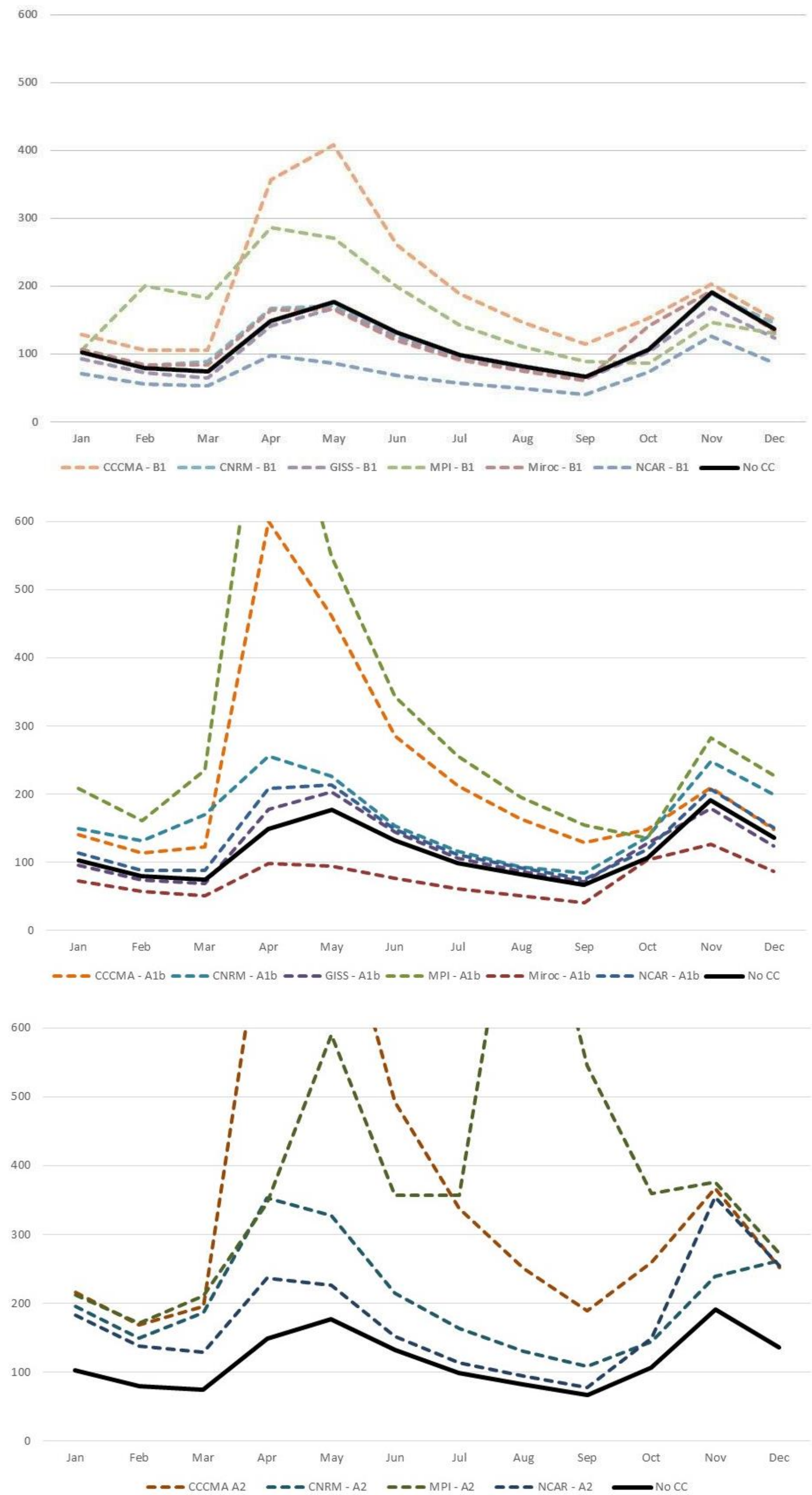

Figure 20 hydrographs for discharge (m^3/sec) at Garissa under three emissions scenarios for 2080 (B1, upper panel; A1b, middle panel; A2, lower panel)

3.5 Combining anthropogenic interventions and climate change scenarios

In the above sections the individual effects of anthropogenic interventions (Scenario 1, 2a and 2b) and climate change (6 GCMs, 3 emission scenarios) have been explored. In this section, their combined effects are determined. This is not done for all scenarios, but three climate change scenarios (for 2050) have been taken for this which encompass the possible future responses of the Tana basin to climate change. As shown in Figure 21, these include:

- **CCCMA – A1b:** which yields an increase in discharge during the first rainy season;
- **CCCMA – A2:** which yields an increase in discharge during both rainy seasons;
- **Miroc – A1b:** which yields a decrease in discharge in both rainy seasons.

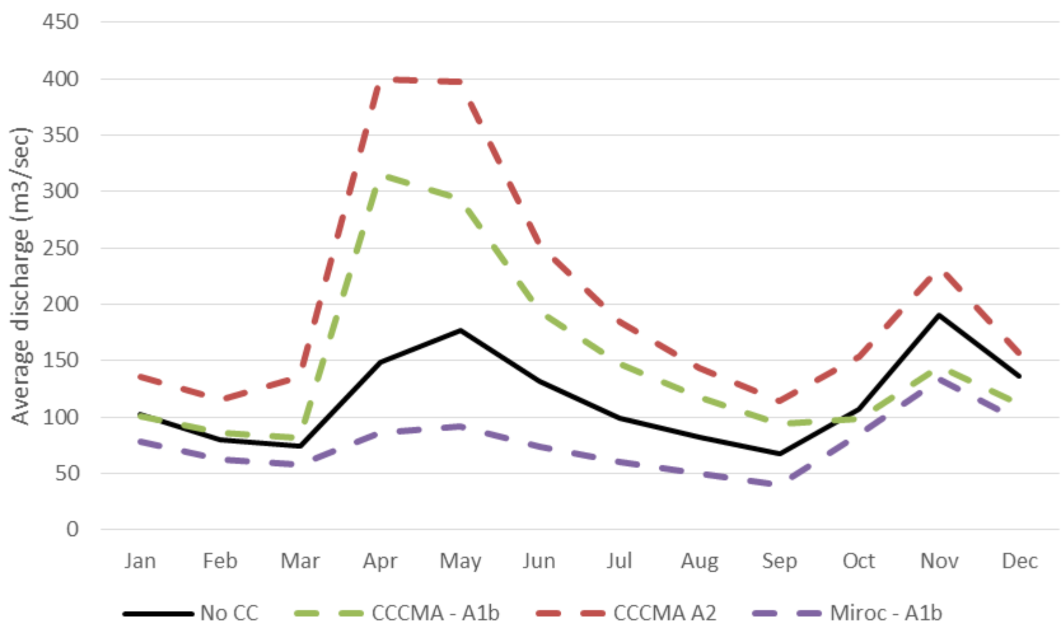

Figure 21 hydrograph of monthly discharge of the three climate change scenarios used for joint evaluation with anthropogenic interventions

The joint effects are shown in the Figure 22. This shows how the average mean monthly discharge changes (bars), as well as the average minimum and maximum monthly discharges (bars). Also the results without climate change (i.e. similar to Table 9) are shown. It can be seen, that both climate change and human interventions can have substantial effects. The general result of the intervention scenarios is also observed here: with lower maxima and higher minima in scenarios 1 and 2a due to the construction of large reservoirs (i.e. Masinga and HGFD respectively), and an overall lowering in scenario 2b because of large scale abstraction from irrigation. However, also the climate scenarios impact mean, minimum and maximum monthly discharge, with the Miroc-A1b scenario yielding considerable lower discharges, and CCCMA-A2 considerable higher (also higher minimums).

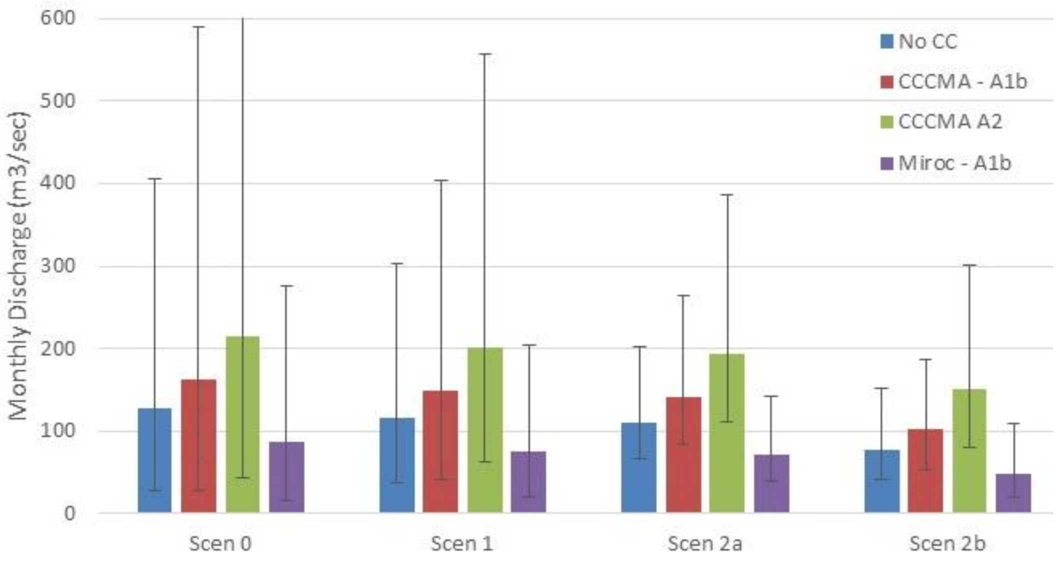

Figure 22 Joint effects of climate change scenarios (CCCMA-A1b, CCCMA-A2, Miroc-A1b) and intervention scenarios (Scenario 0, 1, 2a, 2b) for the Garissa station. The bar graphs indicate the average mean monthly discharge, and the bars represent the average minimum and maximum monthly discharge (same indicators as in Table 9)

These changes can be very important, for instance in intervention scenario 1 (i.e. no building of HGFD) the mean monthly discharge under the Miroc-A1b climate scenario is about equal to the minimum monthly discharge under the CCCMA-A2 climate scenario. Under the intervention 2b scenario this is even more pronounced, with maximum of Miroc-A1b being just a bit higher as compared to the CCCMA-A2 minimum monthly discharge.

It can also be observed, that the reduction in maximum monthly discharge (and corresponding downstream flooding) induced by HGFD and large-scale irrigation (i.e. the lowering of the maximum for the blue (No CC) bar between Scen 1 and Scen 2b) can be offset in case the climate change along the lines of the wet CCCMA-A2 climate scenario. The other two climate change scenarios give substantially lower discharges though.

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4 Ecosystem Assessment of the Tana River Basin

Peris Kamau & Victor Wasonga

4.1 Introduction

The Tana River Basin is ecologically endowed with rich ecosystem services of which some of them are dwindling due to increasing human pressure. For example, flooding of Tana River has profound influence on the ecology of the flood plain as well as the formation and distribution of wetlands in the reserve. Ideally, Tana River floods twice a year in November -December and May -June, depositing a fertile layer of silt on the plain and oxbow lakes. The lower sections of Tana River support unique wetland ecosystems such as riverine forests, oxbow lakes, floodplain grasslands, mangrove forest, sand dunes, and coastal waters. Besides having a huge local significance, the Tana River Basin is of international importance due to its richness in biodiversity which include several IUCN Red-listed species endemic or regional endemic species and CITES listed species. The ecosystems in the Tana Basin which are addressed in this Section include montane/highland forests; agro-ecosystems (cropland); grasslands; Tana delta; coastal forests; mangroves; small wetlands (lakes and rivers); and settlements.

4.2 Methodology and data

Ecosystems of the Tana River Basin will be explored within the framework of DPSIR (Drivers-Pressures-State-Impact-Response) model. The model is used as a convenient organizing framework tool for systematically structuring environmental information. The DPSIR represents a systems analysis view. Social and economic developments exert pressure on the environment and, as a consequence, the state of the environment changes (Kristensen, 2004). This leads to impacts on e.g. human health, ecosystems and materials that may elicit a societal response that feeds back on the driving forces, on the pressures or on the state or impacts directly, through adaptation or curative action. For the application in this ecosystem assessment, the main focus will be on the ecological and environmental dimension of the DPSIR framework. Given the scatteredness and the varying quality of the data, the ecosystem assessment will be mainly qualitative in nature, supported with quantitative information.

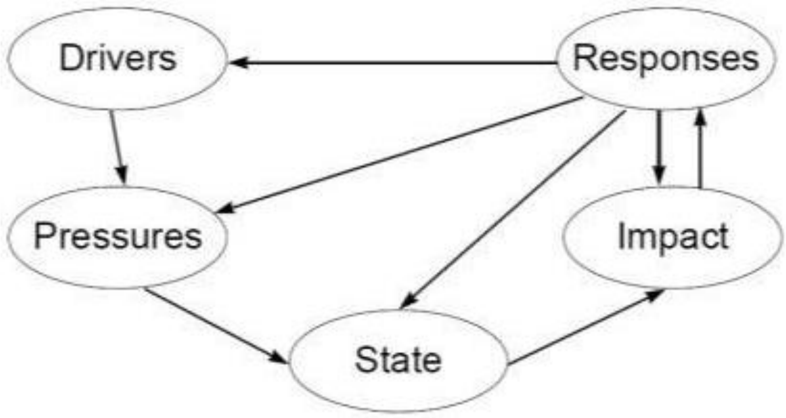
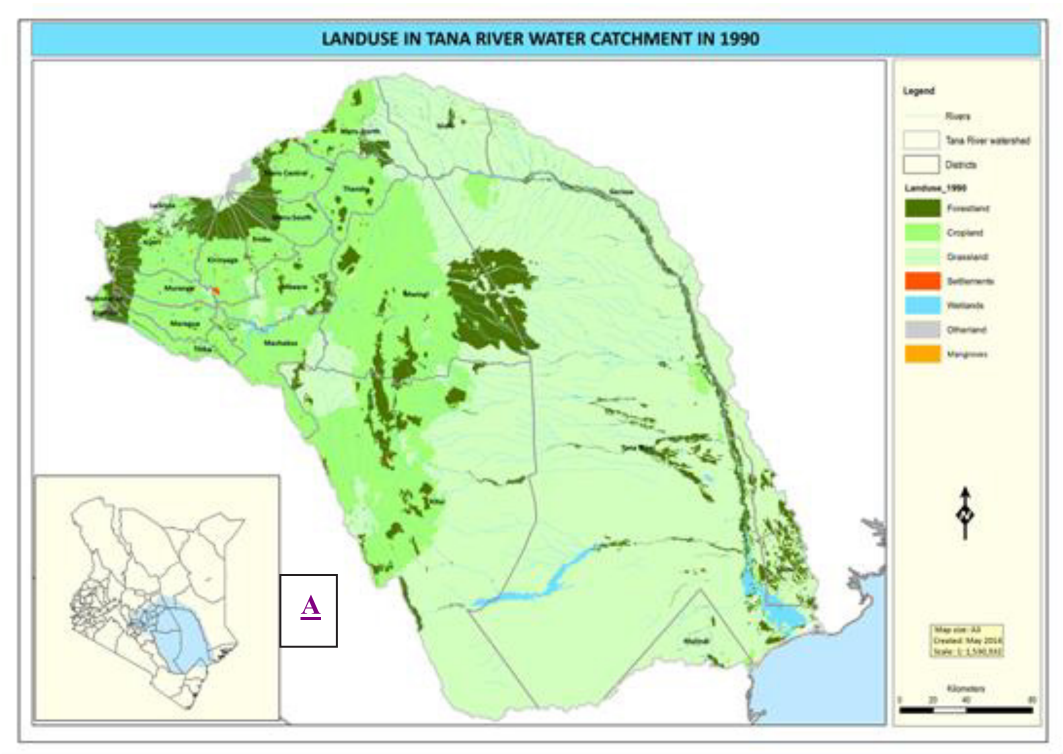
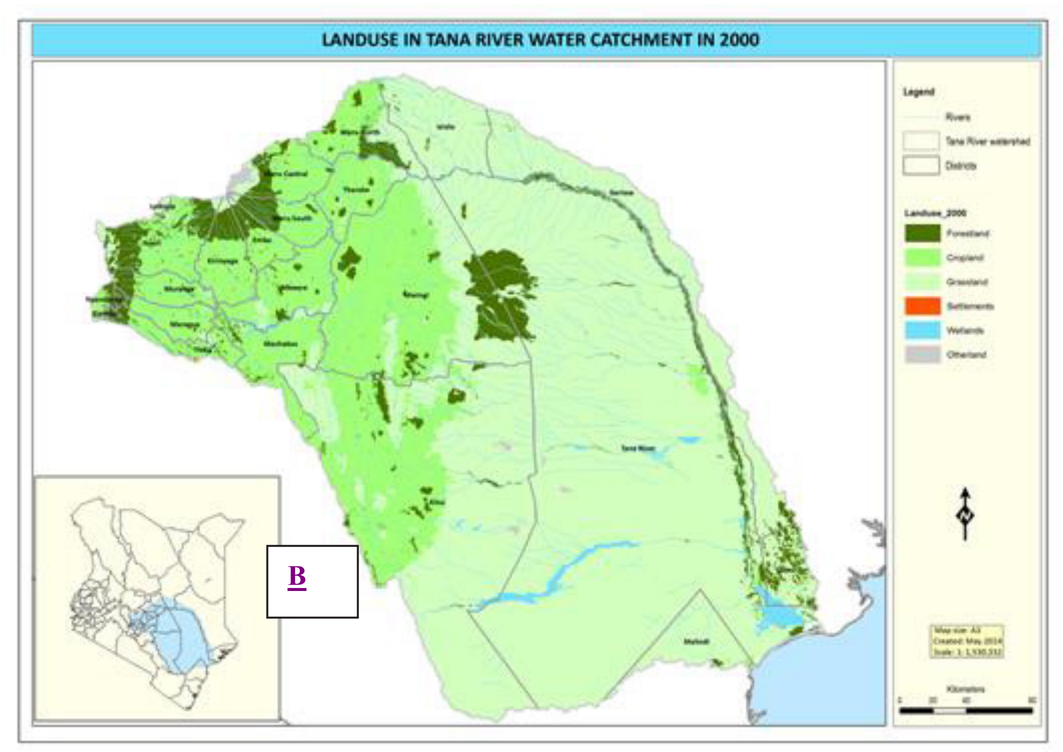


Figure 23 Drivers-Pressures-State-Impact-Response) model (OECD, 1994)

The main data on which the ecosystem assessment is based on, are land cover measurements in 1990, 2000 and 2010. The main land cover changes in ecosystem areas in the Tana River Basin between 1990 and 2010 are summarised in Figure 24 and Table 10.





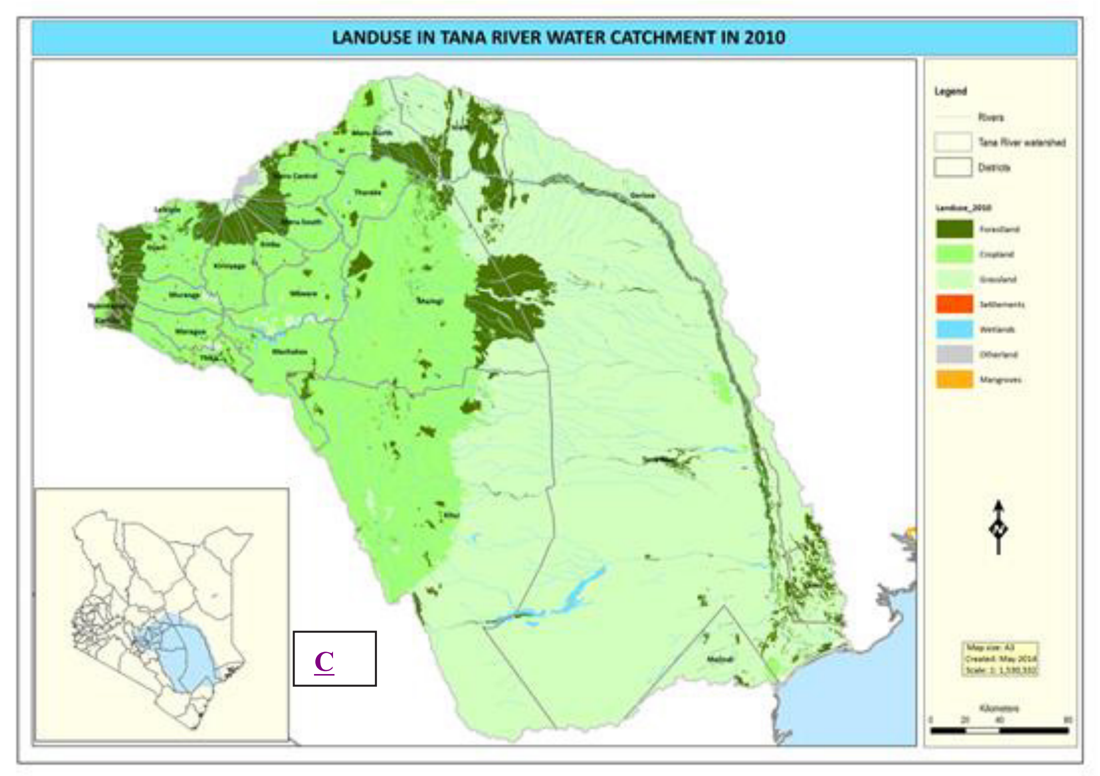


Figure 24 Land cover changes in the Tana River Basin between 1990 (A), 2010 (B) and 2010 (C)

Table 10 Land cover changes between 1990 – 2010 in Tana River Basin.

Land use/cover	1990	2000	2010
Grassland (Ha)	8,588,002	8,794,265	8,209,808
Change (%)		*2.4*	*-6.7*
Cropland (Ha)	4,281,064	4,333,071	4,618,815
Change (%)		*1.2*	*6.6*
Forestland (Ha)	1,320,855	1,005,747	1,318,404
Change (%)		*-23.9*	*31.1*
Wetlands (Ha)	128,193	144,974	114,074
Change (%)		*13.1*	*-21.3*
Settlements (Ha)	23,724	48,978	78,446
Change (%)		*106.4*	*60.2*
Others (Ha)	16,976	31,781	19,268
Change (%)		*87.2*	*-39.4*

4.3 Major Ecosystems of the Tana River Basin

There are various types of ecosystems along Tana Basin stretching from the upper catchment areas all the way to the Delta and finally to estuaries. The selection of ecosystems that were assessed for their status was based on their uniqueness and information availability to characterize them.

These ecosystems were broadly classified into the following categories;

- Montane/Highland Forests
- Agro-ecosystems (Cropland)
- Grasslands
- Tana Delta
- Coastal Forests
- Mangroves
- Small Wetlands (Lakes and Rivers)
- Settlements

4.3.1 Montane / highland forests

Forests are dynamic and diverse ecosystems and cover only about 3% of Kenya's land. Forests serves as essential habitats for plants and animals and other microorganisms and are traditionally important for cultural ceremonies and as sacred sites to local communities. Forests play a critical role as water catchments, regulate water flow across landscape, control erosion, water purification, climate stabilization and forests contribute to availability of water for hydro power generation. Forests also help to reduce siltation in hydro dams, source of timber and non-timber products, as well as other economic benefits.

Status

Mt. Kenya and the Aberdare ranges are designated as national parks, forests reserves and Important Bird Areas (IBAs) (Bennun and Njoroge, 1999). Mt. Kenya is a stronghold for the threatened and endemic species with a rich montane bird fauna of 53 out of Kenya's 67 African highlands biome species, with at least 35 forest-specialists species. It also has six species which are endemic to Kenyan mountains, as well 3 restricted range and 8 regionally/globally threatened species. Its vegetation is equally unique and diverse including 479 genera in 146 families of which 11 are strictly endemic and more than 150 species are near endemic. The large mammals comprise six rare or threatened species, such as the black rhinoceros, as well as other large mammals, fish, reptiles, amphibians and invertebrates.

The Aberdare ranges hold over 200 species of birds including 52 of Kenya's 67 Afrotropical Highland species, and six of the eight restricted-range species in the Kenyan Mountains Endemic Bird Area. There are 4 globally-threatened, 2 range-restricted and 8 regionally threatened species resident in the Aberdare's. Globally threatened mammals are found here as well.

Trends

Data from Kenya Forest Service was reviewed over a 20-year period between 1990 and 2010. Summarized forest cover changes are calculated for Mt. Kenya, Aberdare ranges, Nyambene hills and Mwingi/Tana River areas (Table 11). The extent of vegetation cover of the highland forests/natural forests in the upper catchment of Mt. Kenya and Aberdare have had positive and negative changes. Between the year 1990 and 2000, the forest size declined by 23% owing to anthropogenic pressure as described below. However, between the year 2000 and 2010 there was an increase of 31% forest cover.

The highest decline in forest cover was recorded in Mwingi/Tana River area (-29%) followed by Aberdare's (-8.3) between 1990 and 2000. A minimal decline of -3.9% was documented for Mt. Kenya for the same period (authors calculations). It is probable that increases in human settlement resulted in reduction of forest cover. From 2000-2010, there was a significant increase in forest cover in Mwingi/Tana River area (15%) and minimal increases in Mt. Kenya and Aberdare's (2.8% and 1.8%, respectively). This increase is associated with establishment of forest plantation and regenerating forests.

The Nyambene hills which is situated on the North eastern side of Mt. Kenya covering Meru and Isiolo counties also contribute discharge to Tana Basin. Its forest cover has been increasing since 1990 which registered a 20% increase between 1990 and 2000. The forest cover increased significantly by 325% between 2000 and 2010. The increase is due to afforestation effort that is going on and increased public awareness campaign on the importance of conservation of natural resources spearheaded by Kenya Forest Service (KFS).

Table 11 Forest cover changes for selected forest blocks in Tana River basin between 1990 - 2010

Land use/Cover Type	1990	2000	2010
Mt. Kenya Forest (Ha)	154,166	148,102	152,317
Change (%)		*-3.9*	*2.8*
Aberdare Forest (Ha)	102,203	93,717	95,381
Change (%)		*-8.3*	*1.8*
Mwingi/Tana River Area	225,374	159,788	183,767
Change (%)		*-29.1%*	*15.0%*
Nyambene	41,404	49,924	212,164
Change (%)		*20*	*325*

Pressure

There has been a rapid population growth record in Kenya especially in the high potential areas (KNBS, 2010). This population relies heavily on ecosystem services as a source of livelihood. High population exerts pressure on the natural resources due to increased demands of land, infrastructure, food, and settlement and hence reducing the vegetation cover. Other disrupting activities in the forests include charcoal production, logging, poaching and livestock grazing. Demand for land for agricultural expansion has also led to encroachment into forest land. The land in Upper Tana is very productive and intensively farmed. The agricultural lands increased from 2.3 million Ha in 1990 to 2.6 million Ha in 2010 (Figure 24). Additional lands were excised from the natural forests of Aberdare's and Mt. Kenya through government gazette notice. Most of the area is covered by smallholders who grow cash crops e.g. coffee, tea, rice and vegetables and also practice subsistence farming e.g. maize, beans, potatoes.

Response strategies

To counteract these threats, the government since the year 2000 has put in place new management policies and practices, improved enforcement measures which have significantly reduced pressures and threat initially exerted in these natural forests. Besides that, enhanced capacity of lead agencies such as KWS and KFS has resulted in both biodiversity and watershed protection in the upper catchment. As a result, minimal disturbance and forest regeneration has been realized. Recently, Mount Kenya East Pilot Project for Natural Resource Management (MKEPP) was implemented.

4.3.2 Agro-Ecosystems

Crop production and pastoralism remain the main sources of livelihood for majority of Kenyans. Agricultural activities support about 80% of Kenyans and contribute about 53% of the nation's Gross Domestic Product. Agro-ecosystems in Tana River Basin support about 50% of the basin's population. Most farming in Kenya is rain-fed, so it occurs in areas where rainfall patterns are reliable.

Status

The Tana River Basin accommodates various agro-ecological zones. The upper catchment covers about 15,000 km2 at an altitude of 1,000 metres above sea level. The middle catchment covers an area of 15,700 km2 at an altitude of between 1,000 – 200 metres, while the lower basin covers 95,300 km2 at altitudes of below 200 metres above sea level. Agricultural production in the basin is varied since the basin extends over areas of diverse agricultural potential. On the one hand, the high potential agro-ecological zone supports agricultural activities such as coffee, tea, pyrethrum, wheat and barley, dairy, sheep and poultry. In the medium zone there is maize, sunflower and beans; some poultry, sheep and dairy. On the other hand, the low potential areas have millet, cotton, tobacco and sorghum.

Trends

In Tana River Basin, areas taken up by agricultural activities have been on the rise. As shown in Table 10, there was 1.2 % increment in expansion of agricultural area between 1990 and 2000. The highest expansion of 6.6% was recorded between 2000 and 2010. Upper Tana which is very productive with good soils experienced the highest agro-ecosystems expansion of 8.9% between 2000 and 2010. The total average area under cultivation in Tana Basin continues to increase as crops are introduced into forestland (forest encroachment), some humid grasslands/rangelands are converted into farmlands (Figure 24).

Crops are increasingly being grown on marginal land with low or variable rainfall as witnessed in Middle Tana where cropland areas increased by 9.4% between 2000 and 2010. Amounts of productive land in lower Tana are declining due to growing populations and the introductions/expansion of the irrigation schemes with inadequate water conservation and management. The irrigation potential is estimated at 132,000 hectares. The present developed and planned irrigation cover 54,676 hectares under private and government organizations (Table 12).

Amount of land in agriculturally productive highlands and productivity of these lands are declining due to growing populations. The dwindling landholding and growing pressure on the land has led to higher wind and water erosion rates and declining soil fertility. There is an increase in competing land uses including forestry, wildlife conservation, urban development, and expansion of poorly planned human settlement.

Response Strategies

The lead agencies i.e. KFS and KWS who are in charge of protecting forests/natural resources have revised their policies which prohibit extraction/encroachment of gazetted lands. The government also enforced tight measure relating to forest encroachments and all the people who in the past were living in the forest lands were evicted. The shamba system which was introduced in 1980's was also stopped to avoid people getting into the forests. Despite all these efforts there are cases of small scale cultivating in the forests.

Table 12 Categories of irrigation schemes in the Tana Basin (Source: Agwata, 2005)

Scheme Type	Crops Grown	Coverage
Small-scale group based schemes	Horticulture, floriculture, subsistence crops	30,148 ha
Individual holder schemes	Nurseries for high cost crops such as floriculture, macadamia, and ornamental crops with greenhouses	
Public irrigation schemes managed by government agencies e.g. the National Irrigation Board, Agricultural Development Corporation and the Tana and Athi River Development Authority	Large scale food crops such as maize	24, 528 ha

4.3.3 Grasslands

Large areas of Tana River Basin are covered by flood plain grasslands used as rangeland for livestock grazing. There has been a decline of grassland coverage in some areas. Ecological disturbance do occur as a result of seasonal burning by Orma pastoralists which causes grassland encroachment over areas whereas bushland is the natural vegetation type.

Status and Trends

Grassland coverage in Tana River Basin slightly increased from 8.5 million ha to 8.7 million ha between 1990 and 2000. However, there was a loss of 584, 456 ha of grassland between 2000 and 2010 in Tana basin (Figure 24).The main pressures affecting grasslands include:

- *Conversion of grassland to croplands*. There was a loss of 6.6 % of grasslands in Tana River Basin that was converted into cropland/other land between 2000 and 2010 (Table 2). This is much higher than grassland expansion of 2.4% observed between 1990 and 2000. The loss of grasslands in Tana Basin is highest in Upper Tana (10% decline between 2000 and 2010) and the lowest in the lower Tana (6.7% increase between 1990 and 2000, and 0.6% decline between 2000 and 2010).
- *Overstocking*: The carrying capacity of Tana River grassland is 5.5 million animals. However, the current estimate is 6.8 million animals which is 23% more than carrying capacity (KNBS, 2009).

The remaining grassland in Tana Basin is under stress. The rich soils of grasslands have been converted into croplands, leaving remaining grasslands on less productive soil. Traditional land rights are ignored and growing human and livestock population degrade pastures and water resources. Access to grazing land has diminished as more lands are converted into croplands, others have been set aside for development e.g. LAPPSET, resort cities, camping sites and hotels, nature conservancy areas, etc. Grasslands are subject to recurring drought, which exacerbates land degradation and threaten the lives and livelihood of many farmers and pastoralists.

Response Strategies

Strategies to mitigate resource use conflicts e.g. implementation of appropriate policies and legislations to be put in place. Resource use conflicts have intensified in the Tana Delta as a result of increased pressure on the natural resources due to rapid population increase, climate change, land use conversions, and insecurity of land tenure. The conflicts manifest themselves in the form of wildlife – human and human – human conflicts. Human – human conflicts have been associated with competition for pasture and farmland. Such conflicts could be managed through designating grazing and farming zones as well as rationalizing livestock numbers against available pasture.

4.3.4 Tana River Delta

Tana Delta sits astride two counties of Lamu and Tana River. The core of the delta covers an area of about 130,000 ha, mainly in Tana River District. It is one of the largest wetlands in Kenya, rich in diversity of flora and fauna and home to pastoralists, farmers and fishermen. It provides ecosystem services to the County and the nation, including shoreline protection and carbon sequestration (Odhengo et. al. 2012).

Status

The settlement patterns within Tana River County (the main location of the Tana Delta) are randomly concentrated close to the river. The main economic activities in the delta are farming, livestock keeping and fishing. Agriculture employs about 60% of the population while 40% work in the livestock sector. The estimated population of the delta is 96,664. The communities living in the delta are made up of Pokomo - 44%, Orma - 44% and Wardei - 8%, while other ethnic groups, including the Luo, account for the remaining 4% (Government of Kenya, 2009).

The delta wetland is a refuge for wildlife of all kinds, ranging from endangered primates to hippos, crocodiles, elephants, buffaloes, fish, amphibians and huge congregations of birds that make the delta to qualify as an Important Bird Area (IBA) and Key Biodiversity Area (KBA) on a global scale. There is no formally designated conservation area for wildlife and tourism in the delta, but the core area has been designated as a Ramsar site.

Trends

The wetlands of Tana River Basin are changing rapidly, raising concern for the wetlands' health and for communities relying upon its ecosystem services. The extent of Tana Delta wetland decreased significantly from 43,334 ha in 2000 to 4,112 ha in 2010 representing 91% loss in a span of 10 years (Table 13). The wetlands' ecosystem services are being eroded and they are no longer able to provide services at levels that can sustain local communities.

Table 13 Trend of Tana Delta wetland cover between 1990 - 2010

Land use/Cover Type	1990	2000	2010
Tana Delta (Ha)	51,750	43,334	4,112
Change (%)		*-16.3*	*-90.5*

Pressures

The main drivers and pressures leading to wetlands deterioration in the Tana Delta are caused by a multitude of factors.

Wetland reclamation and draining for commercial irrigation schemes. There have been indications of unplanned expansion of irrigation schemes especially in the Tana Delta initiated by the government and also private companies. For instance, the findings of the Strategic Environmental Assessment for the Tana Delta highlighted land grabbing by the government and private entities as major concerns for local community interests (Nature Kenya, Unpublished Report). The main irrigation schemes are Tana Development Irrigation Projects (TDIP) (200 acres), Hewani and Wema settlement irrigation scheme (135 acres), biofuel, sugarcane and maize plantations. As shown in Table 13, expansions of irrigation schemes have adverse effect on wetland ecosystems due to wetland reclamation. Besides causing wetland loss, intensive agriculture through the release of agro-chemicals causes water pollution. Moreover, soil erosion coming from the land left bare causing siltation of the floodplain. This is likely to exert pressure on the land and resources in the Delta due to vegetation clearance, pollution and increase in water demand. In addition, the tapping of water from the river for irrigation will worsen the low water discharge from the river.

High population growth: The population of the Delta is estimated to be 102,000, distributed across 12,457 households giving an average household size of about 8 persons, with 65,000 people living on the drier terrace areas, 35,000 people living in the floodplain and fewer than 2000 people living on the coast.

Introduction of alien species: Approximately 2,000 ha of land in Tana River basin have been invaded by Prosopis Juliflora. The species spread rapidly causing problems to traditional pastoral livelihoods as well as affecting the functioning of ecosystems. Where it colonizes, suppresses other plant species and outcompetes even the agricultural crops. There are alien fish i.e. Nile perch which prey on indigenous fish species. The catches of indigenous fish species has been on a decline which is partly attributed to presence of these invasive predators

Water quantity/Declining water levels: Water availability has declined over the years. This is partly due to construction of dams in the upstream which have reduced the water flow in Tana River especially from middle Tana to the lower Tana. Moreover, water diversion to commercial irrigation schemes is common in Tana Delta. It is estimated that the irrigation schemes abstract thousands of metric tons of water. The reduction in seasonal flooding has severely affected fish breeding since fish spawn in shallow waters.

Water quality: According to Duvail, et al (2012), the water quality in the Tana Delta is of low quality because of (1) pollution; chemicals released from the irrigation schemes, dumping of various industrial, agricultural and domestic wastes in wetlands; (2) Contamination from runoff water during rainy season; and (3) Soil erosion from the farms. Generally sanitation is poor with majority of the population having no access to basic sanitary facilities such as pit latrines. Only Garsen has a sewerage system. Solid waste disposal facilities are poor or non-existent and as a result the majority of residents throw the rubbish outside. Note that good quality water is also essential to maintain healthy fish populations in the river channels and ox-box lakes within the Delta.

Human settlement: The rapid growth in population and sedentarisation has contributed to permanent and dense settlements. The human settlements increased by 8.8 % between 1990 and 2000. An increase in settlement was seen when the irrigation schemes were established leading to migration of people looking for employment in the Tana Delta. However, the settlement declined to 4.9% between 2000 and 2010. The decline was occasioned by people leaving Tana Delta after the collapse of the much hyped irrigation schemes. Human settlement leads to encroachment and degradation of wetlands and other protected areas. Nowadays, there is widespread charcoal burning for domestic use and income generation.

Overstocking: The numbers of livestock that graze around Tana delta in the dry season exceed the carrying capacity of the environment leading to both environmental damage and conflicts. Though at times it might be difficult to know the exact number of livestock, it is estimated that there are around 220,000 head during the wet season rising to around 735,000 in the dry season.

Over-exploitation of resources: There is increased demand for wetland goods such as plants, fish. Fishing takes place in coastal waters, the main river and subsidiary channels and open water bodies including ox-bow lakes (former river meanders cut off from the main channel). In addition, aquaculture is being introduced involving rearing of fish in both natural and artificially constructed ponds. In 2007, the total weight of fish caught was 613,003 kg.

Infrastructure development: From 1980s to present, up to 12 key development projects had been implemented or proposed within the Tana Delta (Odhengo et. al. 2012). The most notable one was the Mumias Sugar Company and TARDA proposed sugarcane plantation which was projected to cover 20,000 ha. of the Delta.

Response Strategies

Various initiatives have been taken to reduces the environmental pressures causing degradation in the Tana Delta. These include the Tana Delta Land Use Plan Framework presented in the Sustainable Management Plan for Deltas in Kenya by the Inter-ministerial Technical Committee (IMTC) (Odhengo, et. al., 2012). Several Environmental NGOs are active in the Tana Delta as well such as Nature Kenya and Birdlife International as part of the IBA framework and Wetland International monitoring the Tana Delta as a Ramsar Site. Moreover, research teams are present in the Delta as well, aimed at gaining a better understanding on how to create a more sustainable situation in the Delta. This includes among other The Kenya Wetlands Biodiversity Research Team (KENWEB) which aims at providing information for conservation and sustainable use of ecosystem services.

4.3.5 Coastal Delta

Kenya has a total of 107 coastal forests, out of which 14 (listed in Table 14) are found within Tana River basin (Matiku, 2003). The Coastal forests in Kenya provide the basis for a number of different forms and scales of economic activity, which provides both food for national and international consumption (Matiku, 2003). Important mainstream livelihood activities along the coast are carving, agriculture, tourism, aquaculture, medicinal plants, salt production, harvesting of poles and wildlife hunting.

Table 14 Coastal forests in the Tana River basin (NR – national reserve, UP – unprotected) (Source: Matiku, 2003)

#	Forest	District	Protected Status	Area (Ha)
1	Boni NR	Garissa	NR	87,000
2	Boni proposed FR	Lamu	UP	18,466
3	Dodori NR	Lamu	FR	78,100
4	Lunghi proposed FR	Lamu	FR	9,517
5	Witu FR	Lamu	FR	3,937
6	Witu FR extension	Lamu	FR	10,000
7	Ras Tewani	Tana River	UP	-
8	Bura Gallery Forests	Tana River	UP	-
9	Arawale Reserve	Tana River	FR	-
10	Wayu I, II, III& Kokani Forests	Tana River	UP	-
11	Mbia	Tana River	UP	-
12	Tana River Primate NR	Tana River	NR	17,100
13	Lower Tana Forests	Tana River	UP	-
14	Kanwe Mayi forest fragments	Tana River	UP	-

Status and Trends

The coastal ecosystems of Kenya are biodiversity hotspots which offer unique habitats for some endemic, threatened and rare species. These forests are under intense pressure and their coverage has declined over the years. Between 1990 and 2000, there was a loss of 25.8% of the coastal forests. However, there was an increase of 24.5% in forest cover between 2000 and 2010 (Table 10). Increasing human population and development of coastal regions is resulting in ongoing loss and degradation of coastal ecosystems. Infrastructure development, industry, commercial activity, and settlements near the coast have depleted and altered natural systems and made coastlines more sensitive to erosion. Bouillon et al. (2007) conducted a biochemical analysis of the Tana Delta and concluded that wetlands, including salt marshes and estuarine habitat in East Africa's Indian Ocean, are severely depleted due to organic fluxes. These trends can be extrapolated for the 230 km of the Kenyan coast line that's falls within Tana River basin (Authors' measurement)

Pressures

Encroachment, illegal exploitation, deforestation, fires and overgrazing are the main threats facing coastal forests in the basin. Unsustainable use leading to pressure on forest resources (Timber; Pole wood; Charcoal; Carving wood; Hunting; Tourism; Salt Mining); Agriculture (Cultivation; Encroachment; Fire; over grazing); Settlement; Urbanization; Lack of legal protection; and wildlife human conflicts. Beside that human population pressures and coastal settlements, are causing conflict over rights to the use of land and natural resources. Further losses occur as sea levels rise, especially where development now leaves only a narrow margin of habitat.

Settlements in coastal areas increased steadily by 8.8% between 1990 and 2000 before declining by 5% between 2000 and 2010. Population increase and the associated expansion of subsistence agriculture, which permanently converts natural habitats to farmland is a major threat to coastal forests. Population increases are also linked to habitat degradation associated with increased demand for firewood, charcoal, timber, fuelwood, and bush meat. This is compounded when rural people out of employment are involved in commercial activities such as industrial fuel wood collection, commercial pole cutting and charcoal burning.

Sand dunes within the Tana Delta shoreline (and elsewhere) are unique habitats which are breeding ground for turtles and important habitat for other biodiversity. The Kenyan coast is home to two of the world's most endangered sea turtles (the Green sea turtle and the Hawksbill Turtle) which nest in the Lamu archipelago. The population of the sea turtles has been fluctuating mainly due to illegal trade and water pollution. However, increased monitoring of the trade and use of CITES regulations has seen the population these turtles increase since the year 2005 (Figure 25).

Another negative impact on the Coastal Delta Ecosystem is siltation and soil erosion. This is largely driven by fluctuations in the flooding regime due to the construction of the hydroelectric dams in the upstream that have disrupted the rate and extent of the flooding the availability of both water and rich sediment to the forest patches away from the immediate riverbank. In coastal zone especially along the mangroves forests, siltation level has been so high which in turn negatively affects the status of ecosystem. Siltation has a negative impact by having less water reaching the flood plain areas where flood recession agriculture depends on alluvial waters for irrigation since sediment takes up useful storage space (Agwata, 2005).

Response Strategies

A number of conservation projects have been in place to alleviate the threats facing the coastal forest ecosystem:

- Critical Ecosystem Partnership Fund
- Nature Kenya/Birdlife International – IBA framework

- WWF – EARPO
- Kenya Coast Development Project
- Kenya Coast Forest Survey Project – Kaya forest conservation

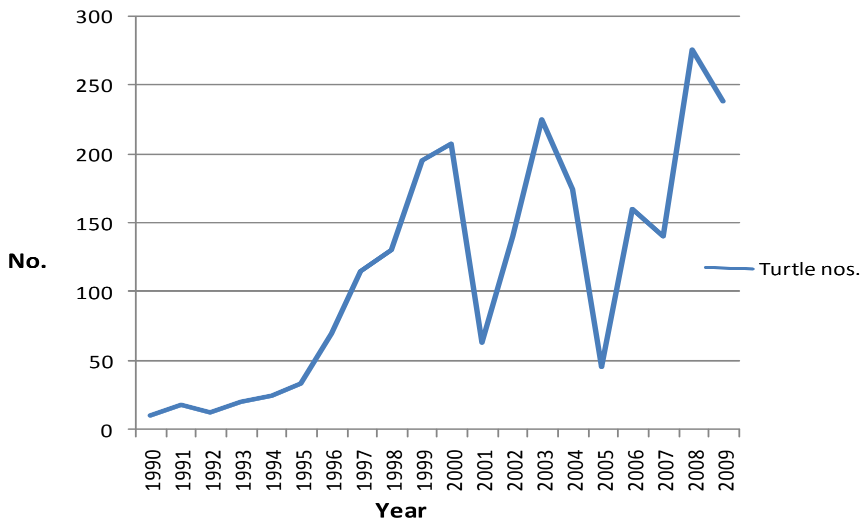


Figure 25 Annual number of sea turtles recorded at Lamu from 1990-2009

4.3.6 Mangroves

Mangrove forests shown in Figure 26 are not included as eastern African Coastal Forests, since they are treated as a zonal vegetation unit outside of the Zanzibar-Inhambane region (White, 1983). The mangrove ecosystems are an important habitat for a variety of terrestrial and aquatic plants and animals. They are associated with many animal species, which occur in the same inter-tidal zone for part or their total lifecycle. Several species of molluscs, crabs, fish and prawns depend directly on the mangrove ecosystem. A wide range of fish species use the mangroves as spawning sites and also as a crucial habitat for the young fish. Other animals such as insects, birds (migrant and resident) may feed, rest or inhabit the mangroves. Large mammals and reptiles may occur within and utilize the mangroves. The ecological functions include shoreline stabilization by prevention of shoreline erosion by the ocean waves and prevention of sea water intrusion. Apart from their ecological and biological values, these ecosystems are equally important for tourism development as well as a wide variety of socio-economic and cultural values to the local communities.

Status

At the Tana River near Kipini as well as at the Ramisi River, the animal life is abundant when compared to other mangrove areas in Kenya. Very large crocodiles are very evident here as are herds of hippopotamus. Other smaller mammals found in the mangroves of Kenya are baboons, duikers, rodents and fruit bats. Bird life is rich and most varied in most mangrove forests but especially so in Mida creek. Aquatic flora and fauna are much more diverse. Many (possibly up to 90%) of the species found in the mangrove forests are known to spend their entire life, or at-least a major part of their life cycle in these areas. These species include a number of prawns, crabs, oysters and cockles.

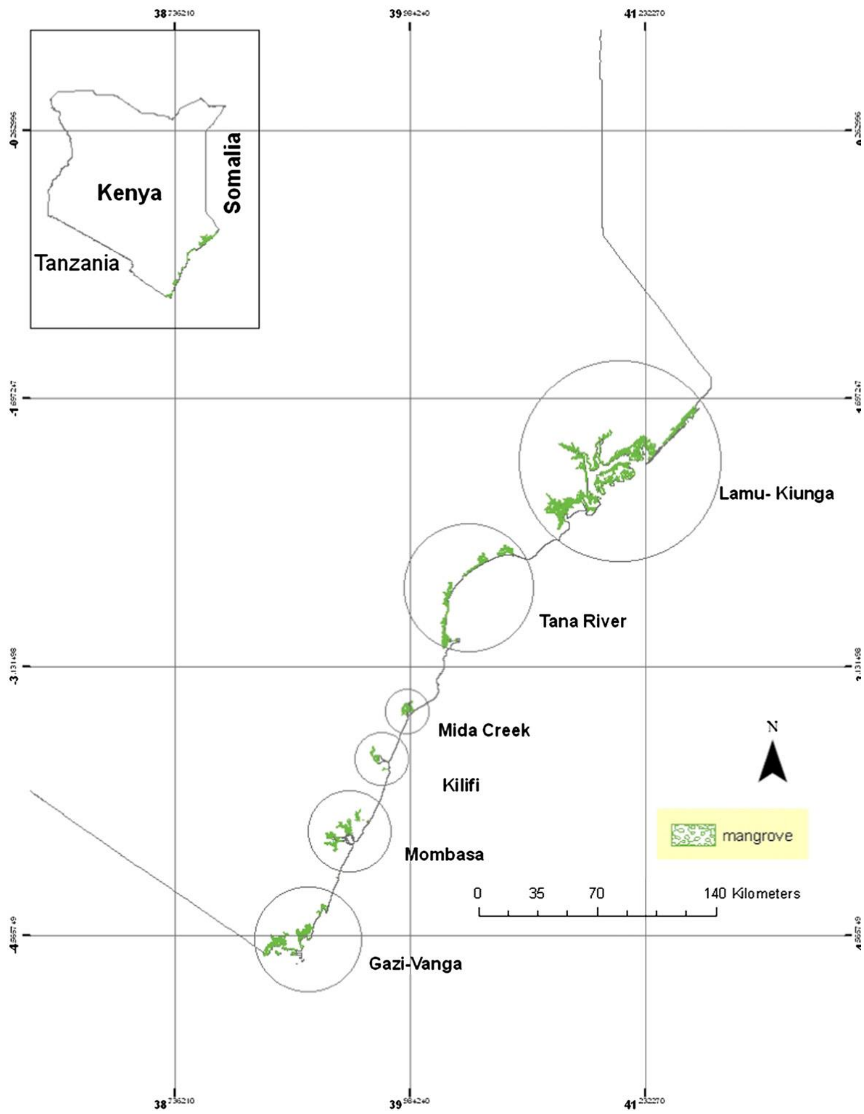


Figure 26 Distribution of mangrove formations along the Kenyan coast (Source: Kirui et al., 2012)

Kirui et al. (2012) reported that the largest formations occur within the Tana River Basin covering Lamu-Kiunga and the Tana Delta areas, making up more than 50% of mangrove cover in Kenya. Nine species of mangroves are found in Kenya with Rhizophora mucronata and Avicennia marina being the dominant species (Abuodha and Kairo, 2001). From analysis of Landsat imagery over a 25-year period from 1985 to 2010, there was 18% decline of mangroves at the rate of 0.7% per annum (Kirui et. al. 2012). The authors noted that the overall rate of loss was not uniform and was slowing. In 1985 there was an estimated 55,280 ha of mangrove. By 1992 this had reduced to 51,880 ha, a loss of 6.2% over the period or an average of 0.89% per annum. Total coverage in 2000 was 46,930 representing a further loss of 9.5% (1.19% per annum) and in 2010 it was 45,590 ha (2.8% loss or 0.28% per annum).

Mangroves populations of Tana River showed highest rates of loss with an overall reduction of 38% compared to Lamu-Kiunga region which had a loss of 12% reduction (Figure 27). This is a worrying trend considering that there is ongoing conversion of mangroves habitats to aquaculture is an ongoing practice along coast line.

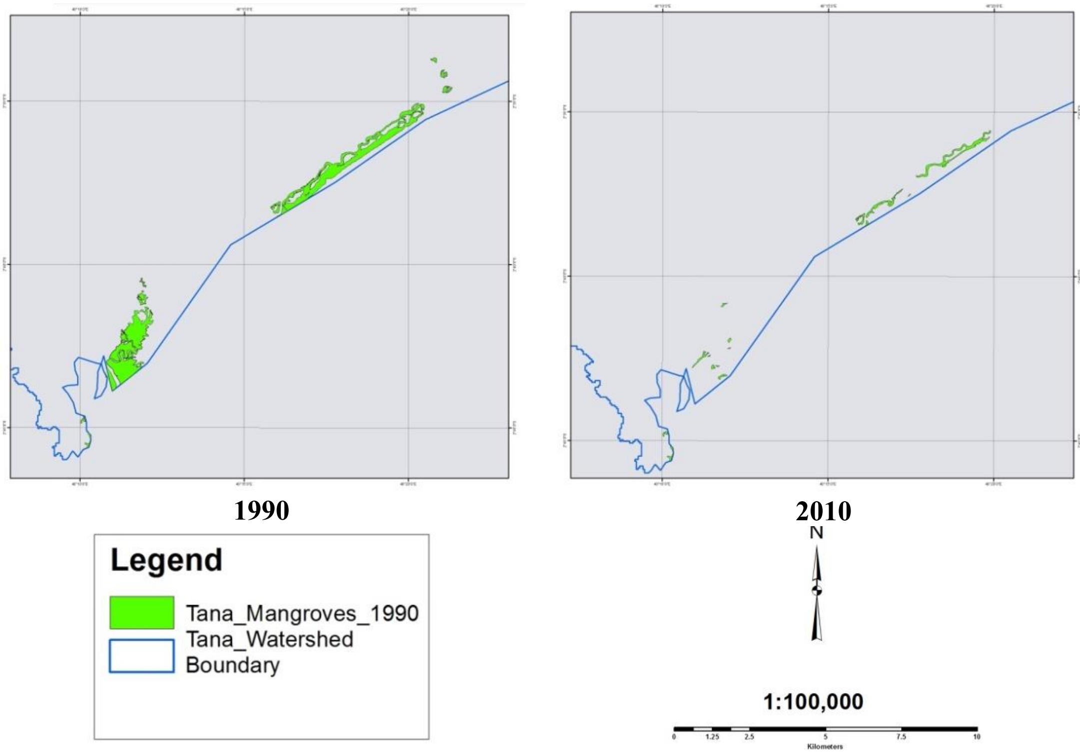


Figure 27 Distribution of Tana River Basin mangrove in 1990 and 2010 (Source: KFS)

Pressures

Pressures on the mangroves in the Tana Delta are comparable to those reported to previously mentioned ecosystem, such high population growth leading to increased demand for land, illegal logging and mangroves clearing, a recent trend in rapid urban and industrial development, pollution of the environment, reclamation for agriculture, salt ponds, aquaculture, coastal roads and embankments. More specific for mangroves, climate change which lead to rise in sea level, which puts significant pressure on mangrove forests from the seaward side.

Response Strategies

Most of the project interventions discussed under coastal forests are also applicable for mangroves. Some of these include introduction of participatory forest management (PFM) initiatives, enrichment planting, policy enforcement by relevant agencies such as KFS and KWS, and upper-catchment management.

4.3.7 Lakes, rivers and dams

Small wetlands are critical ecosystems both in terms of ecosystem socio-cultural values to local communities and general contribution to surface water in the entire basin. However, most of these wetlands remain unprotected, exposing them to over-exploitation by the neighbouring communities. Some of the small wetlands are found in Tana River Basin as:-

- *Lake Bututia/Mbututia*: L. Bututia is located in Amatu village, Kianjai location, Tigania West Division, Tigania West District. It covers an area of 1000 acres. The lake is regarded as a sacred site by the Ameru people and was gazetted as National Monument in December 2003 (Kariuki et al., 2014). The greatest challenge facing the lake is encroachment by the neighbouring farmlands (Muhando and Thuku, 2005).

- *Nkunga Sacred Lake*: Nkunga Sacred Lake measures approximately 96 acres and is located two kilometres off Meru-Nanyuki highway on the slopes of Mt. Kenya. The lake falls within the lower Imenti Forest Reserve. The Ameru use the lake as a sacred site to offer sacrifices by the Council of Elders (Njuri Nceke) to in cases of calamities like drought (Muhando and Thuku, 2005). It is surrounded by forest habitat with notable spiritual and medicinal plants such as fig tree (Mugumo). The local communities are often granted user rights by the management of the forest reserve.
- *Dams/Man-made wetlands*: Creation of dams in the upper basin has had a measurable impact on downstream flows in the lower Tana River. In general, construction of the two regulating reservoirs has augmented the dry weather, or minimum, flow while reducing peak floods. Floods during the month of May have seen a reduction of 20% since the dams were completed and the variability of monthly discharges in the Tana River has been drastically reduced. Vegetation characteristics have been affected by a reduction in the average duration of flood events (from 8.2 to 5.2 days). In addition the meandering rate (rate of movement of the river channel due to cutting of meanders) has fallen since the Masinga Dam was constructed.

Status and trends

Tana River has a pronounced seasonal variation in flows. In an average year, discharge at Garissa ranges from 1,000m^3/s in the wet season to as little as 20m^3/s in the dry season, with a mean annual rate of discharge of about 51m^3/s.

The variation is attributed to the following pressures:

- *Annual flooding*: Peak flows commonly occur in the Tana River during the two rainy seasons. These flood events follow a standard 'hydrograph' in which the volume of water in the Tana increases rapidly to a peak within a few days of the onset of heavy rain and then declines gradually over several weeks. Highest flood discharges are 'recorded' with the maximum discharge of 3,568m^3/s being achieved at Garissa in November 1961.
- *Dry weather flows*: The marked seasonal patterns of rainfall are separated by periods with little or no rain during which river flows steadily decline. In dry years the flow at Garissa may drop to as little as 20 cubic metres per second. Droughts are less prevalent in the Delta than flooding but they cause extreme hardship and lead to increased social tension and insecurity when pastoralists compete with farmers for access to grazing and water.
- *Exceptional flood events*: Exceptional flooding (and drought) occurs periodically, for reasons that are not fully understood. The most recent floods occurred in 2012 during the long rains season and also in 2006/7.

Pressures

Water availability is decreasing in the Tana River Basin and this is attributed to the following pressures. First, increasing water demand results from a rapidly growing population and related livelihood needs. Second, the principal uses of water in the Tana River Basin are for hydro-power generation, irrigation and public consumption. However, for power generation, the proposed water sharing policy (WRMA, 2006), does not provide for inter-basin water transfer. On the other hand, provisions are made for intra-basin transfers to meet other demands e.g. water for domestic use in Thiba location in Kirinyaga County is sourced within Tana River basin.

Water quality of the basin is generally declining, due to point and non-point pollution. The main point sources of pollution in Tana include agro-based industries (coffee and tea factories); Livestock based industries (slaughter houses, milk plants and tanneries); and sewerage works in large towns. The main non-point sources of pollution include pollutants from land degradation due to deforestation and erosion; encroachment into wetlands and riparian lands; and poor agricultural and farming practices. Quantification of water quality and the extent of pollution from these sources are difficult to determine. This is because information and data on the status of water quality is insufficient. In general, water quality varies spatially.

- The *Upper Tana* is characterized by catchment destruction, high population, higher number of agro-based factories and urbanization. These contribute to quite substantial pollution of surface water resources by tea factories, poor sanitation and wildlife in the forest. Groundwater quality can be adversely affected by high fluoride levels.
- The *middle Tana* experiences aggressive agricultural practice and overstocking, leading to catchment degradation and consequent higher erosion. Other pollution emanates from quarrying activities, sand harvesting and farm chemical wastes. Erosion and sediment transport and deposition are major pollutants in this reach in addition to similar pollutants of the upper Tana. Groundwater contains pockets of heavy metals and fluoride.
- The *lower Tana* is characterized by water scarcity in time and space with high evapo-transpiration rates which places a heavy reliance on groundwater for local drinking water supplies. Groundwater faces challenges of salinity (fluorides and iron) due to the nature of rock formations. Other challenges include sea water intrusion, tourism by-products, poor domestic water disposal and poor sanitation.

4.4 Ecosystem degradation hotspots in Tana River Basin

The map in Figure 28 illustrates the degradation levels in Tana River basin as at 2011. The upper catchment is most degraded as indicated by very high scores. There is moderate degradation in the middle catchment while very low degradation levels were scored in the lower catchment. Areas with high degradation scores appear to closely overlap with the distribution of cropland in land cover map for 2010 (Figure 24). Therefore, it is most likely that poor agricultural practices are the main causes of land degradation. On the other hand, the main factors that may contribute to degradation in the middle catchment (classified in this assessment as moderate) are wildlife and livestock grazing. This area is mostly covered by rangelands for pastoralists, game parks (e.g. Meru National Park, Kora Game Reserve and Kitui Game Reserve) and wildlife dispersal corridors.

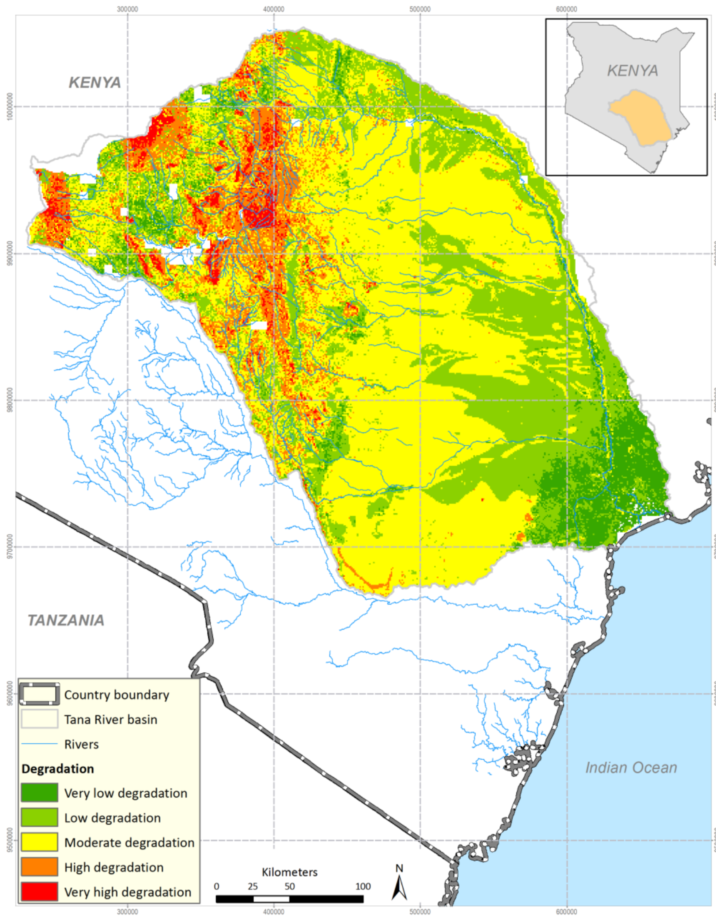


Figure 28 *Map of Tana River Basin showing land degradation hotspots*

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5 Valuing Ecosystem Services of the Tana

Niek Overgaauw, Pieter van Beukering, Elissaios Papyrakis, & Richard Mulwa

5.1 Introduction

As explained in Chapter 2, the current five hydropower stations along the Tana and the planned construction of the High Grand Falls (HGF) provide various valuable functions for the people in and around the Tana River Basin. Benefits of these infrastructural works include flood regulation, hydropower, irrigation and supply of potable water. However, the reduced availability of water downstream, or more specifically reduced flooding, is expected to have negative effects on local ecosystem service provision (Maingi & Marsh, 2002; Leauthaud *et al.,* 2013). If we are to obtain a clear picture of the full costs and benefits that are associated with the HGF Multipurpose Development Project, the social costs entailed by these downstream impacts will need to be incorporated in the overall assessment. Moreover, the spatial variability of the changes in ecosystem services needs to be considered in order to find out which communities will benefit from the dam construction and the million acres project and which will suffer negative consequences.

The objective of this sub-component of the study is to provide a baseline of ecosystem service provision and to explore means to link ecosystem service output to water availability and ecosystem health in the Tana River Basin. This economic research contributes to the extended cost benefit analysis, presented in Chapter 8, by providing dose-response functions which relate hydrological input in terms of river discharge and flooding, to ecosystem service outputs such as agriculture, livestock, hydropower, health and fisheries. The dose response functions were obtained by statistical analysis of time-series data. Significant results were obtained for rice production, beef cattle population and human health in Tana River County and Garissa County, which are all strongly correlated to changes in water flow. Additionally, the benefits of irrigation schemes and hydropower were calculated. Other ecosystem services were planned to be incorporated, however, because it proved impossible to obtain the required datasets several of these ecosystem services could not be estimated. These excluded ecosystem services and organisations that monitor these data include:

- Water-related conflicts potential (Water Resources User Associations - WRUAs);
- Biodiversity and species (Kenya Wildlife Service - KWS);
- Tourism and wild-life park visits (Kenya Wildlife Services – KWS)
- Human-wildlife conflicts (Kenya Wildlife Services – KWS)

5.2 Methodology

This section explains the methodology used to analyse the relations between the outputs of beneficial ecosystem processes, e.g. agriculture, to the input of the ecosystem services related to the river hydrology, e.g. flooding. A mentioned, these relations are used in the extended cost-benefit analysis to monetise the ecosystem services provided by the river.

Dose-response function

Dose-response functions, also known as factor income functions (Korsgaard & Schou, 2010) or production functions (Zwarts *et al.*, 2005) are a method used to "*assess the effects of changes in* *quality/quantity of ecosystem services on the profitability/size of related productions/outputs"* (Korsgaard & Schou, 2010). In this study a slightly different definition is used in which the *quality/quantity of ecosystem services* refers to the hydrological regime and the *related productions/outputs* are the ecosystem end-services or beneficial ecosystem processes (Balmford *et al.,* 2008). By this definition the river's hydrological regime is considered a supporting ecosystem service which is essential for the supply of a range of benefits. By just considering end-services and benefits, double counting is avoided (Balmford *et al.,* 2008).

The DR approach, originating from toxicology was presented in a report by the European Commission on methodologies to assess externalities of the energy sector (Bickel & Friedrich, 2004). In this study, it was proposed as a method to quantify the impacts of air pollutants on public health. As the name *dose-response* suggests, it investigates the relationship of a dose of a pollutant to the physical impact (*response*) on a receptor. A receptor in this case can be a person or even a population.

In the Niger study by Zwarts and co-authors (2005), it was used to assess the impacts of changes in hydrology on ecosystem services. In analogy with the EC report (Bickel & Friedrich, 2004), the *dose* is the quantity and timing of water provided by the river and the *response* is its impact on ecosystem service supply.

As in Zwarts *et al*. (2005), the DR functions in this study were constructed through statistical regression analysis of time-series of indicators of the output of ecosystem services – such as crop yields for agriculture – with hydrological indicators like discharge. The dependent variables, in this case, are the end-service indicators while the independent variable is the river regime. The resulting equation expresses output of an end-service as a function of, for example, river discharge.

Ideally, a differentiation would be made for the DR functions on the level of the smallest administrative units, in this case sub-counties. However, due to unavailability of data it has not been possible to construct DR functions on the sub-county level. Instead, specific DR functions were constructed for the counties that strongly depend on the Tana Basin for their water supply and are located downstream from the planned HGF Dam.

Data collection

In order to construct the DR functions, tables containing time-series of the output of end-services (as an indicator) were gathered, as well as time-series of indicators of the hydrology, e.g. discharge at a number of points. The data on end-services was collected primarily from Kenyan ministries and (government) institutions, and supported by scientific literature. The *Water Resources Management Authority* (WRMA) provided the hydrologic data consisting of daily discharge along 30 points along the river and daily rainfall from 31 stations in the Basin. Supporting qualitative data was gathered from scientific literature, government and NGO reports and interviews with experts, stakeholders and representatives of local communities.

Data analysis

The aforementioned discharge data contained quite some data gaps of varying sizes. One explanation for this is that the river sometimes changes course after which the gauging station is circumvented. All years containing data gaps larger than 30 consecutive days were omitted. For the months in the rainy season – April-June and October-December – a more stringent threshold of 20 days was maintained. If the gaps were outside of the rainy season, the variable average discharge during rainy season was still used. Data gaps lower than the thresholds were interpolated by using the average of the last and next known data points.

The data for livestock and agriculture contained some outliers, which may be explained by the fact that the datasets are people-managed. Where possible, outliers were crosschecked with different data sources. In other cases, it was quite obvious that a decimal was displaced as values were a factor 10 higher than the normal range. Moreover, in the years after 2007, a large annual variation was observed in livestock data. This can be explained by the altered system and boundaries of administrative divisions[1]. Unfortunately as a result, data was not comparable and therefore the years 2008-2013 were omitted.

5.3 Agriculture

Agriculture is of great importance to the Kenyan economy. This is even more so in rural areas where it is essential for people's income and food security, such as in Tana River County where 86% of the inhabitants live in a livelihood zone based on farming (Muraguri & Gioto, 2013). Most of these people rely on farming either directly or indirectly for their income. Many different crops are cultivated in the Tana Basin including cereals, beans, vegetables, fruits, cotton and flowers. However, there is a strong variability of grown crops between the different counties. In the Upper Catchment, water availability is relatively high and crops with a high added-value – such as tea – are typically grown (Knoop *et al.*, 2012). In the Lower Catchment, cultivable land is scarcer and agriculture focuses more on subsistence crops.

Production systems

Different agricultural production systems are practiced within the Tana Basin. First, a frequently practiced method is **rain-fed farming** in which rain supplies the water for farming during the wet seasons (Leauthaud *et al.,* 2013; A. Munguti, personal communication, April 30, 2014). As a result of the biannual rainy seasons of the Kenyan climate, two crop cycles can be sustained per year. However, seasonal rainfall is erratic and it is not uncommon for harvests to fail. Different crops are grown using rain as the main water source, the main one being maize but also green grams, beans, pigeon peas and cow peas are cultivated.

Second, **flood recession farming** is another traditional method, practiced by an estimated 115,000 people in the Basin (Leauthaud *et al.,* 2013; Emerton, 2003). This type of farming relies on the Tana's floods as a source of water and sediment to make the land fertile and thus cultivable (Thomas & Adams, 1997). This is especially important in the Lower Catchment which is typified by poor soils and little rainfall (Knoop *et al.*, 2012). As a result, any changes in the flood regime of the Tana are a direct threat to farming on floodplains. As mentioned earlier, past interventions in the river have already had an impact on the flood regime and as a result adversely affected flood recession agriculture (Leauthaud *et al.,* 2013; Emerton, 2003; Maingi & Marsh, 2002). The main crop grown in the Tana floodplains by recession agriculture is rice (Leauthaud *et al.,* 2013; A. Munguti, personal communication, April 30, 2014). Additionally, supplementary crops such as bananas are grown.

Third, an alternative practice, which is comparable to flood recession agriculture, is **farming near seasonal rivers**, also known as lagas (Mahadi *et al.*, 2012; A. Munguti, personal communication, April 30, 2014). Many of the lagas are tributaries to the Tana which are flowing mainly in the rainy season. As such, they show a similar biannual pattern as flood recession agriculture.

Fourth, several **irrigation schemes** are in place in the Tana Basin. The towns of Hola and Bura have large-scale irrigation schemes which use pumps to abstract water from the Tana in order to grow maize and cotton (Maingi & Marsch, 2002; Adams, 1990). The schemes at Bura and Hola

[1] Between 2007 and 2013 many new districts were created by the Kenyan government. In 2013 the High Court of Kenya ruled these administrative changes to be unconstitutional. Only 46 constituencies (plus Nairobi) were legally constituted, henceforth known as counties (Machuka, 2009).

have collapsed in the late 1980s, due to mismanagement and a change in the river's course, respectively (Mutero, 2002). However, the responsible authority, the National Irrigation Board, is working on rehabilitating the schemes since 2005 and 2009 respectively (NIB, 2014a, 2014b). Further upstream, in Kirinyaga County, the Mwea Irrigation Scheme is run to grow rice and in the Tana Delta irrigation is practiced by the *Tana Delta Irrigation Project,* operated by TARDA (Lebrun *et al.,* 2010). Moreover, some small-hold farmers have pumps which they use to water their crops and some farmers have organised in cooperatives to acquire pumps (I.A. Mkala, personal communication, April 30, 2014). Furrow irrigation is the predominant irrigation method – also for the large-scale schemes – due to its low capital investment costs (P. Njiro Waganagwa, personal communication, April 30, 2014). The water efficiency of this method is, however, low due to the high evaporation rates in the area. As a result, highly valuable water is wasted.

Dose-response function flood recession farming

Focussing on the relationship between flooding and agriculture, the dose-response function should ideally be corrected for rain-fed and irrigated agriculture, leaving only the relationship between flood recession agriculture and the Tana's hydrology. However, because the data on agricultural crop yields do not distinguish between the different production systems, regression results for most crops were not significant, with the exception of rice, which happens to be the main crop cultivated in flood recession agriculture. Out of the four counties downstream from Grand Falls, rice is only grown in Tana River and Lamu counties. Due to a lack of suitable hydrological data for Lamu, the DR function could only be obtained for Tana River County (see Figure 29). The hydrological parameter is the number of days above the flooding threshold at Garissa. The threshold is a consecutive discharge of over 300 m³/s for at least seven days. Thus, a set of days can be very long and the number of overruns of the threshold can range from zero to multiple times a year.

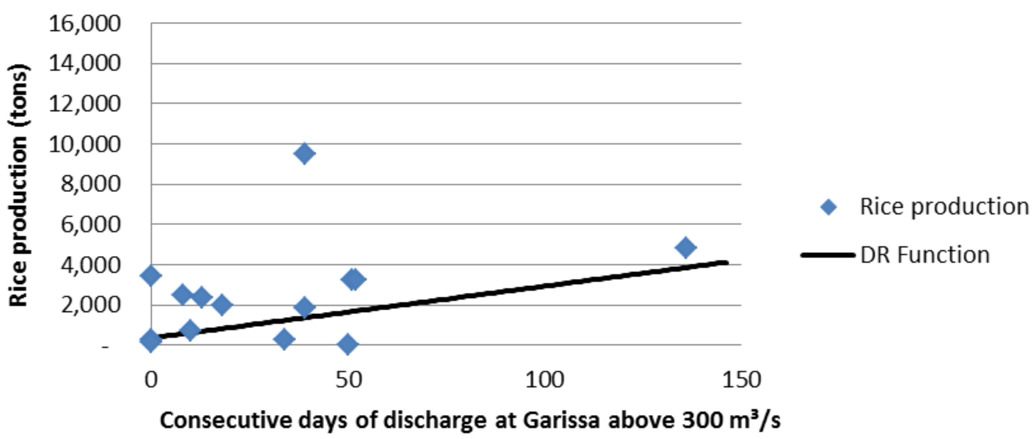

Figure 29 Regression results for Tana River County rice production and the number of days above the flooding threshold

The dose-response function is given below, in which *y* represents the rice production in tons (dependent variable), *x* is the cultivated area in hectares and *z* is the amount of days above the flooding threshold.

$$y = 363.9 + 1.855x + 25.73z$$

As shown in Table 15, good results were obtained for the R^2 and the P-values of the independent variables. However, the P-value of the constant is quite high meaning it is not proven with significance that the constant is different from 0. Nonetheless, considering the nature of the hydrological parameter, we would expect the constant to be higher than 0. After all, during years in which the flooding threshold was not reached the rice production was never 0.

Table 15 Regression table for rice production in Tana River County

Rice production in Tana River County	Coef.	Std. Err.	t	P>|t|
Cultivated area	1.856	0.213	8.71	0
Number of days above flooding threshold Garissa	25.73	7.437	3.46	0.005
Constant	363.8	560.7	0.65	0.53
Number of observations	14			
F(2, 11)	41.22			
Prob > F	0.000			
R^2	0.723			
Root MSE	1431			

5.4 Irrigation

To assess the change in benefits resulting from the HGF Multipurpose Development Project, the crop production of its related irrigation schemes need to calculated. A straightforward way to do so is to multiply the cultivated area of the schemes with the yields of the grown crops under irrigated agriculture. However, yields of irrigation schemes are unclear since many different sources report contradictory information. For example, Table 16 shows the large variation for irrigated maize yields, ranging between 1 and 8 tons per Ha per year. Similar problems were encountered for rice. The reported long term average (5 years) rice production on irrigated land in the 2011/2012 and 2012/2013 *Short Rains Reports* were 4,200 bags and 104,000 bags, respectively (Wambua *et al.*, 2012; Muraguri, 2013). This large difference sheds doubts on the reliability of these data. When compared to the annual average crop yields on the national and county level, the crop yields as stated by Kiptala (2008) appear to be the most suitable data for irrigated rice and maize (see Table 17). Note that the cotton and sugar cane yields seem rather high.

Table 16 Productivity of irrigated maize agriculture in Tana River Basin

Source	Yield per year	Reference
NIB at Bura Scheme	8 tons/Ha	A. Omar, personal communication, April 29, 2014
Ministry of Agriculture at Tana River County	Max. 2.5 tons/Ha Avg. 1 ton/Ha	*Data Compendium* - KIPPRA, 2007
Potential average	2.7 tons/Ha	Kiptala 2008
2011/2012 Short Rains Assessment Report	1.8 tons/Ha for only single crop cycle	Wambua *et al.* 2012

Table 17 Crop parameters of Tana irrigation schemes (Kiptala, 2008)

Crop	Crop yield (tons/Ha)	Return date (month)
Rice	5.2	4; 12
Cotton	2.5	2
Sugarcane	90.0	1
Maize	2.7	3; 9

Also, concerning the cultivated area of the irrigation schemes there is also much contradictory information. By combining values provided by the National Water Masterplan, the websites and reports of TARDA and the NIB and interviewees of the NIB, Eiselin (2014) derived the values as presented in Table 18 below. Using the crop yields as provided by Kiptala (2008), the total production of staple crops was calculated to be 64,000 tons.

Table 18 Irrigated land and crop yields of large-scale irrigation schemes in the Tana Basin. Adapted from Eiselin (2014)

Name	Crop type	Irrigated area (ha)	Yield (tons/Ha)	Production (tons)
Mwea	Rice	7,860	5.2	40,872
Hola	Maize	1,000	2.7	2,700
Bura	Maize	3,000	2.7	8,100
TDIP	Rice	2,000	5.2	10,400
KGK	Maize	700	2.7	1,890
Mitunguu	Horticulture	600	unknown	
Total		15,160		63,962

Note: KGK stands for Kagaari-Gaturi-Kyeni

5.5 Livestock

The livestock industry in Kenya is large, contributing roughly 7% of national GDP (ADEC, 2009). Most production is small-scale: herds owned by a family or shared by a small community. As such, animal husbandry is of great importance to food supply and welfare for many communities living in the Tana Basin. In some counties, such as Isiolo, pastoralism directly or indirectly accounts for the livelihoods of up to two thirds of the inhabitants, with another 26% of people depending on an agro-pastoral lifestyle (Matheka & Kinyanjui, 2013). Apart from being their main source of income and food, livestock is an integral part of daily life as it provides transport, is used for paying fines and capital investments and savings and is involved in marriage and other social traditions (Matheka & Kinyanjui, 2013).

Pastoralist systems

The types of kept livestock are cattle (beef and dairy), goats, sheep, camels, poultry, donkeys and pigs. Pastoralist communities typically live (semi-)nomadic lives, moving their herd from one place to another in search of water and pasture. This is especially important in the semi-arid regions of the Lower Tana where flooding serves a crucial function as it provides for dry season grazing grounds (Leauthaud *et al.*, 2013). Meanwhile, during the wet season, the floodplains are avoided and the herds are moved to the pastures in the hinterlands (Catley *et al.*, 2002). One of the reasons for this seasonal migration is that floods, when too severe, can be hazardous to livestock as they destroy grazing fields and prevent herds from moving to higher regions. This was observed in the extremely wet years – such as during the '97/'98 El Niño and the 2013 heavy downpour – when large losses of herd were reported (Leauthaud *et al.*, 2013; Kenya Red Cross, 2013a).

As a strategy to increase food security, some pastoralists diversify their herds keeping both cattle as well as more drought resilient species as camels and goats. However, it should be noted that loss of herd is not the only negative impact for farmers. Availability and security of proper grazing areas is also essential for if the livestock is not fed well, their health and bodily condition diminishes (Matheka & Kinyanjui, 2013; OPM, 2011). Meat and milk production decrease and birth rates are lower. As a result, pastoralists receive less money for selling livestock and livestock products. For some families, up to 80% of the income is livestock-related (Matheka & Kinyanjui, 2013). These families are impacted heavily in years with poor grazing conditions.

Dose-response functions livestock

The ambiguous relation between livestock and water availability is reflected in the estimated Dose-Response functions. For Garissa and Tana River counties, good correlations were found when regressing the beef cattle population (dependent variable) with: 1) the population of the previous year; 2) the average water height at Garissa, and; 3) the square of the water height. The resulting relation between water height and beef cattle population is visualised in Figure 30.

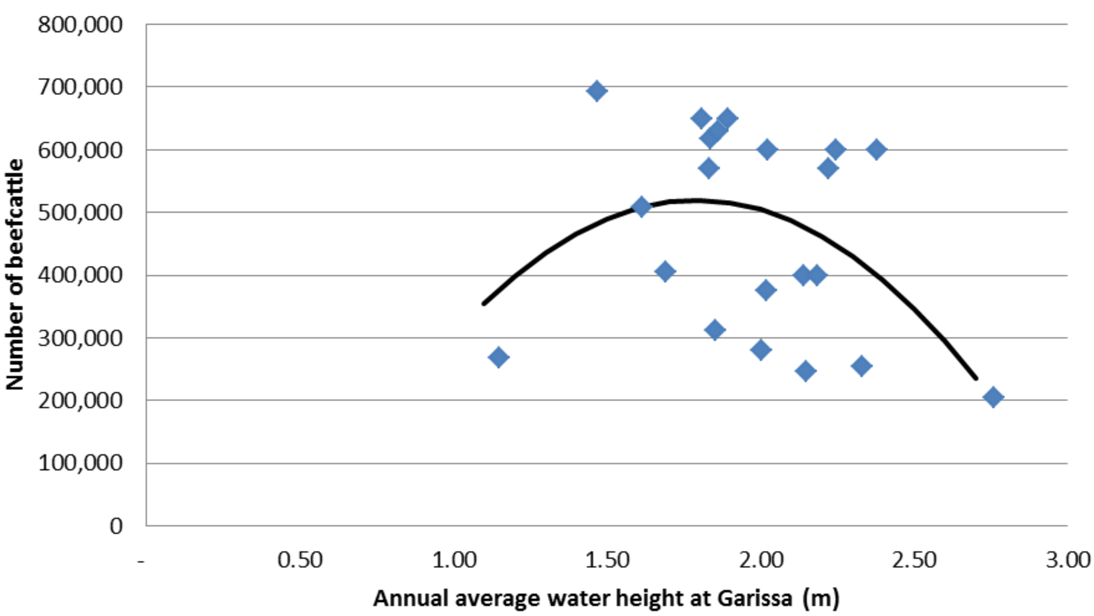

Figure 30 Relation of the beef cattle population in Garissa with the average water height. Note that the variable of previous year's population is not included in this graph

For Tana River County, very similar results were obtained. The resulting dose-response functions are displayed below, where x are the respective beef cattle populations, x_{t-1} previous year's populations, and y the annual average water height at Garissa.

Dose-response function beef cattle Tana River County:

$$y = -225347 + 0.842y_{t-1} + 312644\text{x} - 80994\text{x}^2$$

Table 19 Regression table for beef cattle in Tana River County

Beef cattle Tana River County (y)	Coef.	Std. Err.	t	P>|t|
Population last year (y_{t-1})	0.842	0.141	5.95	0.000
Average height at Garissa (x)	312644	108980	2.87	0.009
Squared average height at Garissa (x^2)	-80994	31119	-2.60	0.017
Constant	-225347	92128	-2.45	0.023
Number of observations	25			
F(3, 21)	21.62			
Prob > F	0.000			
R^2	0.767			
Root MSE	61226			

Dose-response function beef cattle Garissa County:

$$y = -578229 + 0.754y_{t-1} + 789627x - 217968x^2$$

Table 20 Regression table for beef cattle in Garissa County

Beef cattle Garissa County (y)	Coef.	Std. Err.	t	P>|t|
Population last year (y_{t-1})	0.754	0.145	5.20	0.000
Average height at Garissa (x)	789627	350616	2.25	0.039
Squared average height at Garissa (x^2)	-217968	82832	-2.63	0.018
Constant	-578229	374478	-1.54	0.142
Number of observations	20			
F(3, 21)	26.16			
Prob > F	0.000			
R^2	0.753			
Root MSE	89182			

In the Lower Tana, the predominant livestock species are beef and dairy cattle, goats and sheep. Regression analyses were undertaken for each of the species and for Garissa and Tana River counties. However, good DR functions were obtained only for beef cattle. Data for dairy cattle populations is poor for both counties. The same holds for data on goats in Garissa County. For goats in Tana River County and for sheep no good results were acquired however, despite data availability. A possible explanation is the drought resilience of goats, which could cause a decrease in grazing areas not to be reflected in the respective population.

5.6 Public health

The relation between water availability in the Tana Basin and public health is a delicate balance. On the one hand, in dry years, lack of flooding decreases food production thereby increasing malnutrition. Moreover, the amount of clean drinking water is reduced and aquifers are refilled to a lesser extent, thus reducing the future availability of drinking water from water pumps (J. Kilonzo, personal communication, May 1, 2014). On the other hand, during extreme floods, people are displaced and crop harvests are lost (Kenya Red Cross, 2013b). Also, extreme floods are paired with outbreaks of water borne diseases (Terer *et al.,* 2003) and increased population of disease vectors such as mosquitos (Kenya Red Cross, 2013b). Boreholes are more difficult to access and the habitat of crocodiles and hippopotamuses is expanded, leading to more human-wildlife conflicts (J. Kilonzo, personal communication, May 1, 2014).

Dose-response function of health

For modelling the relationship between health and the Tana, different health parameters were sought, such as malnutrition rates and cases of water borne diseases. Regrettably, it proved impossible to obtain these data. Malnutrition rates seem not to be well-recorded on a yearly basis on the county level. The amount of cases of water borne diseases should be recorded at local hospitals but it is unclear whether these are aggregated on a national level and individual hospitals could not be contacted due to time-constraints.

Alternatively, mortality rates have been used in constructing the dose-response function for health. As time-series of mortality rates were not very long in the available data sets, the rates of Garissa and Tana River counties have been combined. That way, the number of observations and reliability of the results were increased. As both counties are separated by the river and cover roughly the same area, mortality rates as a result of dry or extremely wet years are assumed to be comparable.

The result of the regression analysis is shown below in Figure 31. The aforementioned relationship between health and water – high mortality in dry years but also in extremely wet years – can also be observed in the DR function.

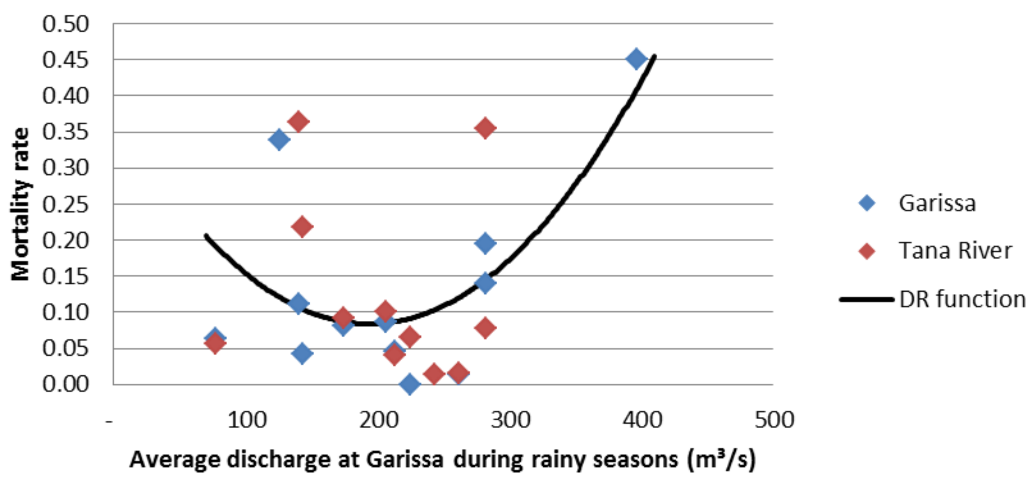

Figure 31 Dose-response function for health in the Lower Tana (Garissa and Tana River counties)

- Dose-response function:

$$y = 0.382 - 3.07 * 10^{-3}x + 7.93 * 10^{-6}x^2$$

Table 21 Regression table for health in Tana River and Garissa County

Mortality rate TR and Garissa counties (*y*)	Coef.	Std. Err.	t	P>|t|
Average rainy season discharge Garissa (*x*)	3.15e-03	1.31e-03	-2.41	0.026
Squared average rainy season discharge Garissa (x^2)	8.11e-06	2.41e-06	3.36	0.003
Constant	0.388	0.169	2.30	0.032
Number of observations	23			
F(2, 20)	15.13			
Prob > F	0.0001			
R^2	0.290			
Root MSE	0.116			

The results of the regression are satisfying. P-values are low for the variables as well as the constant, meaning the results are significant. At 0.29 the R^2 is not high but this is easily explained by the fact that there are many other variables affecting mortality rates.

5.7 Fisheries

Fishing in the Tana Basin occurs both in the river itself as well as the inundation zones (Leauthaud *et al.*, 2013). The floodplains serve as a breeding ground and thus have a nursery function for the fish. Furthermore, fishing activities in the Indian Ocean near the mouth of the river are related to the Tana River as the riverine mangroves too have a nursery function for certain species which move on to the ocean when they mature (A. Bwanaker, personal communication, May 1, 2014).

Among the species caught in the river are catfish, white snappers, king prawns, jumbo prawns, cocktail prawns and triple tails. Together, the different prawn species account for roughly 70% of the freshwater catch in the delta (A. Bwanaker, personal communication, May 1, 2014). There is a positive link between river discharge and fish catch. As such, water level is the limiting factor to fisheries production (A. Bwanaker, personal communication, May 1, 2014).

Dose-response function fish catch

Records on fish catch are kept on a voluntary basis and have not yet been documented for long for Tana River (A. Bwanaker, personal communication, May 1, 2014). As a result, very little data is available and it was possible only to get fish catch records for the years 1999 to 2006. However, due to some data gaps in the hydrological data, only 5 observations could be used for the regression analysis. Moreover, it is unclear whether the data represent only fish caught in the river or rather all fish caught in the county, including ocean and floodplain catch.

Different hydrological parameters were tried for the regression. The best results were obtained when applying a time-lag of one year on the hydrological parameter *average water height at Garissa* (Figure 32).

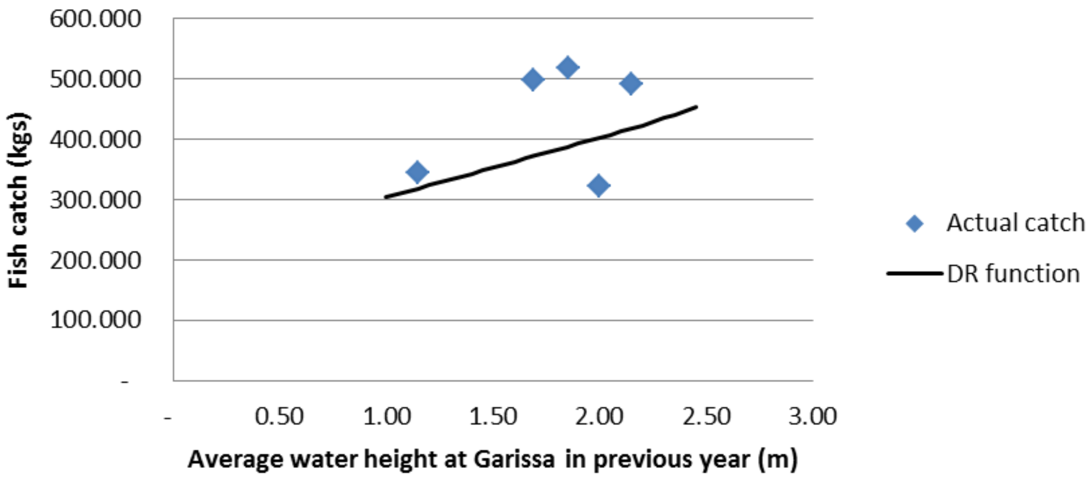

Figure 32 Fish catch in Tana River County related to last year's water height

Dose-response function of fish catch (y) and previous year's water height (x):

$$y = 204.6 + 98.91x$$

Table 22 Regression table for fish catch in Tana River County

Fish catch Tana River County(y)	Coef.	Std. Err.	t	P>|t|
Average water height Garissa in previous year(x)	98.91	27.18	3.64	0.036
Constant	204.6	56.60	3.61	0.036
Number of observations	5			
F(1, 3)	13.24			
Prob > F	0.036			
R^2	0.850			
Root MSE	28.024			

The R^2 and P-values are adequate. However, due to the low number of observations and indistinctness of the data the usefulness of the dose-response function remains uncertain and additional data collection is needed to substantiate this relationship.

Benefit transfer

Alternatively, a benefit transfer can be applied using data from comparable ecosystems. Table 23 gives an overview of floodplain fish catch from various African rivers. A prerequisite for using these values is that the relation between river discharge and inundated area is known for the Tana Basin. This is one of the objectives of the overall study which was not yet completed when conducting this analysis.

Except for some outliers, yields of fish catch seem to be of comparable size for the different sites. The median and mean values are practically identical – respectively 43.73 and 43.82 kgs/ha. In future studies, these yield estimates can serve as a good approximation for fish catch in the floodplains.

Table 23 Fish catch in floodplains (Welcomme, 1975)

Name of floodplain	Area at peak flood (ha)	Catch (tons)	Yield (kg/ha)	Year
Barotse	512,000	2,395	4.68	1967
Kafue Flats	434,000	5,984	13.79	1961–1972
Shire (total)	140,000	8,972	64.08	1969–1973
Central Delta (Niger)	2,000,000	134,000	67.00	1971
Massilli	1,500	475	31.00	1972
Ouémé	100,000	6,484	64.84	1969–1970
Senegal	600,000	36,000	60.00	1972
Niger (Niger)	90,704	4,700	51.82	1970
(Dahomey)	27,440	1,200	43.73	1970
(Nigeria)	480,000	14,350	29.90	1969
Benue	310,000	9,570	30.87	1969
Yaérés	700,000	17,500	25.00	1955

Tana River dams fisheries

Fishing activities are also undertaken in the reservoirs of the dams in the Tana River. Data for the annual fish catch thereof have been better recorded than fish catch in the downstream counties. Still, it was not possible to obtain a good regression for dam fisheries because the catch from all dams is aggregated even though the dams are located at different points in the river and thus have varying quantities of water flowing through. It is therefore not satisfactory to link them to the discharge at a certain gauging station. Moreover, it remains unclear how catch relates to availability of water in the reservoirs and what the other limiting variables are. It is therefore difficult to assess what the potential catch is. The average catch is 934 tons per year, yet as can be seen in the data overview in Figure 33, annual catch can vary substantially over time. Generally, it shows a declining trend although the catch seems to recover since 2001. Due to missing data after 2006 it is unclear whether this recovery continues in the years after.

5.8 Hydropower

At a growth rate of production of roughly 10% per year, the Kenyan electricity sector is developing rapidly (MoE, 2012). In 2011, the country had a total installed capacity of almost 1,600 MW, roughly half of which was supplied by hydropower (see Figure 34).

While electricity is becoming more and more important to the Kenyan economy, power outages are frequent and can pose a problem for households and economic activities. In 2010/2011, unserved energy demand, or the share of demand which cannot be met because of constraints in energy supply, was on average 25 GWh (MoE, 2012). On a total consumption of 6,123 GWh, the unserved portion seems negligible (less than 0.5%). However, 30-80 MW of load is shed on a daily basis which, on a peak demand of 1,194 MW is quite substantial (2.5-6.7%). The shortages are mainly felt by large and medium-scale industrial and commercial companies as in case of a surplus of demand Kenya Power, the Kenyan grid operator, is obliged prioritise supply to regular consumers (MoE, 2012). In 2011, the cost of unserved energy was estimated at 0.84 US$/kWh.

At 25 GWh of unserved energy this adds up to a total cost of US$21 million. The electricity generation costs of the HGF are projected to be between 0.12 and 0.185 US$/kWh, depending on the discount rate (8-12%). Thus, the potential benefits of supplying unserved electricity demand are roughly US$16.4-18 million.

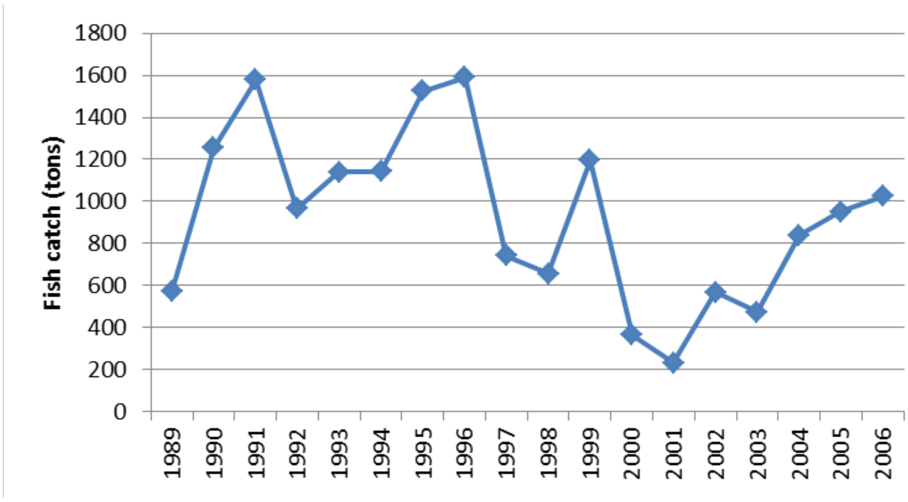

Figure 33 Fish catch in Tana River dams

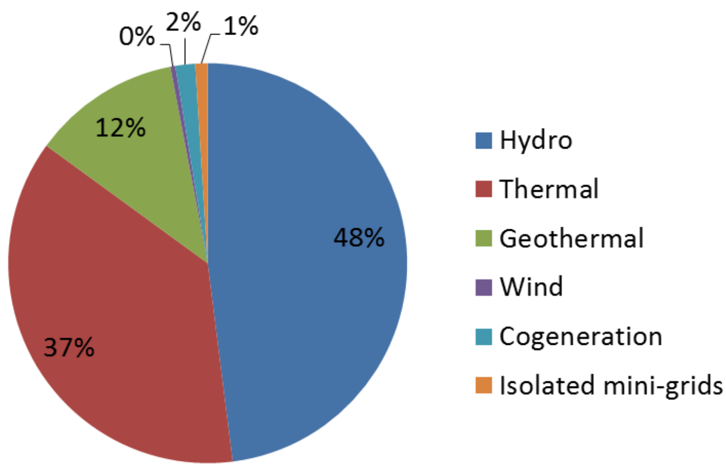

Figure 34 Energy Mix of Kenya in 2011 (MoE, 2012)

However, to truly assess the benefits provided by hydropower, a comparison needs to be made with the opportunity costs of alternative sources of power generation. The alternatives for peak power in Kenya are medium speed diesel (MSD) and gas turbines (MoRDA, 2011). For this analysis gas turbines have been chosen since they are cheaper than MSD plants in the Kenyan context (MoE, 2011). Base load energy could alternatively be generated by coal fuelled thermal plants, geothermal installations and nuclear. In this case, geothermal energy is being assessed since it is a fossil fuel free power source, as is hydropower. Moreover, nuclear is not an option on this time-horizon as the licensing process for a nuclear plant must be completed six years in advance of the commissioning date (MoE, 2011).

The power output of the HGF Dam is divided into two stages. Stage I will start when the reservoir is filled, which is expected to be in 2017/2018. Stage II is supposed to commence ten years later after a regulatory dam is built downstream from the HGF. The second stage has a stronger focus on peak power production than the first.

Prices of hydropower and the natural gas/geothermal alternative were compared for the power output that is planned to be provided by the dam. A distinction is made between the two stages. The outcomes of the price comparison can be seen in Table 24. Prices per kilowatt hour are based on the HGF feasibility study (MoRDA, 2011) and the *Least Cost Power Development Plan* by the Kenyan Ministry of Energy (MoE, 2011).

Table 24 Price comparison of desired power output using the HGF Dam and a natural gas/geothermal alternative

	Stage I			Stage II		
	Base	**Peak**	**Total**	**Base**	**Peak**	**Total**
Average annual output (GWh)	609	604	1213	518	752	1270
Annual costs (million US$)						
Hydropower HGF	73.1	72.5	**145.6**	62.2	90.2	**152.4**
Gas thermal + geothermal	43.3	127.4	**170.7**	36.8	158.7	**195.5**

At these rates, hydropower comes out as the cheapest option to realise the desired electricity supply. In stage I, the annual cost difference is approximately US$25 million. This figure goes up to slightly over US$43 million in stage II. It should, however, be noted that dam projects, especially the multipurpose ones, have a tendency to overrun costs. A study by the World Commission on Dams (2000) found that the out of 45 assessed projects, the average overrun was 63%. Care should be taken when building the dam as such a cost overrun would make the natural gas/geothermal alternative the cheaper method.

5.9 Conclusion and discussion

The estimated dose-response functions clearly show that, even though regulation of extreme floods can be a positive side-effect of additional dams in the Tana River Basin, further reduction of river discharge and moderate flooding can have considerable adverse effects on the benefits provided by ecosystem services downstream. It therefore seems likely that the HGF Dam will increase the disparity of water availability between the Upper Basin and the Middle and Lower Basin, as have the dams that were built in the past.

A number of insights on improving the methodology of the economic model were obtained and applied during the research. For example, the regression results were improved by using multiple variables. For livestock population, this involved including the population of the previous year and for rice production the cultivated area was added. Moreover, by doing the regressions for livestock and health with both the hydrological parameter as well as its square, non-linear relationships could be established. In doing so, validity of the results is increased as the non-linear functions better reflect the interrelation between flooding and livestock/health as described in literature and by interviewees. Overall, it should be added that qualitative information from literature and interviews have proven to be crucial to strengthen the statistical results and understand the limitations. More suggestions for improving the estimated dose-response functions are provided in Overgaauw (2014).

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6 Household Survey in the Tana Delta

Phillip Otieno, Richard Mulwa, Wouter Botzen & Pieter van Beukering

6.1 Introduction

Estimating the impact of changes in hydrological conditions in the Tana River Basin in the previous Chapters concentrates mostly on tangible market values simply because this is where the largest effects are foreseen and because those are the ecosystem services that are best recorded in the statistical record. Although this choice is justified for methodological reasons, it also excludes potential ecosystem services that are less visible and less well recorded. By excluding such values, the extended cost benefit analysis runs the risk of giving an incomplete picture of the societal effects of dams and irrigation schemes. Therefore, a case study has been selected on the benefits of mangrove ecosystems in the Tana Delta which are claimed to serve a numerous local communities in various ways. Not only will this case study emphasize that downstream effects often go beyond the strict financial domain, it will also demonstrate that at the local level dramatic effects may occur that are less visible in an aggregated analysis.

The case study will focus at the value of mangrove ecosystem services which are likely to be effected by local threats as well as changes in the upstream water regime. Mangroves form part of important natural resources around the world including Kenya, where studies have shown that they provide a range of ecosystem based goods and services such as protection of coastal shoreline, carbon sequestration, nursery for both offshore and on-shore fisheries, purification of water and timber for various uses by local communities such charcoal, building among others. Mangroves also constitute a significant habitat for various plants and animals such as hippos, reptiles like snakes and crocodiles, various bird species and several invertebrates.

Despite the importance of mangrove ecosystems, there is continued threat to their existence; they face great threat from conversion into aquaculture, over harvesting, pollution among others (FAO, 2010). It is estimated that 10,310 ha of mangrove forest in Kenya have been lost due to conversion to other land uses, overexploitation and pollution (NEMA, 2010). This is in line with the analysis of Landsat imagery, presented in Chapter 4, over a 25-year period from 1985 to 2010 which recorded a decline of 18% decline of mangroves which is equivalent to 9,950 ha (Kirui et. al. 2012).

The conversion of mangroves into aquaculture, other unsustainable use and upstream developments that threatens the availability of freshwater flooding downstream is due to lack of acknowledgement of the values of the goods and services that they provide, particularly in economic terms. There is therefore need to assess the economic values of these ecosystem services of mangroves to provide information on the ecosystem services that benefit society and the economy, and assess the suitability of the current institutional arrangements for an integrate river basin management approach.

This sub-study aims at determining the economic values of the mangrove ecosystem services in Tana River from the perspective of local communities in the Tana Delta and investigate the suitability of the existing institutional arrangements to harness the values within a broader integrated river basin management framework. Understanding the values of mangroves can help to improve decision making, such as policies about upstream dams and irrigation schemes, when trade-offs are necessary and useful information is lacking and provide a basis for policy formulation and analysis.

6.2 Methodology

The research was conducted in Tana River delta covering specifically mangrove habitats located within Kipini division (see Figure 35). The delta has mangrove forests with nine species (Tana River Delta, 2004)[2]. There are also a significant number of animals within the study area such as large crocodiles as are herds of hippopotamus (Matiku, 2004). The mangrove at the study site covers a total of 2,350 ha. Kipini division which is the area of study focus has a population of over 19,635 people and households number of 3,743. The main socio economic activities of the local people include; pastoralism, livestock keeping, farming, business, and fishing (KNBS, 2009).

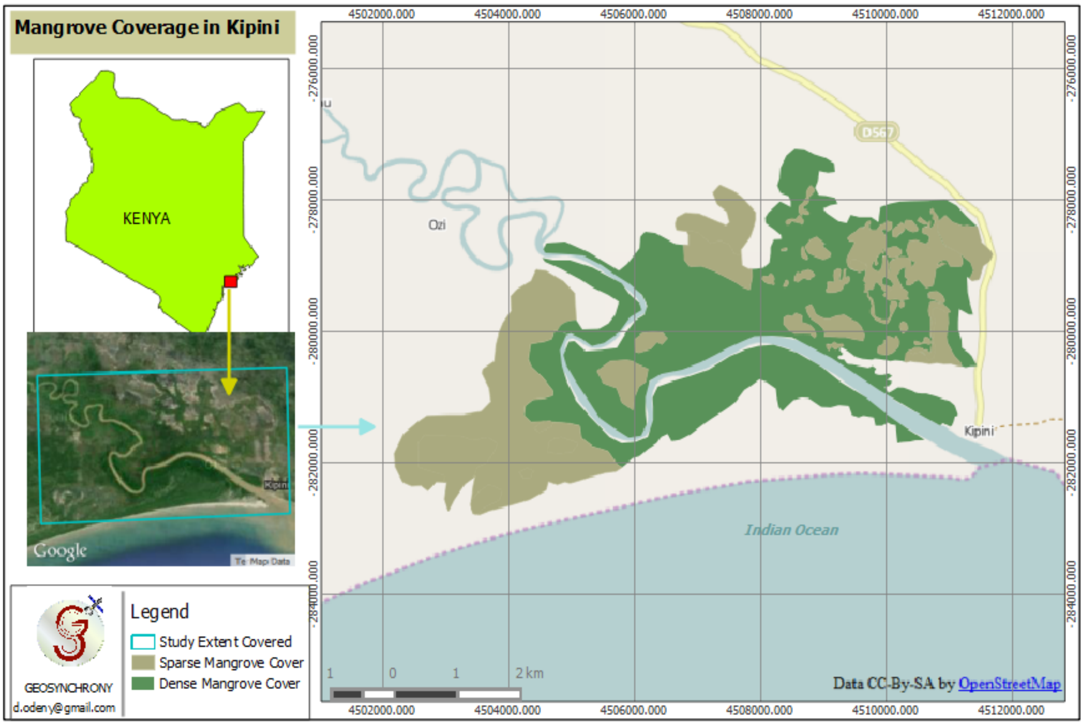

Figure 35 GIS Map showing the state of Mangrove Forest in Kipini

Study Design and Sampling Procedures

The necessary data for this study was collected using Market Price Method and Choice Experiment Techniques (for more explanation of the latter method, go to 8.9Annex A.). For Market Price Method, random sampling was conducted to collect market prices of the forest products. The sampling unit was households within Kipini division which has 3,743 households according to population census of 2009 and using the formula:

$$n = \frac{N}{1 + Ne^2}$$

Where n = sample size, N= total number of households in the area (3743), and e = design margin of error (5 percent error assigned), a sample size of 210 households were sampled.

In the choice experiment, individuals are asked to choose their preferred alternative from several options in a choice set, and they are usually asked to respond to a sequence of such choices. Each

2 Lumnitzera racemosa, Heriteria littoralis, Avicennia marina, Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza, Xylocarpus granatum, Sonneratia alba & Xylocarpus muluccensis

alternative is described with a number of attributes or characteristics, where the levels of the attributes change from one alternative to the other. A monetary value is included, as are other significant attributes, when presenting each alternative. Thus, when individuals make their choices, they implicitly make trade-offs between the levels of the attributes in the different alternatives presented in a choice set (Alpízar et al. 2003).

There are four steps involved in the design of a choice experiment (Martinsson et al., 2001):

1. definition of attributes, attribute levels and customisation,
2. experimental design,
3. experimental context and questionnaire development, and
4. choice of sample and sampling strategy.

Definition of Attributes and their levels: The attributes identified in this study include; shoreline protection, storm protection, nursery and breeding ground for fish, groundwater recharge, flood control, tourism and recreation, cultural values, and the payment vehicle is volunteer time for mangrove conservation. The attributes however, have been reduced to four which are nursery and breeding ground for fish, shoreline protection, flood control and tourism and recreation after consultation with practitioners and a cross-section of the community resident of the study site. The levels of the attributes are being proposed in line with management options within the ecosystem and predicted impacts the upstream development will likely have on the future productivity of the mangroves. The proposed levels therefore include 'high', 'moderate', 'low' corresponding to the ability of mangroves to continue providing the services under three different policy scenarios. The monetary attribute level will be based on the labour that community members will be willing to offer to ensure the flow of the services.

Experimental design: Experimental design refers to the process of generating specific combinations of attributes and levels that respondents evaluate in choice questions (Carías Vega & Alpízar, 2011). In choice experiments, design techniques used for linear models were popular in the past. Orthogonality in particular has often been used as the main component of an efficient design. More recently, researchers have developed design techniques based on D-optimal criteria for nonlinear models in a choice experiment context (ibid). Huber and Zwerina (1996) identified four principles for an efficient design of a choice experiment based on a nonlinear model: 1) orthogonality, where attribute levels within each choice set are not correlated; 2) level balance, where attribute levels occur the same number of times within a choice set; 3) minimal overlap, where attribute levels are not repeated within a choice set; and 4) utility balance, where each alternative within a choice set has approximately the same utility (Carías Vega & Alpízar, 2011). There are a number of conjoint analysis soft wares that can be used to generate efficient designs, including SPSS and Sawtooth (Ryan et al, 2012). In this study Sawtooth was used to generate efficient cards.

Experimental Context and Questionnaire Development: The components of the questionnaire included knowledge about the mangroves, the benefits derived from the mangrove ecosystem services, choice experiment and a contingent valuation question section, demographic and socioeconomic characteristic.

Table 25 Attributes and their assigned levels for choice experiment

Attributes	Description	Alternative level	Business as usual level
Nursery and breeding ground for fish	Total number of catches both in the River and nearby ocean waters of fish that breed in the mangroves	6000T, 4000T	2000T
Tourism and Recreation	Numbers of tourists visiting the delta for bird, crocodile and hippo watching among others	600, 400 tourists	200 tourists
Shoreline protection	Extent of damaged coastline/ avoided coastline erosion	1 metre width of coastline loss, 5metres of width of coastline loss	15 metres width of coastline loss
Flood control	Frequency of settlements being flooded and the linked damages avoided	2 times in 10 years, 4 times in 10 years, 8 times in 10 years	Every year
Volunteer time for conservation	Cost to respondents in terms of Labour that they will provide towards restoration and sustainable use of mangroves	3hrs/month, 5hrs/month, 10hrs/month, 15hrs/month 20hrs/month, 30hrs/month	1hr/month

Choice of sample and sampling strategy: Choice experiment was used to collect data on the following attributes: volunteer community time for mangrove conservation as the payment vehicle, nursery and breeding ground for fish, Tourism and recreation, shoreline protection and flood control. A survey was conducted using simple random sampling with the households being the target units of survey across six sub-locations that have direct access and benefits from the mangroves. Louviere et al. (2000) provided a formula to calculate the minimum sample size. The size of the sample, n, is determined by the desired level of accuracy desired. In order to estimate the true proportion within a per cent of the true value p with probability or greater, then the required minimum sample size must satisfy the requirement that:

$$\text{Prob}(|\, p_n - p \,| \geq ap) \geq \alpha \,.$$

Given this, the minimum sample size is defined as:

$$n \geq \frac{1-p}{rpa^2} \Phi^{-1} \left(\frac{1+\alpha}{2}\right)$$

where $\Phi^{-1}(.)$ is the inverse cumulative normal distribution function. Note that *n* refers to the size of the sample and not the number of observations. Since each individual makes *r* succession of choices in a choice experiment, the number of observations is much larger.

The formula above is only valid for a simple random sample and with independency between the choices. With a household population of 3,743 the sample size that was obtained was 370 and this was increased to 400 a common practice in choice experiment studies, to increase efficiency.

Data Collection

To collect data for Market Price analysis survey, a questionnaire was developed. The ecosystem goods that were surveyed included firewood, charcoal, timber, poles for fencing, building huts, boat traps, and boat construction, Tannins and dyes, medicinal values, fodder, furniture, honey, and fish. For choice experiment, a questionnaire was used to elicit the respondents willing to volunteer time for the conservation of the mangroves.

Ethical Considerations

Respondents were assured of their individual privacy and confidentiality through use of aggregate results only and the study being conducted in anonymity, in which case the respondents were not required to give their contacts or names. In addition, they were informed that the research was for academic purposes only, and there were no personal benefits or risks involved. They were also informed that they reserved the right to terminate the interview at any stage should need to do so. Furthermore their consent was always being sought before commencement of interviews. The research was designed to be as objective as possible and respondents were allowed to make informed choices without any influence

6.3 Results

Demographics

Among the respondents interviewed, 68% were male (277 respondents) while 32% were female (127 respondents). The average household size was seven members with three adults (above 18 years) and four children (below 18 years). The mean age of the respondents was around 39 years.

Most (58%) of the respondents have had primary school education, while those with secondary school level education comprise 22%. Those with post-secondary education comprise 5% of the respondents while those who never went to school constituted 15% of the respondents.

About 66% of the respondents earn a cumulative annual income of between 28,801 to 180,000 shillings. Around 16% of the population earn less than Kenya shillings 28,800 per annum. The main sources of income in the three locations of Kipini division were crop farming (58%) and fishing (16%). Other sources of income include pastoralism, businesses, and salaries through formal employment, wages, and boda boda operations. There are, however, some differences on the main sources of income by sub-locations, for example in Kipini sub-location, it is fishing which is the main source of income.

Respondents were asked if they belonged to a social or an environmental group and 24.81% reported not to belong any group. Majority of the respondents who reported to belong to any group were members of environmental groups (28.99%), followed by those belonging to the fishing industry 14.59%. Respondents do not necessarily belong to one group only though.

Valuation results

The mangrove ecosystem in the Tana river delta occupies an area of approximately 2,350ha and is surrounded by three locations namely Kipini, Kilelengwani and Ozi. The ecosystem provides goods and services. The services present indirect use values (IUV) of the mangrove and include provision of nursery and breeding ground for fish, shoreline protection, flood control and a source of tourism and recreational attraction. The ecosystem goods provided represent direct use values (DUV) of the mangroves and include: biomass fuel (firewood); poles for fencing, poles for building houses, poles for boat traps and boat construction; dyes; medicinal herbs; fodder; honey; and fish. The following section present results on use and appreciation of ecosystem goods and services among the local communities in the Tana Delta. On a scale of 1 to 4 respondents were asked to state condition of the mangrove forest in terms of degradation and 51.85% said that the forest is in good state while 4.94% were of the view that it was heavily degraded.

Respondents were presented with a list of twelve mangrove ecosystem products and were asked if they visit the forest to harvest the products for subsistence or for sale, buy and sell the products or are just consumers who buy from those who harvest the products. Among those who were considered as *producers*, 47% said that they visit the forest to collect firewood, and another 42% said that they visit the forest to harvest fish. None of the respondents mentioned that they ever use the forest products to make furniture. Among the *consumers* of already collected mangrove forest products, 53% use fish harvested from the mangroves, 47% use building materials obtained from the mangroves, 30% use firewood collected from the mangrove forest, 27% use honey obtained from mangroves, and 20% use mangroves for herbal medicine.

The survey focused in more depth on four specific ecosystem services which are likely to be affected by project induced changes. Therefore, it is important to understand the current level of use of the ecosystem services, before analysing their values.

- *Fish that breed at the Mangroves*: Among the respondents interviewed, 75% reported that they depend on fish that breed at the mangroves either for domestic use or both domestic and commercial use. With 41 % of those interviewed reporting to be involved in fishing. The total monthly catch of such fish was reported to be 65944 Kilogrammes.
- *Shoreline Protection*: 75% of the respondents have witnessed shoreline erosion with the lowest level of erosion being 1 metre and the maximum erosion reported being 700 metre. The average shoreline erosion is 95 metres. 18% of the respondents indicated that there have been intervention efforts by the community, government agencies or NGOs to address the shoreline erosion.
- *Flood Control*: Flooding is a common phenomenon in Kipini division with 36% of the respondents reporting to have encountered floods every year and 14% saying that they experience floods twice in a year. Those who reported to having never experienced floods constitute 16% of the respondents. 23% and 27% of the respondents affirmed that flooding was severe and very severe, respectively. Residents of Ozi and Mpeketoni sub locations are the most impacted by flooding.
- *Tourism and recreation*: Respondents were asked how often, in a month, they see tourists in their villages. The responses were varied, with the highest frequency being once per month by 28% of the respondents. 36% reported to having never seen tourists in their villages.

Respondents were asked to grade (on a Likert scale of 1 to 5) if they agreed that mangroves provided ecosystem services. The values in the Likert scale were represented as shown in Figure 36. Overall, all four ecosystem services were strongly acknowledged by the respondents. The most recognised ecosystem services are fish habitat and mangroves as a tourist attraction. Flood control and shoreline protection are slightly more hidden and are therefore slightly less agreed upon. There was also a clear spatial difference between the acknowledgements of the four ecosystem services. For example, the residents of Ozi revealed the greatest approval of mangroves acting as a provider of ecosystem services, while Matangeni recorded the least recognition of these ecosystem services.

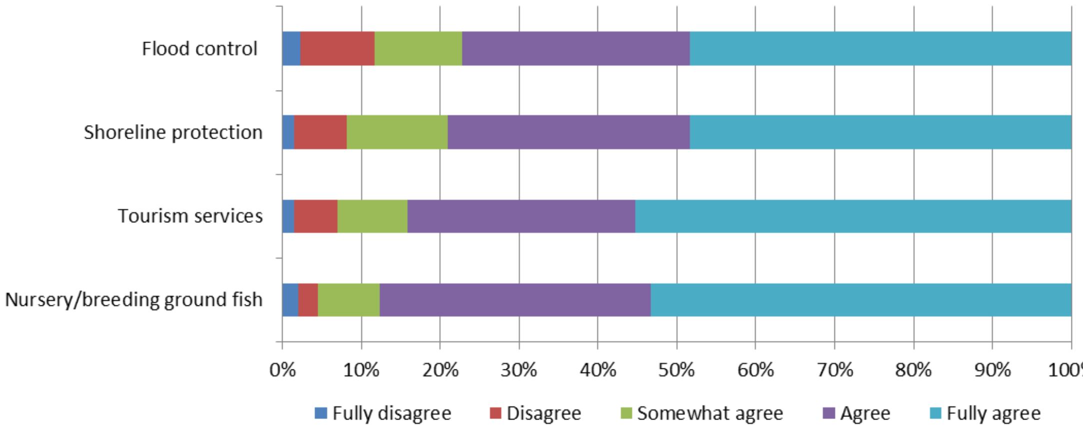

Figure 36 Percent response on provision of mangrove ecosystem services

Various large projects are planned in the Tana River Basin in the coming future. First, as part of vision 2030, the Government of Kenya plans to construct 165 square kilometre dam at the middle stream of River Tana aimed at generating electricity, supply of domestic and irrigation waters. Second, the government has a plan to establish one million acre irrigation project at the Galana/Kulalu, located at the counties of Kilifi and Tana River counties. The project will draw some of the water needed for irrigating the land from the Tana River. Third, the Lamu port project is part of the Lamu Port-South Sudan-Ethiopia Transport (LAPSSET) project and it will benefit from the waters of the High Grand Falls dam that will be constructed on the Tana River. The local communities are not always aware of these interventions, which in turn may affect the level of ecosystem services provision in the Tana Delta.

To test their level of awareness, respondents were asked to indicate their awareness on a Likert scale of 1 to 5. As shown in Figure 37, the Lamu port project is known among the large majority of the respondents (73%). The HGF dam and the million acres project, on the other hand, are hardly known to the general audience. More than half of the respondents have never heard about these projects.

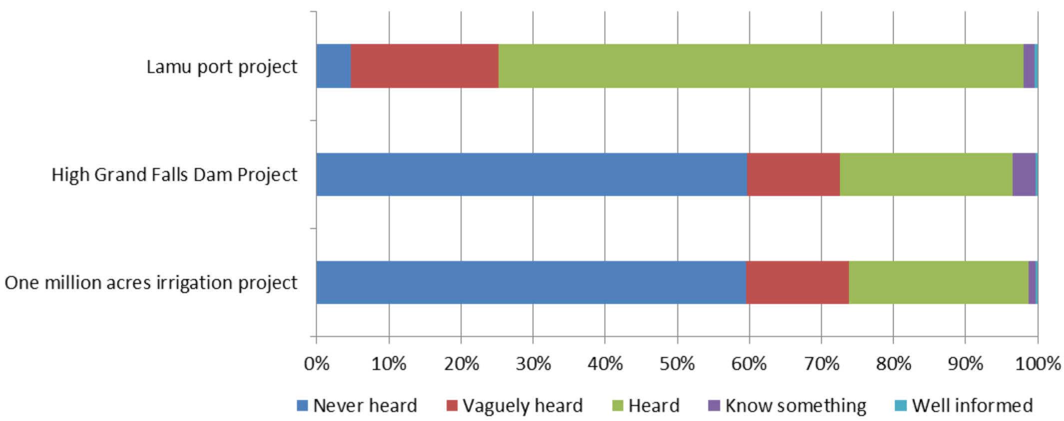

Figure 37 Percent response on awareness of large infrastructural projects

Majority of the respondents are of the view that upstream development projects will have a negative impact on the future availability of the mangrove ecosystem services. About 88% of the respondents felt that the availability of the habitat and nursery breeding ground for fish offered by the mangroves will be reduced with the upstream developments on the Tana River. A further 84% of the respondents felt that the tourism and recreation potential will be greatly reduced.

Almost 79% feel that shoreline protection offered by mangroves will decline, while 77% felt the flooding control role will be also be reduced.

Choice experiment

The mangrove ecosystem services, mainly nursery and breeding ground for fish, shoreline protection, flood control and tourism and recreation constitute indirect use values (IUV) which was obtained by calculating the willingness to pay to continue enjoying the services. This was done by converting the amount of volunteer time that respondents were willing to give to help in mangrove restoration and protection into monetary times using rates of earnings of the respondents. Multinomial logit model was used to estimate the probability that an individual will choose improvement in a certain mangrove ecosystem service. Variable definitions and their coding are provided in Annex A. An example card used in the choice experiment is shown in Figure 42.

	Option A	Option B	Option C Business as Usual
Volunteer community time	3hrs/month	15hrs/month	1hr/month
Nursery and breeding ground for fish	6000T	4000T	2000T
Tourism and Recreation	400 tourists	200 tourists	200 tourists
Shoreline Protection	5m width of eroded shoreline	5m width of eroded shoreline	15 m width of eroded shoreline
Flood Control	8 times in 10 years	2 times in 10 years	Every year
Which option do you prefer? (Tick one only)	☐	☐	☐

Figure 38 Example of a choice card used to measure the value of various non-market ecosystem services among inhabitants of the Tana Delta

Table 26 presents the results of an *attribute only choice model* that includes an interaction variable with volunteer time and membership. All coefficients are statistically significant at the 1% level. As expected, the utility of the environmental protection alternatives is positively related to the nursery of fish and the number of tourists, while this utility is negatively related to shoreline erosion and the flood probability. An attribute only model that includes volunteer time without an interaction term (not shown here) shows that the coefficient of this variable is insignificant. The interaction variable of volunteer time with membership in Table 26 shows that volunteer time has opposite effects for members and non-members. The coefficient of volunteer time is positive and significant for those who are members of an environmental group meaning that they prefer environmental policy options that require more volunteer time. For non-members, the coefficient of volunteer time has the expected negative significant sign, meaning that they prefer to spend less volunteer time on environmental protection.

In addition to the model coefficients, Table 26 reports the marginal effects and elasticities which, respectively, represent the absolute and percentage change in the choice probability for one of the environmental protection options that results from a one unit or 1% increase in the explanatory variable. The marginal effects show that especially the nursery of fish and flood probability attributes have a large influence on respondents' choices. All elasticities are in absolute value smaller than unitary, which means that they are relatively inelastic. The elasticities of volunteer time have a similar size between members and non-members, but are opposite in sign.

Table 26 Estimation results of an attribute only model with volunteer time interacted with membership to environmental or social group

Variables	Coefficient	Marginal effect	Elasticity
Nursery fish	0.14270***	0.03	0.29
Tourists	0.04953***	0.01	0.11
Shoreline erosion	-0.02475***	-0.006	-0.08
Flood probability	-0.68285***	-0.16	-0.19
Volunteer time	-0.02906***	-0.007	-0.20
Volunteer time × Membership	0.03821***	0.009	0.20
Constant of the opt out	-1.95730***		
AIC	1.646		
Psuedo-R^2	0.05		
Log-likelihood	-1968		
Observations	2412		

*Notes: *** stands for significant at the 1% level.*

Table 27 shows individual maximum willingness-to-pay (WTP) for non-members per attribute in terms of volunteering time per month or monthly opportunity costs. The results show that individuals are on average willing to spend approximately 5 hours monthly for gains in fish nursery per 1000 additional ton of fish, 2 hours per month for attracting 100 additional visitors, 1 hour per month to prevent a meter of shoreline protection and 2 hours per month to prevent each 0.1 increase in flood probability. It should be noted that the flood probability is bounded between 0 and 1 which is why the WTP is expressed per 0.1 probability unit. The figures about willingness to put in volunteer time are translated to opportunity costs amounts by multiplying hourly time with the local average hourly wage of 300 Ksh. This results in monetary WTP values of 1,473 Ksh per 1000 ton of fish, 511 Ksh per 100 tourists, 256 Ksh per 1 meter prevented shoreline erosion, and 705 Ksh per prevented increase in the flood probability of 0.1.

Table 27 Maximum willingness- to-pay for non-members per attribute in terms of volunteering time per month or monthly opportunity costs

Variables	WTP in time	WTP in opportunity costs
Gain in nursery per 1000 ton of fish	4.91	1473 Ksh.
Gain in tourist per 100 visitors	1.70	511 Ksh.
Prevent shoreline erosion per meter	0.85	256 Ksh.
Prevent increase in flood probability per 0.1	2.35	705 Ksh

Furthermore we estimated several models that examined how individual choices depend on geographical and socio-economic characteristics by creating interactions of these variable with the choice experiment attributes and the-opt out alternative. Final results of a model with only significant interaction variables are shown in Table 28. In particular, we tested whether preferences for the nursery of fish, shoreline erosion, the flood probability or the-opt out option have significant (at the 5% level) interactions with variables of distance to the shoreline, the mangrove or flood-prone areas. Only the interaction variable of distance to the mangrove with the-opt out is statistically significant and shows that people who live farther away from mangroves are more likely to choose for the-opt out. Moreover, we examined whether preferences for the attributes and the-opt out significantly relate with gender, age and the number of children in a household. Interactions of these variables with the attributes are insignificant (at the 5% level). These models did reveal that choosing for the-opt out positively relates with age and negatively with the number of children.

Table 28 Estimation results of an attribute only model with volunteer time interacted with membership to environmental or social group

Variables	Coefficient	Marginal effect	Elasticity
Nursery fish	0.14342***	0.03	0.29
Tourists	0.04819***	0.01	0.11
Shoreline erosion	-0.02524***	-0.006	-0.09
Flood probability	-0.70530***	-0.16	-0.19
Volunteer time	-0.02905***	-0.007	-0.20
Volunteer time × Membership	0.03807***	0.009	0.20
Constant × distance to mangrove	0.63129***	0.05	1.01
Constant × age	0.03439***	0.003	1.30
Constant × number of children	-0.11549**	-0.009	-0.36
Constant of the opt out	-3.84421***		
AIC	1.617		
Psuedo-R^2	0.08		
Log-likelihood	-1911		
Observations	2412		

*Notes: *** stands for significant at the 1% level.*

Each household is willing to contribute between Ksh.256 to 1573 for each of the four ecosystem services of the mangroves as shown in Table 29. The households willingness to pay can also be expressed annually in which case, each of the monthly willingness to pay by the households are multiplied by 12. Therefore, every single year—assuming constant returns to scale of the mangrove wetland values—each household will be willing to contribute between Ksh.3072 and Ksh. 17676 depending on the ecosystem service.

Table 29 Households mean willingness to pay (in kshs. per month)

Mangrove Ecosystem Service	Monthly WTP (Ksh/month)
Fish Nursery and Breeding Ground	1,473 Ksh.
Tourism	511 Ksh.
Shoreline Protection	256 Ksh.
Flood control	705 Ksh

6.4 Total value of ecosystem services

In assessing the mangrove forest areas that contribute to various production activities, the assumptions summarized in Table 30 have been made: Note that that the mangrove forest area has the potential for joint-production-functions and, for this reason, the same amount of forest area can jointly produce two or more products. This is why the total percentage under different products does not add up to 100 percent. In calculating the total value of the mangrove ecosystem, a distinction is made between direct [extractive] use values and indirect [non-extractive] use values.

Table 30 Key assumptions regarding the Flow of Goods at Present

		Percentage (%)	Area (ha)
	Total Mangrove forest Area		**2,350**
1	Mangrove area contributing to fisheries production.	70	1,645
2	Mangrove area contributing building materials	17	400
3	Mangrove area contributing to firewood.	17	400
4	Mangrove area contributing honey.	10	235

Direct use values

Firewood, fish, honey and building materials are considered to make a significant economic contribution to the welfare of the communities living around the mangroves in the Tana River delta. These goods are used in estimating the direct use values of the mangrove ecosystem.

Fisheries: The Mangroves of the Tana delta, despite being a nursery and breeding grounds for fish that comprise significant fish population and diversity of the Indian Ocean, is also rich in fisheries that are harvested by both artisanal and commercial fishermen. The socio-economic survey carried out in this study shows that a total of 791,338 kg of fish was harvested in 2013 and with modal price of selling 1 kg of fish being Ksh.100, the total, the annual fish values is therefore Ksh.79,133,800 which is equivalents to US$920,160. This translates to a marginal value of Ksh.48,105 ha/year or US$559 ha/year.

Building materials: Mangroves in the Tana delta are also used for the construction of houses by the community living in the surrounding environment. According to the community members, mangroves are preferable to other plants because of their durability and resistance to termites and spoilage from water logging. A total 5,131 poles of mangrove was harvested and sold for building houses in the Tana delta, with modal price of Ksh.100 per pole. The total annual value of building poles is Ksh.513,100 which is equivalent to US$5,966 translating to a value of Ksh.1284 ha/year or US$15 ha/year.

Firewood: A total of 9,149 bundles of firewood were harvested in 2013. Using a prevailing price of firewood of Ksh.100 per bundle gives annual value of firewood at Ksh.914,900 or US$10,638 which translates to Ksh.2,287 ha/year or US$27 ha/year.

Honey: Though honey fetches relatively good price of Ksh.300 per litre, its exploitation from the mangroves is exceedingly underdeveloped, with only 178 litres being extracted annually. The honey is mainly used by the local communities living around the forest. The annual value of honey from the mangroves is Ksh.53,400 or US$621 translating to Ksh.227 ha/year or US$2.60 ha/year.

Indirect use values

From a policy perspective, it is prudent to also take the indirect use values of the mangrove ecosystems into account, when deciding on its future. These indirect use values are resembled by the measured annual households' willingness to pay for the ecosystem services for sampled households. Assuming that the sample is representative for the overall population, the willingness to pay estimates can be extrapolated across all residents of the Tana delta. Table 29 show the marginal willingness to pay for the sampled households.

A total of 405 households were sampled and this translates into a total annual willingness to pay ranging from Ksh.1,244,160 and Ksh.7,158,780 for the sampled households for the different mangrove ecosystem services. Considering the total population that directly benefit from the mangrove ecosystem services, the total household population estimated to be 3,746 (KNBS, 2009) was then multiplied by the mean household willingness to pay. The annual willingness to pay for the society range from Ksh.11,507,712 to Ksh.66,214,296 as shown in Table 31 below. The societal willingness to pay values was converted into monetary values per hectare. This was done by dividing them by the total mangrove size in hectares (2350ha). With an assumption that each hectare contributes equally to the various mangrove ecosystem services, then these values known as the average value per hectare ranges from Ksh. 4897/ha/year for shoreline protection and Ksh.28,176/ha/year for nursery and breeding ground for fish. The total average value of indirect use services of mangrove ecosystems is Ksh.56,333.

Table 31 Societal total willingness to pay for different mangrove ecosystem services (Ksh per Year & US$)

Mangrove Ecosystem Service	*Ksh/Year*	*US$/year*
Fish Nursery and Breeding Ground	66,214,296	769,934
Tourism	22,970,472	267,099
Shoreline Protection	11,507,712	133,811
Flood Control	31,691,160	368,502
Total indirect use value	**132,383,640**	**1,539,345**

Total economic value

The main purpose of this sub-study was to estimate the total economic value (TEV) of the mangrove ecosystem goods and services in the Tana Delta. Table 32 summarises the direct and indirect use values estimated through the residential survey, thereby capturing an important part of the TEV. The aggregated annual amount adds up to Ksh 213 million or US$2.5 million which implies an average value of Ksh 90,638 per ha/year or US$1,054 per ha/year.

Although this estimate is of considerable value, it should still be considered an underestimation of the real economic value for a number of reasons. First, a number of important ecosystem services have not been estimated due to limited data. These include for example carbon sequestration values, international biodiversity values and local non-use values such as cultural and bequest values. Second, the level of use recorded in the survey is most likely an underestimation because formally no harvesting of the mangrove products in the Tana delta is allowed.

Moreover, this TEV also disguises the spatial heterogeneous nature of the estimated economic value. Appreciation of the mangrove ecosystem services appears to decline with distance from the mangroves. First, residents of the most distant community (i.e. Matangeni) attached the lowest values for the mangrove ecosystem services. Second, residents of Ozi and Mpeketini experience more flooding and therefore attach a high value for the flood prevention services of mangroves. Finally, shoreline erosion appears to be a great challenge particularly on the eastern side of Kipini settlements where mangrove population is almost non-existing. Depending on age and duration of stay in Kipini sub-location, respondents reported to have witnessed an average extent of shoreline erosion of over 500 metres. Indeed, a hotel has lost most of its buildings to constant erosion of the shoreline by the ocean waves, suggesting urgent need to protect the shoreline.

Table 32 Total Economic Value of Mangrove Ecosystem Services in Tana Delta

Ecosystem Goods and Services	Area (ha)	US$/ha/year	Ksh/ha/Year	Economic value (US$)	Economic value (mill. Ksh)
Fishing	1645	559	4,8105	920,147	79.1
Firewood	400	27	2,287	10,640	0.9
Building materials	400	15	1,285	5,980	0.5
Honey	235	3	227	611	0.05
			Total direct use values	**937,378**	**80.6**
Nursery/breeding ground for fish	2350	328	2,8176	769,934	66.2
Shoreline protection	2350	57	4,897	133,811	11.5
Tourism & recreation	2350	114	9,775	267,099	23.0
Flood control	2350	157	13,486	368,502	31.7
Carbon sequestration	2350	…………….	………….	……………..	………..
			Total indirect use values	**1,539,345**	**132.4**
			Total Economic values	**2,476,723**	**213.0**

6.5 Conclusions and discussions

This study concludes that the mangroves in the Tana Delta contribute significantly to the well-being of the people by providing a number of products such as fuelwood and building poles, and indirect use values such as nursery and breeding ground for fish, flood control, tourism and recreation and shoreline protection. The mangroves ecosystem services play a key economic role in the livelihoods of the people of Kipini division and as such should be safeguarded, enhanced and accounted for during planning for the development of the delta and indeed the Tana basin.

In order to harness the economic benefits of the mangroves best, it is imperative that adequate ecological balance is maintained so that resource inputs necessary for their good health is not disturbed. Sufficient water discharge into the Tana Delta is of great importance for its ecosystems and communities. A linked ecological requirement is the salinity range and that is also affected by the frequency and duration of the flooding of the delta largely by the upstream water through the Tana river that usually breaks its bank. Because mangroves need regular flooding of the delta to neutralise the potential salinity increment beyond the tolerable levels of the various species that inhabit the area, a better design of upstream dams and irrigation projects is needed to allow the ecosystem receive its fair share of the important resource input. Moreover, mangroves should be planted along the shorelines particularly on the eastern/northern side of Kipini settlements to help check coastline erosion. In addition, the forest needs a restoration plan to reclaim its original state through reforestation.

Contrary to the popular notion that the flooding havoc in the delta is caused by excess rainfall upstream, local communities believe that before the dams on the Tana river were constructed, they used to cope well with natural flood events. Instead it is post-dam construction floods usually occurring when the dam waters are released due to overflow that cause destruction at the delta. They are therefore sceptical about the prospect of an additional dam being any better. To ensure that livelihood sources are secured for everyone depending on the delta, a more collaborative approach in the appropriation of the Tana River water resources and the delta is needed within the principles of integrated river basin management.

The public awareness of future plans for the Tana River Basin proved to be limited. Out of the three major development projects on the Tana River, majority of the respondents have awareness of the Lamu port. However, more than half of the respondents have no knowledge of the proposed one million acre scheme and the High Grand Falls dam. Apparently, the method of public consultation and participation to sensitize the communities on the planned development projects on the Tana River has not been effective. In this context, it is important to note that the residential survey showed that those residents who have membership in environmental groups, chose policy options that demanded more volunteers time for mangrove conservation than non-members. This positive relationship between engagement and willingness to contribute is a strong indication that involving communities through environmental education will enhance their commitment to conservation of nature and natural resources. Therefore, public education on the significance of the mangroves and its contribution to the economic well-being of the residents of Kipini division has to be promoted among policy and decision makers at county as well as the national levels. This will help in harnessing the economic values during appropriation of the Tana basin decision moments.

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7 Stakeholder Analysis of the HGFD

Eise van Maanen

7.1 Introduction

Future infrastructural interventions in the Tana River Basin such as the High Grand Falls (HGF) dam project will affect many people, positive but also in negative ways. A plausible manner to assess the impact of projects such as the HGF dam project is to analyse the change in the provisioning of ecosystem services, as has been demonstrated in the previous chapters. An important aspect of the change in ecosystem service provisioning is the distributional dimension. Who will gain and who will lose welfare as a result of changed hydrological and ecological conditions?

This sub-study will provide an overview of the distribution consequences that originate from a modification of ecosystem services for the population downstream due to the HGF dam project. A qualitative stakeholder analysis (SA) will be conducted in order to assess the awareness, perceptions, interests, concerns, influence and relationships of the different stakeholders of this project. The research question of this sub-study therefore is 'how are the negative economic effects of the High Grand Falls dam project in the lower catchment area of the Tana River Basin perceived by its stakeholders and assessed by quantitative analyses?'

7.2 Methods

It is of vital importance in a SA to identify and categorize all relevant stakeholders and to observe how various stakeholders relate to each other in order to create an understanding of different viewpoints. When crucial decisions are to be made, that many people, organisations and groups need to be considered. However, clear limits to the number of stakeholders have to be set in order to keep the size of the SA manageable (Billgren & Holmén, 2008).

There are several definitions of whom or what might constitute a stakeholder; these definitions originate from different types of research. As Table 33 shows, the literature offers a wide variety of definitions of a stakeholder (Billgren & Holmén, 2008). This sub-study adopts the third definition in Table 33 any group or individual who may directly or indirectly affect—or be affected— planning to be at least potential stakeholders' (Buanes et al, 2004, p. 211). This definition thus also covers any group or individual who is planning to be a stakeholder; this is essential for this SA since the HGF dam project is still in the planning phase. All relevant stakeholders can thus be included in this SA, including individuals and groups who are planning to obtain a stake in the HGF dam project. The most fundamental distinction between stakeholders is between those 'who affect (determine) a decision or action — and those who are affected (whether positively or negatively). The distinction may not be absolute, however, as some groups within resource management (e.g. local farmers) may be involved in both active and passive ways' (Grimble, 1998, p.2).

The first categorisation of stakeholders is between formal and informal stakeholders. The formal stakeholders consist of stakeholders who are organised or institutionalised, informal stakeholders are not or barely organised.

Table 33 Who (or what) is stakeholder?

Source	Definition	Type of research
Freeman (1984, p.46)	'Can affect or is affected by the achievement of the organization's objectives'	Business Management
Grimble & Wellard (1997, p.175)	'(…) any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system (…)'	Natural Resource Management
Buanes et al. (2004, p. 211)	'(…) any group or individual who may directly or indirectly affect—or be affected—…planning to be at least potential stakeholders.''	Natural Resource Management
ODA (1995, p.2)	''(…) persons, groups or institutions with interests in a project or programme.'	Development
Röling et al. (1998, p.7)	'natural resource users and managers'	Natural Resource Management

Stakeholders may be truly diverse, varying from highly powerful politicians to large-scale farmers and tourist operators, to small-scale subsistence farmers and families that depend on a natural resource for their livelihood. Stakeholders can be divided into smaller and smaller sub-groups. The increasing number of groups may mean more problems and discussions when developing a SA; but omitting certain stakeholders could lead to problems in the long run when conducting a SA (Ramirez, 1999). After all, stakeholders within one project might be able to influence the decision or action but also other stakeholders by e.g. forming an alliance; omitting certain interdependent stakeholders within a SA can therefore cause incompleteness of a SA.

In order to minimize problems and discussion a second categorisation has been conducted in this SA: after key stakeholders are identified, they should be weighted as stakeholders with a primary, secondary or tertiary interest or stake in the area or its resources (Shepherd, 2004). Shepherd describes primary stakeholders as 'those who are most dependent upon the resource'; while secondary and tertiary stakeholders are (potentially over-powerful) voices that may include local government officials and those who live near the resource but do not greatly depend on it (secondary); and national level government officials and international conservation organisations (tertiary) (2004). Some stakeholder groups require a more detailed analysis concerning this categorisation. An example concerns the categorisation of fishermen, i.e. full-time fishermen may be recognised as primary stakeholders while seasonal fishermen may be recognised as secondary stakeholders.

Differences between stakeholders result from factors including tenure, ownership, history of use, social organisation, values and perceptions, and pattern or type of use (Renard, 2001). All stakeholders incur and perceive a different impact from a project. The next subchapter will discuss the direct and indirect effects that stakeholders incur, with a focus on MP dam projects.

Qualitative Stakeholder Analysis

We define SA as a process that: i) defines aspects of a social and natural environment affected by a decision or action; ii) identifies and categorizes individuals, groups and organisations who are affected by or can affect this decision or action; and iii) analyses these stakeholder categories in order to establish a framework of relations of influence and impact. The absence of a SA involves a risk that particularly powerful and well-connected stakeholders can exert a greater influence in the decision-making process than more marginalised groups; a problem that is especially relevant in projects in developing countries such as the HGF dam project in Kenya (Chambers, 1994). A

SA is most often a descriptive qualitative study; this specific qualitative SA was conducted by a participatory research approach through employing the following data gathering instruments:

- *Structured in-depth interviews* of 0.5-2.5 hours were carried out with systematically selected individual stakeholders representing local communities, groups, and institutions. This technique was employed to capture the views of individuals representing these different stakeholders on particular topics.
- *Focus group discussions (FGD)* were conducted with 2-5 representatives of the farming and fishing community groups in the Tana River Basin.

The research team conducted 43 structured in-depth interviews and FGDs during a fieldtrip in April-May 2014. The purpose of the FGDs and structured in-depth interviews was to estimate the size of the effects of the HGF dam project, capture the awareness, perceptions, interests, concerns, influence and relationships of the different stakeholders regarding the HGF dam project, from the perspectives of their respective institutions, communities or groups. This will reveal existing patterns between stakeholders in order to interpret conflicts that originate from competing demands of water in the Tana River Basin, and help find ways to resolve them. Understanding the nature of interest each stakeholder category has, and degrees of influence stakeholders can exert on the HGF dam project facilitates change and potentially increase the influence of marginalised groups.

The attitudes and reservation of the inhabitants of the upstream catchment areas have been treated and incorporated briefly in the analysis, although they have not been targeted as a study community. This sub-study after all aims to focus on an overview of the negative economic effects on the population living downstream of the HGF dam, since these effects are most often overlooked by decision-makers compared to the other effects of MP dams.

SAs need to start by understanding the context in which they are to be conducted. It is essential to establish a clear focus when conducting a SA. The next step is to identify stakeholders and their stake. Often the perception of what is at stake in one project differs amongst the stakeholders since different stakeholders experience a different impact. Using this information the researcher can subsequently differentiate between, and categorize stakeholders in order to analyse the stakeholder relationships (Billgren & Holmén, 2008).

7.3 Stakeholders identification

This Section will commence with the identification of the formal stakeholders of the HGF dam project and subsequently identify the informal stakeholders. A rainbow diagram for the identification and classification of stakeholders is provided in Figure 39. This rainbow diagram classifies key stakeholders in several categories, which are on a relative scale to all stakeholders of the HGF dam project. These categories are least, moderate and most influence on the HGF dam project; and least moderately and most affected by the HGF dam project.

Formal stakeholders

The **Ministries** of Agriculture, Livestock & Fisheries; Energy & Petroleum; Health; Environment, Water & Natural Resources; and Tourism are and will be the ultimate decision-makers in their respective fields concerning the HGF dam project. These Ministries are therefore identified as key stakeholders of this project. For megaprojects like the HGF dam project inter-ministerial approval is obligatory. This means that all relevant Ministries do have a certain minimum degree of influence, but this degree of influence may deviate. The HGF dam project is a large infrastructure project; this project therefore is likely to be moderately decisive for the reputation of the Government of Kenya. The Government of Kenya after all encounters many other projects of equal importance; the Ministries are thus moderately affected by the HGF dam project. This analysis subsequently assumes that Ministries in a democracy base decision-making on the public interest in order to satisfy the needs of the 'general population'. Ministries are therefore moderately affected by the HGF dam project.

Stakeholder participation in water resource management at the local level is anchored around the emergence of community-based **Water Resource User Associations (WRUA)**. A WRUA is an association of water users, riparian land owners, or other stakeholders who have formally and voluntarily associated for the purposes of cooperatively sharing, managing and conserving a common water resource. The local population can thus voluntarily organize itself in WRUAs, but is not obliged by law to do so. When organising the total Kenyan population in WRUAs, 1500 WRUAs are to be established but in 2014 only 500 WRUAs have been developed; low awareness and a low population density in the Tana River Basin are reasons for the sluggish growth in the number of WRUAs. The region including the stakeholders that are most affected by the HGF dam project is yet underdeveloped in terms of number of installed WRUAs. This low number of installed WRUAs causes the influence of WRUAs in general on the HGF dam project to be low. Therefore, WRUAs currently have little influence in the HGF dam project.

The **Water Resource Management Authority (WRMA)** uses the framework of WRUAs to channel investment in water management to the local population. WRMA is based in Nairobi and is a national government body that is moderately affected by the HGF dam project. Permission of the WRMA for the construction of this dam is obligatory by law so WRMA has a certain amount of influence.

The **Lamu Port Southern Sudan-Ethiopia Transport (LAPSSET)** Corridor project is a US$35 billion transport and infrastructure project in Kenya that, when complete, will be the country's second transport corridor. The components of the LAPSSET Corridor project are a port, crude oil pipeline (from Southern Sudan and Ethiopia to the Kenyan coast), road network, railway lines, three airports, three resort cities and water and power supply. The aim of the project is to cut over-dependence on Kenya's main port of Mombasa as well as open up Kenya's largely under-developed northern frontier. The HGF dam project is part of the LAPSSET Corridor project and falls under the authority of the LAPSSET Corridor Development Authority. The LAPSSET Corridor Development Authority is the main executive institution of the HGF dam project and is responsible for the actual implementation of the LAPSSET corridor. The LAPSSET Corridor Development Authority is a key stakeholder and has a high degree of influence. But the LAPSSET Corridor Development Authority is not directly affected by the HGF dam project since the LAPSSET Corridor project is likely to proceed, also without the construction of the HGF dam.

The main objective of the **National Irrigation Board (NIB)** is to increase the amount of irrigated land. The national government chooses which irrigation project will be implemented; the NIB is subsequently responsible for the execution of this project according to the Chief Engineering at the NIB. Therefore the NIB has moderate influence and is least affected.

The main objective of the **Tana and Athi Rivers Development Authority (TARDA)** is to undertake integrated planning of the water management in the Tana and Athi Rivers in order to improve the socio-economic well-being. Many experts mentioned TARDA as the main responsible institution for the operations of the HGF dam. Therefore TARDA has a high degree of influence, in particular during the operational phase. However, TARDA is moderately affected by the HGF dam project. A representative of the Tana River Basin management in TARDA explained the research team during an in-depth interview that the future of TARDA is insecure. A direct interest TARDA thus has in the HGF dam project is the validation of existence of TARDA since many comparable parastatals have been abolished in recent years.

KenGen is a parastatal which is owned by the government for 70% and controls 70% of the energy market in Kenya. KenGen will supposedly be responsible for the hydropower generation of the HGF dam project. The national government did not approach KenGen at the time of writing this sub-study but when the HGF dam will be financed through bilateral funding, the operations of the power generation within the HGF dam project will certainly be contracted to KenGen according to a representative of KenGen. Therefore KenGen so far has moderate influence and is moderately affected since the HGF dam project increases the potential to increase profits moderately.

Approval by the **National Environment Management Authority (NEMA)** of all plans that somehow have an impact on the environment is obligatory by law. The HGF dam project clearly imposes an impact on the environment and thus requires approval by the NEMA before construction can commence. NEMA has a moderate degree of influence; it can only influence the approval of the project, not the implementation and operation phase. NEMA will not be affected by the HGF dam project.

Several **NGOs** operate projects in the Tana River Basin and ergo have a stake in the HGF dam project. NGOs are moderately affected by the HGF dam project since the NGOs use funds for projects that will be affected by the HGF dam project. An example is a project of The International Union for Conservation of Nature (IUCN) concerning the construction of 'water passageways' at the riverbeds of the Tana River in order to decrease the number of water related conflicts. The HGF dam project will decrease the flooding regime and the availability of water, which will impose an increasing pressure on water related conflicts. The HGF dam project will thus impose an increasing pressure on the demand of water passageways, which will affect the projects of NGOs operative in the Tana River Basin. The approach of the NGOs varies from cooperative to anti-movements, and therefore the amount of influence also varies.

Informal stakeholders

The informal stakeholders of the HGF dam project within the scope of this SA consist of five categories: agriculturalists, fishermen, pastoralists, tourism operators and the resettled population. Informal stakeholders are predominantly unorganised, hence can merely influence the HGF dam project through representative democracy.

There are three categories of **agriculturalists**: i) farmers who work on the irrigation projects of the NIB or collectively own one water pump at their own expense, ii) farmers who rely on rainwater to supply water during the wet season and iii) farmers who rely on flooding of the Tana River, i.e. flood-recession agriculture. All agriculturalists will be most affected by the HGF dam project compared to all stakeholders of the HGF dam project. The degree of influence of agriculturalists also differs among the various categories of farmers. Farmers who work on the irrigation projects of the NIB can exercise influence on the NIB headquarters (HQ) through a framework of farmer leaders who represent ±900 farmers each at the local NIB departments. However, a representative of NIB HQ valued the direct influence of the NIB HQ on the HGF dam project to be low. This would mean that the local farmers cannot influence the HGF dam project through the farmer leaders and the local NIB departments, and therefore have negligible influence. The 'NIB farmers' will predominantly reap benefits of the HGF dam project since this project will increase the amount of irrigated land with the development of the Galana project. The Galana project is an ambitious irrigation project; the objective is to turn Kenya from a food-importing country to a food-exporting country. Farmers who collectively own a water pump are not dependent on floods and will supposedly still have access to a sufficient amount of water. Farmers who collectively own a water pump meanwhile incur merely negative effects from floods since they do not depend on floods for irrigating their land, while these floods do flush away their water pumps that are located at the riverbeds. Farmers who collectively own a water pump also have a near-zero degree of influence on the HGF dam project since they are merely represented through representative democracy. Farmers who depend on floods for irrigating their land merely incur costs from the HGF dam project. One objective of the dam is flood control, but ‘when there are no floods in this area, we shall be out of food in this area and we will all die’ says a farmer leader during a FGD in Hola at the local NIB department. The majority of agriculturalists in the Tana River Basin consists of farmers who are not attached to the NIB nor have a water pump. These farmers are not represented in any way and therefore have zero influence.

Fishermen in the Tana River Basin suffer from a negative impact from the HGF dam due to several reasons. The HGF dam will decrease the availability of water that will decrease the catch. The HGF dam will also decrease the extent of flooding which results in a decreasing amount of lakes around the Tana River, which served as breeding grounds for fish and thus have a nursery function. The decreasing amount of lakes around the Tana River therefore decreases the catch. Lastly, the HGF dam will reduce the water flow of the Tana River which will endanger the mangroves at the Tana Delta where many fish species breed, this worsening of the nursery function will supposedly decrease fisheries at the coast as well. Fishermen leaders in Kipini explained that the construction of the five dams of the Seven Forks Scheme already decreased the catch. Fishermen in the Tana River Basin are hardly organised. Fishermen leaders represent ±500 fishermen but are not numerous. Fishermen thus have a marginal degree of influence, but are strongly affected.

Pastoralism in the Tana River Basin is semi-nomadic. Livestock are herded in order to find fresh pastures on which to graze. Pastoralists will be affected due to the decreasing availability of water due to several reasons. A decreasing availability of water requires the pastoralists to go to the riverbed where the agriculturalists are farming, and let their livestock graze. The pastoralists’ livestock subsequently destroy the farmers’ crops; this has been a major cause of conflicts and casualties. Most pastoralists originate from the Orma tribe, which already is in a protracted conflict with the Pokomo tribe that consists mainly of agriculturalists. The pastoralists are not organised hence have no influence on the HGF dam project.

Tourism activities in the Tana River Basin are marginal but are included within this SA for the sake of completeness. Tourism activities in the Tana River Basin are centred on the Tana River and are dependent on the availability of water in the Tana River. The latter activities will ergo be categorised as most affected by the HGF dam project. The HGF dam project will on the other hand create opportunities for tourism activities around the reservoir; TARDA will operate a hotel at this lake. The tourism operators are not organised and currently of negligible economic importance, therefore the influence of the tourism operators on the implementation phase of the HGF dam project is near zero. The degree of economic importance can increase when tourism opportunities are developed at the reservoir of the HGF dam, this will increase the influence of the tourism operators on the HGF dam project.

The **resettled population** is exposed to a negative impact of the HGF dam project due to loss of livelihoods, construction of new houses and facilities and feelings of stress. A Resettlement Action Plan (RAP) is required before construction of the HGF dam can commence. A RAP takes all quantifiable costs of resettlement into account, and compensates the population financially and by designating an area for relocation. Another objective of a RAP is to increase the degree of influence of the resettled population through public consultation. The actual effectiveness of a RAP is controversial due to several reasons that will be discussed later in this analysis. The degree of influence of the resettled population on the HGF dam project is low since the resettled population is not organised.

Figure 39 gives an overview of the degrees of impact and influence the relevant stakeholders have. Figure 39 clearly shows the marginalised and vulnerable stakeholders on the lower right of the rainbow diagram. These stakeholders have the least amount of influence while being most affected.

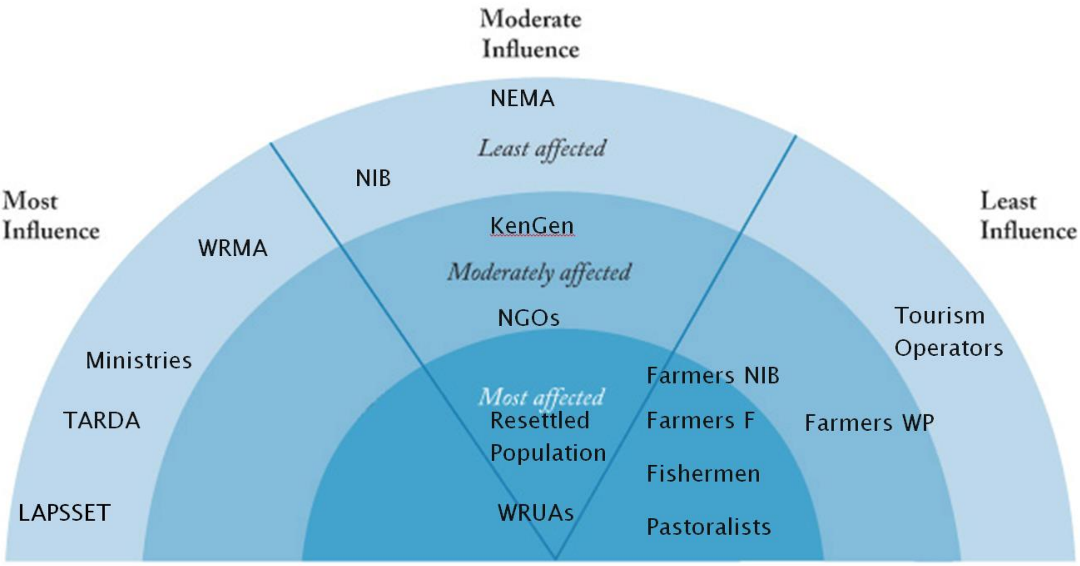

Figure 39 A rainbow diagram for the identification and classification of stakeholders (Based on Chevalier & Buckles, 2008) - (Farmers NIB=Farmers who work on the irrigation projects of the NIB; Farmers F=Farmers who depend on floods; Farmers WP=Farmers who collectively own a water pump.)

7.4 Stakeholder categorisation

The stakeholders of the HGF dam project within the scope of this sub-study are categorised in formal and informal, and primary, secondary and tertiary stakeholders (see Table 34). Primary stakeholders have the greatest and most direct dependency on the Tana River; secondary stakeholders include local government officials and those who live near the resource but do not greatly depend on the Tana River. Tertiary Stakeholders are national level government officials and NGOs whose direct dependence on the Tana River is negligible. Stakeholders were selected and categorised by interviewing experts or other stakeholders, self-selection and through written accounts of other stakeholder meetings. All stakeholders mentioned in Table 34 were consulted through structured in-depth interviews or FGDs, excluding the Ministry of Tourism, Kenya Forest Service, KenWeb, Red Cross Kenya, A Rocha Kenya, Community Action for Nature Conservation (CANCO), Kenya Wetlands Forum, Tourism Operators and the Resettled Population due to time constraints. Although the latter stakeholders are not interviewed, they are taken into consideration in this SA.

Table 34 Categorisation of stakeholders

	Formal Stakeholders	Informal Stakeholders
Primary Stakeholders	Water Resource Users Association (WRUA)	Agriculturalists Fishermen Pastoralists Tourism Operators Resettled Population
Secondary Stakeholders	Water Resource Management Authority- Tana Catchment Area (WRMA-TCA) Tana Water & Sewerage Company (TWSC)	

Tertiary Stakeholders	Ministry of Agriculture Livestock & Fisheries Ministry of Energy and Petroleum Ministry of Health Ministry of Environment, Water and Natural Resources Ministry of Tourism Kenya Water Towers Agency (KWTA) Water Resources Management Authority (WRMA) LAPSSET Corridor Development Authority National Environment Management Authority (NEMA) National Irrigation Board (NIB) Kenya Wildlife Service (KWS) Kenya Forest Service (KFS) Kenya Marina and Fisheries Research Institute (KMFRI) Tana and Athi Rivers Development Authority (TARDA) KenGen United Nations Environment Programme (UNEP) Wetlands International Nature Kenya World Wide Fund for Nature (WWF) KenWeb Red Cross Kenya A Rocha Kenya Environmental Liaison Centre International (ELCI) Community Action for Nature Conservation (CANCO) Kenya Wetlands Forum International Union for Conservation of Nature (IUCN) The Nature Conservancy (TNC)

Table 34 clearly shows that the **primary stakeholders** of the HGF dam project include all informal stakeholders and WRUAs. From Figure 39 we can infer that all informal stakeholders have the lowest degree of influence on the HGF dam project. Stakeholder participation in water resource management at the local level through the framework of WRUAs is also low; only 500 of 1,500 WRUAs have been installed up to now. Since the number of WRUAs is yet underdeveloped, WRUAs have the lowest degree of influence on the HGF dam project. All primary stakeholders thus have the greatest and most direct dependency on the Tana River but are least organised and thus have the lowest degree of influence on the HGF dam project. This low degree of organisation of the primary stakeholders combined with a primary stake in the HGF dam project is a threat to the equal distribution of costs and benefits of the HGF dam project. An unequal distribution of costs and benefits of the HGF dam project can increase income inequality, which is already high in Kenya. This low degree of organisation of the primary stakeholders combined with a primary stake in the HGF dam project can thus impose a risk to the Kenyan economy.

The **secondary stakeholders** include local government officials. i.e. the WRMA-TCA and TWSC. The secondary stakeholders do not greatly depend on the Tana River but have a moderate degree of dependence. The WRMA-TCA is a government institution of significant size and is involved in the HGF dam project. The presence of the TWSC is not significant in the Tana River Basin, but TWSC is a stakeholder of the HGF dam project.

Tertiary stakeholders are stakeholders with the smallest direct stake in the HGF dam project. It is noteworthy that the tertiary stakeholders have the highest degree of influence on the HGF dam project (see Figure 39). In brief: the more primary the stake of the stakeholder is, the less is the degree of influence on the HGF dam project. This adverse relation between importance of stake and degree of influence causes an inequality amongst stakeholders that may threaten the equal distribution of costs and benefits of the HGF dam project. The latter adverse relation between importance of stake and degree of influence is not necessarily disadvantageous.

Stakeholders often have different views of resource management due to cultural differences and various methods of utilisation of natural resources. Many scholars are convinced that indigenous people and local communities are superior custodians of nature (e.g. Ostrom, 1990; Pimbert et al., 1997). That might be the case when the population pressure is low. But in a situation like Kenya, where the population has multiplied in just a few decades, local knowledge about e.g. agriculture and water management may not be sufficient to satisfy the increasing demand on e.g. food and water (Billgren & Holmén, 2008). Distant decision makers, such as the government in Nairobi, might have superior knowledge and also the resources and tools to implement optimal Natural Resource Management (NRM). Therefore, active participation by all stakeholders should not necessarily mean local autonomy. Even if 'all' stakeholders are involved in a democratic spirit, it is also the quality of the proposed measures that is of importance for how NRM will be implemented. Local communities might not have sufficient knowledge to develop optimal policy measures. 'This is a classic planning dilemma: if local people's worldviews and priorities are not reflected in a management plan, its implementation is likely to falter. At the same time their priorities may not provide for sustainable NRM' (Billgren & Holmén, 2008, p. 560). The research team also experienced this during the in-depth interviews; the interviewees at the Ministries had at least a basic scientific knowledge within their respective fields, but the interviewees located in the Tana River Basin have specific knowledge about e.g. the optimal course of a river that the interviewees at the Ministries do not have.

7.5 Analysis of effects

This subchapter presents a qualitative analysis per stakeholder category. The qualitative results are obtained by semi-structured in-depth interviews and FGDs, where possible supported quantitative data from the previous Chapters. When all information of the SA is compiled and verified in a matrix (Table 35), it may reveal overlapping interests, conflicts and potential synergies among stakeholders.

Agriculturalists

Agriculture is of great importance to the Kenyan economy since it is essential for people's income and food supply. Most of the inhabitants of the Tana River County rely on farming either directly or indirectly for their income. As previously stated, there are three categories of agriculturalists in the Tana River Basin: i) farmers who work on the irrigation projects of the NIB or collectively own one water pump at their own expense, ii) farmers who rely on rainwater to supply water during the wet season and iii) farmers who rely on flooding of the Tana River, i.e. flood-recession agriculture.

A scheme manager at the NIB Bura Irrigation Scheme claims that 'there are no socio-economic costs involved in the construction of the HGF dam project for the Bura area'. He argues that the Bura area (see Figure 40) will merely benefit due to the improved availability of water and decreased amount of siltation for the irrigation scheme. The HGF dam project will distribute water to the Bura irrigation scheme, even though this project is located downstream of the HGF dam itself. 'Everybody can join the NIB and obtain a piece of irrigated land; the minimum is three acres per family' says the Bura Irrigation Scheme Manager. He states that the crops cultivated by these families are sold on the free market through contract farming. This contrasts with the assertions made by a water specialist at the Embassy of the Kingdom of the Netherlands in Kenya. He states that crops grown at the NIB irrigation projects are bought directly by the NIB for fixed prices below market value. 'This scheme resembles the historic system of landlords' according to the Embassy representative.

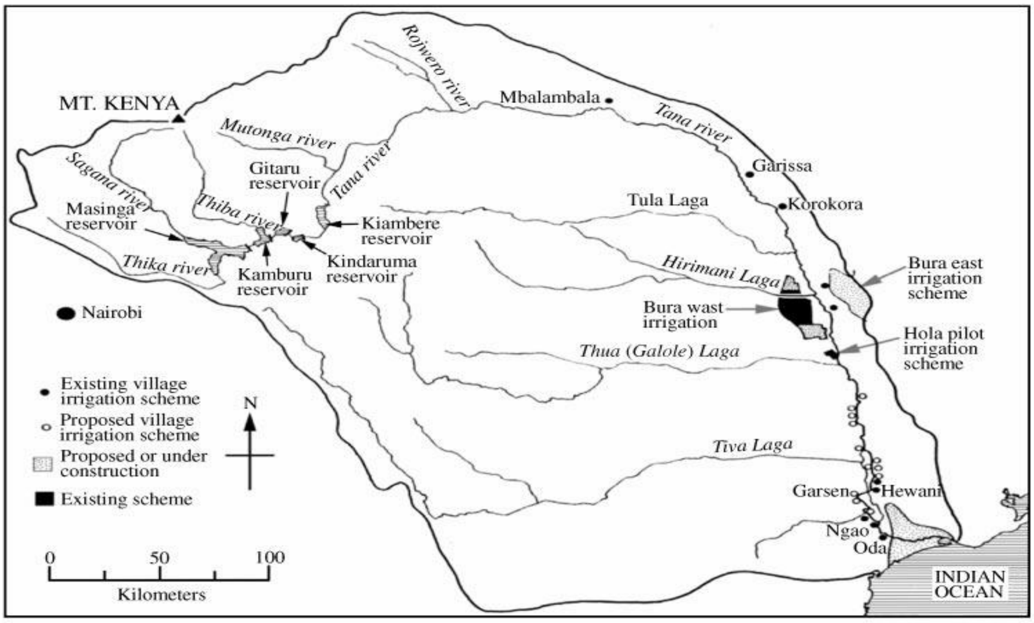

Figure 40 Land use and irrigation projects in the Tana River Basin (Nippon Koei, 2013a)

The agriculturalists who are not attached to an irrigation project merely incur costs since the discharge of water downstream will decrease and none of the four main benefits of the HGF dam will accrue to these farmers. At first, these farmers (mainly Pokomo) rely on floods hence do not benefit from flood control. Second, only a few villages or settlements are yet connected to the national power grid and therefore do not benefit from an increase in the power supply. Thirdly, all drinking water of the HGF dam project will be distributed to Nairobi, which means that the availability of safe drinking water for the farmers living downstream of the irrigation projects does not improve. Lastly, there are no plans yet to distribute the crops grown at the irrigation projects to the middle and lower catchments areas, the farmers will thus reap no benefits of an increased food security.

The aforementioned decrease in discharge of water in the Tana River due to the HGF dam will decrease the extent of floods, which subsequently worsens the downstream ecosystem and its ecosystem services. 'Many people depend on flooding for farming and fishing, the five dams of the SFD project already proved that dams located upstream do decrease the extent of floods downstream, people will therefore experience a negative impact' (of the HGF dam project), according to the Community Extension Officer at Nature Kenya based in Garsen. He also states that 'the government is not committed to its people, because once it is committed to its people it would conduct consultation for any such project'.

In total, it is estimated that over a million people depend on the river's flooding regime for their livelihoods. Almost 200,000 crop farmers, livestock keepers and fisher folk live permanently in areas that are directly adjacent to the Tana River and the Tana Delta, including an additional 800,000 nomadic and semi-nomadic pastoralists as well as seasonal fisher folk and fish traders. Almost 2.5 million livestock, including over a million cattle, rely on the Tana's floodplain grasslands and water bodies for dry season pasture and water (CADP, 1991b).

The majority of farmers are not attached to the NIB nor collectively own a water pump, hence depend on floods for the irrigation and fertilising of their land. 'For the farmers who cannot afford a water pump living in this downstream region, the HGF dam will mean chaos. It is more than a disaster because these people live below the poverty line. They already depend on famine relief and food security programmes', explains the chief of Shirikishko who represents the interests of 7,000 people. He subsequently elaborates on the first five dams of the SFD project, which decreased the harvest of all agriculturalists who are not working on the irrigation projects of the NIB.

Another threat to the equal distribution of costs and benefits of the HGF dam is the lack of awareness downstream. When the research team interviewed five farmer leaders in Hola, each representing ±900 farmers, no one had heard of the HGF dam. Furthermore, of all interviewees associated with agriculture located downstream of the HGF dam, only the Scheme Manager of the Bura Irrigation Scheme was aware of the HGF dam project. After illustrating the potential impact of the HGF dam, the farmer leaders fear that 'people will only get employed, and thus reap benefits of the HGF dam project, near the dam' and misdoubt the distribution of costs and benefits of this project, says a farmer leader. This fear has a right to exist since all farmers who are not attached to the NIB will not reap any benefit of the HGF dam. The only option for the latter agriculturalists to reap benefits of the HGF dam project is by working on the irrigation projects of the NIB. This creates an incentive for the NIB to buy crops grown by these farmers below market value in order to increase profits of the NIB. A vast amount of farmers will after all not have access to alternative cultivable land due to the changes in flooding regime and discharge of the Tana River.

The farmer leaders do feel that their voices can be heard at the national government through the local NIB department and NIB HQ. However, the Chief Engineering of NIB HQ stated in another in-depth interview that the influence of the NIB on national government is negligible. The amount of influence of the local farmers through the local NIB department and the NIB HQ on the national government therefore is dubious. The lack of awareness of the HGF dam combined with the lack of knowledge of such mega projects causes the influence of agriculturalists to be low. When farmers do not know what the potential impact of such a mega project is, they will after all not have an incentive to form an alliance in order to influence the HGF dam project. The relative importance of interest of the agriculturalists on the other hand is high due to the low degree of food security.

The agriculturalists that are attached to the NIB will benefit from the HGF dam project since the availability of irrigated land will increase. Constructing a dam improves irrigation possibilities at the areas in which irrigation is present but will deteriorate water availability and thus irrigation possibilities more downstream; the effect on the income of farmers is therefore ambiguous.

Fishermen

Fishing in the Tana River Basin occurs both in the river itself as well as in its inundation zones. The floodplains serve as a breeding ground and thus also have a nursery function for several fish species. Furthermore, fishing activities in the Indian Ocean near the mouth of the river are related to the Tana River as the river's mangroves too have a nursery function for certain species which move on to the ocean when they mature according to a fishermen leader representing ±500 fishermen and research associate at KMFRI.

In the only area where the availability of water will increase for fishermen, i.e. the reservoir of the HGF dam, fishing is formally prohibited. Fishermen will for this reason only experience a decreasing availability of water as a consequence of the construction of the HGF dam, which will decrease their catch. The main challenge that the fishermen downstream of the HGF dam currently face is the decrease in catch due to the five dams of the SFD project already built. These dams decreased the discharge of the Tana River that caused the catch to decline. The HGF dam will decrease the discharge of water in the Tana River even more and this will consequently decrease the extent of flooding of the Tana River, which will also decrease the catch. The fishermen representative states that the main concern related to the HGF Dam is the five-year filling period of the reservoir of the HGF dam and a potential increase in the agrochemical pollution of the water due to the increase of irrigated land upstream. None of the main benefits of the HGF dam will accrue to the fishermen. Fishermen will thus merely incur costs from the HGF dam.

Fishermen are organised through a framework of fishermen leaders, but again a lack of awareness about the HGF dam project and knowledge of such megaprojects cause the fishermen to have no influence on the HGF dam project. None of the four fishermen leaders interviewed had heard about the HGF dam project. 'The least TARDA can do is to come here and consult the local population' says the fishermen representative. Construction of the HGF dam did not commence yet; so TARDA obviously still has the opportunity to consult the local population before the construction phase initiates. However, it is essential to involve the local population in the implementation process that has been on-going for an extensive period, in order to increase a feeling of ownership amongst the local population. Ownership will enhance acceptance of the HGF dam and increase stability in the Tana River Basin.

Pastoralists

The livestock industry in Kenya is large, contributing roughly 7% to national GDP (ADEC, 2009). Most production is small-scale: herds are either owned by a family or shared by a small community. Husbandry is therefore of great importance to food supply and welfare for many communities living in the Tana River Basin. In some counties, such as Isiolo, pastoralism directly or indirectly accounts for the livelihoods of up to two thirds of the inhabitants, with another 26% of people depending on an agro-pastoral lifestyle (Matheka & Kinyanjui, 2013). Apart from being their main source of income and food, livestock is an integral part of daily life as it provides transport, is used for paying fines and capital investments and savings and is involved in marriage and other social traditions (Matheka & Kinyanjui, 2013). The types of livestock are cattle (beef and dairy), goats, sheep, camels, poultry, donkeys and pigs.

Pastoralists in the Tana River Basin are semi-nomadic which makes them less sensitive to short-term hydrological changes, but livestock is sensitive to long-term changes in the hydrological regime of the Tana River. The HGF dam project will impose long-term changes in the hydrological regime of the Tana River.

The Tana River Basin is one of the very few areas in the Kenyan inland where their livestock can graze since Kenya consists of 70% arid/semi-arid land. This makes the pastoralists in this area more reliant on the water from the Tana River despite their flexibility of their semi-nomadic existence.

The decrease in availability of water due to the HGF dam project will cause two types of costs for pastoralists. First, the decreasing availability and security of forage imposes a downward pressure on the health of the livestock. This will decrease meat and milk production and lower animal birth rates, which will decrease the income of pastoralists. Second, a decreasing availability of water will increase water-related conflicts. A decrease in discharge will cause the extent of flooding to decrease. These floods normally supply water to the lakes and brooks around the Tana River where the pastoralists let their livestock graze. The pastoralists are now designated to the riverbeds of the Tana River itself when these floods do not supply water to these lakes and brooks anymore. The riverbeds of the Tana River in the middle- and lower catchment areas are largely used for flood-recession agriculture. This has been a major cause of conflicts in recent years. The research team experienced this phenomenon in Witu, when a farmer stabbed a pastoralist to death because the pastoralist let his livestock graze on the farmer's land. The water-related conflicts will increase as a consequence of the construction of the HGF dam due to a decrease in the availability of water in the Tana River Basin. The research team has not been able to interview pastoralists since communication with pastoralists turned out to be problematic due to their nomadic existence. This also shows the fact that pastoralists are not organised in any way, and as such have no influence on the HGF dam project.

Society as a whole

This subsection provides the SA of the remaining stakeholder categories of the HGF dam project. These include tourism, resettlement communities, ministries, government agencies and NGOs.

There are several **tourism operators** active in the Tana River Basin. The number of water-related conflicts will increase due to the HGF dam project. The increase in conflicts will impose a negative impact on the income of the tourism operators; this happened already when the number of visitors in the Tana River Basin decreased during the 2007-2012 conflicts. Yet, because only few tourism operators are active in the Tana River Basin; the relative importance of interest is therefore negligible.

Resettlement has an enormous impact on the livelihood of people but the impact resettlement imposes on the population has proved to be hard to measure. The project developer of the HGF dam is obliged by law to develop a Resettlement Action Plan (RAP) in order to compensate the resettled population (see Figure 41). The RAP concerning the HGF dam project is an extensive document of 373 pages including a report of all quantifiable costs that the resettled population incurs. Extensive and intensive consultations were held with affected people in the HGF dam project area. The consultations were accomplished through various techniques: semi- structured individual interviews, structured household socioeconomic and income questionnaires, both instruments administered to the household sample; unstructured interviews with key stakeholders; focus-group discussions; and, community meetings. The relative importance of the resettlement population is high and the influence is medium. The resettlement population after all incurs a loss of livelihood due to the resettlement and can only influence its allotment through a RAP. The RAP seems extensive and detailed, but it is hard to say whether all costs of all Kenyans are compensated. Many other costs of resettlement are non-quantifiable; e.g. many tribes have been living in the Tana River Basin and justify their existence to this. Resettlement can thus impose large non-quantifiable costs due to the change in habitat.

elaborate on the effectiveness of WRUAs concerning the water management of the Tana River. In the Tana River Basin only 17 WRUAs are operative. The potential of the framework of WRUAs is high but has not yet been fully utilised. The chairman of the Madogo WRUA, states that ‘all water users are stakeholders of this HGF dam project, therefore they should all be involved in the WRUAs’. The Senior Programme Officer at the Freshwater Ecosystems Unit of UNEP, states that ‘the framework of WRUAs is very potent, but is not successful yet due to a lack of awareness and knowledge’. The chairman of the Madogo WRUA feels that his influence on national governance is ‘not much’; he obtains a lot more support from NGOs. A solution to this lack of influence would be for the national government ‘to conduct more, proper and open public consultation by doing fieldwork, in order to get a better idea of the real situation’ according to him. He explains that the five dams of the Seven Forks Dam project already affected the Madogo WRUA negatively without being compensated for this negative impact. He has never heard of the HGF dam project before, but after explaining this project he is afraid that ‘another dam would cause a massacre’ referring to the negative impact earlier dams imposed on the Madogo WRUA. The chairman of the Madogo WRUA observes that especially the Pokomos are affected by the dam projects. ‘Many young Pokomos do not want to farm anymore and are leaving from the rural areas to the cities in the hope for white-collar jobs’ he says. The HGF dam project will thus affect the local population directly, but they cannot exert influence on the HGF dam project through the framework of WRUAs due to its underdevelopment. In short, the development of WRUAs is an on-going process.

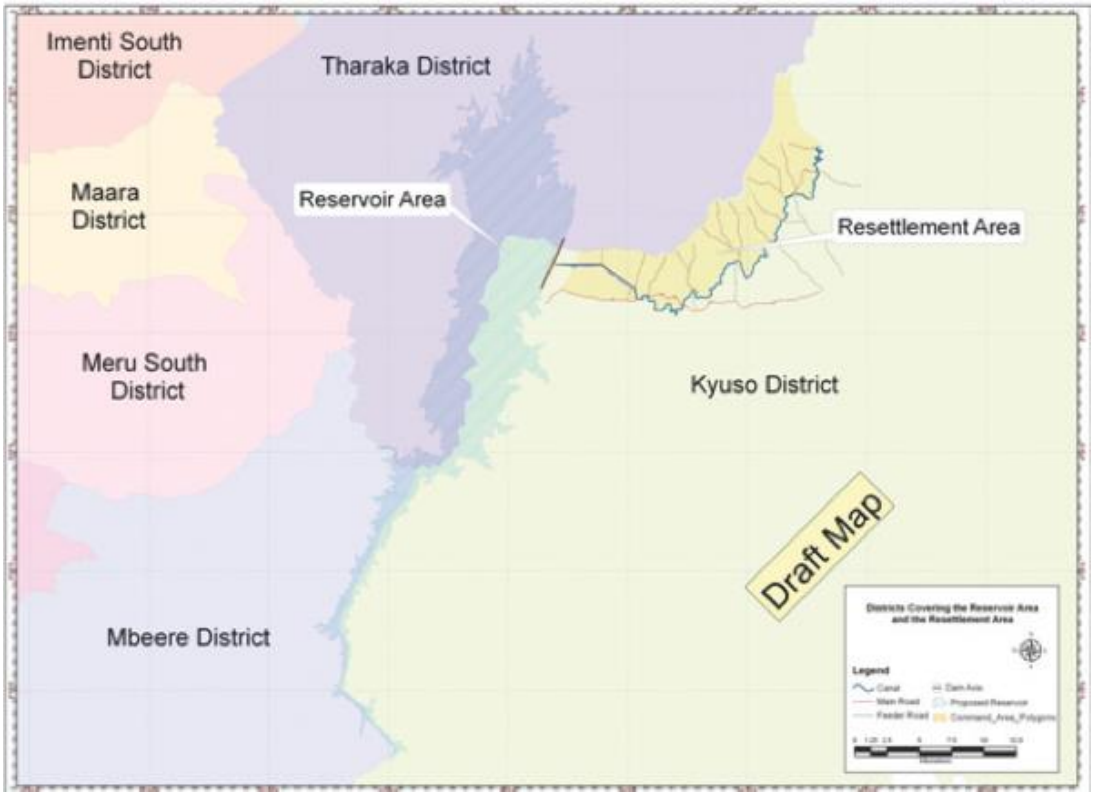

Figure 41 Map of Resettlement Area (Republic of Kenya, 2010)

As mentioned before, only 500 of 1500 **WRUAs** have yet been installed. This subsection will The Chief Engineer at the **Ministry of Agriculture, Fisheries and Livestock** and states that 'Kenya currently is too dependent on the import of food'. 'The Hola, Bura and Galana irrigation projects can create a more independent and food-secure Kenya' says the chief engineer. He wants to commercialize the Kenyan farming system in order to optimize the agricultural production system. He 'wished that the dams built in Kenya were more for irrigation'. With this statement the chief engineer affirms the idea that the main objective of the HGF dam is hydropower generation.

The awareness about the HGF dam project of the **Ministry of Energy & Petroleum** is low despite the fact that experts and other stakeholders have identified this Ministry as the main stakeholder. The Freshwater Chief at UNEP, states that 'amongst the stakeholders, it ultimately is a power game, the energy sector is loaded with money and therefore is the main decision-maker'. The Chief Engineer Electrical at the Ministry of Energy & Petroleum was not sufficiently aware of the HGF dam project during an in-depth interview. He explained the research team that the officials at this Ministry are currently working on a Least Cost Power Development Plan. This Ministry commenced in 2014 with a highly ambitious 40-month power generation expansion programme aimed at bringing down the cost of energy by 40 per cent. The lack of harmonisation of interests amongst the relevant Ministries again clearly comes forward. The Ministry of Energy & Petroleum merely focuses on increasing the power supply for the lowest tariffs, 'why would you buy or generate expensive power when you can import cheaper power?' explains the chief engineer. The Ministry of Energy & Petroleum is not concerned with the potential environmental or socio-economic impact involved in power generation. A lack of harmonisation of interests amongst the relevant Ministries thus clearly comes forward. 'The reduction of the number of Ministries from 44 to 18 Ministries in 2010 has contributed to the harmonisation of interests of Ministries, but still this problem exists' says the Freshwater Chief at UNEP. The lack of harmonisation of interest amongst the relevant Ministries and the fact that the Ministry of Energy & Petroleum has been identified as the main stakeholder can result in a situation where this Ministry overrules all other Ministries. This can result in a decision that does not take a potential trade-off of e.g. the environmental impact and power generation into account. This Ministry has a high degree of interest in the HGF dam project and a high degree of influence on the HGF dam project; 35 out of 43 interviewees mentioned the Ministry of Energy & Petroleum as the main stakeholder.

The Senior Deputy Director at the **Ministry of Water, Environment and Natural Resource**s and explains that the main benefit of the HGF dam project is the generation of hydroelectricity. 'The main beneficiary of the HGF dam is therefore the industrial class' says the Deputy director. The benefits for the industrial class will be discussed in the quantitative analysis of this subchapter. The Chief Engineer Electrical at the Ministry of Energy & Petroleum confirms the latter statement. He states that 'energy is one of the biggest inputs in production costs; therefore a lower energy price will benefit the industry sector'. The Senior Deputy Director at the Ministry of Water, Environment and Natural Resources also states that the impact of the HGF dam is adverse for the population in the Tana Delta; 'mainly because the lifestyle of the local population in this area will get worse'.

The Deputy Chief Public Health Officer at the **Ministry of Health**. He states in an in-depth interview that there are also health risks involved in the creation of a reservoir at the HGF dam. 'People are attracted to water, it often happens that public facilities such as medical practices are not sufficient for the number of people living there'. The reservoir at the HGF dam will attract many people and therefore might cause health issues for the local population due to a shortage of health facilities and an increase in waterborne diseases. Another main interest of the Ministry of Health concerning the HGF dam project is that it will provide safe drinking water to 1.5 million people. 'Safe drinking water is after all one of the main concerns of this Ministry since Kenya is a highly water scarce country' says Deputy Chief Public Health Officer. The drawback of the supply of safe drinking water to Nairobi is that 'many other health issues arise such as lack of enough drinking water downstream and increasing number of conflicts due to decreasing availability of water'. He states that the costs and benefits of the HGF dam project will not be equally distributed, the population downstream therefore have to be compensated according to him. He mentions a comparable project at the Ndakaini dam that distributes water through a one-meter-wide pipeline to Nairobi. "Nobody in the area where the water comes from can touch this water, the pipeline is passing through peoples' farms, through peoples' whatever, then I sometimes really feel like puncturing the pipe, because it is passing through really arid areas without safe drinking water, and taking it to Nairobi", says the Deputy Chief Public Health Officer. Lastly, he states that a Health Impact Assessment should also be undertaken next to an Environmental Impact Assessment before TARDA can obtain approval for the construction of the HGF dam project.

The Deputy Director at the Regional Development Directorate of the **Ministry of Water, Environment and Natural Resources**. He is currently responsible for the implementation of the HGF dam project. He states that the main benefits of the HGF dam project are flood control, generation of hydroelectricity, augment water storage and improve food security. He also states that the number of conflicts will decrease after construction of the HGF dam due to several reasons: i) stable environmental-flows3; ii) artificial floods twice a year; iii) irrigation projects such as the Galana Project totalling 300.000 hectares; and iiii) water supply to Lamu. The Deputy Director also mentions the risks involved in the dependency on food imports of Kenya. He states that there are no socio-economic costs involved in the construction and operation of the HGF dam project other than resettlement. The Kenyan Government wants to finance the HGF dam project for 85% by external debt and 15% by issuing waivers, increasing the VAT and other public policy measures. He also states that 'one reason why countries in Africa have suffered is because they remained conservative, they fear because they're being poor and therefore they continue being poor'. He also states that he does not want Kenya to follow this same path. This Deputy Director at the Regional Development Directorate of the Ministry of Water, Environment and Natural Resources thus sees the HGF dam project as one way to economic advancement. He argues that his influence on the HGF dam project is 'really big and unique'. Finally, he states with full certainty that the HGF dam project will be implemented.

The Deputy Technical Coordination Manager at **WRMA**, states that the major challenge WRMA currently faces is to create more awareness about the framework of WRUAs. Since only 500 of 1500 WRUAs have been installed so far, people might not know how to participate or organize in WRUAs. WRMA has to permit the construction of this dam so they do have a certain amount of influence in the approval. WRMA has no influence in the implementation phase of this project.

The CEO of the **LAPSSET** Corridor Development Authority states that 'the HGF dam project and the LAPSSET Corridor are definitely intertwined, the Lamu Port needs power which the HGF dam can produce, the agricultural input and flood control also benefit the LAPSSET Corridor and the Lamu Port'. According to him the LAPSSET Corridor will provide 'dynamic promotion of regional socio-economic development along the transport corridor'. When the research team asks him about examples of the implementation of this latter provision, he cannot mention any project. He also states that Kenya needs a paradigm shift, 'Africa did not have its fair share of growth because the focal point has not been on growth. Africa will now pivot in economic growth that will create trust, which attracts private investment'. After asking the LAPSSET CEO how the distribution of costs and benefits will be, he gives an analogy: 'listen, when a father who tells his daughter that she should stay a virgin, but he then realizes that he cannot be a grandfather. So he has to give up his daughter's virginity in order to be a grandfather'. From this analogy it appears that the LAPSSET CEO is well aware of a potential unequal distribution of costs and benefits of the HGF dam project among the Kenyan population. But he takes this for granted and sees it as inevitable. Likewise, the Tana Basin Manager at TARDA explains that 'you have to make sacrifices in order to progress, in order to stimulate economic growth sacrifices have to be made such as the extinction of monkey species'. During the two-hour in-depth interview with TARDA representative, who is in charge of this ± US$35 billion project, it appeared that he tends to talks in visions and objectives without mentioning pragmatic examples of how these visions will be implemented. He has a high degree of influence but seems to be less knowledgeable about the full impact of the HGF dam project.

The Compliance & Enforcement Officer at the Environmental Impact Assessment Section of **NEMA** states that the degree of public consultation of the population affected by the HGF dam project is good since several instruments check the validity of reports such as a list of attendance and a summary of what has been discussed. The NEMA only checks these documents by reading, and not by e.g. by at random visits to the consulted villages. The NEMA has to approve the assessments concerning the HGF dam project and therefore has influence on the execution of the HGF dam project.

[3] Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems.

The Chief Engineering at the **NIB** explains us that the principal objective of the HGF dam is hydropower generation. ‘Since the plans are to build a high dam, irrigation and flood control also became objectives of the HGF dam, therefore we have an interest in this dam’, he says. The NIB is just an executive body of the Government of Kenya, hence has no influence on the implementation phase. The national government, i.e. relevant Ministries, develop irrigation projects and the NIB is merely executing these projects.

The Capital Planning & Strategy Manager at **KenGen** states that KenGen has not been approached by the Government of Kenya concerning the HGF dam project. The awareness of the HGF dam therefore is very low at KenGen: the manager did not hear about the HGF dam before.

All **NGOs** want to advocate through providing scientific evidence to the decision-makers, in order to decrease the socio-economic and environmental impact of the HGF dam project. But all NGOs operative in the Tana River Basin share different approaches of exerting influence on the national decision-makers. The awareness amongst the NGOs is high. Of all NGOs active in the Tana River Basin, Nature Kenya and KenWeb seem to be the most activist. The Executive Director at Nature Kenya fears that ‘whenever the choice has to be made between maintaining a natural flow of the Tana River and generating power, the latter will be chosen’. The Senior Programme Officer at the Freshwater Ecosystems Unit of UNEP, likewise states that ‘there is a conflict between energy generation and flow regulation at the HGF dam project’. ‘There should be a system harmonising the interests of these both essential aspects’ he says. The influence Nature Kenya can exert on the Government of Kenya is mainly through providing scientific information. Nature Kenya has a high degree of knowledge and applies this through a moderate anti-attitude.

The Water Fund Manager at The Nature Conservancy (**TNC**) and states that TNC merely wants to cooperate with the decision-makers of the HGF dam project. TNC is convinced that in order to influence the decision-making process, all parties should be included from the very start of the planning phase. TNC does not have any concerns about the implementation of the HGF dam project, TNC ‘just wants it to be implemented in a good way’ he says. Unlike all other NGOs, TNC does not think that the population living downstream of the HGF dam will be negatively affected.

The Country Manager of the **WWF** explains the research team his concerns on the enormous capacity of the HGF dam project that imposes many negative effects on: biodiversity, livelihoods of the population in the Tana River Basin and the flora & fauna. The approach of the WWF can be positioned between Nature Kenya’s moderate anti-attitude and TNC’s cooperative attitude. ‘The WWF does not want to influence whether this project will be implemented, only how it will be done; let’s do it in a smarter way’ he says.

All NGOs interviewed do agree that the awareness of the **general public** in the Tana River Basin concerning the HGF dam project is below par. ‘The main concern of the WWF is that the local population must be informed through tools such as a Strategic Environmental Assessment in advance’ says WWF country manager. With this information various scenarios can be drawn up together with the local population in order to develop the best implementation of the HGF dam project with the least impact on the environment and livelihood of the population in the Tana River Basin. All NGOs but Nature Kenya share this view, the NGOs are not against the dam but want the HGF dam project to be implemented in a different way with less impact on the environment and livelihoods in the Tana River Basin. ‘Economic development always has an impact on the environment, but there should be a healthy balance between development and the environment’ says the UNEP representative. The Freshwater Chief at UNEP states that ‘the socio-economic costs could potentially be quite high, I used to be in the dams and development project sector, and the environmental and socio-economic impact of such dams are frequently underestimated, it can be huge’. He also explains that ‘the challenge of stakeholder engagement is in the implementation, the decision-makers also have to consult the hidden stakeholders and take their input seriously; the good will is there but is not sufficient yet'.

Synthesis

Table 35 presents a summary of the results of the SA. On the one hand, the actual interest of the various stakeholders can be much more specific than the matrix above shows. On the other hand, it is also important to keep in mind that any stakeholder analysis will have a certain level of uncertainty. The participating representatives will always have their own characteristics, and therefore cannot objectively represent their whole organisation or institution. Yet, given the scope of this study, possible subjective biases are difficult if not impossible to verify.

Table 35 Summary of the results of the stakeholder analysis

Stakeholder Group	Nature of Interest	Relative Importance of Interest*	Importance of Group†	Influence of Group
Primary Stakeholders				
Agriculturalists	Improved production/decrease in availability of water/flood control	High	High	Low
Fishermen	Decrease in catch/increase in fish farming	High	Medium	Low
Pastoralists	Decrease in income/increase of conflicts	High	Low	Low
Tourism Operators	Decrease in income	Low	Low	Low
Resettled Population	Loss of livelihood/increase in social conflicts	High	High	Medium
WRUA	Sustain water resource availability/reduce water-related conflicts	High	High	Medium
Secondary Stakeholders				
WRMA-TCA	Improve water resources management in Tana Catchment Area	High	High	High
Tana Water & Sewerage Company	Water and sewerage services	Medium	High	Low
Tertiary Stakeholders				
Ministry of Agriculture, Livestock & Fisheries	Improve food security	High	High	High
Ministry of Energy & Petroleum	Increase power supply/decrease energy tariffs	High	High	High
Ministry of Environment, Water & Natural Resources	Improve distribution of water	High	High	High
Ministry of Tourism	Increase tourism activities	Low	Low	Low
Ministry of Health	Improve food security/increase safe drinking water/livelihoods of the population downstream	High	High	Medium
Kenya Water Towers Agency (KWTA)	Preserve watershed function of water towers	High	High	Low

WRMA	Improve water resources management	High	High	Medium
LAPSSET Corridor Development Authority	Supports transport linkage between South Sudan, Ethiopia and Kenya	Very High	Very High	Very High
National Environment Management Authority (NEMA)	Monitor and regulate environmental impact	High	High	High
National Irrigation Board	Increase irrigated land	High	High	Medium
Kenya Wildlife Service (KWS)	Threatened wildlife in Tana basin	High	Medium	Low
Kenya Forest Service (KFS)	Threatened state forests and Tana Delta	High	Low	Low
Kenya Marina and Fisheries Research Institute	Threatened marine and freshwater fisheries	Medium	Low	Low
Tana and Athi Rivers Development Authority (TARDA)	Implement HGF dam project	Very High	Very High	Very High
KenGen	Increase power supply	High	High	Low
United Nations Environment Programme (UNEP)	Minimize environmental and socio-economic impact	High	Medium	Medium
Wetlands International	Minimize environmental impact on Tana Delta	High	Low	Low
Nature Kenya	Minimize environmental impact on Tana River Basin	High	Low	Medium
Environmental Liaison Centre International	Minimize environmental impact on Tana River Basin	High	Low	Low
WWF	Minimize environmental and socio-economic impact	High	Low	Medium
KenWeb	Minimize impact on biodiversity and Ecosystem services of Tana River basin	High	Low	Low
Red Cross Kenya	Minimize water-related conflicts	High	Low	Low
International Union for Conservation of Nature (IUCN)	Minimize environmental and socio-economic impact	High	Low	Low
The Nature Conservancy (TNC)	Minimize environmental and socio-economic impact through collaboration	High	Medium	Medium

*Source: adapted from (ODA, 1995). * Indicates importance to the natural resource project/ programme leader. † Indicates importance and representation within local/national power structures and institutions.*

It can be clearly observed that the primary stakeholders of the HGF dam project all have a low to medium degree of influence on the HGF dam project. This is a threat to the equal distribution since the primary stakeholders have the greatest dependency on the Tana River, but the lowest degree of influence of all stakeholders. This results in a situation where the stakeholder category with the highest degree of interest has the lowest degree of influence. A lack of awareness, lack of knowledge and lack of capacity cause the low degree of influence of the primary stakeholders.

The research team observed that the awareness of the HGF dam among the primary stakeholders is low. Only 1 out of 16 local interviewees who hold a primary stake in the HGF dam project heard about the HGF dam project before. It also appeared that the local population could not well imagine the impact of a mega-dam; this might be grounded in a lack of education in the Tana River Basin. This lack of knowledge and education causes a risk that the local population does not understand the effects of the HGF dam project when public consultation is taking place in the affected locations. At the same time, the primary stakeholders do have valuable information of the Tana River. The local population often knows best what the optimal policy is on a micro-level and should therefore be utilised as a source of information.

Figure 42 provides a visualisation of the summary of results of the stakeholder analysis; the misunderstanding between decision-makers and the local population due to the lack of knowledge and education is magnified in the first lower box in Figure 42.

Table 35 also shows that the lower the dependency of the stakeholders is, the higher the influence of the stakeholder on the HGF dam project gets. On average, the secondary and tertiary stakeholders have a higher degree of influence than the primary stakeholders. All Ministries except the Ministry of Tourism included in this SA have a high degree of influence on the HGF dam project. The Ministries have a high degree of influence but they would do well to harmonize their interests. The powerful Ministries tend to work against each other due to this lack of harmonisation (see left upper box in Figure 42), which decreases the effectiveness of their influence.

The increasing demand of power fostering economic growth in Kenya tends to overrule other interests of the Kenyan population. This implies that the Ministry of Energy & Petroleum has the highest degree of influence of all Ministries, which is consistent with the views of the majority of interviewees. The Ministry of Energy & Petroleum is merely focused on the increase of the power supply at low costs due to the independent of the interests of other relevant Ministries (see Figure 42). The risk of a lack of harmonisation of interests is that one Ministry obtains a disproportionate amount of influence instead of all Ministries influencing the HGF dam project from own interests.

TARDA and the LAPSSET Corridor Development Authority are the respective implementing and operational key stakeholders. These institutions experienced much criticism in the media and amongst the local population and therefore tend to have a negative reputation in Kenya, which is certainly not always justified. As a result, the local population focuses on the disadvantages of projects undertaken by either TARDA or the LAPSSET Corridor Development Authority. These institutions could improve their reputation by increasing the level of public consultation of the local population. This would, besides improving their reputation, also reveal local perspectives about the Tana River to TARDA and LAPSSET.

The users of electricity and the population upstream of the HGF dam and the LAPSSET Corridor Development Authority reap most of the benefits of the HGF dam project. All indirect costs are incurred downstream of the HGF dam and at the construction site: the decrease in availability of water will deteriorate ecosystem services and will increase water-related conflicts, the increase in agrochemical pollution of the Tana River will deteriorate the ecosystem services and resettlement also will cause indirect costs (see Figure 42). The only benefit reaped by the local communities downstream is flood control, which concerns only a part of the population.

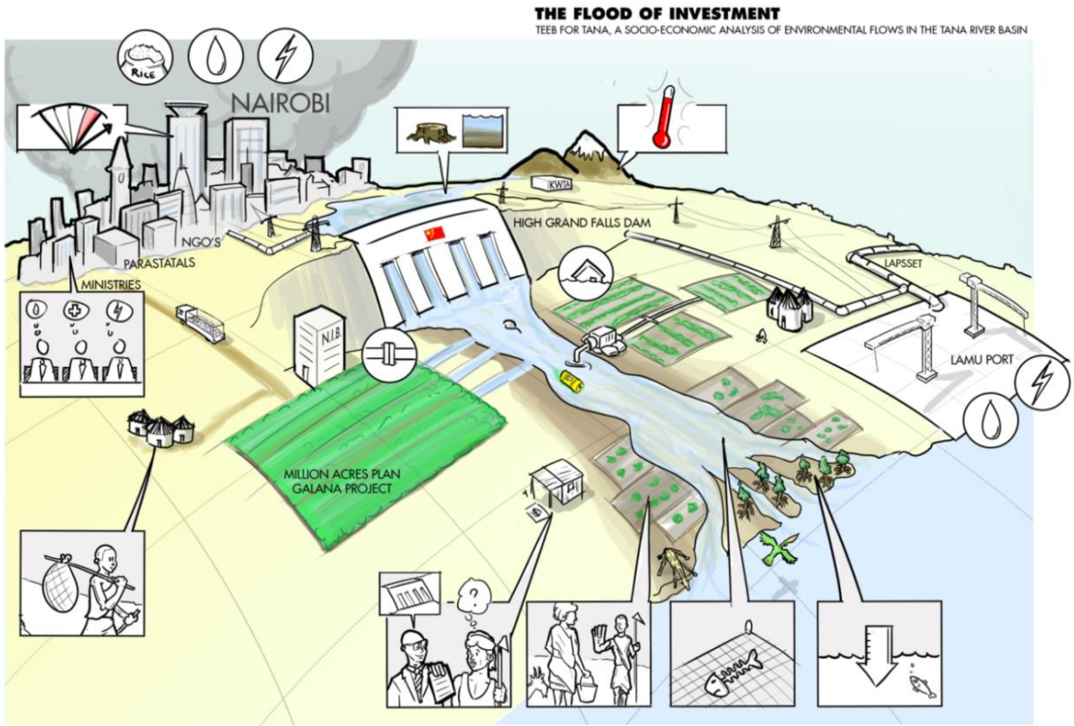

Figure 42 Visualisation of the various stakeholder interests in the Tana River Basin in relation to the HGF dam project

7.6 Conclusion and discussion

This qualitative Stakeholder Analysis (SA) was conducted to capture the awareness, perceptions, interests, concerns, influence and relationships of the different stakeholders regarding the HGF dam project.

The HGF dam project has several clear **benefits** for the Kenyan society. For example, the benefits of the generation of hydropower electricity, relative to natural gas for peak-supply and geothermal power for base load, within the HGF dam project are calculated to be US$41-61 million annually. Moreover, the HGF dam project also provides 1.5 million people with safe drinking water. The availability of safe drinking water has been recognised as one of the main objectives of the Ministry of Health. In terms of flood control, a distinction has to be made between stakeholders of the HGF dam project who are flood-reliant, and those who are not flood-reliant. In total, it is estimated that over a million people depend on the river's flooding regime for their livelihoods. But the flooding of the Tana River also imposes an adverse impact on thousands of households annually due to drowning and loss of livelihoods. The effect of flood control of the HGF dam project is therefore ambiguous. Lastly, the HGF dam project will provide water for irrigation projects which will diminish the Kenyan dependency on food imports.

The HGF dam also imposes **costs** on the Kenyan population. For example, the majority of the agriculturalists in the Tana River Basin consist of flood-recession agriculturalists, who will merely incur costs from the HGF dam project due to a decrease in crop yield. Moreover, fishermen will catch less fish, which was suggested by interviews and the observations of fisheries catch and average water height. In addition, the number of livestock in the Tana River Basin is estimated to depend on the annual average water height. The HGF dam project will also affect the health of the Kenyan population, although the exact impact proves to be difficult to analyse. Finally, the number of water-related conflicts will increase due to the HGF dam project and this will increase the instability of the Tana River Basin.

Through interviewing 43 stakeholders this sub study concludes that the general degree of awareness and knowledge regarding the HGF dam project is insufficient. This lack of awareness and knowledge especially affects the primary stakeholders who have the greatest dependency on the Tana River. Despite their primary stake, it turned out that these stakeholders have no opportunity to influence the HGF dam project.

The in-depth interviews also revealed that there is a lack of harmonisation of interests amongst the relevant Ministries. The risk of a lack of harmonisation of interests is that one Ministry obtains a disproportionate amount of influence instead of all Ministries influencing the HGF dam project from their respective fields of interest. The Ministry of Environment, Water and Natural Resources is the only Ministry that is able to harmonize the interests of all relevant Ministries through the allocation of water due to the many economic purposes that water serves.

In conclusion, this sub-study shows that the HGF dam involves many costs that the decision-makers do not take into account. The distribution of costs and benefits proved to be unequal; the population downstream of the HGF dam (except farmers who are attached to the NIB) mainly incur costs without being able to exert influence on this decision. Several decision-makers seem to be aware of this unequal distribution but seem consider it as inevitable in the process of increasing economic growth in Kenya. Monetisation of the societal costs and benefits will inform primary, secondary and tertiary stakeholders, thereby allowing for a better informed decision making.

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8 Extended CBA of Interventions in the Tana Basin

Pieter van Beukering & Hans de Moel

8.1 Introduction

Although Kenya's hydro-electric and hydro-agricultural potential have yet to be fully realised, it is assumed that the costs and benefits of such mega-investments are not yet properly estimated. Besides the financial feasibility (i.e. direct costs and benefits) of additional dams, it is still unclear what the indirect economic effects of hydro-electric and hydro-agricultural schemes are on downstream beneficiaries of rivers.

The overall aim of this Chapter is to support decision making at a basin level with regard to the management and construction of dams and irrigation schemes in the Tana River Basin, and how this may affect economic and ecological conditions downstream. This is achieved by conducting an extended cost benefit analysis (CBA) for the main economic, environmental and social effects of current development plans in the Tana River Basin. To define the economic feasibility of a project investment the Extended Cost-Benefits Analysis (CBA) is applied to the economic comparison with the option of no intervention. Besides taking into account the financial feasibility of the project, an extended CBA, allows determine the societal feasibility of the project by incorporating social, economic and environmental externalities.

The Chapter is structured as follows. The scenarios and the model underlying the cost benefit analysis of dams and irrigation schemes in the Tana River Basin are explained in Section 8.2. Underlying demographic information is presented in Section 8.3 and the positive and negative benefits of the dams and the irrigation schemes are explained in Section 8.4. The financial costs of the dams and irrigation schemes are addressed in Section 8.5. Section 8.6 presents the extended cost benefit analysis and Section 8.7 follows with a sensitivity analysis. Conclusions are drawn in Section 8.8.

8.2 Methodology

8.2.1 Scenarios

Various developments are planned in the Tana River Basin, focused on increasing food, energy and water productivity and economic growth. Planned land use, water use, and infrastructural interventions are assumed to provide several benefits, of which the most important are generation of electricity and stable provision of water in (semi-)arid regions (reservoirs) (Nippon Koei 2013). However, the interventions also contain the risk of adversely affecting the ecological and economic systems, and in turn people's livelihoods (Hamerlynck et al. 2010). Often, the costs and benefits of large infrastructural works in the river basin are not equally distributed in space and time. The potential adverse effects of the planned interventions may therefore result in a degradation of the services provided by the Tana River to a point where it can have direct and indirect adverse effects on people living in the downstream regions (Temper, 2010; Martin, 2012; Duvail et al., 2012).

In line with the hydrological analysis presented in Chapter 3, the interventions with the presumed largest impact are included in this cost benefit analysis. For clarity's sake, the scenarios are listed again below:

- **Scenario 0 – No Dams**: The naturalized state of the river, without any interventions. This parameterization has been used to calibrate the hydrological model and can also be used to determine the economic feasibility of the current dams as captured in Scenario 1.
- **Scenario 1 – Masinga+ dams**: This business-as-usual (BAU) scenario represents the current situation[4]. In total five hydropower dams (Masinga, Kamburu, Kindaruma, Gitaru and Kiambere) have been constructed in the Tana River (upper basin), providing almost three quarters of the national energy demand. Additionally, two dams have been constructed in the Chania (Sasumua) and Thika (Thika) rivers, which supply water to Nairobi (Nippon Koei, 2013). Flooding volume and frequency have greatly decreased since the last dam was constructed in 1989 (Dickens et al., 2012). The five dams have resulted in less variability in discharge, with a 20% decrease in peak flows in May and a roughly 70% increase in low flows in February and March (Maingi & Marsh, 2002). The locations of the dams in this scenario are shown in Figure 8.1.
- **Scenario 2a – HGF dam**: This policy scenario represents a future situation in which the High Grand Falls Dam (HGFD) is completed and additional irrigation in Bura, Hola and the Delta is established. The HGFD is a flagship project for the Kenyan government within the National Water Master Plan 2030 (Nippon Koei, 2013). The HGFD will be used for – in order of priority – flood management, power generation and supply of irrigation, drinking and industrial water (Republic of Kenya, 2011a). Its hydropower generation capacity will exceed that of the five existing dams combined (Nippon Koei, 2012; Government of Kenya, 2013). A feasibility study has been conducted on the HGFD, which forms the most comprehensive document with respect to the HGFD project (Republic of Kenya, 2011a). The planned location of the HGF dam and the related irrigation projects are shown in Figure 8.1 and Figure 8.2.
- **Scenario 2b – Million Acres**: This policy scenario is the same as 2a, but with the addition of one million acres (~400.000 ha) of irrigated land for which water is extracted from the HGFD reservoir. Within the Kenya Vision 2030, agriculture has been identified as one of the key sectors to help reach the envisaged annual economic growth rate of 10%. In order to increase the agricultural productivity, irrigation has to be further developed (Government of Kenya, 2007). Irrigation is by far the biggest consumer of water in Kenya. It is expected to contribute to roughly 91% of the total water demand in 2030, of which 94% will be extracted from surface water (Nippon Koei, 2012). With irrigation being the largest water consumer, its effect on the water balance is expected to be significant. Along the entire Tana River there are plans for new irrigation schemes. There is a multitude of plans but only the large-scale irrigation schemes are included in this study.

Note that the construction of the Lamu Port has been excluded from this analysis. We expect the Lamu Port project to put additional claims on the scarce water resources, thereby magnifying the negative impacts on water dependent stakeholders elsewhere in the Tana River Basin. However, given the limited information available on this major investment this study cannot include this intervention as one of the scenarios.

[4] Formally speaking, the business-as-usual (BAU) situation should not be labelled as a "scenario" because it is not a hypothetical situation but instead represents the current costs and benefits. However, because we use the "Scenario 0 – No Dams" instead of the BAU situation to compare with future scenarios with, we decided to label the current BAU situation as Scenario 1 – Masinga+ dams. Although this violates economic terminology, it simplifies the presentation and allows us to analyse whether the current dams have been a economically feasible investment for Kenya.

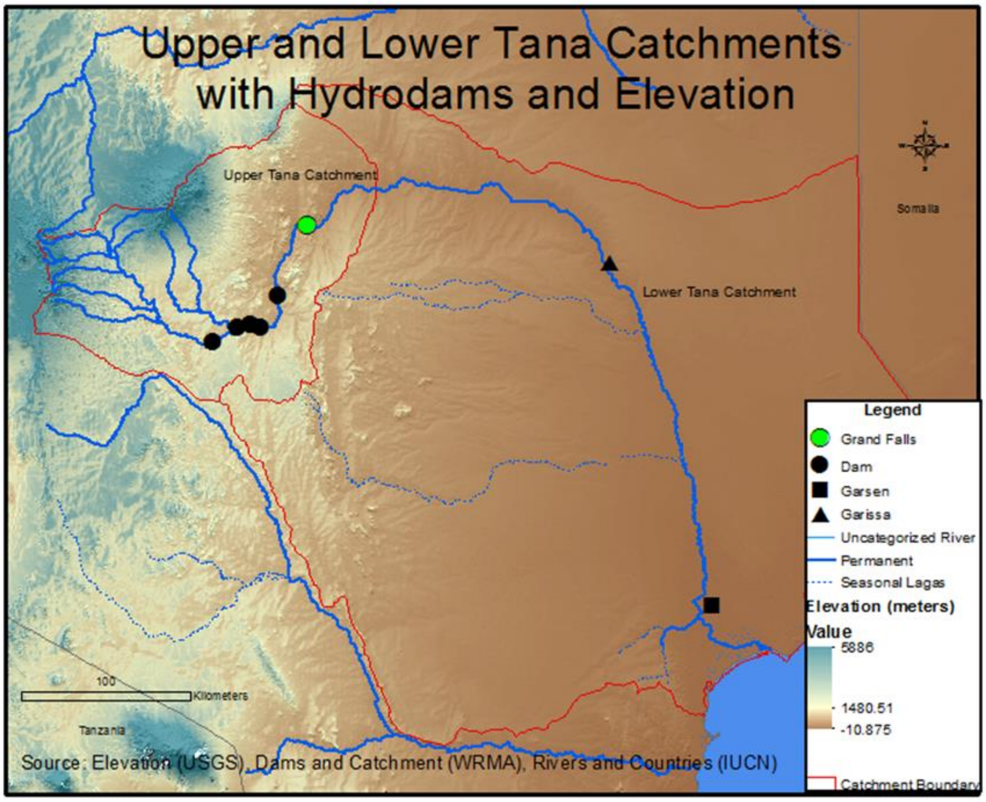

Figure 8.1 *Current and proposed dam infrastructure in the Tana River Basin*

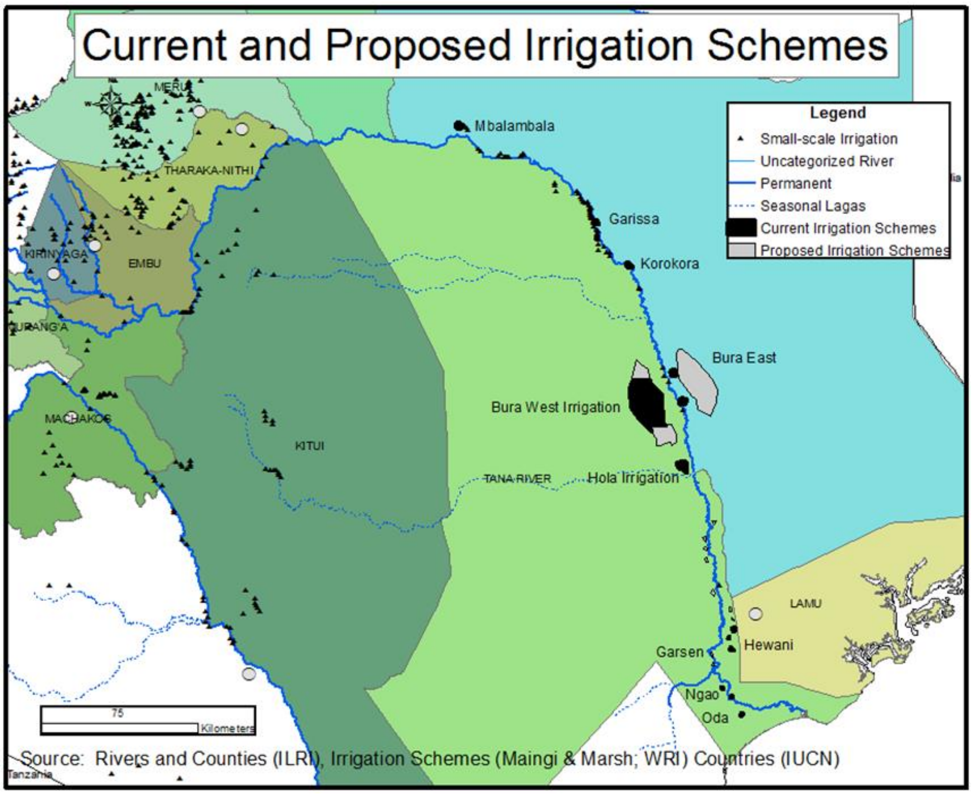

Figure 8.2 *Current and proposed irrigation schemes in the Tana River Basin*

8.2.2 Extended CBA

Cost-Benefit Analysis (CBA) is an indispensable economic tool in any large infrastructure project. Dams and irrigation schemes are no exception. Traditionally, a CBA was performed using a limited set of parameters. In most cases the costs were restricted to the direct capital investment, construction costs and operational costs. Likewise, only direct (measurable and financial) benefits, such as power generation, irrigation benefits were taken into account. Nowadays, social and environmental effects are increasingly considered in the planning of large infrastructural projects such as the dams, through the application of an extended CBA (European Commission, 2008). This analysis requires economic valuation of indirect costs and benefits (Ranasinghe, 1994; Aylward et al., 2001; Chutubtim 2001).

Several extended CBA studies on dams have been carried out in the past. The World Commission on Dams (WCD 2001) investigated eight projects in detail. Several of these are situated in Africa: (1) the Orange River Development Project in South Africa; and (2) the Lake Kariba dam in Zambia and Zimbabwe. A third interesting study in Africa, which was commissioned by IUCN, looked at the effects of the Maga Dam on the Waza-Logone floodplain area in Cameroon (Loth 2004). More recently, an extended CBA was conducted on dams in the Niger River in Mali (Zwarts et al. 2006).

8.2.3 The model

To determine the costs and benefits of dams and irrigation schemes in the Tana River, a wide range of information is required. A consistent way to organise this information is according to the sequence of underlying processes. This involves looking at the cause of an impact, then taking into account the physical impacts and finally considering the social and economic effects. This so-called "impact pathway approach" is a methodology that proceeds sequentially through the pathway, linking causes to impacts, and subsequently valuing these impacts (Zwarts et al. 2006). The framework of the impact pathway is shown in Figure 8.3 and represents the physical and socio-economic processes resulting from the management of dams and irrigation schemes in the Tana River.

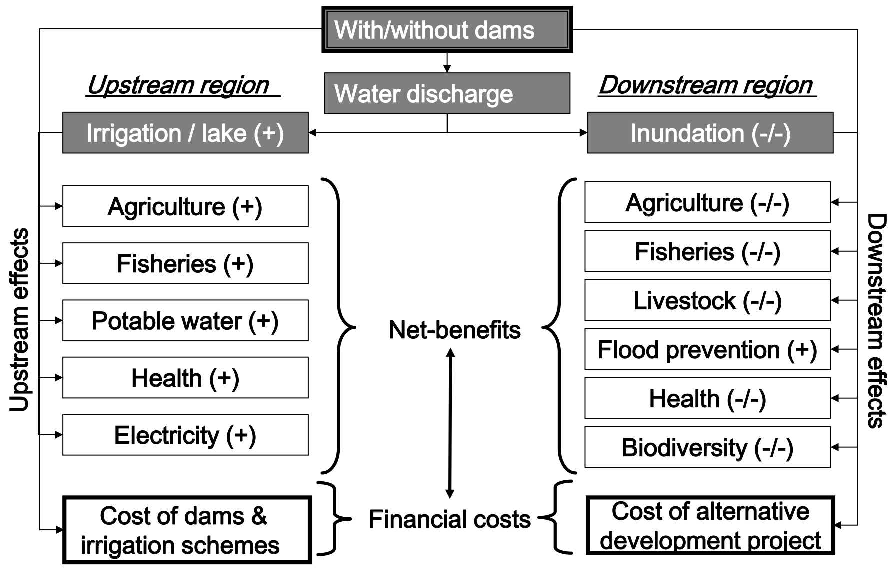

Figure 8.3 Analytical framework for the extended CBA on dams and irrigation schemes (to be read from top to bottom)

The impact pathway approach proceeds in a series of methodological steps. These include:

(1) Defining the ***boundaries*** *of the study*: The study aims to evaluate different water management scenarios along the Tana River. The scenarios have been described in Section 8.2.1. The temporal boundaries of the project are a 25-year period. This period leaves enough time for the main environmental impacts to come into effect, while it is sufficiently short to make a reliable prediction about future developments. Because different scenarios in reality have different starting years (i.e. Scenario 0 in reality starts in the 1980s whereas Scenario 2b may very start in reality in ten years from now) each scenario is assumed in a hypothetical starting year 0 and ends 25 years later. The biophysical and economic background (exogenous) conditions are the same for each scenario. Dams and irrigation schemes are assumed to be built gradually over a period of five years.

(2) Identifying ***significant impacts***: Due to practical limitations, the analysis includes the most significant effects only. Inevitably, judgement must be used in deciding what is and is not significant. To judge the magnitude and significance of environmental effects, a range of criteria is identified: (a) The effect on the natural and human environment depending on their relative sensitivities; (b) The location of the effect, whether within the confines of the site or beyond (local, regional, national and international scale); (c) Timing of the effect (during the construction, operational and post-operational stage); and (d) Whether the effect is reversible or irreversible. Using expert judgment for these criteria as well as the statistical analysis presented in Chapter 5, it was decided that the impacts on fishery, agriculture, livestock, human health can be regarded as economic activities in the Tana River Basin that are significantly affected. Effects that are potentially significant, but on which little knowledge is available, are for example the biodiversity impacts of dams. As described in Chapter 4, dams and irrigation schemes are very likely to have negative effects on biodiversity. Due to a chronic lack of information on biodiversity impacts, this effect has not been included in our study.

(3) ***Physically quantifying*** *the significant impacts*: Evaluating the physical effects of the management of dams and irrigation schemes is a complex exercise. The hydrological model presented in Chapter 3 calculates the changes in flood dynamics (i.e. level, timing, high flows/floods, low flows/drought). In Chapter 4 and 5, the relationship between the hydrological conditions and the physical production levels of individual sectors has been estimated, using the production function approach. To assist in predicting the aggregated physical consequences of the various scenarios, a dynamic simulation model was developed. The model approximates the main effects of each scenario on the various benefit categories and evaluates the changes for the various districts (i.e. upstream and downstream). To calculate these impacts, simplifying assumptions were adopted, such as for climatic and hydrological conditions, and future economic activities.

(4) ***Calculating monetary values***: Having established and tabulated the full range and significance of the effects, changes are valued in monetary terms. The main impact pathways covered include agriculture, fisheries, livestock, health, energy supply, drinking water and flood prevention. Different valuation techniques are used for these benefits. The most commonly used valuation technique in this study is the 'net factor income approach' which estimates the value of an environmental input in production by subtracting the costs of other inputs from total revenue, and ascribes the remaining surplus as the value of the environmental input. For most of the sectors considered, statistical production functions were estimated. The results of the choice experiment presented in Chapter 6 have been used to estimate the value of flood prevention. These were incorporated in the integrated model simulating the four scenarios. The main welfare indicator of the model is the net-benefit of each scenario, which expresses the overall welfare level minus the financial costs of the dams and irrigation schemes. Another important dimension of the impact pathway approach is the spatial allocation of welfare. Besides having an impact on the absolute level of welfare in the Tana River Basin, establishing dams is likely to generate a

transfer of economic benefits from one region to another. The model has been designed at the county level, so that a distinction can be made between benefits that occur in different counties.

(5) Conducting a ***sensitivity analysis:*** A sensitivity analysis was conducted to test the robustness of the final result, in relation to several crucial parameters such as climate change, cost overrun and the discount rate.

8.3 Demographics

The CBA is based on a wide range of demographic information, such as population and household size, income and poverty levels, population density, and the level of access to electricity as well as drinking and potable water. As shown in Table 8.1, Table 8.2, and Figure 8.4, these parameters are recorded at the county level. Due to lack of district level information, no distinction could be made in this study between those parts of a county that are within or outside the Tana River Basin. In other words, counties are treated as homogeneous geographical units.

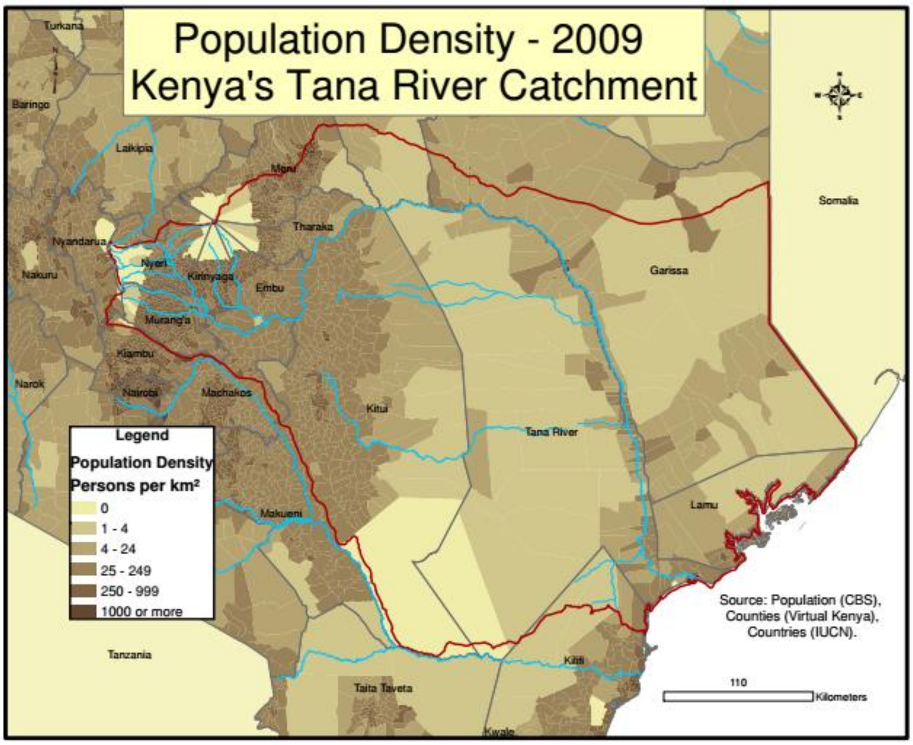

Figure 8.4 Population density by county in 2009

Table 8.1 Demographic information at the county level of the Tana River Basin

Year	Population (2011)	Household size (2008)	Poverty rate % (2005/2006)*	Household income (US$ 2013)
Upstream				
Embu	516,212	3.9	42.0	1,432
Kirinyaga	528,054	3.4	25.2	1,891
Machakos	1,098,584	4.1	59.6	951
Meru	1,356,301	4.2	28.3	1,807
Muranga	942,581	3.7	29.9	1,763
Nairobi	3,138,369	3.2	22.5	1,965
Downstream				
Garissa	623,060	6.3	49.2	1,235
Isiolo	143,294	6.0	72.6	596
Kitui	1,012,709	4.9	63.5	845
Lamu	101,539	4.6	32.7	1,686
Tana River	240,075	5.1	76.9	478
Tharaka	365,330	4.1	48.7	1,249
Source:	**CRA 2011**	**KNBS 2007**	**CRA 2011**	**World Bank 2015**

** Variation based on poverty rate (2005/2006)*

Table 8.2 Demographic information of the Tana River Basin (continued)

Year	Surface area (km2)	Population density (people km2 2009)	Electricity access (% - 2009)	Access piped/potable water (% - 2009)
Upstream				
Embu	2,818	183	10	41
Kirinyaga	1,479	357	16	41
Machakos	6,208	177	10	15
Meru	6,936	196	29	63
Muranga	2,559	368	29	26
Nairobi	695	4,515	56	63
Downstream				
Garissa	44,175	14	10	26
Isiolo	25,336	6	56	41
Kitui	30,496	33	6	7
Lamu	6,273	16	16	41
Tana River	38,437	6	4	15
Tharaka	2,639	138	10	15
Source:	*CRA 2011*	*CRA 2011*	*CRA 2011*	*CRA 2011*

Besides geographic variation, demographics also vary over time. Most importantly, population transitions need to be taken into account when making projections for future developments. This temporal information was not available at the county level, and therefore demographic changes are assumed to be similar across the eleven counties in the Tana River Basin. For example, we assume population to grow by 2.11% annually in our scenarios (2014 estimate) (CIA 2015). This leads to an increase in population in the Tana River Basin of 11 million in 2015 to 17 million in 2040. This also implies that Tana River Basin has to provide the needs of substantially more people in the future than today. In the analysis of health effects in the Tana River Basin, the crude death rate (CDR) is assumed to remain at its present level of 8 deaths per 1,000 mid-year total population of the given geographical area during the same year (World Bank 2015).

All historical price estimates are converted into 2015 values by correcting for historical inflation of consumer prices in Kenya (see Figure 8.5). Prices and values are expressed in terms of US dollars by applying the appropriate exchange rate of the respective period.

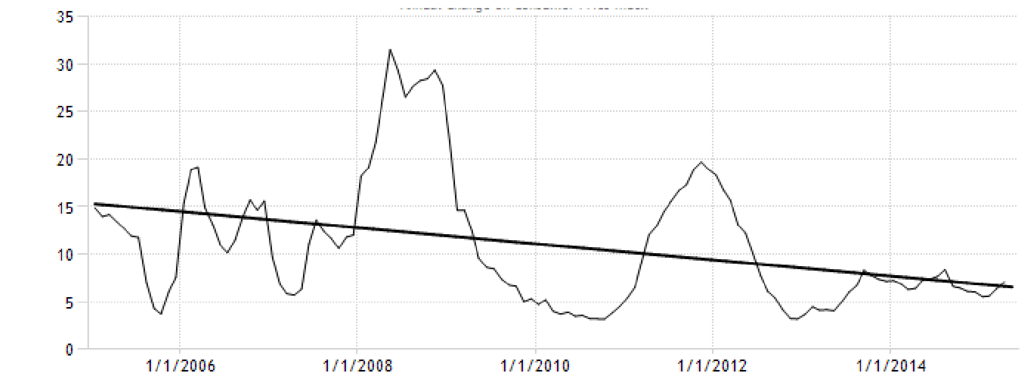

Figure 8.5 Inflation rate in Kenya (source: Kenya National Bureau of Statistics 2015)

8.4 Positive and negative benefits of the dams and the irrigation schemes

8.4.1 Crops

To determine the impact on the agricultural sector of changes in the water discharge in the Tana River Basin, we need to take into account, on the one hand, which crops are being grown in the Tana River Basin[5], and on the other hand, where the agricultural activities that are impacted by changes in water discharge takes place. Four combinations of crop types and locations are distinguished.

First, we exclude crops that are strictly rain-fed. Because the time series on crops at the county level do not indicate whether crops are rain-fed, literature has been used to justify the allocation of this crop category at 50% of the overall agricultural production (Nederveen, 2012). This implies that 50% of the agricultural sector in the whole basin is assumed to be independent of river discharge.

Second, rice production is identified as completely flood- or irrigation dependent (Nederveen, 2012) which implies that water discharge is a strong determinant of the productivity of rice fields in the Tana River Basin regardless of the location of production.

Third, we distinguish the other 50% of the overall agricultural output, excluding the rice yields, in the downstream counties are flood dependent. These crops suffer from low water levels in the Tana River.

Finally, the fourth category of crops is the large-scale irrigation crops which are among others grown in the million acres project. We assume that whenever sufficient water is available in the reservoir, these flood independent crops are grown in an autonomous manner. The location of

5 Time series of the following crops have been analyzed in this study: avocado, banana, beans, cassava, citrus, cotton, cow beans, French beans, green grams, Irish potato, kale, maize, mango, millet, onion, passion fruit, pawpaw, pigeon peas, pineapple, rice, sorghum, sweet potato, tomato, wheat, yam.

these large scale irrigation schemes is presented in the previous Chapters and is also visible in the rice producing counties shown in Figure 8.6. The productivity and profitability of the future irrigation schemes is based on Liangzhi You et al. (2014) which conducted an in-depth country-wide study on the irrigation potential and investment return of schemes in Kenya.

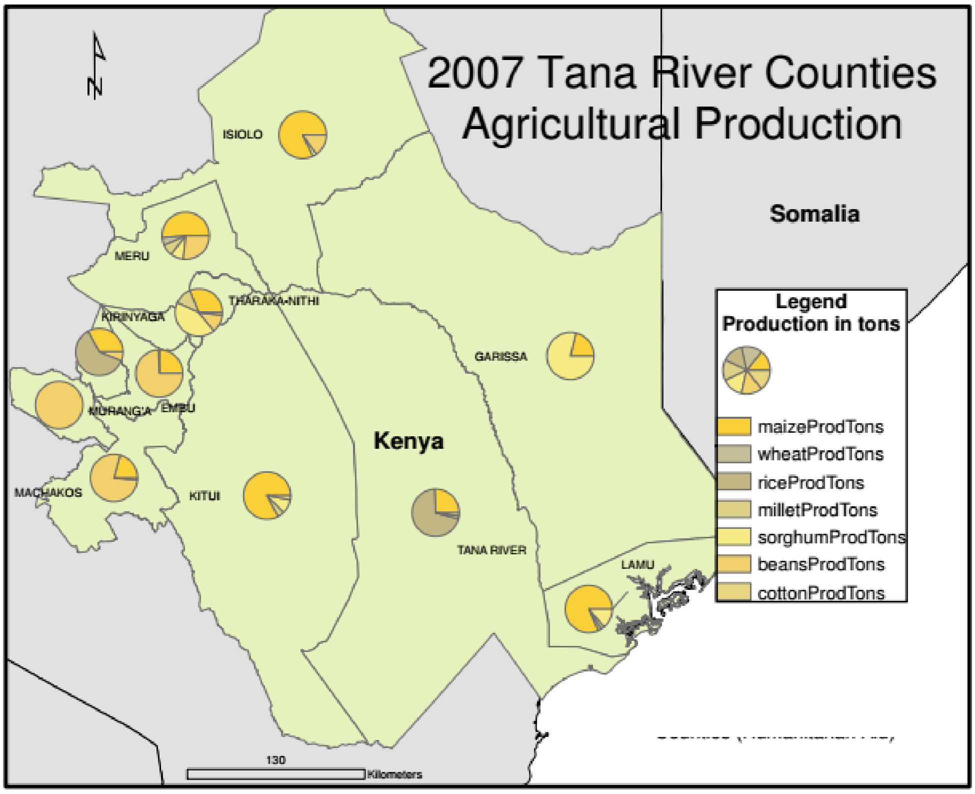

Figure 8.6 Agricultural production in 2007 in the counties of the Tana River Basin (source: compiled by the authors)

Figure 8.7 shows that the scenarios have limited impact on the upstream region while significant changes can be observed in the downstream region. Because of the large contribution of the agricultural benefits in the overall economy, these changes are likely to affect the results of the cost benefit analysis. The million acres project will mainly benefit agricultural production in the downstream region, more specifically in Tana County. It is uncertain, however, whether these benefits also really accrue to the people in the Tana County and leading to more welfare in the Tana County. This will depend on who owns the land and where the revenues of the million acres project will go.

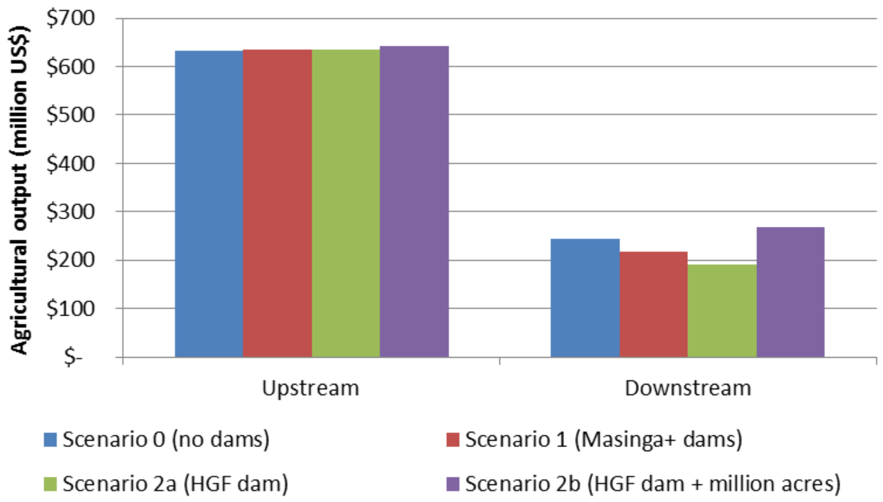

Figure 8.7 Gross agricultural output in the Tana River Basin by up- and downstream region (in millions US$/year)

8.4.2 Livestock

With a contribution of 7% to the GDP, the livestock industry in Kenya plays an important role in the national economy (ADEC, 2009). The geographical variability in the livestock sector is large. While in the downstream counties, most livestock owners operate on a small scale mainly producing meat and other animal products, the upstream counties in the Tana River Basin are focusing more on dairy production at a larger scale (see Figure 8.8 and Figure 8.9). For example, in the county Isiolo, pastoralism directly or indirectly accounts for the livelihoods of up to two thirds of the inhabitants (Matheka & Kinyanjui, 2013).

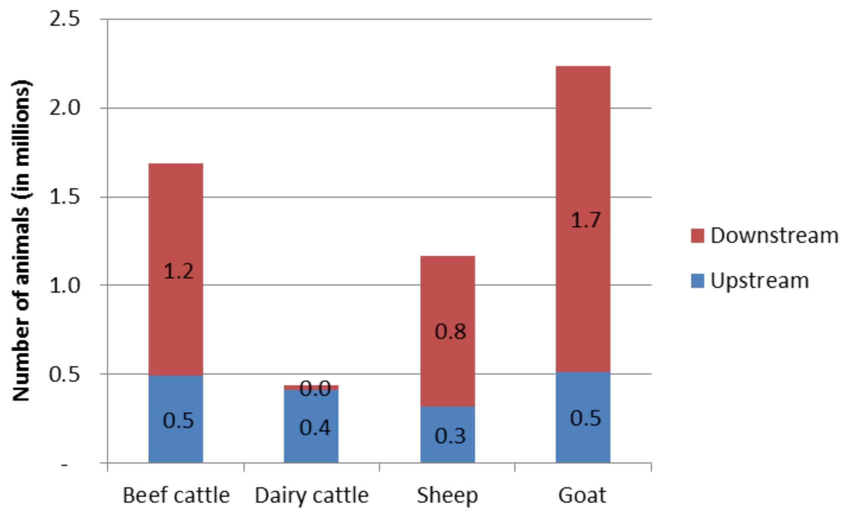

Figure 8.8 Present number of livestock in the Tana River Basin (in million animals)

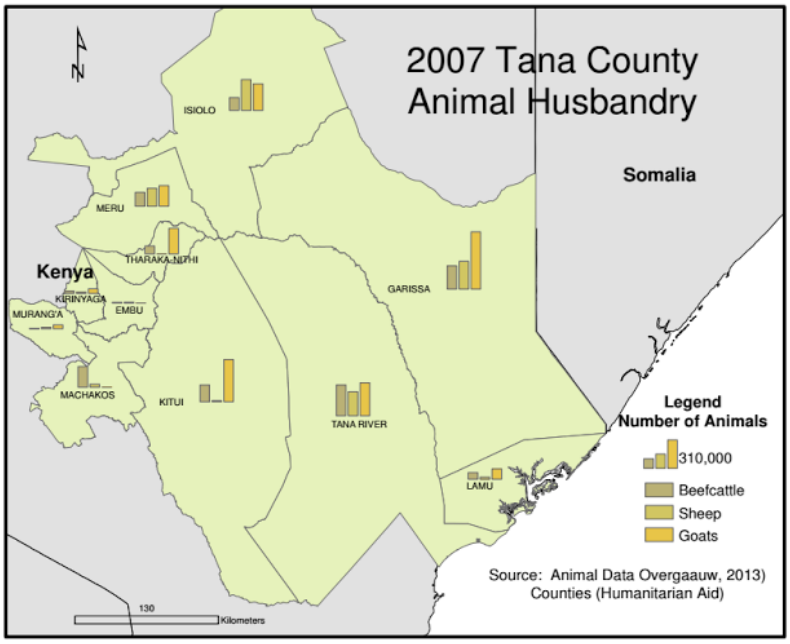

Figure 8.9 Composition of animal husbandry at the county level in 2007

To convert the current number of livestock into economic value, the meat and milk productivity of the animals is estimated on the basis of the constructed database of milk and meat production in the 25-year period of 1982 to 2007 for each county. To rule out data reporting and entry errors, the average rates across all counties was determined. The dairy productivity per cow has been adopted from TechnoServe Kenya (2008). This resulted in the following average slaughter and milk productivity rates:

- Cattle slaughter rate 5.3% of the cattle herd per year
- Dairy slaughter cattle 0.3% of the dairy cow herd per year
- Sheep slaughter rate 6.8% of the sheep flock per year
- Goat slaughter rate 7.7% of the goat tribe per year
- Milk production per dairy cow 564 litres per year

Meat and milk prices are also based on collected time series and were converted into 2015 values. The value of cattle is assumed to be $1,402 per ton, sheep and goat at $2,008 and $2056 per ton, respectively, and the milk value is set at $0.37 per litre. The estimated dressing weight, the amount of meat derived from each animal, is based on estimates by Farmer and Mbwika (2012), being 182 kg per cattle, and 15 kg per goat or sheep.

Because upstream counties do not experience negative effects of the HGFD and the million acres irrigation schemes, the effects of changed hydrological conditions is assumed to be absent. Thus, the livestock value remains constant across the scenarios in the upstream counties. The downstream counties suffer from reduced water availability and less inundation in drier years (Leauthaud et al., 2013), although they also may gain small livestock benefits from reduced events of extreme floods. Overall, the value of the livestock is determined by combining the current stock levels of livestock with changed hydrological conditions, applying the normalised production function presented in Chapter 5. This leads to the following change in livestock values. The high value in the upstream region is determined by the large contribution of dairy products in the total livestock value (i.e. 86%) while dairy products are much less important in the downstream regions (i.e. 16%).

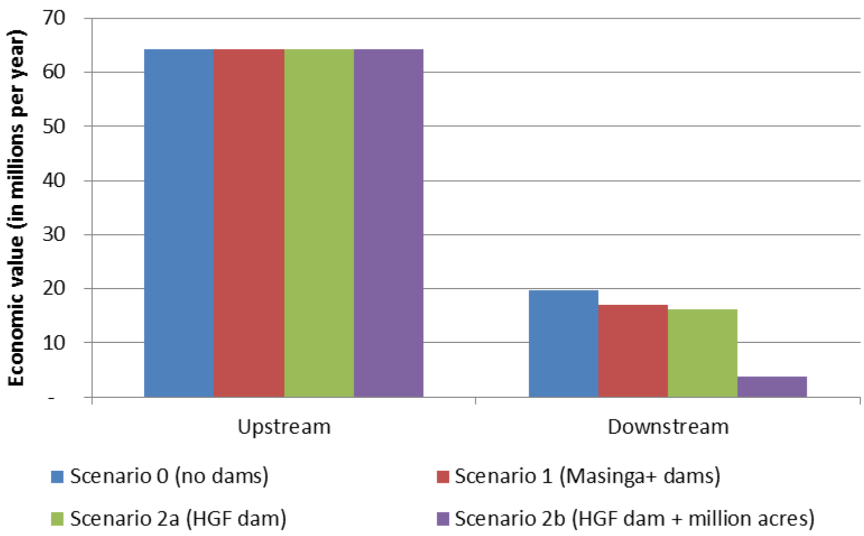

Figure 8.10 Livestock value in the Tana River Basin by up- and downstream region (in millions US$/year)

Note that the effect of transhumance is not incorporated in this CBA. In times of drought many pastoralists coming from Garissa county and Lamu county and sometimes as far as Somalia tend to move towards Tana Delta as that area then still tends to have green pastures. After feeding they move back to their own county.

Figure 8.11 Stylised representation of seasonal livestock influx into the Tana Delta, superimposed over stock routes (Source: Smalley and Corbera, 2012)

8.4.3 Fisheries

The production function for fisheries presented in Chapter 5 demonstrates the strong dependency of the fishery sector in the basin on sufficient water discharge in the Tana River. Both the fishing in the river itself as well as in the flooding zones benefit from the breeding and nursery function of the inundation areas. Because of the limited quantitative information available on fish catch in the Tana River Basin, only time-series at the county level for the years 1999 to 2006 were used. No differentiation is made in the available data between fish species.

The average fish value is set at US$1,750 per ton (Otieno, 2011). The average annual fish catch in the Tana River Basin adds up to more than US$2 million with 65% of this catch being caught in the upstream areas and 35% of this amount caught in the downstream counties (i.e. Lamu and Tana River county). In the total economy of the Tana River Basin, fisheries does not seem to play a dominant role, although at a more individual level, changes in this sector can have serious welfare implications for a specific group of especially poor people. Due to reduced water discharge in the consecutive scenarios, the fishery value in the downstream counties will decline from US$0.67 million in scenario 0 (no dams) to $0.60 million in scenario 2b (HGF dam and million acres project). This loss of fishery benefits in the Tana River Basin is largely compensated by increased fisheries in the new reservoirs in the upstream counties.

8.4.4 Public health

As explained in Chapter 5, water discharge in the Tana Basin and public health are related in a complex manner. In dry years, the reduced food production increases malnutrition and the availability of drinking water, and may also lead to an increase in violent conflicts. In wet years, extreme floods displace people, destroy crops, cause outbreaks of water borne diseases and malaria, and may enhance human-wildlife conflicts. The scenarios investigated in this study reduce water levels. The negative health effects in the scenarios are therefore mainly caused by droughts rather by extreme floods (see Figure 8.12). How this increase in mortality exactly occurs cannot be determined in this study, because it is based on aggregated health figures. Most additional mortality is likely caused by gradual malnutrition and increased vulnerability due to weaker health conditions.

The dose-response relationship between mortality rates and water levels in the Tana River presented in Chapter 5 is used to determine the damage of reduced water availability on health in the downstream counties. Valuation of changes in the mortality rate is complex and controversial. Yet, by excluding health effects from the cost benefit analysis, for this reason, the evaluation of future scenarios will be incomplete and incorrect.

In evaluating trade-offs between health and other issues, economists often consider the value of a statistical life (VSL). The VSL is the value that an individual places on a marginal change in their likelihood of death (United Nations, 1991). It is important to stress that the VSL is not the same as the value of an actual life. The VSL is the welfare people are willing to sacrifice to reduce the likelihood of death. The VSL is not the price someone would pay to avoid certain death.

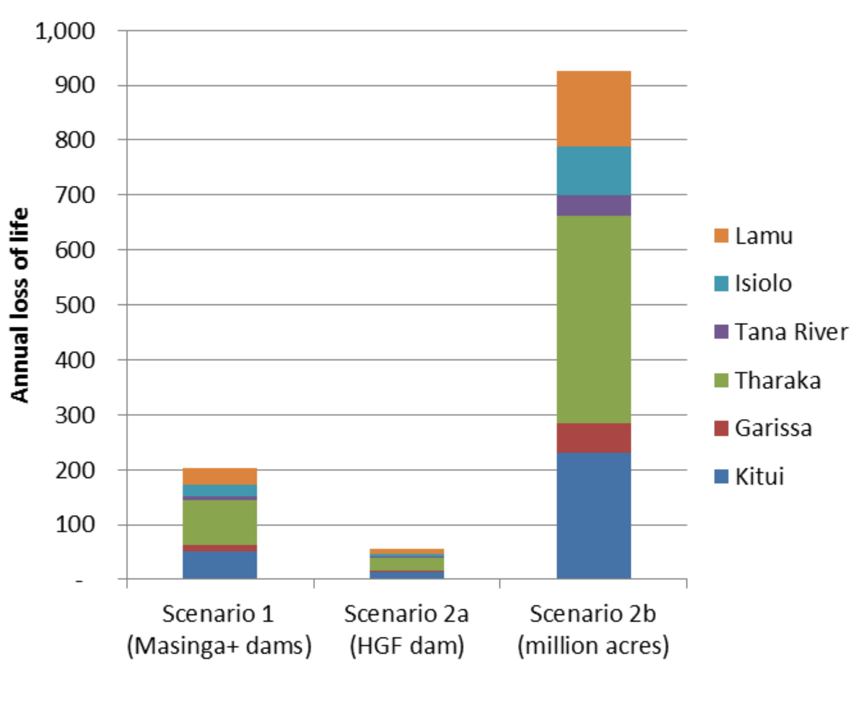

Figure 8.12 Change in mortality of each individual large infrastructural project in the Tana River Basin relative to Scenario 0 – No Dams

In this study, we adopt benefit transfer techniques for VSL estimates derived from an international meta-analysis of economic studies (Hammitt and Robinson, 2011; Biausque, 2012). From this study, which explicitly addresses the issue of transferring estimates between high and low income populations by accounting for differences in income elasticity, a VSL for the Kenyan context is set at $211,600 per statistical life. The baseline mortality rate is set at 0.8% (World Bank, 2015). Reduced water availability will increase this rate to varying degrees.

8.4.5 Potable water

The Tana River is an important source for potable water in the basin. Dam infrastructure facilitates efficient extraction of water for domestic and industrial purposes allowing for easier access to piped and potable water. At the same time, by maintaining water reserves upstream, downstream stakeholders suffer from reduced availability of water. As a result, their costs to cope with water shortages, mainly in terms of the additional time burden of water collection is likely to increase.

Cook, Kimuyu and Whittington (2015) measure the coping costs incurred by households in rural Kenya. They conclude that 60% of households collect water outside the home, spending an average of two to three hours on water collection each day. They value these time costs using an individual-level value of travel time estimate based on a stated preference experiment. In addition, coping cost estimates also include capital costs for storage and rainwater collection, money paid either to water vendors or at sources that charge volumetrically, costs of treating diarrhoea cases, and expenditures on drinking water treatment .Cook et al. (2015) find that the median total coping costs per month can be as much as US$20 per month. The coping costs are found to be higher among poorer households. Providing piped and potable water at people's home therefore avoids major costs to the households. The benefit of stable and convenient water supply in the Tana River Basins is based on the difference between the median monthly coping costs in the rainy season (Ksh 101 per household) and the dry-season (Ksh 1,236 per household), which is Ksh 1,135 per month per household. These are comparable to the avoided coping costs estimated by Cook et al. (2015).

In determining the value of water provision of the Tana River Basin, a distinction is made between, on the one hand, counties that are benefiting from the water infrastructure constructed in combination with the dams, and on the other hand, households in counties that are too remote to benefit from these large scale storage facilities and that therefore are more dependent on the water level in the natural water level in the Tana River. The first “upstream” group is assumed to be supplied with sufficient water in scenarios 1, 2a and 2b. Only in scenario 0, they suffer from reduced water availability, leading to lower water benefits. The second “downstream” group, experiences an opposite trend. Because water is kept upstream for various purposes, the water availability downstream is reduced, thereby increasing the coping costs, or reducing the water benefits for that matter, with every additional infrastructure upstream. In other words, the “downstream” group receives the highest natural water benefits in Scenario 0, and experiences reduced benefits with each consecutive scenario.

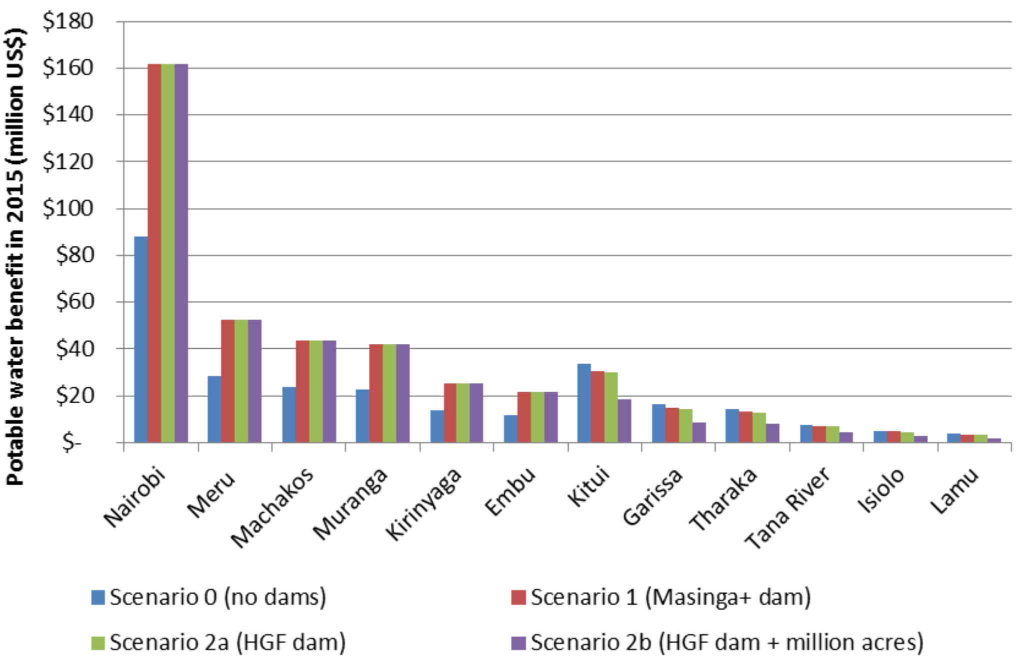

Figure 8.13 Potable water benefits in the Tana River Basin by county (in millions US$/year)

8.4.6 Electricity

With a contribution of half of the electricity production at the national level, hydropower is an important benefit derived from Kenya’s water sources. The Tana River is especially important in this regard for the capital Nairobi which depends for a large share of the hydropower produced by the five dams in the region. In this study, the electricity generated by the current and future dams in the Tana River Basin can be valued at its current production costs or at the costs of unserved energy. As explained in Chapter 5, the avoided cost of unserved electricity is estimated at 0.84 US$/kWh. However, since the HGFD aims to bridge the gap between electricity demand and supply in the region, this value type seems less justified. Therefore, we adopt the “market price” approach costs of 0.12 US$/kWh, which represent the generation costs at a discount rate of 8%. With the varying degree of grid-connection in the counties of the Tana River Basin (see Table 8.2), hydropower serves almost 3 million people in the region, varying from 56%

electricity access in Nairobi to only 4% access in the Tana River county (CRA, 2011). Due to this unequal division of electricity access, 91% of the power generated by the dams is assumed to serve upstream counties while the remaining 9% is delivered to downstream beneficiaries. The current value of the electricity supplied by the dams is estimated at almost $400 million per year. The map by Parshall et al. (2009) below shows how the middle and down-stream sections of the Tana River Basin are extremely expensive to connect to the grid. The high connection costs in rural areas are confirmed by Abdullah and Markandya (2009). Therefore, we assume modest increases in these regions as a result of the addition power supplied by the HGFD, proportional to its current level of connections.

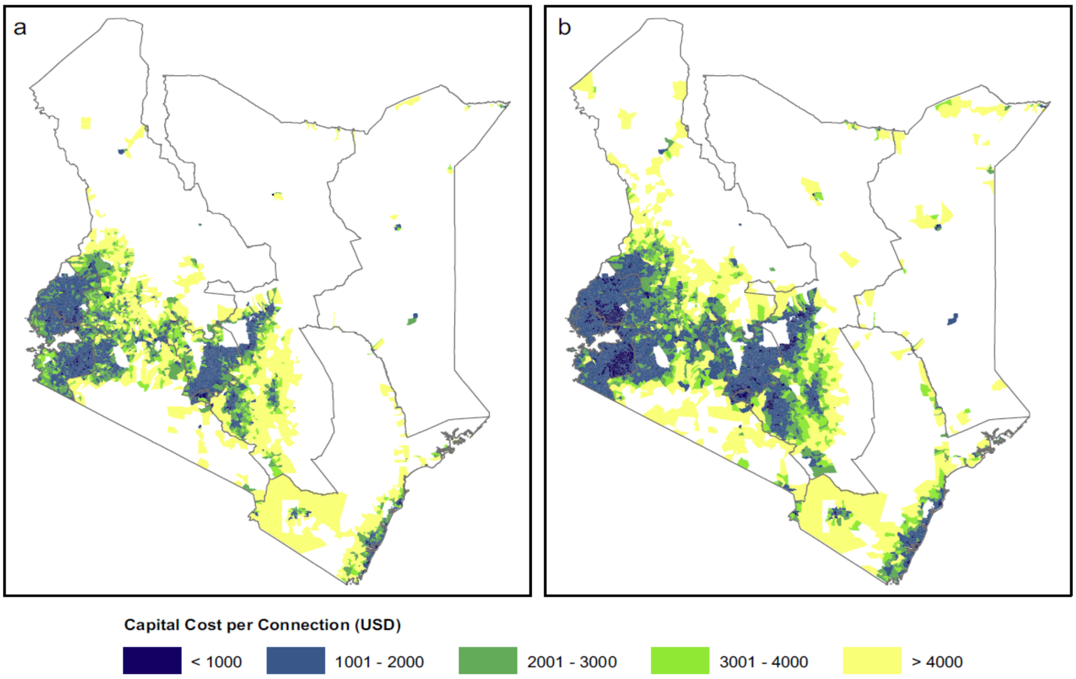

Figure 8.14 Capital cost per household connection, averaged by sub-location (demand node) and shown for each sub-location that is grid compatible in Kenya. (a) Realistic penetration scenario. (b) Full penetration scenario (source: Parshall et al. 2009)

8.5 Costs of the dams and irrigation schemes

Like any other large infrastructure project, dams and irrigation schemes require substantial investments in the planning and construction phase. Investments take the form of financial capital as well as technology and human resources. In comparison with initial investment costs, operation and maintenance costs for dams are relatively low. Besides initial investments and operational costs, large dam projects often have significant impacts on society and the natural environment. These represent an additional cost of the project. A typical example of social impacts caused by large dam projects is the displacement and resettlement of inhabitants of the flooded area. Whereas in the past, resettlement used to be overseen in the planning phase, at present, resettlement costs are increasingly budgeted in project planning. Environmental impacts associated with dams include reduction in water discharge to downstream areas. As with social impacts, the costs of mitigating environmental impacts are also more likely to be included in project planning.

The World Commission on Dams (2000) conducted a worldwide survey on the costs of dams and concluded that the direct costs of dams can be divided into four main categories: (1) construction costs (major component of the total project); (2) resettlement costs (zero to 25%, depending on the local demographic situation) ; (3) environmental mitigation costs (fish migration systems, habitat restoration and artificial flooding of wetlands) and (4) operation and maintenance costs (1-3%). One of the benefits of large dam projects is that, once the construction is completed, the operational costs are proportionally lower than those of smaller dams. On average, these costs amount to only 1-3% of the total project costs. For irrigation projects, these costs are generally higher due to high maintenance costs of the irrigation network. Often the costs are covered by charging user fees for irrigation.

Site characteristics significantly affect the direct costs for dam construction projects. Construction costs are the major component of total project costs in most cases. Construction costs refer to the building of the dam itself, as well as all related elements, such as turbines, canals, irrigation schemes etc. Costs depend mainly on the physical setting of the project, and vary significantly according to local geology, making it difficult to generalize about construction costs. A study by Head (1999) gives a range of US$1,000 to US$3,000 per KW of generated electricity for hydropower projects, while Ljung (2000) provides a range of US$1,500 - US$2,250 per KW.

A recurring issue with dam projects worldwide is the enormous cost overruns. A study of 70 World Bank financed hydropower project shows that the average cost overrun is around 27%. In another study on multipurpose dams, costs overrun allocated budget by an average of 39%. The most recent study on cost overruns is one by Ansar et al. (2014) who show comprehensive evidence that the average cost exceedance of large dam projects is +99%. The majority of cost overruns are due to unpredicted geotechnical conditions. Other causes include late delivery of materials, labour unrest, legal challenges, as well as changes in dam design and natural disasters. The economic performance of a dam is also influenced by how the projected time schedule compares to the actual construction time. 'Schedule slippage' amounted to 80% in a survey by the Asian Development Bank in 1995. Cost overruns and schedule slippages have large implications for the performance of dam projects. Around 8 to 10% of scheduled dams actually become financially unviable if these unforeseen overruns and slippages are taken into account (Gutman 1993, OED 1996).

With support of the insights derived from the above worldwide experiences, total construction costs and operation and maintenance (O&M) costs have been determined for the current dams and the planned HGFD and the million acres project. The location of the irrigation schemes are shown in Figure 8.1 and Figure 8.2.

In calculating the investment costs needed for the current and future irrigation projects, Liangzhi You, et al. (2014) was used which calculated an average investment costs of $9,514 per hectare in the Tana River Basin. Because the O&M costs of irrigation schemes could not be found, knowing that these costs are significantly higher than O&M costs of dams, we assume these are 6% of the investment cost per year. Table 8.3 and Table 8.4 summarize the investment costs and O&M costs of the dam infrastructure and the irrigation schemes in the Tana River Basin, respectively. The costs of the investments are assumed to be evenly spread across the population of the Tana River. The reason for this allocation rule is that in principle, the projects are government funded through tax payers' money and therefore represent trade-offs on behalf of the whole populations. The construction of the dams and the irrigation infrastructure is assumed to be realised in the first five years of the scenarios.

Table 8.3 Costs of dam infrastructure in the Tana River Basin

Scenario	Power capacity (MW)	Investment costs (million US$)	Resettlement costs (million US$)	O&M costs (million US$/yr)
1. Masinga+ dam	567	$1,396	$35	$40
2a. HGFD	700	$2,985	$35	$85
2b. HGFD & million acres	700	$2,985	$53	$85

Table 8.4 Costs of irrigation schemes in the Tana River Basin

Scenario	Irrigation (ha)	Investment costs (US$ million)	O&M costs (million US$/yr)
1. Masinga+ dam	9,160	$87	$5
2a. HGFD	22,260	$212	$13
2b. HGFD & million acres	446,430	$4,247	$255

8.6 Extended Cost Benefit Analysis

The next step in the extended cost benefit analysis (CBA) is to combine the costs side (i.e. the financial inputs resulting from the interventions) and the benefits side (i.e. the socio-economic consequences that result from these interventions). Figure 8.15 shows the aggregated change in the various benefits for the upstream and downstream regions accumulated over a 25 year period at a 4% discount rate for the three scenarios (1, 2a and 2b) relative to the baseline scenario (0) of the naturalised state of the Tana River without dams. Clearly, the construction of the existing dams (i.e. Masinga and others) generated abundant welfare for the upstream region in terms of electricity, potable water and agricultural outputs. The downstream region lost slightly more benefits than it gained. This loss mainly resulted from reduced agricultural productivity and increased health issues. The benefits of scenario 1 for downstream counties come from an increase in power supply and flood prevention. The improvement of the HGF dam compared to the current situation is especially the increase in electricity supply. The downstream positive and negative effects show a similar but less pronounced pattern as occurred in scenario 1. The million acres scenario seems to create significant agricultural benefits in the downstream region (i.e. Tana River county) yet the large water demand of the irrigation schemes is likely to cause serious water shortages in this same region which will lead to substantial declines in health, potable water availability and livestock. The fishing sector is also negatively affected yet compared to the other societal effects this impact is small at a macro-economic level.

Box 1. Definition of costs and benefits

In the field of CBA, ambiguity may arise with regard to the exact definition of costs and benefits. The main basis for the demarcation of costs and benefits in this study is the stakeholders' perspectives. In this study, 'costs' only refer to direct financial effects relevant for the decision-maker who is directly responsible for the financial feasibility of the investment. These values are internal or private to the investment decision. An example cost in this study is the investment of constructing and maintaining the dams. 'Benefits' are referred to as those effects that arise external to the direct domain of the financial decision-maker. The value of benefits can be both negative (e.g. decline of fisheries in the Delta) and positive (e.g. increase of revenues from irrigation schemes).

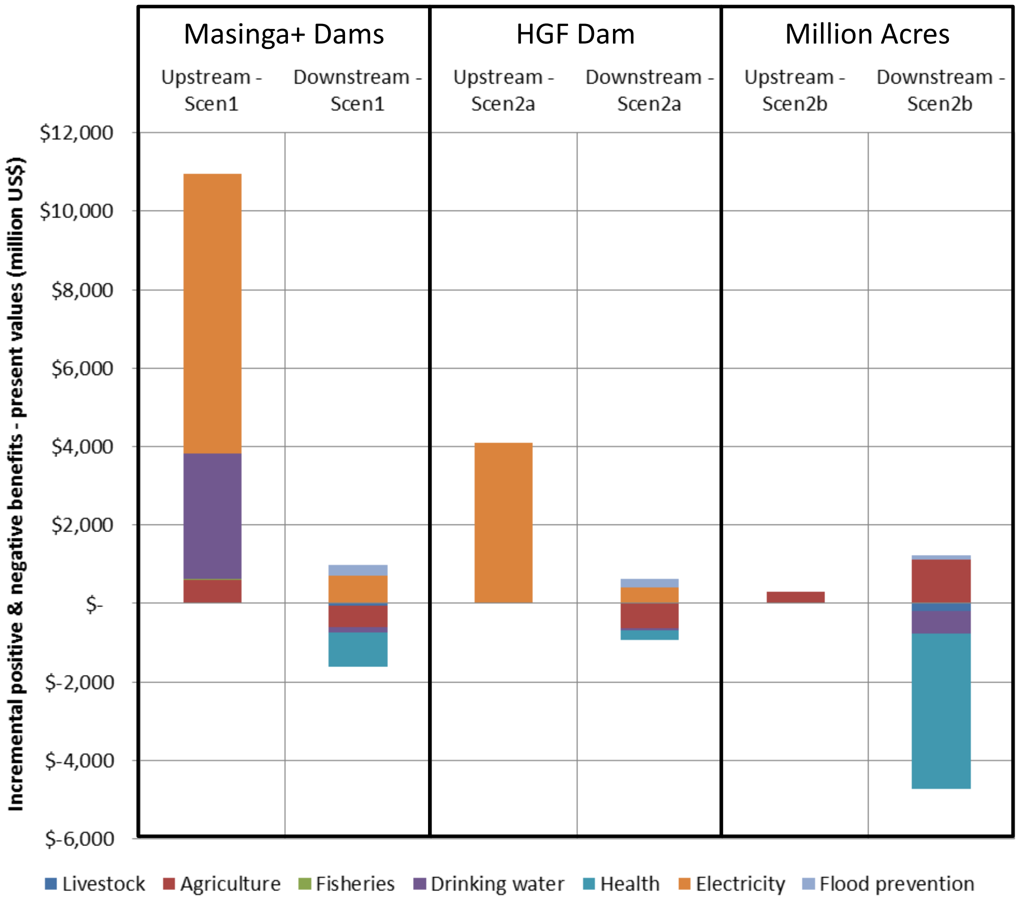

Figure 8.15 Present value of incremental benefits of each additional infrastructural work in the Tana River Basin, 25 years, discount rate 4% (in million US$)

Figure 8.16 presents the incremental costs of each additional infrastructural work in the Tana River Basin, discount rate 4% (in million US$). The temporal pattern shows the assumed five years of initial investment and resettlement costs after which the annual operation and maintenance costs continue at a constant level. The decline in the three curves is caused by the discounting of the costs at 4%. It is good to restate that, based on worldwide experience of large-scale dam construction costs, the costs of the HGF dam is assumed to be twice as high as the US$1.5 billion reported in the media.

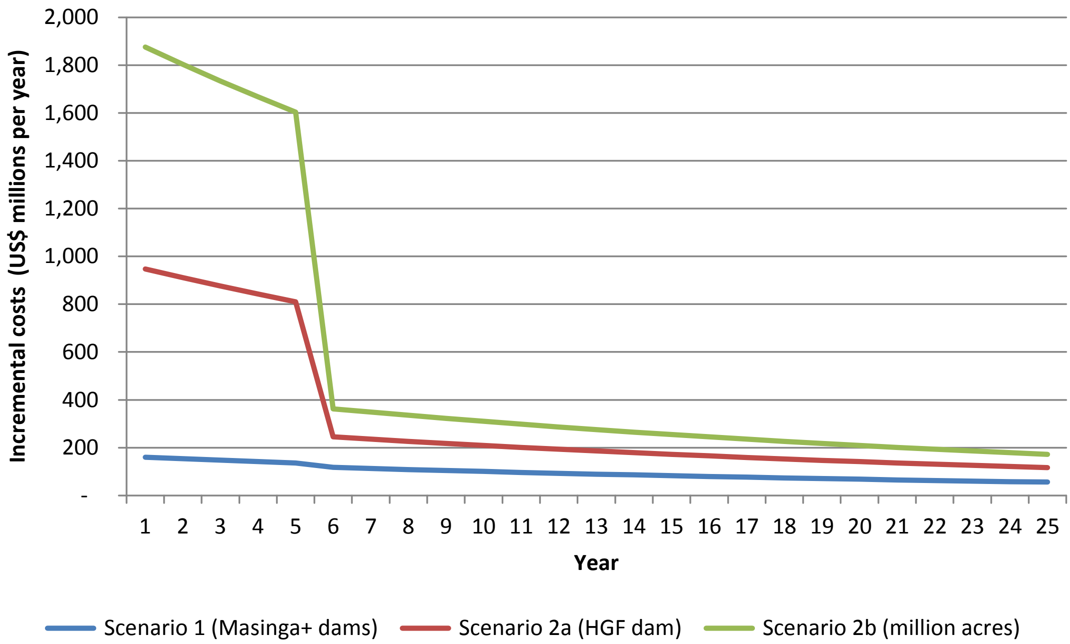

Figure 8.16 Annual incremental costs of each additional infrastructural work in the Tana River Basin, discount rate 4% (in million US$)

Table 8.5 combines the incremental benefits and costs in the CBA reporting the benefit cost ratios (BCR) of each intervention over a period of 25 years and with a discount rate of 4%. Knowing that an intervention is economically feasible at a BCR of 1 or more, it is clear that only the current situation with a BCR of 4.3 a is economically feasible for the Tana River Basin at the given assumed conditions. At the regional level, however, is clear that downstream counties mainly lost in terms of welfare. The HGF dam project scores slightly below 1 although for the upstream region, this project breaks even. The addition of the million acres project, however, is economically undesirable at both the basin and region level. Because the overall net benefits are negative, the BCR even changes sign. This implies that this project is not only very costly, it also causes more damage than it serves society.

Table 8.5 Benefit costs ratios of the incremental changes of each additional infrastructural work in the Tana River Basin, 25 years, discount rate 4%

	Upstream	Downstream	Total Basin
Scenario 1 (Masinga+ dams)	6.0	-1.1	4.3
Scenario 2a (HGF dam)	1.0	-0.2	0.7
Scenario 2b (million acres)	0.1	-4.0	-0.9

Note: Several of the Benefit Cost Ratios of the Downstream counties have a negative sign due to the fact that instead of positive net benefits, negative effects of the interventions dominate. In other words, for the downstream regions the interventions do not only cost money in terms of capital investment, they also experience a reduction in welfare due to the dominance of negative consequences of these interventions.

When looking at the distribution of costs and benefits at a higher resolution by moving the perspective from the basin/region level to the county level, the winners and losers of the three interventions are more specifically revealed (see Figure 8.17). Clearly, upstream counties such as Nairobi and Kirinyaga benefit most from the interventions. For each dollar invested in the current dams, eight dollars were returned in terms of electricity and water benefits within the county. These positive effects in the upstream counties are less pronounced in scenario 2a and 2b, yet the benefits still outweigh the costs (measured proportional to the population share in the Tana Basin). The “losers” of the current dams are the counties Kitui, Tana River and Isiolo. All downstream counties suffer from the million acres project, except for the Tana River county where most of the planned irrigation is scheduled to take place.

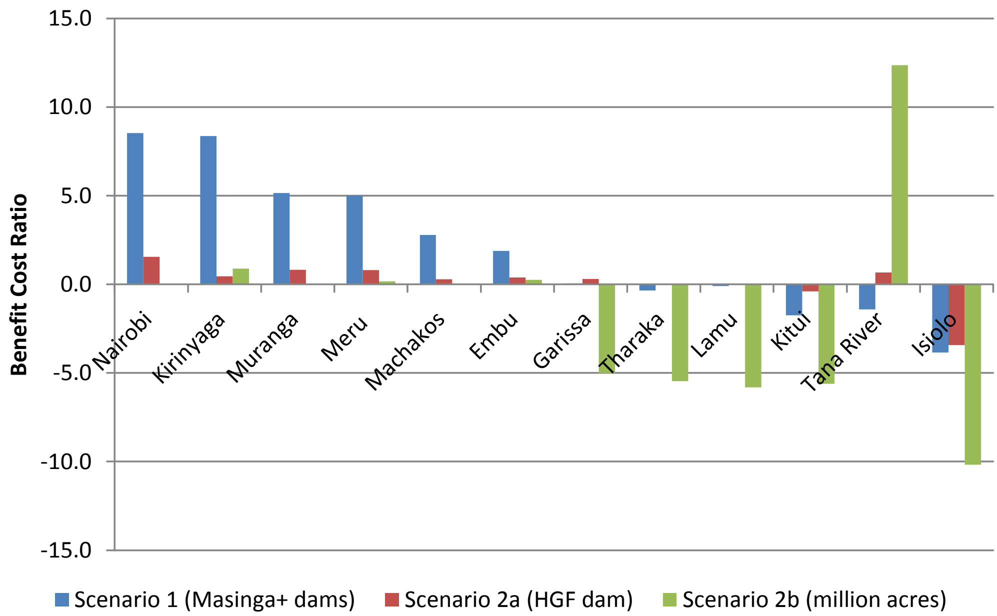

Figure 8.17 Benefit costs ratios of the incremental changes of each additional infrastructural work in the Tana River Basin, 25 years, discount rate 4%

8.7 Sensitivity analysis

The CBA is based on a wide range of assumptions, which we tried to justify as good as we could. The impact of each of these underlying assumptions may affect the final outcome to a smaller or bigger degree. In this Section we test the sensitivity of the results for a number of basic assumptions that are likely to have a notable impact.

8.7.1 Discount rate

First, we test for the sensitivity of the results for the choice of the discount rate. The choice of the discount rate is a controversial issue, because different rates are used by different organisations in different countries. In this study, a discount rate of 4% was used which is common practice in projects with both financial, environmental and social impacts (Pearce 1994). As shown in Figure 8.18, the economic feasibility of the three interventions does not strongly depend on the choice of the discount rate. Adopting an alternative discount rate for the CBA will not fundamentally change the outcome: Scenario 1 remains economically feasible under all discount rates between 0 and 15%, while Scenario 2a and 2b become slightly less economically feasible.

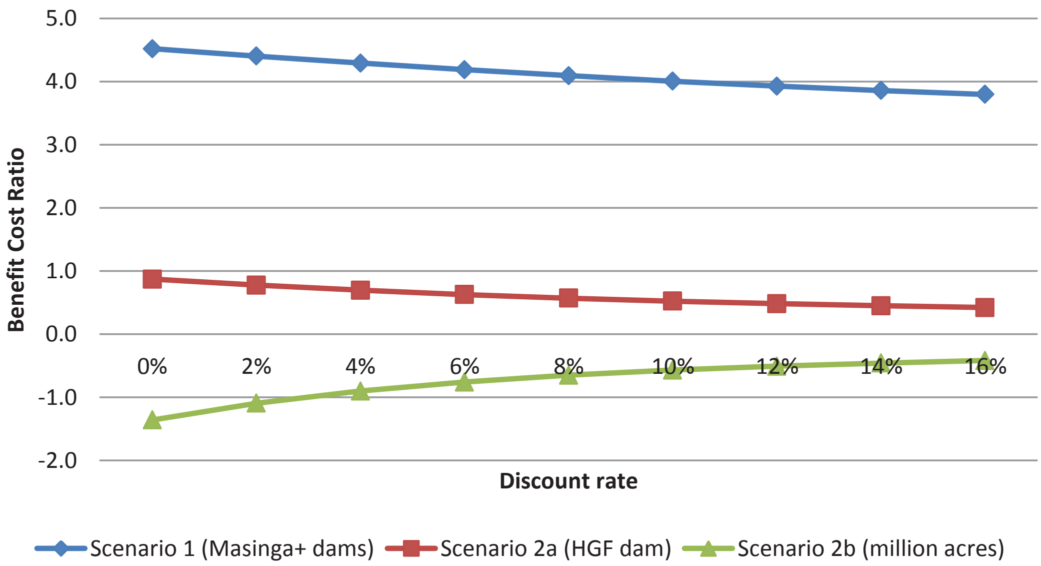

Figure 8.18 Sensitivity of the benefit costs ratios for the discount rate, 25 years (note that the original CBA assumes a discount rate of 4%)

8.7.2 Cost overrun

Similarly, the choice for the cost overrun level of 99% for large-scale dams, as adopted from Ansar et al. (2014) may affect the economic feasibility of the HGF dam significantly. Figure 8.19 shows how the HGF dam becomes economically feasible at the basin level at a cost overrun level of around 50%. At levels of cost overrun below the 50%, the BCR exceeds 1, making it a desirable project from the social planners' perspective. At the county level, however, the HGF dam may lead to higher costs than benefits.

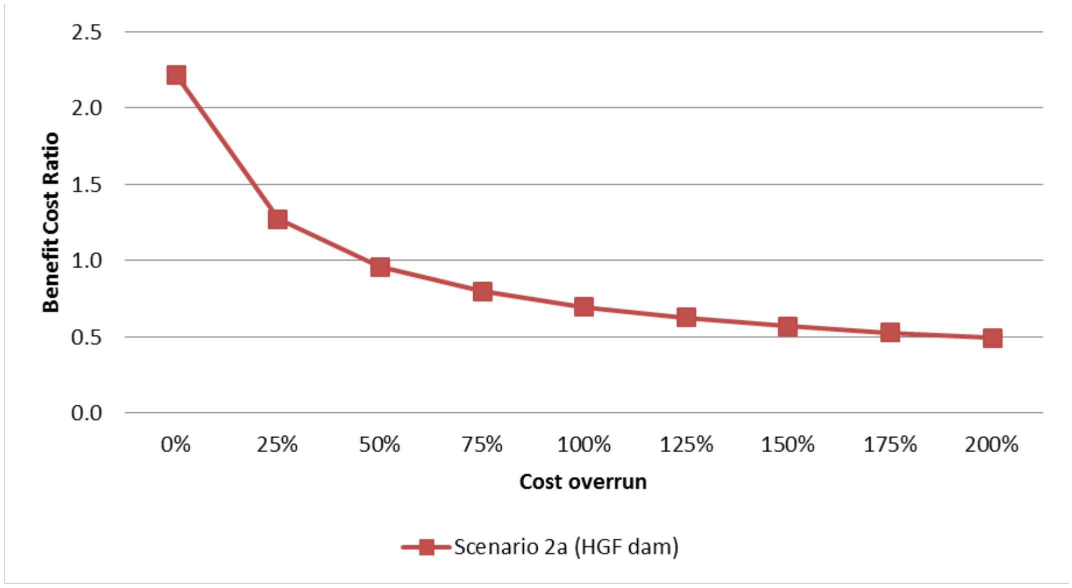

Figure 8.19 Sensitivity of the benefit costs ratio of the HGF dam for the cost overrun (discount rate 4%, 25 years) (note that the original CBA assumes a cost overrun level of 100%)

8.7.3 Climate change

As shown in Figure 8.20, the water discharge varies substantially, depending on the emission scenario and the climate model used for the analysis. Compared to the current baseline without climate change (i.e. no CC), two scenarios were simulated leading to increased precipitation in the region, both run by the CCMA model, and one similar scenario A1b was run with an alternative climate model: Miroc.

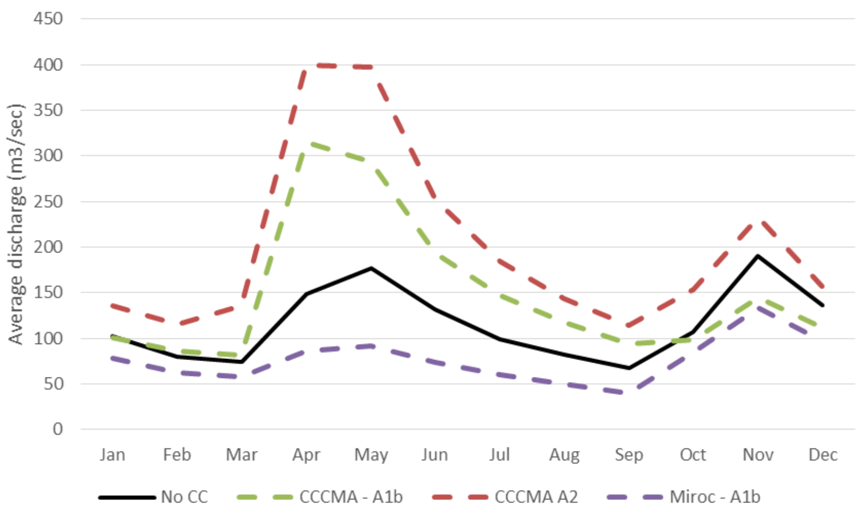

Figure 8.20 Hydrographs for average discharge at Garissa under three alternative emission scenarios for 2050

Figure 8.21 shows how the BCR changes with different climate scenarios. The feasibility of all scenarios is significantly lower in the drier climate scenario (Miroc – A1b). The wetter climate scenario CCCMA – A1b shows little improvement because this the climate scenario lead to a higher peak in the first rainy season and a lower peak in the second season, thereby compensating the gains and the losses. The improvement of the wettest climate scenario (CCCMA - A2) is the highest due to more precipitation throughout the season, leading to a break-even BCR for the HGF dam in Scenario 2a.

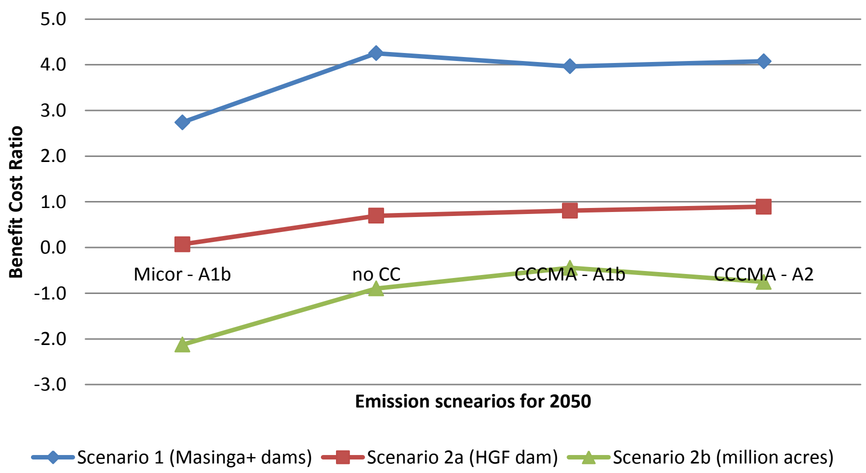

Figure 8.21 Sensitivity of the benefit costs ratio for the climate scenario (discount rate 4%, 25 years)

8.8 Conclusions

This study aimed at clarifying the different values and perspective of the ecosystem services of the Tana River basin and their significance to the Kenyan economy, with a view to providing evidence for development planning and water resources allocation, so as to safeguard its hydrological, ecological and socio-economic benefits. In doing so, strict research boundaries had to be set, which also implies that the study has limitations in terms of the extent to which concrete policy recommendations can be formulated. In other words, the study clearly shows that current development plans in the Tana River Basin have positive but also serious negative effects for various stakeholder groups in the basin. It is beyond the scope of this study to determine whether these negative effects can be mitigated in a cost-effective manner. Although these research boundaries limit the direct use of this study for policy implementation in the Tana River Basin, it also helps to identify a number of critical areas that deserve further attention before the proposed development projects are implemented.

First, the study shows that the negative downstream effects of the HGF dam often outweigh the positive effects of the dam upstream. This outcome does not imply that the HGF dam should not be developed, but instead calls for further investigations to what extent alternative dam management regimes could mitigate the negative effects of the HGF dam downstream. A next study could use the basic information collected in this research to optimize water allocation across the various uses.

Second, although the study shows that several planned development projects fall short in terms of economic efficiency, it does not provide an immediate alternative for the basic economic services provided by these interventions, since this is beyond the scope of the current study. We think these questions are excellent topics for future research. For example, the study shows that the million acres project is difficult to achieve with the present water resources available and that the external costs of this project are significant. Next studies could elaborate on alternative, more water efficient methods of food production.

In summary, the current study is a first step towards a truly integrated analysis which aims at optimising water use within the Tana River Basin, taking into account the development goals of the Kenyan government, the limits to the hydrological system, as well as the capability of stakeholders to adapt to new conditions. For that ambitious goal, this study provides an excellent starting point.

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Annex A Random Utility Theory & Choice modelling

The Choice modelling method that was used to value non- marketed direct values and the indirect values of the mangrove ecosystem services has its theoretical grounding in Lancastrian characteristics theory of value (Lancaster, 1966) and its econometric basis in the random utility theory (Luce, 1959; Mcfadden, 1973). The random utility theory assumes that the utility U that individual i gains from the consumption of a good j is made up of an observable deterministic component V (the utility function) and a random componentε.

$$U_{ij} = V_{ij} + \varepsilon_{ij} \qquad (1)$$

Lancaster proposed that consumers derive satisfaction not from the good per se, but from the attributes of the good. In case of an environmental good, this can be represented as;

$$V_{ij} = \alpha_{ij} + \beta(Bid_j) + \gamma X_j + \mu Z_i \qquad (2)$$

Where X represents environmental attributes and Z are respondents' characteristics. Bid represents the price attached to a certain choice of good j, while α, β, γ and μ are constants. The error component ε is independent of the deterministic part and follows a predetermined distribution. This implies that predictions cannot be made with certainty. The choice made among alternatives will be a function of the probability that the utility associated with a particular option is higher than that associated with other alternatives (Luce, 1959). To illustrate the basic model behind the CE presented here, consider a respondent's choice of forest management option. As illustrated by Hanley *et al*. (1998), assume that utility depends on choices made from some set, C of alternative forest management options. The representative individual is assumed to have a utility function of the form:

$$U_{ij} = V(X_j, Z_i) \qquad (3)$$

Where, for any individual$i$, a given level of utility will be associated with any alternative forest management option$j$. Alternative j will be chosen over some other option k *iff* $U_j > U_k U_i > U_j$.
Utility derived from any forest management option is assumed to depend on the attributes of the management option X_j (Lancaster, 1966). These attributes may be viewed differently by different agents, whose socioeconomic characteristics, Z_i will also affect utility. However, a consumer may not choose what seems to the analyst to be the preferred alternative. To explain such variations in choice, a random element, ε is included as a component of the consumer's utility function. Equation 3 can then be re-written as:

$$U_{ij} = V(X_j, Z_i) + \varepsilon(X_j, Z_i) \qquad (4)$$

and the probability that individual $i$will choose option j over other options k is given by:

$$Pr[i|C] = Pr[U_j > U_k], \quad \forall j \in C \qquad (5)$$
$$= Pr[(V_j + \varepsilon_j) > (V_k + \varepsilon_k)]$$
$$= Pr[(V_j - V_k) > \xi]$$

Where C is the complete choice set. In order to estimate equation 5, assumptions must be made over the distributions of the error terms. A typical assumption is that the errors are Gumbel-distributed and independently and identically distributed (McFadden, 1973). This leads to the use of multinomial logit (MNL) model to determine the probability of choosing j:

$$Pr[i|C] = \frac{\exp(\mu V_j)}{\sum_{j \epsilon C} \exp(\mu V_k)} \qquad (6)$$

Here, μ is a scale parameter, which is usually assumed to be equal to 1 (implying constant error variance). As μ tends to infinity, the model becomes deterministic. An important implication (Hanley *et al.,* 2001) of this specification is that selections from the choice set must obey the Independence from Irrelevant Alternatives (IIA) property (Luce, 1959). IIA, also known as the Luce's choice axiom, states that relative probabilities of two options being selected are unaffected by the introduction or removal of other alternatives.

Each respondent's multinomial responses that were obtained from the choice sets were interpreted as the choice results from the respondents' utility maximization problem. In this study, each respondent will be given 4 choice sets and asked to choose among 3 alternatives including the status quo. The choice results for alternative j of respondent i will be either 'yes' or 'no'. The log-likelihood function can be written as:

$$ln = \sum_{i=1}^{N} \sum_{j=1}^{3} \left[y_{ij} \, ln \, Pr[i|C] \right] \qquad (7)$$

Where y_{ij} is a binary variable (1 when respondent i chooses alternative j among 3 alternatives and 0 otherwise) and N is the total number of respondents. The parameters of this log-likelihood function are estimated by maximum likelihood estimation.

Annex B Water extraction by dams

			DAM			EVAP	TRANSFER	IRRIGATION												
	Direct (D) / Reservoir (R)	Crop Calender	Min res.	Max res.	Through	Evap res.	Trans	Area irri	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Developments in TCA			m3	m3	m3/day	m3/day	m3/day	ha	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day	m3/day
Sasumua Dam - Nairobi water transfer	RESERVOIR		0	$16*10^6$	64800	1469	56200													
Kamburu Dam (electricity)	DIRECT					20548														
Gitaru Dam (storage)	DIRECT					2740														
Kindaruma Dam (electricity)	DIRECT					2192														
Intake Hola irrigation	DIRECT	Maize						1000	64927	0	0	0	129854	129854	64927	0	0	0	129854	129854
Thika Dam - Nairobi water transfer	RESERVOIR		0	$69*10^6$	63072	1728	440700													
Masinga Dam (water storage) - intake Mwea Irrigation - Kitui water transfer	RESERVOIR	Rice	$150*10^6$	$1560*10^6$	6480000	67392	63014	7860	658307	658307	658307	658307	658307	329154	329154	329154	658307	658307	658307	658307
Kiambere Dam (electricity) - Mwingi water transfer	DIRECT					80137	1390													
Intake Kaggari-gaturi-Kieni Irrigation	DIRECT	Year-Round						700	50033	50033	50033	50033	50033	50033	50033	50033	50033	50033	50033	50033
Intake Mitunguu Irrigation	DIRECT	Year-Round						600	12040	12040	12040	12040	12040	12040	12040	12040	12040	12040	12040	12040
Intake Bura Irrigation	DIRECT	Maize						3000	183115	0	0	0	366230	366230	183115	0	0	0	366230	366230
Intake Tana Delta Irrigation	DIRECT	Rice						2000	260370	260370	260370	260370	260370	130185	130185	130185	260370	260370	260370	260370
HGFD	RESERVOIR	Maize	$231*10^6$	$5757*10^6$	10800000	756986		400000	4718033	0	0	0	9436066	9436066	4718033	0	0	0	9436066	9436066
Intake Bura Irrigation Expansion	DIRECT	Maize						6500	396776	0	0	0	793553	793553	396776	0	0	0	793553	793553
Intake Hola Irrigation Expansion	DIRECT	Maize						3000	194781	0	0	0	389562	389562	194781	0	0	0	389562	389562
Intake Tana Delta Irrigation Extension	DIRECT	Year-Round						20000	1451520	1451520	1451520	1451520	1451520	1451520	1451520	1451520	1451520	1451520	1451520	1451520
Nanigi - Lamu water transfer	DIRECT						181550													
Karimenu 2 Dam - Nairobi water transfer	DIRECT						46656													
Chania B Dam - Nairobi water transfer	DIRECT						65664													
Maragua 4 Dam - Nairobi water transfer	DIRECT						132192													
Thiba Dam - Intake Mwea Irrigation Extension	DIRECT	Rice						11000	1176421	1176421	1176421	1176421	1176421	588211	588211	588211	1176421	1176421	1176421	1176421
Intake Kagaari-Gaturi-Kyeni Extension	DIRECT	Year-Round						2000	142953	142953	142953	142953	142953	142953	142953	142953	142953	142953	142953	142953
Intake Muringa Banana Irrigation	DIRECT	Year-Round						3570	127008	127008	127008	127008	127008	127008	127008	127008	127008	127008	127008	127008
Intake Kanuti Irrigation	DIRECT	Year-Round						500	18144	18144	18144	18144	18144	18144	18144	18144	18144	18144	18144	18144
Kora Dam - Intake Kora Irrigation	RESERVOIR		$543*10^6$	$1172*10^6$	14299200	86164														
Umaa Dam - Nairobi water transfer	DIRECT						2500													

Table 6 Water extractions and parameterisations of scenarios o, 1, 2a and 2b