Integrated Water Resources Management in a Changing Climate: The Implication of Anthropogenic Activities on the Tana and Athi/Sabaki Rivers Water System for Sustainable Development

Saeed Mwaguni, Renison K. Ruwa, Jacob Odhiambo-Ochiewo, and Melckzedec Osore

Abstract

This paper highlights the effects of damming and farming activities on the Tana and Athi/Sabaki Rivers' water system. The two activities are responsible for freshwater shortages, pollution, and habitat and community modification downstream. Damming has resulted in modification of the stream flow, and in changes in the water table; while nutrient loading and sedimentation from irrigated agriculture, human settlements and industrial activities upstream are responsible for the pollution effect. The resulting effects were evaluated using the Global International Waters Assessment scoping methodology backed with hindsight experiences of the team members in both environmental and socio-economic issues. The individual scores when averaged led to the following results: 1) the effect of damming the river system was scored at 3 in a scale of 1–3, signifying a severe impact as attested by the freshwater shortages experienced downstream; 2) the effect of nutrient loading and sedimentation, using the same scale, was score at 2, a score that exhibited a moderate pollution problem. The degree of impact from nutrient and sediment loading varied with seasons. It was localized and more pronounced in hot spots in the dry season; while in the wet period, it occurred throughout the system as flooding occurred; 3) reduced stream flow and pollution affected ecosystem functions, resulting in habitat and community modification, 4) the impact of global climate change was difficult to score at the river basin level. However, deforestation resulting from slash and burn agriculture and harvesting of wood to meet domestic energy needs were practiced in a large scale, reducing the action of forests as carbon sinks, while promoting the emission of carbon-dioxide, which contribute to global climate change. This study concluded that freshwater shortages and pollution were issues of major concern and they were causing socio-economic conflicts. To address the concerns, a proactive approach borrowing from the tenets of Integrated Water Resources Management, Ecosystem Based Management and Integrated Coastal Zone Planning and Management, need be adopted as the vehicles that would promote sustainable development in the river basin.

Keywords

Damming • Irrigated farming • Pollution • Habitat and community modification • Global change • Freshwater shortages

S. Mwaguni (✉)
Department of Environment and Health Sciences, Technical University of Mombasa, P.O. Box 90420, 80100 Mombasa, Kenya
e-mail: smwaguni@tum.ac.ke

R.K. Ruwa • J. Odhiambo-Ochiewo • M. Osore
Kenya Marine and Fisheries Research Institute, P.O. Box 81651, 80100 Mombasa, Kenya
e-mail: reniruwa@yahoo.com; jacobochiewo@yahoo.com; babaalmasi@yahoo.co.uk

S. Diop et al. (eds.), *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean*, Estuaries of the World,
DOI 10.1007/978-3-319-25370-1_7

Introduction

This paper highlights the effects of human activities on the Tana and Athi/Sabaki Rivers water system –specifically analyzing the effects resulting from damming and farming activities along the river banks. The issues of concern discussed in this paper are 1) *freshwater shortages*, resulting from stream flow modification due to damming of the river upstream to produce hydro-electricity, and 2) *pollution* of the water system due to nutrient loading and sedimentation from irrigated agriculture and discharges of effluent from both industrial establishments and domestic sources. The concerns arising from freshwater shortages and pollution of the water system, including their socio-economic effects were scoped for score and impact, taking into consideration the influences rapid economic growth, population increase and global change, which allowed for the prediction of the possible future outlook for the two concerns and the interventions needed in order to promote sustainable use of the water system.

Geology and Climatic Conditions

The Tana River traverses the Tana County, an area that is geologically composed of the Mesozoic peri-oceanic troughs that are block shaped mono-clinical structures made of thick folded and faulted Meso-Cenozoic strata (Carbone and Accordi 2000), that comprise two structural layers –the upper layer sedimentary rocks, and the lower metamorphic rocks. In addition, Jurassic deposits, mainly composed of sandstones and carbonates are found. There are also Karoo deposits of clay and sand, and Paleogene deposits of up to more than 3,000m thickness.

It is through this terrain that the Tana River, later joined by the perennial rivers Athi/Sabaki in its upper catchment, travel from its mouth in the flanks of Mount Kenya in the Tharaka County in the North, flowing east to Mbalambala and Garissa –forming the Lower Tana River Basin, then continues southwards to Kipini (located half way between Malindi and Lamu) to the East, before discharging its contents into the Indian Ocean. From its source to discharge, the river stretches a distance of 1012 km, (Saha 1982).

The profile of the Tana-Athi/Sabaki river system is given in Table 1, while the extent of its drainage basin, which covers an area of approximately 120,000 km^2 (Ogwenyi et al. 1993a), is shown in Fig. 1.

As is characteristic for the rest of Kenya, rainfall experienced in the Tana River Basin is bimodal with the major rainfall peak, occurring during the South East Monsoon (SEM) between April and June. The minor rainfall period peak occurs between October and December, a season where the North East Monsoons (NEM) predominate.

The rainfall distribution in the Tana River Basin is given in Fig. 2, while the characteristic conditions of climate and the Agro-ecological zones found within its confines are presented in Tables 2 and 3.

The Tana River is regularly replenished by a number of tributaries that have their headwaters on Mount Kenya. However, from Mbalambala to Kipini, the river flows through a semi-arid region, with characteristic hot and dry weather conditions where it is joined by the perennial rivers Talu, Hirimani, Galole and Tiva. Being dry for most of the year, their replenishment contribution to the River Tana is insufficient to counter the continuous loss of water through evaporation in the prevailing hot and dry weather conditions. Rainfall comes in two rain seasons. It decreases both towards the interior and northwards, resulting in increased aridity index. The rain increases southwards with a recording of 350 mm per annum registered at Garissa, 470 mm per annum at Hola, and up to over 1000 mm per annum at Kipini. As a result the lower Tana Belt experiences semi-arid to arid tropical climate with a bimodal pattern of rainfall, influenced by the monsoon winds (McClanahan and Young 1996; Carbone and Accordi 2000). The rainfall is generally low and erratic and with a mean average ranges of between 300mm–500mm.

Before entering the Indian Ocean, this river system branches off to a complex system of tidal creeks, flood plains, coastal lakes and mangrove swamps –collectively referred to as the Tana Delta. The Delta covers an area of approximately 1,300 km^2 behind a 50m high sand dune system that protects it from the wave action of the open sea in the Ugwana Bay (UNEP 1998). The mangrove cover supported by the Tana estuarine environment, is estimated to span an area of 39,825 Ha while that of the Athi//Sabaki is 13,155 Ha (Doute et al. 1981; UNEP 1998). The Tana Delta is characterized by wetlands of great potential for agriculture, seasonal grazing and attraction for tourism.

The river discharges large volumes of freshwater and sediment into the Indian Ocean annually. The distribution and median monthly discharges for the period 1941–1996 are given in the Fig. 2. The peaks in May and November

Table 1 Profile of the Tana-Athi/Sabaki River system

Drainage Basin	Size (km^2)	Mean annual run-off (m^3 × 10^6)	Length (km)	Source
Tana River	132,090	4,700	708	Mt Kenya & Aberdare ranges
Athi-Sabaki	69,930	1,295	(547)	

Source: Hartziolos et al. (1994), Hirji et al. (1996), UNEP (2001), Vanden Bossche and Bernacsek (1990), and FAO (2001)

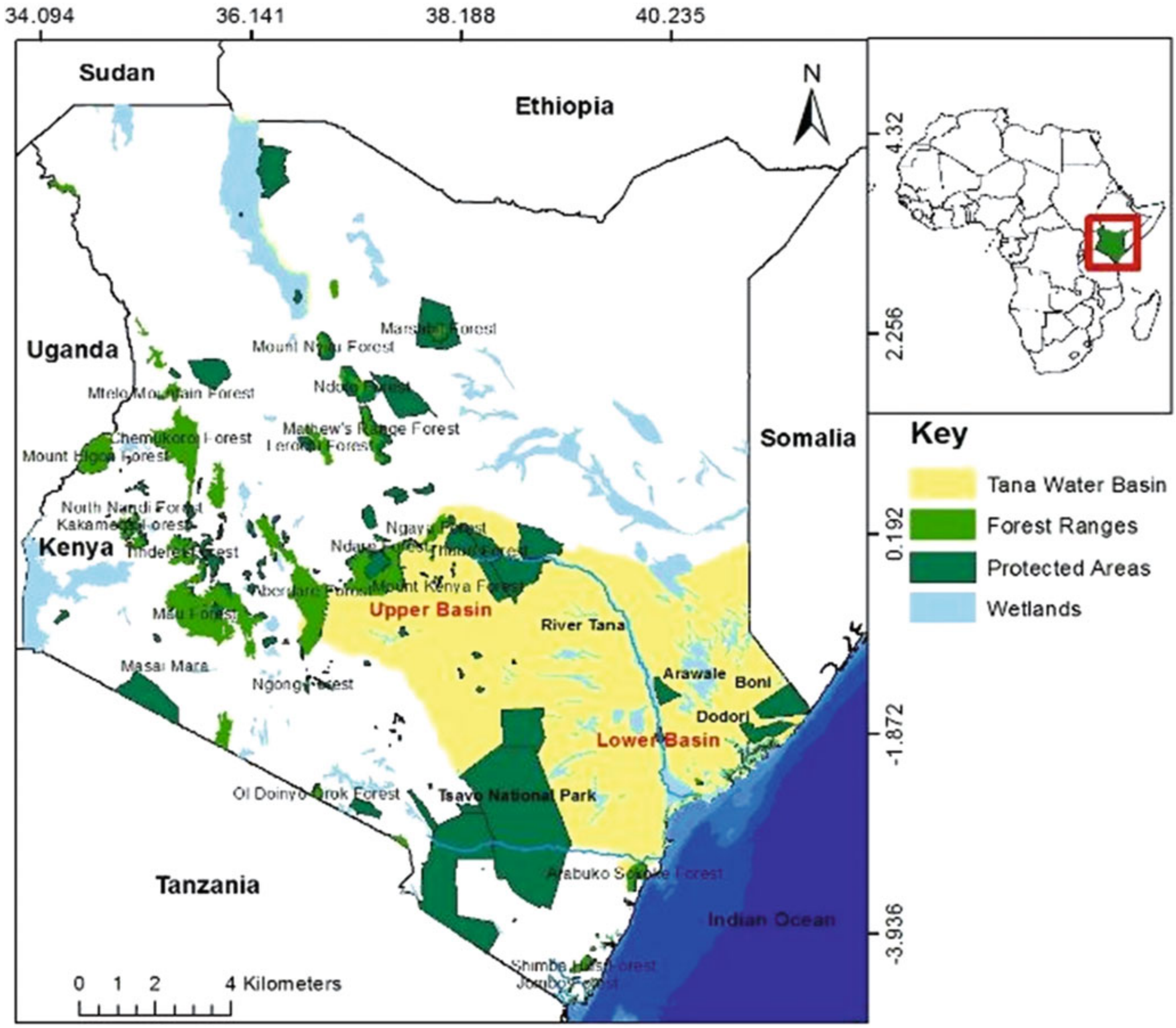

Fig. 1 Map of Kenya showing the Tana River, its Major Tributaries and Drainage Basin

correspond to the peak rainfall season during the long rains and the short rains.

The Tana and Athi/Sabaki Rivers system define the hydrology of the coastal area of the Tana River County. The rivers' drainage systems link the hinterland with the Indian Ocean and have a catchment that extends from the coastal hinterland into Mount Kenya and the Aberdare Ranges. The catchment ecosystem structure and function of the two rivers is dependent on rainfall and drainage process of water discharge, sediment transport, flooding, inundation and alluvial deposition (Brinson 1990), Fig. 3.

The rivers' water discharge therefore follows the bimodal precipitation pattern with the extent of their watershed environment defined by the dynamics of seasonality –where, as the rivers flow into the hot and arid areas, the tributaries decrease in volume of the water flow, and in some cases, even disappear completely due to evaporation and soil infiltration. Owing to the large volume of water from their sources, the Tana, Athi/Sabaki rivers system is generally perennial. As the rivers system recharge surrounding areas through floods and/or groundwater, an environment suitable for the development of unique ecosystems is provided. Against this background, the water-shed of the Tana-Athi/Sabaki rivers system has a flood plain of evergreen forest with riverine endemic *Populus ilicifolia* (Medley and Hughes 1996), which explains the existence of several areas of forest, woodland and grassland in the lower Tana.

The riverine forest starts from Mbalambala to Kipini. It extends 0.5–3.0 km on either side of the river. This forest is a remnant of the rainforest belt extending from the Congo Basin

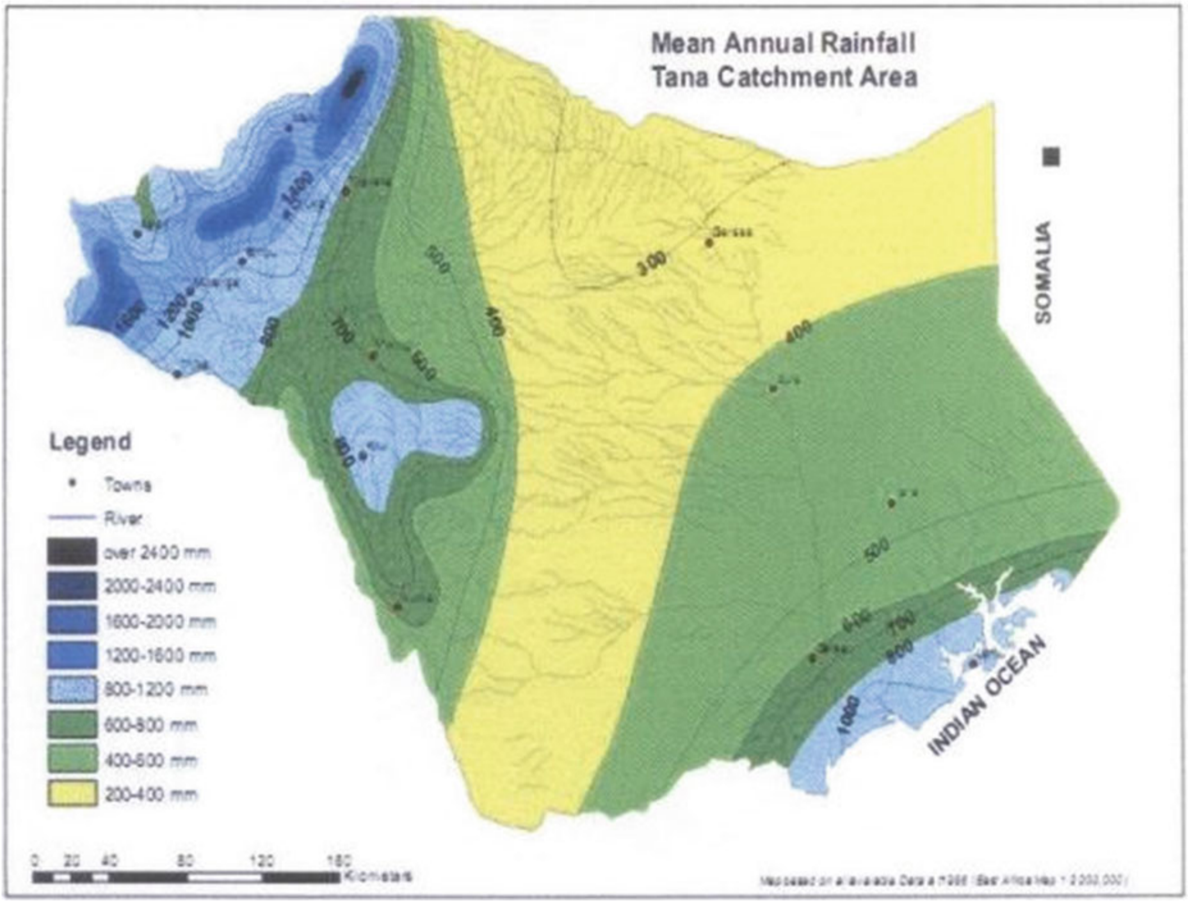

Fig. 2 Mean rainfall distribution in the Tana River Basin (Source: Kasper Lange 2014)

Table 2 Climatic conditions in the Tana River Basin

Zone	Ratio RF/Ep. %	Class	Rainfall mm	Potential evaporation, mm	Vegetation	Potential plant growth
I	>80	Humid	1100–2700	1200–2000	Moist forest	Very high
II	65–90	Sub-humid	1000–1600	1300–2100	Moist forest, dry forest	High
III	50–65	Semi-humid	800–1400	1450–2200	Dry forest, moist land	High to medium
IV	40–50	Semi-humid to Semi-dry	600–1100	1550–2200	Dry woodland, bush land	Medium
V	25–40	Semi-arid	450–900	1650–2300	Bush land	Medium to low
VI	15–25	Arid	300–550	1900–2400	Bush land, scrub land	Low
VII	<15	Very arid	150–350	2100–2500	Desert Scrub	Very low

Source: WARMA 2009: in Tana Delta Strategic ESA, GOK 2012
Key *RF* Rainfall, *Ep*. Evaporation

to the Eastern Coast of Africa (Livingstone 1975, adapted from Medley 1990). The extent of the forest in the river basin is determined by the depth of the water table, as it drops off significantly from the edge of the river (Marsh 1978; Hughes 1985). Away from the flood plain, the land is characterized by bush land, common in dry regions; scattered and dominated by thorny bushes. The riverine forest is unique because of its biodiversity. The Tana riverine forest houses the Tana River Red Colobus and the Tana River Mangabey –two endemic sub-species of the primate, giving the area a high conservation value. The composition, structure and the dynamics of the forests are influenced by the hydrological characteristics of the river system (Marsh 1978; Hughes 1988). The Tana riverine forest has been declining due to lack of regeneration, attributed to decreased peak flows (Marsh 1976; Hughes 1985; Medley 1990).

Table 3 The agro-ecological zones in the Tana Basin

AEZ	Zone	Characteristics and types of crops and livestock reared
Tropical Alpine	TA 0, I, II	No land use, National Park, Limited grazing
Upper Highland	UH 0, 1, 2, 3, 4	Very wet, important as catchment areas, bamboo thickets and forest reserves pyrethrum barley, oats, peas, radish, rapeseed, Irish potatoes, kohlrabi, celery, leeks, wheat, plums, pears, apples, pasture and forage, white clover, rye grass, grade dairy & beef cattle, merino sheep, 0.8–2 ha/LU
Lower Highland	LH 0, 1, 2, 3, 4, 5	Forests, long cropping season, good crop yield for lettuces, tea, kales, peas, cabbage, carrots, Irish potatoes, pyrethrum, hybrid maize, leeks. Napier grass, clover and grade dairy cows, black wattle, kikuyu grass, apples, pears, plums, avocadoes, wheat, barley, Rhodes grass, white clover, 0.5–6 ha/LU
Upper Midland Zones	UM 1, 2, 3, 4, 5, 6	Coffee-tea and sunflower zone. Crops grown includes; tea, coffee, Irish potatoes, tomatoes, cabbages, maize, bananas, beans, sun flower, tobacco, sweet potatoes, citrus, mangoes, pawpaw, avocadoes, passion fruits, cassava, yams, sugarcane, miraa, taro, fodder crops/legumes, 0.5–5 ha/LU
Lower Midland Zones	LM 3, 4, 5, 6	Cotton-livestock-millet zone. Crops grown include; cotton, dry land maize, sorghum, dolichos, ground nuts, tobacco, sweet potatoes, cassava, pineapples, cowpeas, chick peas, soya bean, pumpkins, green grams, mangoes, onions, castor, bulrush/proso/finger millet, pigeon peas, macadamia nuts, sisal, *leucaena leucocephala,* bana grass, zebra grass, sirato, 0.8–4.5 ha/LU
Lowland/Inner lowland	L 5, 6	Livestock millet zone-short cropping season. Crops grown include; bulrush/proso millet green grams, gourds, dry land composite maize, dwarf sorghum, sisal, castor, jojoba, cowpeas, bambara nuts, 2.5–5.5 ha/LU, game ranching with Oryx, gazelle and gerenuk
Coastal lowland	CL 3, 4, 5, 6	Coconut-cassava zone: composite maize, white sorghum, finger millet, bulrush millet, foxtail millet, green grams, sunflower, ground nuts, lima beans, cucumber, garlic, water melons, bixa, pepper, chilies, sisal, cashew nuts, pineapples, bananas, lemons, ground nuts, cow peas, cassava okra, Indian avocadoes, pawpaws, bocoboco, jatropha, rice, sugarcane, castor, sweetpotatoes, dolichos, gourds, eggplant, simsim, limes, oranges, mangoes, *leucaena leucocephala,* bana grass, fodder legumes, maram beans, buffel grass, siratro, centro, acacia, albida, 0.2–5 ha/LU, sclerophytic evergreen (infested with tsetse fly) bush land, seasonally flooded grasslands

Source: (WRMA 2009) in Tana Delta Strategic ESA, 2012

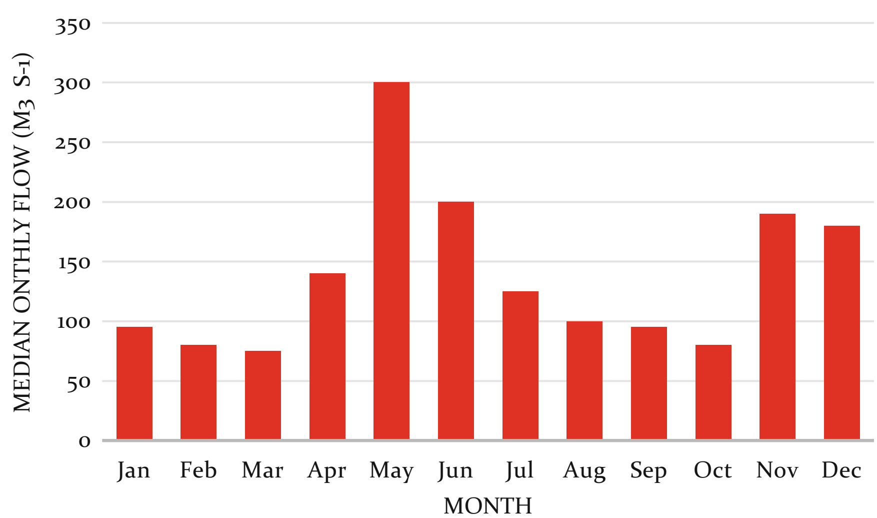

Fig. 3 Distribution of median m discharges for the River Tana 1941–1996: (Maingi and Marsh 2002)

Despite the large size of the Tana River County −38,782 km^2, only 240,075 people live there. This gives a population density of only 6.2 people per km^2. Harsh environmental conditions have made the County sparsely populated. The Pokomo, the Orma and the Wardey are the three major communities living here. 72% of the population lives below the poverty line, and the poverty index is 62% (GoK 2009). Weather conditions determine the socio-economic activities taking place in the county and population mobility in the area is attributed mainly to nomadic pastoralism in response to drought and flood episodic events, trade movements and rural to urban migration of the population in search of employment opportunities.

The population of the Tana County, comprising the Tana River and Tana Delta districts grew by 40.9% between 1989–1999. Its growth in the period 1999 to 2009 was 32.7, indicating a decline of 8.2%. The decline in the population over the period may be attributed to several causes

Table 4 Population census figures Tana River District 1989–2009

1989	1999	2009	
District Pop: 128,426	District Pop: 180,901	Tana River: 143,411	Tana Delta: 96,664
Divisions:	Divisions	Divisions:	Divisions:
Galole 37,712	Galole 34,948	Galole 44,981	Garsen 43,346
Garsen 47,206	Garsen 51,592	Bura 31,786	Tarassa 33,741
Bura 25,035	Bura 28,848	Madogo 27,464	Kipini 19,577
Madogo 16,473	Madogo 21,731	Bangale 23,295	
	Bangale 14,853	Wenje 15,885	
	Wenje 12, 868		
	Kipini 16,243		

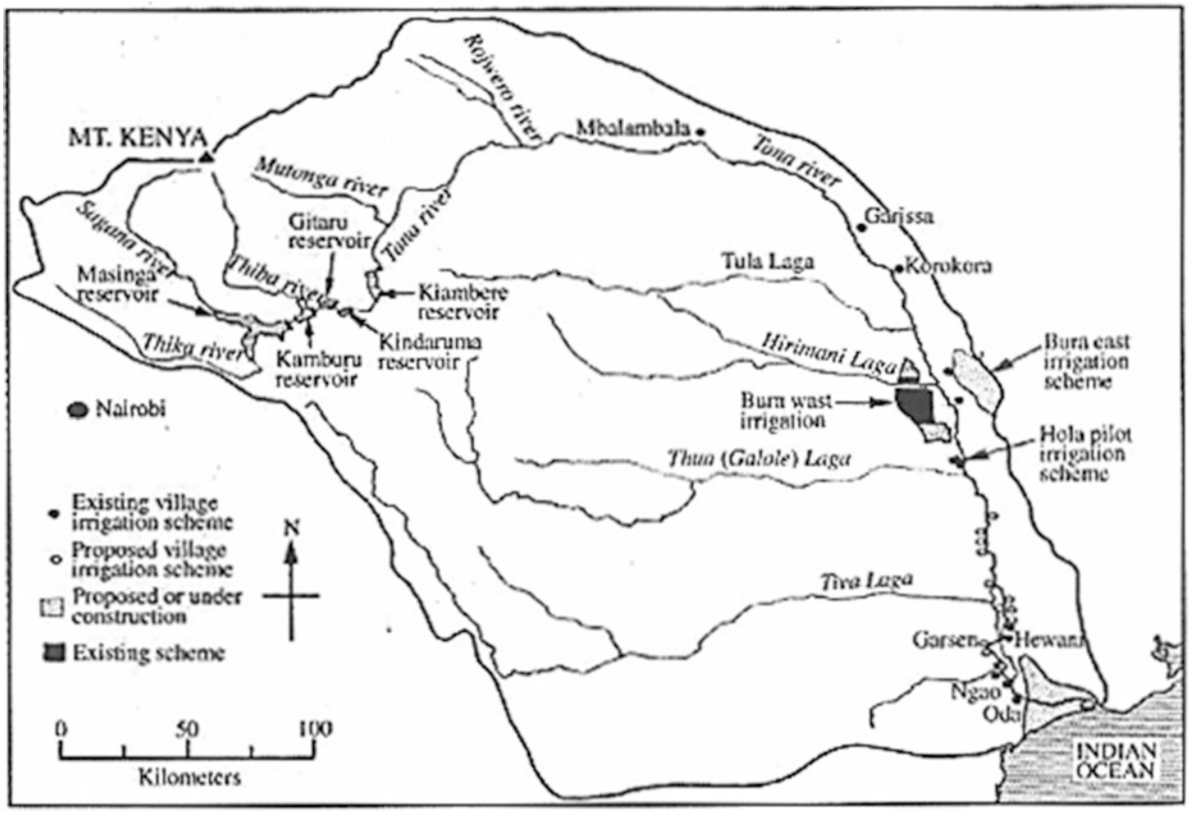

Fig. 4 Location of dams and irrigation schemes on the River Tana (Source: Maingi and Marsh 2002; Vanden Bossche and Bernacsek 1990; Maingi and Marsh 2001)

including insecurity, or people escaping the harsh environmental conditions to seek solace in other areas as shown in the information in Table 4.

The socio-economic wellbeing of the people residing in the Tana River Basin is dictated by availability of, and patterns of use of natural resources for a majority of people depend on it for support of their livelihoods. As a result, the waters of the Tana-Athi/Sabaki system are utilized for both consumptive and non-consumptive purposes. The consumptive uses include water abstraction for irrigated agriculture, for potable and domestic needs, for commercial uses and for industrial development purposes. The non-consumptive uses include transportation, exploitation for its aesthetic beauty in tourism and, damming for hydroelectric power production. The economic sectors supported by the river system include agriculture, fisheries, industry, manufacturing and services, tourism and transportation. The largest and most important uses of this water system remains to be commercial irrigation and hydro-electric power generation, with 5 dams so far having been built in the upper basin for the two purposes. There are also several irrigation schemes that support subsistence farming, Fig. 4.

Table 5 Profile of the dams in the Tana River water system

River	Reservoir	Volume (10^6 m^3)	Area (km^2)	Fishery (ty^{-1})
Tana	Masinga (1981)	1,560	120	480
	Kamburu (1975)	156	15	–
	Gitaru (1978)	20	3.1	–
	Kindaruma (1968)	16	2.4	–
	Kiambere (1988)	535	25	50

Kindaruma, Kamburu and Gitaru were the first to be built following each other. These three dams had small reservoirs, leaving the Tana River, essentially unregulated (Hughes 1985).

Masinga dam –the largest so far, stored more water, and had a capacity to generate 40 MW of electrical power. It is sited upstream the other dams to serve as the regulating reservoir, besides –improving electrical power generation during the dry season, increase irrigation potential in the lower Tana basin; thereby increasing the utilization of dry season flows in the upper parts of the river. The Kiambere Dam, which took four years to complete had an installed hydro-power generation capacity standing at 140MW. The profile of the dams in this water system, which is found in the river Tana alone, is as shown in Table. 5.

The agricultural practice within the river basin is dominated by peasant farming, mostly for subsistence crop production and animal husbandry. These activities form the mainstay of the economy of the rural people. Pastoralism is practiced by the Orma and Wardey while the Pokomo engage in crop production. The farming practice is rotational with slash and burn method being applied for land clearance. Due to the large population in the Tana Basin, agricultural land is scarce, resulting in short fallow periods and the parcels of land to cultivated more frequently. In the long-run, this has led to poor yields due to loss of soil fertility from the frequent use of the land. To counter the scarcity of parcels of land for farming, deforestation has been taking place to increase the size of land available for agriculture. This has in turn led to desertification in the upper stretches of land that is already poorly vegetated, due to the semi-arid and arid environments, making farming in the new acquired lands difficult to sustain.

Apart from the subsistence farming, there is irrigated agriculture, which is practiced mainly for commercial crop production. Though the potential for irrigated agriculture is not established, it is t known that the full potential is yet to be exploited. Since large scale irrigated farming and livestock production activities use large amounts of fertilizers and pesticides to enhance productivity, their effects on the water quality in the river system cannot be ignored. Needless to say, however, despite the efforts in crop and animal production, the lower Tana catchment is still a food deficient area with incidences of undernourishment reported (Source: GoK 2009).

High sediment loading into the river system, partly attributable to poor land use practices in the upper catchments, is responsible for the high discharge rate of sediment into the ocean, threatening the sustainability of the marine environment, its resources and livelihoods. Similarly, the high concentration of silt –pouring in, undermines the aesthetic beauty of the marine environment, rendering it unattractive for recreational uses, including tourism in the areas where large sediment and silt discharges occur.

The damming of a river, for whatever purpose, results in the formation of a lake behind the dam, and the consequent alteration of the natural flow of that river downstream. Dams on a river therefore cause impacts to both upstream and downstream environments. Freshwater unavailability in time and space is a major constraint to economic development. Its availability, or otherwise within the lower Tana Basin has been a source of conflict, pitying pastoralists against farming communities. The long periods of dry weather and frequent flooding in the river basins have thus posed challenges in terms of general security and food insecurity. It is against this background that the effects of damming and irrigated farming on the Tana-Athi/Sabaki River water system were studied in this research. The investigations determined the impacts arising from freshwater shortages downstream due to the reduced river flow regime and from pollution on the water system due to anthropogenic activities; establishing the level of these concerns –through scoring and ranking, as baseline for predicting the future situation in a global changing environment, where effects are exacerbated by the impacts of climate change; and to draw conclusions from the situation for recommendations that would lead to efficient utilization of the water system in order to realize sustainable development goals.

Materials and Methods

The study was accomplished through the Global International Waters Assessment methodology (UNEP 2006) that provided a holistic and comparable assessment of the world's trans-boundary aquatic resources. The assessment incorporated both environmental and socio-economic factors and recognized the inextricable links between freshwater and the marine environment. As the method dictated, the work was achieved through an interactive process, guided by a Methods Task Team, comprising of experts on water science, environment and socio-economics backgrounds.

Though the GIWA assessment focused on the impacts of five pre-defined concerns of freshwater shortages, pollution, habitat and community modification, overfishing and other threats to aquatic living resources, and global change, including evaluation of the impacts arising from the said concerns. This paper concentrated on pollution and freshwater shortages, including their future look as the major concerns based on their scores, which were derived as the summation of contributions from both environmental and socio-economic inputs on a scale of 1–3 as determined through expert hindsight/knowledge, integrating the environmental and socio-economic data, to determine the severity of the impacts from each of the two concerns evaluated, including their constituent issues. Two participatory meetings were held with experts in the fields being studied. During the workshops, preliminary analyses based on collective knowledge and experience were performed. The results were then substantiated with the best available information to feed in the report.

The GIWA methodology is divided into four logical steps: 1) scaling to describe the geographical extent of the study area; 2) scoping to identify and prioritize problems based on the magnitude of their impact on the environment and human communities; 3) Causal chain analysis to define root causes of the problems; and 4) Policy option analysis to assess the various policy options that address the root causes of the problems in order to reverse negative trends in the aquatic environment. The latter two were pursued only the extent where it provided the information necessary for this study.

Scoping assessed the severity of environmental and socio-economic impacts caused by each of the two concerns and their constituent issues in order to prioritize the most important issues for remedial action. The issues were evaluated using a standard scoring system involving a four point scale where, 0 = no impact recorded; 1 = slight impact; 2 = moderate impact; and 3 = severe impact. Once each issue had been scored, it was weighted according to the relative contribution it made to the overall environmental impact of concern and a weighted average score for each of the concerns calculated.

The socio-economic impacts were also assessed for each concern not issue. These impacts were grouped into economic impacts, health impacts and other social and community impacts. For each of these categories, the size, degree and frequency of the impact was evaluated and a weighted average score calculated for the overall socio-economic impact of the concern. To ensure applicability and sustainability of the mitigation options for the concerns, scoping not only analyzed the current impacts of the concerns, but also their future predicted outlook according to the most likely scenarios of demographic, economic, technological and other changes with potential influence on the water environment.

In order to identify top priority concerns, a final overall score based on the present and future scores of the environment and socio-economic impacts of each of the prioritized concerns was calculated, and analyzed further in the Casual Chain Analysis and Policy Option Analysis. The assessment recognized that the concerns interact with each other, and therefore the links between the concerns were highlighted to enable the identification of the interventions measures that would yield the greatest benefits for the environment and society.

Results and Discussions

The results of the freshwater shortages and pollution concerns to give a picture of the present situation, and using these results to make predictions for the future outlook as extrapolated from this baseline and, taking into account the influence of a globally changing environment.

Freshwater Shortage

Alteration of the rivers regimes due to anthropogenic activities has impacted both surface and ground water supplies with the same effects applying to changes in the water table. Similarly, modification of the rivers basins has had significant effects on the natural resources allied to the rivers course with consequences to the economy in general as well as to the social and welfare of people of the Tana River County. The effects of arising from freshwater shortages as a result of modification of stream flow, pollution of existing supplies and changes in the water table are presented as the baseline information for rating the score and impact resulting there-from.

Modification of Stream Flow

The main anthropogenic activity that has directly contributed to the modification of the Tana and Athi/Sabaki River basin stream flow is the damming the river Tana for (i) hydroelectric power generation and (ii) irrigated agriculture in both rivers. The two activities are elaborated on below.

(i) Damming on the Tana River System

The Tana River has been dammed for multi–purpose uses. However, with an estimated potential of generating 960 MW of hydro-power, damming for this purpose is the force driving the construction. With a total of five dams, already built, the appetite is still there as the desired capacity

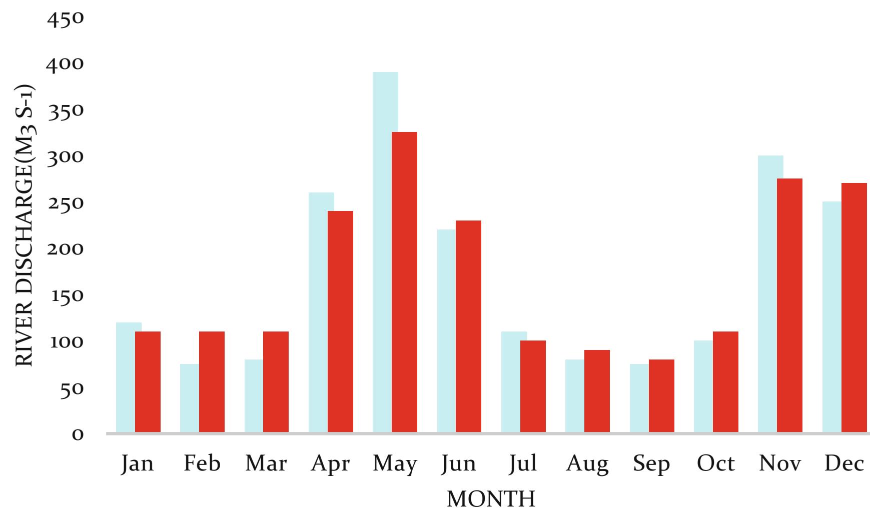

Fig. 5 Mean monthly flows for the Tana River for pre [ ] and post-dam [ ] periods

has not yet been met from those already built. The effects of the dams on the river both upstream and downstream are set to increase as potential sites planned for future development have been identified at Mutonga (Grand Falls), Usueni, Adamson's falls and Kora. Apart from hydropower generation, Masinga and Kiambere, which have large reservoirs were developed with capacities meant for river flow regulation to tame flooding downstream. The effects on the river flow regime before and after the construction of the dams, analyzed by Maingi and Marsh 2001) contribute to the discussion.

Maingi and Marsh 2001; through analysis of rainfall distribution, using data from Meru, Embu, Muranga and Nairobi, segregated into pre-and post-dam periods using both parametric and non-parametric tests to compare if there was statistically significant differences in means, medians, and distribution of rainfall between the two periods, established no such significant differences, confirming that any reductions observed in river discharge between the two periods are solely attributed to dam construction.

The river discharge volume is dictated by the bi-annual rainfall pattern experienced in the catchment. This results in the biannual floods, with peaks in May – (the long rain), and in November, (–the short rain) season. The May river flows are generally higher and less variable (Maingi and Marsh 2001), an indication of more rainfall during this period than that in November, which may be more variable. The lowest river flows occur in February–March and September–-October, corresponding to the end of the dry weather in the upper river catchment, and the lower Tana River floodplain.

High rainfall signify high daily discharges as exemplified by high river flows observed throughout East Africa in the 1960s, which were attributed to higher than average rainfall observed in that period. Analysis of the flood frequency from data on daily river discharge pre and post-dam periods over 5, 10 and 20 year periods, have indicated the pre-dam discharges calculated from their medians were significantly greater ($p < 0.01$) than the post-dam discharges, and the discharges from the two periods were also significantly different ($p < 0.01$) Fig. 5.

Consequently, it can be generalized that while the dams have augment the minimum river flows, their major impact have been the significant reduction of peak floods in May and November (Maingi and Marsh 2001). This observation is consistent with the studies of Petts (1984) and Toner and Keddy (1997). Of particular note is that May, the month of the highest discharge during the year, experiences the largest reduction in flow, while the flows for April, June, and July see virtually no change in median flows since the dam constructions. Reduced peak flows in many have the implication of reduced flood plain area, with effects on irrigated farming downstream.

(ii) Irrigated agriculture and Livestock Keeping

The area under irrigated agriculture is about 54,676 Ha. (JICA/GOK 1992) encompassing 30,148 Ha of private development and 24,528 of Government irrigation development schemes. The basin has a potential of 132,000 ha for irrigation development. The National Irrigation Board (NIB) has Mwea Paddy Rice Scheme and Tana River Scheme for cotton and subsistence cereals. The Tana and Athi River Development Authority (TARDA) manages Masinga Horticulture Irrigation Project (12,000 ha) and Kiambere Fruit Irrigation Project (150 ha). The Bura Irrigation Project, initially to cover 6,700 ha on completion, has 2500 ha.

In upper Tana, private irrigation schemes, coffee, horticulture and floriculture are intensively practiced in Muranga, Thika, Lower Kiambu and Nyeri using sprinkler irrigation. Along the main Tana River, rice, bananas and fruit irrigation schemes exist. Other irrigation sites on Tana River include

Muka Mukuu settlement and Irrigation Scheme, a development of 500 ha of coffee and fruit trees as well as rehabilitation of a 1,200 ha sisal plantation. Flood recession agriculture is practiced on the Tana Delta, especially during and immediately after heavy rains when floods reach lower Tana River, overflow the banks, and enter previously prepared depressions. These depression or basins are closed to return floodwater when floods recede. The basins are then planted with rice, green-grams and other vegetables. Sometimes these agricultural activities are interrupted by retention of floodwater in hydroelectric dams located upstream (Bobotti 1996).

The downstream meandering of River Tana caused by sediment loading led to a shift in the river coarse in the late 1980's, impacting negatively on Bura Irrigation Scheme. Abstraction of the water from the River Tana to meet the domestic water supply needs of Nairobi and other urban centers is also associated with modification of stream flow and consequent freshwater shortages downstream.

In the lower Tana basin, livestock farming is the main socio-economic activity. It is practiced by the Orma and the Wardei. This is so because a major part of this area is suitable for livestock farming. Small scale crop production along the river flood plain is practiced by the Pokomo who grow maize, bananas and mangoes. Other socio-economic activities that support livelihood include fishing and small scale businesses. The Tana County has potential for rice production and eco-tourism development. The per-capita herd size of animals is 8.8 for the Orma and 13.7 for the Wardei (Nema 2009). The mean number of cattle held by a house hold is 12. Bearing in mind that the household size is about 14 individuals, then there are as many people as there are cattle in the area. Movement of cattle in the area resonates with the rain seasons. Hence the movement of livestock in and outside the delta corresponds to the rainfall pattern. Cattle move into the delta from January to March, after which they move into the plains in anticipation of the rain in April. They stay in the pains until June, when the herds head back to the delta, staying there until October. With the on-set of the short rains in this month, the cattle head back to the plains, remaining there until the end of the year. Thus the migration to and out of the delta in search of pasture sustains livestock keeping in the area. However, the movement of animals creates a number of problems, including resource use conflicts when the cattle graze on the crops belonging to the agrarian Pokomo tribe. The movement of the herds also exposes them to the tsetse fly menace and risk from trypanosomiasis, risk with the loss of many animals. Movement of the animals is also associated with diseases such as rinderpest and the foot and mouth disease. The Tana River being a source of water for the animals has also led to conflict at watering points along the river and to other watering points, provided through wells away from the river. The watering points are thus a source of conflict over water among the two pastoral communities and also from the farming Pokomo community.

A livestock population census, 2006 showed that there were 370,000 cattle, 280,500 sheep, 369,000 goats, 58,000 camels and 19,600 sheep in Tana River County. Challenges met in maintaining such huge livestock population include the problem of extended drought, rainfall failure, predation particularly on sheep, and farmer/pastoralist conflicts. This problem is compounded by the influx of additional livestock from Ijara and Garissa Counties. Key environmental issues associated with livestock include persistent drought, denying the animals water for drinking, influx and movement of animals and livestock, overgrazing in the Tana Delta, human conflicts, trampling, overgrazing and lack of sanitation in livestock markets/holding grounds, livestock/wildlife conflict at watering points and soil erosion, inadequate water supplies for both human and livestock and water user conflicts between farmers and pastoralists.

Another effect resulting from the large herd of animals is habitat loss/deterioration, pollution from increased turbidity in the water due to erosion of de-vegetated land, reduced farmland, loss of water through evapotranspiration etc.

The demand for water in the lower Tana River has caused excessive water abstraction in the river, resulting in salt water intrusion upstream as has been reported in some rice irrigated schemes of the Tana Delta, leading to reduced productivity, (Nema 2009). The appetite for water upstream, salt water intrusion and pollution contribute to water unavailability for some intended uses, causing water scarcity, and fueling the conflicts in resources use with dire downstream consequences.

Pollution of Existing Supplies

Pollution of existing water supply is another cause for freshwater shortages downstream. Field information shows that the upstream has severe soil erosion, leading to runoff of soil debris into the river. This is hauled as sediments within the channel down to the reservoirs. The reservoirs or hydropower settlement dams have been filling up with these sediments, reducing –capacity of the reservoirs, transparency of the water, and silting of the turbines. Sediments cause pollution of water in these rivers, limiting access of its waters to people for domestic use. (Dubois et al 1985; Delft Hydraulics Laboratory 1970a, b; Kitheka 2002) have reported that suspended sediments in the Tana are a course of pollution in these water bodies.

Besides, sewage and industrial effluents from the major cities and towns upstream are catchment areas that contribute to pollution of the water systems with effluents discharged from both Nairobi and Thika (Njuguna 1978; Mwaguni 2009) contributing to the pollution concern. Analysis of water from the Tana River, during the rainy season,

Sharing Water with Animals

Animals away from farmlands

Man/Animals waiting for their turn to water

Herder invading a road searching for pasture

Drinking under guard from farmland

waiting for her turn as goats drink

Shell well scoped to provide water

Animals waiting for their turn to drink

Photos depicting conflicts in resource use has yielded coliform counts of above 100/100ml and E. coli values greater than 10/100ml, which is indicative of pollution by sewage, (Mwaguni 2008). Thus, poor management of effluents from human settlements has effects on both surface and groundwater as it renders water sources unavailable for human needs through the effects pollution causes, which in turn, results in freshwater shortage as the consequence. The city of Nairobi with approximately 3.4 million people is traversed by the Nairobi River that joins the Athi River downstream; the urban centers of Thika, Murang'a and Nyeri, located within the catchment of the Tana River and other smaller trade centers also contribute to pollution, deteriorating the quality of water for domestic uses. Water pollution results from contaminated storm water discharges, poor disposal of urban and industrial wastes that leach or seep and only eventually end up into the water system.

Changes in the Water Table

Change in the water table is another cause for freshwater shortages. Uneven distribution of water in both time and space makes balancing of water demand and supply quite a difficult challenge. Competition for available water by various uses is high and in order to alleviate the water problem, the government has intensified extraction of groundwater through drilling of boreholes. More than 4,500 have been drilled in the Tana River basin to access groundwater as an alternative source of potable supplies. Majority of the boreholes now require rehabilitation due to non-yielding of the water resource. Consequently, new boreholes have to be dug deeper in order to access the water (GOK 2002).

(i) Rating for freshwater Shortage

Environmental aspects and the socio-economic characteristics of the Tana-Athi/Sabaki Rivers system coupled with specific reviews on the effects of modification of stream flow, pollution of existing water supplies and changes on the water table provided the basis for the justification of the scores on the identified effects. The scores were then averaged to give the present rating for freshwater shortages. Considering the existing socio-economic activities and projecting for future growth, the future effects were predicted and the impacts rated. This gave the overall time and impact averaged score for freshwater shortage in the Tana-Athi/Sabaki River system. Information on environmental conditions and socio-economic activities was required to satisfy or justify the criteria for scoring as indicated in the GIWA methodology.

Natural environmental conditions such as semi-arid to arid conditions, sedimentation and siltation are recognized as the factors that can cause modification of stream flow, promote pollution of existing supplies or affect the position of the underground water-table. Besides the natural factors, anthropogenic activities can exacerbate the problem. When these are taken into account, the use of water for hydroelectric power production, irrigation, domestic consumption, commercial and industrial establishments and for pastoralism –a huge demand is exerted on the water system of these two rivers. The detailed score tables for the Tana-Athi-Sabaki Drainage Basin where scoping environmental impacts under present and future conditions can be seen give an overall score of 3, indicating that the basin is negatively impacted by changes in water table, modification of stream flow and pollution, Table 6.

Table 6 Present and future impact of freshwater shortage, scores and calculated overall time and impact averaged scores based on team scores

Concern	Issue	Score
I. Freshwater shortage	1. Modification of stream flow	3
	2. Pollution of existing supplies	3
	3. Change in the water table	2
	Present impact averaged score	2.67
	Future impact score	3
	Overall time and impact averaged score	2.96

NB: The prediction is that the future impact scenario for each issue will be extreme, and worse

(ii) Rating for Socio-economic Impacts of Freshwater Shortages

Freshwater scarcity will be chronic as the population continues to grow and socio-economic activities expand. This will impose negative impacts on health, reduction in food production, aggravating food security; further spiraling effects on health are anticipated with increased urban growth and discharge of effluents from urban areas, with potable water becoming even scarcer, and worsening with time. Increased damming is geared to harness water for irrigation activities to increase crop production. However, most crops are for commercial production and are not directly related to enhancement of food crops for consumption.

Clear management of the freshwater resources for harmonious use in the various sectors of agriculture industry, hydropower etc. that are using water resources is lacking or inadequate. This makes future socio-economic scenario difficult to gauge (Table 7). Water shortages cause extensive migrations, especially among pastoral communities, contributing towards the distribution of diseases over wider areas. It also leads to poor water quality and other social problems such as resource use conflicts between the migratory pastoralists and sedentary crop farming communities. With time, in the vast rural areas of the Tana River County where these activities are mainstay lifetime enterprises, water scarcity poses real threat to life. Table 7 gives the team scoping for socio-economic impacts under present and future conditions for Tana-Athi/Sabaki Drainage Basin under the freshwater shortage concern.

Table 7 Freshwater shortages socio-economic impacts –the Present and Future Outlook

Economic impacts		Health impacts		Other social and community impacts	
Present	Future	Present	Future	Present	Future
3	3	3	3	3	3

Shortage of freshwater has built an age-old confrontations between pastoralists and crop farmers arising from conflicts over grazing areas and watering points although irrigation schemes have assisted to reduce these conflicts. Increased food production has contributed to food security and assisted in alleviation of malnutrition. Provision of piped water from surface and groundwater has also assisted in combating water borne diseases.

Although the full potential for both hydropower and irrigation have not been fully exploited, frequent occurrences of long periods of drought have constrained achieving it. During dry spells water levels in the dams are reduced to levels where hydropower production is curtailed; similarly, reduced water flow in the rivers has effect on irrigation, resulting in crop failure. The impact of saline water on farming has only been reported in the Tana Delta rice farms.

Pollution

Pollution is another issue of concern in the Tana and Athi/Sabaki Rivers' water system. The sources of pollution include agricultural based activities along the major rivers, human settlements and industrial activities. The causes of pollution considered in detail in the study include eutrophication, sediment loading, solid wastes and human effluents. The effects these cause on socio-economic activities have also been analyzed.

Eutrophication

Nutrient loading is a major problem in the basins of the river system because, about 85% of the population in these catchments practice subsistence and commercial farming, involving mixed crop and livestock husbandry, and irrigated farming, confined mostly to schemes run by public and private agencies. Smallholder farmers hardly use chemicals to improve their crop yields. However, their land use patterns through slash and burn agriculture, overgrazing and nomadic pastoralism, including farming on the fringes of the rivers, contribute to increased eutrophication. Eutrophication occurs through soil erosion, animal and domestic wastes, suspended solids and solid wastes generated in the farms and human settlements, getting discharged through runoff from the basin catchment into the rivers and down to the marine environment, mostly during the short, but high intensity and highly erosive rainfall seasons. The effects of eutrophication are discussed subsequently.

Sediment Loading

Approximately 16.2–21.3 million tonnes of sediments are deposited into the ocean annually from the Tana and Athi/Sabaki river system. River Tana discharges about 7 million tonnes, while the Athi/Sabaki discharges 9.2–14.3 million tonnes. The main cause for this high sediment load, as stated earlier is bad farming management systems in smallholder subsistence agriculture in the drought prone areas (Dubois et al 1985; Kitheka 2002). Historical data shows that the river Tana, according to data recorded at Garsen, contributed 1,661 tonnes per day of sediment in the month of October, 1979; 2,304 tonnes per day in August, 1980; and 3,387 tonnes per day in August, 1982. On the other hand, the Sabaki River, with data recorded at the Baricho water treatment works intake gave the following results; October 1979, 74 tonnes per day; May/July/November 1980, 3,769 tonnes per day; June–October 1981, 846 tonnes per day; January—March 1982, 195 tonnes per day; June/August 1984, 111 tonnes per day; and in August 1994 at the river mouth, 143 tonnes per day, (Kazungu et al. 2001) Though recent data is unavailable, owing to poor monitoring, the volume of sediment discharge should be increasing with increased population and socio-economic activities. As a consequence of the high loads of suspended solids discharged through the Sabaki estuary there is an absence of mangrove vegetation, unlike in other estuaries along the Kenya coast. The coral ecosystem extending into the Malindi National Marine Park and Reserve has been negatively impacted (McClanahan and Obura 1995) as evidenced by the shadowing of corals. Similarly, as a result of the high sediment discharges and deposition seagrass communities have been impacted on negatively resulting in a reduction of species diversity (Wakibia 1996). Also beach accretion is dominant, such that beach hotels have lost their beach frontage and, due to the nature of the river sediment being deposited (brown sand and silt) the aesthetic value of the beach along the Malindi Bay has been reduced considerably making it less attractive to the development of tourism, (Kazungu et al. 2001).

More intensive agriculture is undertaken using irrigation most especially along the Tana River which accounts for 87% of the total irrigated agricultural land. Since irrigation farming is for commercial crop varieties makes use of pesticides and fertilizers to enhance production, it is common that pesticide and fertilizers carried by the sediments cause pollution in the water courses but monitoring studies on the environmental impacts arising from their use is lacking. Examples of the agrochemicals used, and which are of concern include pyrethrins, dimethoate, fungicides, furadan, paraquet, glycophosphate, Atrazine, 2, 4-D, herbicides (Tordon IOI, Hyvar X), Acaricides (Triatix, Stelladone); while the fertilizers include phosphate and muriate of Potash, (Mwaguni and Munga 1997).

Solid and Microbiological Pollution

Urban settlements are regarded as pollution hot spots in the basin because these are places where generation and concentration of industrial and domestic effluent and wastes is greatest in comparison with rural areas. In most urban settlements, water borne and water related diseases account for 50% of all the diseases. Water borne diseases accounted for 30%, Mwaguni 2013). Growth of urbanization has been phenomenal from 1969 reaching its peak in 1989. During this period, there was proliferation of trading centers, which became the genesis of urban centers. Their growth rate was approximately 2.1 percent per year (CBS 1989). Established urban centers such as municipalities or cities have continued to show high growth rates. Ruwa and Mwaguni (2002) observed urban areas generated large quantities solid waste with only a fraction of it being collected. Similarly, domestic wastes and effluents in the urban centers are largely handled on-site. Crude management of solid wastes, including human and industrial effluents means these remain to get washed into the marine environment through surface run-off, or through storm-water drainage. Leachate and seepage from landfills enhance pollution. This observation is supported by the high levels of disease causing pathogens are detected in the creeks along Kenya's coastline (Mwaguni 2002). Human waste discharges into the ocean has also led to high productivity in the creeks around Mombasa and in the Tana-Athi-ASabaki River basins, Osore et al. (1997).

Industrial effluents discharges coupled with domestic waste disposal are most significant in Nairobi and the urban areas in the Tana-Athi/Sabaki water catchment. These wastes are disposed of untreated largely due poor infrastructure and poor provision of services. This problem is compounded by a situation where the country does not have any regular monitoring programs to sound warnings on the effects of such a practice on human health and socio-economic activities.

Environmental Impacts of Pollution

Pollution affects ecosystems in many forms, and leads to debilitation of fauna and flora. Aquatic dependent resources, especially fish and mangroves are particularly impacted by pollution. The intricate relationship between economic activities and pollution, which hurt the bounty for man's survival, has been explicitly shown in the analysis of Tana-Athi/Sabaki basin. On the basis of the reviewed information, using the GIWA Methodology, the scoring for pollution due to environmental issues is shown in Table 8.

From Table 8, the average scores for suspended solids and solid wastes were higher in rivers than for other issues being evaluated. This was attributed to increased sediment and silt loads enhanced by erosion of soils caused by the poor agricultural practices of the peasant farmers, and from increased deforestation, where the land was being cleared to create new farm lands. Similarly, waste disposal from urban areas, contributed to sediment loading into the rivers and in the shoreline. Thus, the Tana-Athi/Sabaki basin is being impacted as a result of increased anthropogenic activities and urbanization, with the latter being the major source of micro-bacteria, nutrients and chemical pollution, magnified in localized "hotspot" areas of pollution downstream. The assessment of the present and future averaged score of 2 for micro-biological pollution, eutrophication from nutrients and chemicals was judged to be a moderate impact. However, the overall time and impact average score of 3 obtained for these issues, indicate an outlook of severe impact in the future.

Table 8 Present and future Environmental Impacts on major systems

Concern 2: Pollution	Issue	Score
	4. Microbiological	2
	5. Eutrophication	2
	6. Chemical	2
	7. Suspended solids	3
	8. Solid wastes	3
	9. Thermal	–
	10. Radionuclide	–
	11. Spills	1
	Present impact averaged scores	2.17
	Future impact averaged scores	2.17
	Overall time and impact averaged scores	2.89

Socio-Economic Impacts of Pollution

The economic activities that support the welfare of households are in themselves the cause of pollution. The effect of pollution is water quality degradation, loss of aesthetic value of environment, provision of habitat for disease causing pests, increased turbidity in the water courses caused by silt, obnoxious ordours in water, resulting from putrefying organic wastes, all of which in turn discourage on water activities and water scarcity for potable uses. The discharge and deposition of silt or sediments on coral reefs reduces species diversity through the gradual death of coral polyps, resulting in negative impacts on nature tourism. Collectively, the loss of aesthetic value of a destination reflects badly on the tourism trade, an industry which contributes approximately 60% of Kenya's total national revenue, either directly or indirectly.

The effects of agrochemicals discharge emanate from the strong toxicity of these substances. As such, these have the potential to destroy flora and fauna, reducing biodiversity and aesthetic value of the impacted environments. The

Table 9 Team for Tana-Athi-Sabaki Drainage Basin (TAS) from the pollution issue of concern

Economic impacts		Health impacts		Other social and community impacts	
Present	Future	Present	Future	Present	Future
3	3	3	3	3	3

consumption of fish or other aquatic species from areas contaminated with agrochemicals may cause serious public health problems. The discharge of human wastes is an issue of major concern. Though documented information on such effects is lacking for the Tana-Athi/Sabaki water system, the sporadic outbreaks of cholera in Tana River County, is as a result of such discharges. Reported cases elsewhere, such as those by Mwaguni (2002) for Mombasa indicate the gravity of human waste discharges into water bodies as exemplified by the waterborne infections of cholera, dysentery, diarrhea, eye diseases, dermal, and intestinal worms. The effects of pollution were rated in terms of economic, health and other social and community impacts for the present and then extrapolated into the future.

Rating Socio-Economic Impacts of Pollution

The results of rating of the impacts from the pollution concern for the Tana-Athi-Sabaki drainage basin are presented in Table 9, giving the Teams scooping for socio-economic impacts under present and future conditions.

The Tana-Athi-Sabaki basin residents face severe socio-economic impacts associated with pollution from the different sources cited in the table above. This is especially so, because residents depend solely on water from this river system for purposes. Pollution in the marine environment, resulting from river discharges is significant around urban areas where it is common for raw sewage and garbage to be disposed of in water bodies. This makes land based-activities the main sources of pollution into ocean environment. The effects of sediment in the marine environment has been detected on the browning of coral reefs, turbidity in the water, affecting its aesthetic value for tourism, McClanahan and Obura 1995. Water Polluted with human waste is a source of water borne diseases, impacting on socio-economic activities of the people as the affected individuals seek medical treatment (Mwaguni 2009). The lost hours lost seeking treatment contribute to loss in productivity time.

Future Outlook and Global Change for the Two Concerns

It is difficult to consider the effects of global change at the drainage basin level, however, impacts associated with changes in hydrological cycle and ocean circulation, have manifested themselves in the occurrences of cyclic events drought and flooding. Global change is associated with anthropogenic increases of carbon dioxide in the atmosphere. Such increase sea temperatures, leading to among other things, sea level rise, and decreased capacity of the oceans as carbon sinks. Activities that contribute to this include deforestation, combustion of fossil and wood fuels, slash-and-burn agriculture, etc. all of which are major activities undertaken in the Tana-Athi/Sabaki rivers' water basins, a situation that is promote global change.

The effects of global change have manifested themselves in the droughts and floods phenomena, which is not new in Kenya with their characteristics -intensity, duration and spatial extent - varying from one event to the other. The frequency of occurrence and severity of these events have been increasing over time. For example, the frequency of drought increased from once in every 10 years in 1970s, to once in every 5 years in 1980s, once in every 2–3 years in 1990s and every year since 2000 (Howden 2009). The occurrences of droughts and flood are shown in Table 10.

Flood and drought events contribute to water scarcity both directly and indirectly through the agent of pollution. Droughts and Floods destroy livelihood sources, and also severely undermine the resilience of the people living in the affected areas (KRCS 2012). In some arid and semi-arid counties, pastoralists have lost more than half of their livestock to droughts in the past ten years, contributing to over 60% of the inhabitants living below the poverty line (Grunewald et al. 2006).

The effects of droughts and floods have been devastating in a number of ways. Floods inundates arable lands, destroying crops, livestock and property; droughts cause deficiency in rainfall, resulting in freshwater shortages, compounding the problem of stream flow and availability of the resource with consequences to agricultural activities, including the rearing of livestock. In Kenya, the worst drought to have occurred in the last one hundred years, was experienced in years 1999–2001. This drought occurrence killed about 60–70% of livestock in the arid and semi-arid areas, caused massive crop failures, drying up of water resources, severe environmental degradation and loss of goods and services. Global change will thus exacerbate both freshwater shortages and spread of pollution in the entire Tana River water system, and export the pollution problem into the marine environment through the water media.

Scoping for Global Change from Environmental Impacts

As stated, due to its scale in terms of time and space the concern for global change cannot be assessed at the basin level. However, considering the environmental parameters associated with global change such as deforestation rates, use of wood fuel, and slash-and-burn agriculture, temperature change is a major concern in the river basins as

Table 10 Recent hydro-meteorological disasters and their impacts in Kenya

Year(s)	Disaster type	Area of occurrence	Impacts
2011	Drought	Garrisa, Isiolo, Wajir, Mandera, Mombasa, Marsabit, Nairobi, Turkana, Samburu,	4.3 million people in dire need of food
2010	Floods	Budalangi, Tana River, Turkana	73 people killed, 14,585 people affected
2009	Droughts	Widespread	70–90 % loss of livestock by Masai pastoralists
2008	Floods	Rift Valley, Ktale Transnzoia, Machakos, Kibwezi	2398 people affected
	Mudslides	Pokot Central	11 people dead
2007–2008	Drought	Widespread	4.4 Million people affected, 2.6 Million at risk of starvation, up to 70 % loss in livestock among pastoral communities
2006	Drought	Widespread	3.5 Million in need of food, 40 dead, 40 % cattle, 27 % sheep, 17 % goats dead
	Flood	Widespread	7 dead, 3,500 displaced
		Isiolo	3,000 people displaced
2005	Storm	Merti-Isiolo	4,000 people cut off between Merti-Isiolo
	Drought	Widespread	2.5 Million people close to starvation, declaration of national disaster
2004	Drought	Widespread	About 3 million people in need of relief food for 8 months up to March, 2005
	Flood/ Landslides	Nyeri, Othaya, Kahuri	5 people dead
2003	Floods	Nyanza, Western, Tana River basin	60,000 people affected
2002	Landslides	Meru-central, Muranga, Nandi	2,000 people affected
	Floods	Busia, Nyanza, Tana River Basin	150,000 people affected
1999–2001	Drought	Widespread	4.4 million affected
1997–1998	El-Nino Floods	Widespread	1.5million affected
1995–1996	Drought	Widespread	2.0 million people affected, declared a national disaster
1991–1992	Drought	N/Eastern, Eastern, Rift Valley, Coast	1.5million affected
1985	Floods	Nyanza	10,000 people affected
1983–1984	Drought	Widespread	200,000 people affected
1980	Drought	Widespread	40,000 people affected

Source: Huho and Kasonei (2014)

exemplified by periodic droughts and flooding, Table 10. As such all issues and impacts associated with freshwater shortages and pollution will worsen.

Socio-Economic Impacts Due to Global Change

The socio-economic impacts due to global change could similarly not be analyzed from the GIWA method on a basin scale. However, such impacts include the observed extreme changes in weather pattern, which cause food insecurity and disease outbreaks that were noted in the water basin. With such a scenario, it is anticipated that future impacts due to global change will adversely affect the socio-economic fabric of society in the basin. As shown in Table 10, loss of property has resulted from droughts and floods. The frequency of such occurrence have also been shown to be increasing, a situation that will undermine livelihood in areas already suffering from extreme whether events.

Conclusions and Recommendations

Freshwater Shortages

Conclusions

(i) Both dam construction and farming activities upstream have been identified as the major causes of freshwater shortages in the Tana River County. Damming is associated with reduced stream flow, change in water courses, changes in water table and general water scarcity downstream while farming is associated with water pollution in the entire river courses.

(ii) There is still unexploited potential for increasing hydropower production and irrigation in the basin with an estimated 155,100 Ha available for irrigated farming, depending on the availability of ample supplies of water (GOK/JICA 1992). A situation, which could lead into more dams being built and more irrigation schemes started.

(iii) Arid and semi-arid areas are significant source of beef and other livestock products. However, owing to conflicts between farming and pastoral communities, both socio-economic activities cannot be developed sustainably to their full potential.

(iv) Pollution of water at watering points where livestock and people compete for this resource is common. This scenario is a common cause of freshwater shortages in that polluted water supplies are not suitable and therefore unavailable for human use, creating the water scarcity situation in the process.

(v) Although there have been efforts to provide piped water there is still a disparity in its provision between rural and urban areas. The proportion of people with access to safe drinking water within reasonable distances remains a pipe dream in the rural areas despite huge investment in the sector. This situation replicates itself in Tana-Athi/Sabaki catchment areas with consequences of waterborne diseases, causing disorders to both human and livestock health.

Recommendations

(i) There is need to plan for the development of the Tana River Basin and its resources in an integrated way, taking into account of all the issues before development decisions are made. Such an undertaking will realize the importance of water conservation and promotion of its quality for the preservation of ecosystem functions downstream.

(ii) Long term monitoring of the activities taking place in the basin should be undertaken and integrated with the monitoring of the total natural resource base of this area to generate plans that guide utilization of the basins resources for sustainable development.

(iii) Water use conflicts are bound to increase in scope and frequency. Consequently, there is need to consider water as an economic good to prevent wasteful use of the resource and, making it available to more users in order to reduce the conflicts among the sectors that compete for this resource.

(iv) There is need for adequate planning for both pastoral and farming activities to reduce the completion of water by these two entities.

(v) Strengthen and enforce land use regulations.

Pollution

Conclusions

(i) Deposition of suspended solids on the coral system of the Malindi Marine Park and Reserve results in shadowing of the coral ecosystem with the consequent loss of the aesthetic value of this system making it less attractive to tourists.

(ii) Decline in biodiversity in the two major habitats i.e. the coral and seagrass meadows, with the disappearance of seagrass species in the Malindi Bay probably due to suspended solid loading having been reported.

(iii) Sediment deposition and beach accretion in the Malindi Bay have resulted in the loss of beach frontage to some beach hotel establishments resulting in loss of tourism revenues.

(iv) There is potential negative impact to fisheries productivity as the major habitats, are impacted by suspended solids. This will translate to decreased fish catches, undermining food security and earnings from fishing.

(v) Health impacts associated with pollution are high due to micro organic/disease causing organisms and water related disease such as malaria.

Recommendations

(i) Promotion of good agricultural practices along river basins and marginal areas

(ii) Enforce the treatment of sewage and industrial effluents before they discharged to the waterways.

(iii) Promote the polluter pays principle to address pollution from agrochemicals.

(iv) Address the root causes of population pressure, institutional governance and macro-economic policies.

Global Change

Conclusions

(i) Unusual patterns of unpredictable climatic extremities in occurrence and magnitudes of drought and floods have been observed in the region besides coastline erosion and coral bleaching. The loss of livelihood options, starvation, deaths, and losses of livestock associated with the extreme weather patterns and their associated effects have been established.

(ii) Activities such as deforestation, combustion of fossil fuels, savannah burning, combustion of wood fuel, burning of refuse etc., take place in the area and these make a contribution to the problem of global change.

(iii) The socio-economic losses associated with extreme droughts and floods such as risk to life, damage to infrastructure and environmental degradation are common in the area.

(iv) Associated with climate change are health problems caused by enhanced opportunistic occurrence of diseases due to the extreme climatic fluctuations and malnutrition, resulting from food insecurity.

Recommendations

(i) As it has been established that anthropogenic activities contribute to global change, with the cyclic events of droughts and floods now predictable, proactive strategies should be put in place to mitigate against, or develop resilience of such impacts.

(ii) Secondly, there is also a need for coordinate actions among countries in mitigation or adaptation to climate change since the problem is global in nature. This notwithstanding, local intervention measures should also be pursued

(iii) There is need to build capacity for monitoring, control and surveillance of activities that contribute to global change to assist understanding of global change to be able to minimize the effects it causes. Monitoring for drought and flooding undertaken as a matter of policy.

References

Bobotti OK (1996) Tana river basin management – a case study. In: Hirji R, Partoni FM, Rubin D (eds) Proceedings of seminar on integrated water resources management in Kenya. Sponsored by government of Netherlands & the World Bank. The Economic Development Institute of World Bank, 227p

Brinson MM (1990) Riverine forests. In: Lugo AE, Brinson M, Brown S (eds) Forested wetlands. Ecosystems of the World, vol 15. Elsevier, Amsterdam, pp 87–114

Carbone F, Accordi G (2000) The Indian Ocean coast of Somalia. Mar Pollut Bull 41(1–6):141–159

CBS (1989) Kenya Population census 1989, Analytical Report vol III, Population dynamics of Kenya, Ministry of Planning and National Development. Nairobi, Government of Kenya

Delft Hydraulics Laboratory (1970a) Malindi Bay Pollution, Part 2: field measurements and recommendations. Report submitted to the Ministry of Agriculture, Kenya. The Netherlands, 11p

Delft Hydraulics Laboratory (1970b) Malindi Bay Pollution, Part 2: field measurements and recommendations. Report submitted to the Ministry of Agriculture, Kenya. The Netherlands, 11p

Doute R, Ochanda N, Epp H (1981) A forest inventory of Kenya using remote sensing techniques. Kenya Rangeland Ecological Monitoring Unit Report, No. 30. Nairobi, 130P

Dubois R, Berry L, Ford R (1985) Catchment land use and its implication for the coastal resources conservation. Programme for International Development. Clark University, Worcester, Massachusetts, USA, 65p

FAO (2001) A synthesis of flood warning and control for the Juba and Shabelle Rivers. FAO SOM/SSF/2001/12. Working Paper. FAO, Nairobi

GOK (2002) Country strategy on the integrated water resource. Management Ministry of Environment and Natural Resources, Nairobi (Draft Paper), 84p

GOK (2009) Kenya National Population and Housing Census, Central Bureau of Statistics, Government Printer, Nairobi

GOK (2012) Tana delta strategic environmental assessment scoping report, 46pp

GOK-JICA (1992) National water masterplan. Government of Kenya (GOK) and Japanese International Cooperation Agency (JICA), Nairobi, Kenya

Government of Kenya (GoK) (2002) National Development Plan, Ministry of Planning, Nairobi, Kenya

Grunewald F, Robins K, Odicoh A, Nicholson N (2009) Kenya. RTE mission final report

Hatziolos M, Lundin CG, Alm A (1994) Africa: a framework for integrated coastal zone management. The World Bank, Washington, DC, 150p

Hirji R, Partorni FM, Rubin D (eds) (1996) Seminar on integrated water resources management in Kenya. Proceedings sponsored by government of the Netherlands and the World Bank. The Economic Development Institute of the World Bank, 227p

Howden D (2009) The great drought in East Africa available at www.infiniteunknown.net/2009/10/3

Hughes FMR (1985) The Tana River floodplain forest in Kenya: ecology and impact of development. PhD thesis, University of Cambridge

Hughes FMR (1988) The environmental impact of river basin development: whose responsibility? Cambridge African monographs. African Studies Center, University of Cambridge, Cambridge

Huho JM, Kasonei RC (2014) Understanding extreme climate events for economic development in Kenya. IOSR J Environ Sci Toxicol Food Technol 8(2):14–24

JICA/GOK (1992) National Water Masterplan. Ministry of Land Reclamation, Regional and Water Development, Nairobi, Kenya. Japanese International Cooperation Agency and Government of Kenya

Kazungu JM, Munga D, Mwaguni SM, Ociewo J (2001) Kenya country report GEF-MSP Sub-Sahara Africa Project, (GF/6010-0016) for the development and protection of the coastal and marine environment, National report. Phase 1: Integrated problem analysis, 70pp

Kitheka JU (2002) Dry season sediment fluxes in the frontwater zone of the mangrove-fringed Mwache creek, Kenya. In: Arthurton RS, Kremer HH, Odada E, Salomons W, Crossland JIM (eds) African Basins: LOICZ Global change assessment and synthesis of river catchment – coastal area interaction and human dimensions. LOICZ Reports and Studies No.25ii+344 pages. LOICZ, Texel, pp 194–202

KRCS (2012) Drought 2011: how Kenya responded. https://www.kenyaredcross.org/PDF/K4K/Drought

Lange K (2014) Hydrological consequences of proposed interventions in the Tana Basin, Kenya, A water Balance study. M.Sc., thesis, Utrecht University, 96pp

Livingstone DA (1975) Late quaternary climate change in Africa. Annu Rev Ecol Syst 6:249–280

Marsh CW (1976) A management plan for the Tana River Game Reserve. Report to the Kenya Department of Wildlife Conservation and Management. Nairobi

Marsh CW (1978) Tree phenology in a gallery forest on the Tana River, Kenya. East Afr Agric For J 43:305–316

Maingi JK, Marsh SE (2001) Assessment of environmental impacts of river basin development on the riverine forests of eastern Kenya using multi-temporal satellite data. Int J Remote Sens 22:2701–2729

Maingi JK, Marsh SE (2002) Quantifying hydrologic impacts following dam construction along the Tana River, Kenya. J Arid Environ 50:53–79

McClanahan TR, Obura D (1995) Status of Kenya coral reefs. Coast Manag 23:57–76

McClanahan TR, Young TP (eds) (1996) East African ecosystems and their conservation. Oxford University Press, New York, 452p

Medley KE (1990) Forest ecology and conservation in the Tana River National Primate Reserve, Kenya. PhD dissertation, Michigan State University

Medley KE, Hughes FMR (1996) Riverine forests. In: McClanahan TR, Young TP and Their Conservation. Oxford University Press, New York/Oxford, pp 361–383, 452p

Mwaguni SM (2002) The cost and benefits associated with addressing the sewage problem affecting the coastal marine and associated freshwater environment with special focus on the town of Mombasa on the Kenyan Coast. A contribution to the implementation in East Africa of the UNEP/GPA Strategic Action Plan on Sewage, 51p

Mwaguni SM (2008) The effects of tourism and related human settlements on the conservation of coastal water resources: a case study of Nyali-Bamburi-Chale. PhD thesis, University of Nairobi, 227 pp

Mwaguni SM (2013) Urbanization and groundwater pollution in Mombasa-Kenya: do we have to transfer the problem due to construction of the Dongo-Kundu by-Pass? J Environ Earth Sci 3(4):2013

Mwaguni (2009) Effects of tourism and related settlements on the conservation of coastal water resources, Unpublished PhD thesis, University of Nairobi, 227pp

Mwaguni S, Munga D (1997) Land based sources and activities affecting the quality and uses of the marine coastal and associated freshwater environments along the Kenyan Coast. National Report, Republic of Kenya, 56p

Nema (2009) Tana River District National Environmental Plan 2009–2013, 57pp

Njuguna SG (1978) A study of the effects of pollution on a tropical river in Kenya. MSc. thesis, University of Nairobi, Kenya, 202pp

Ogwenyi GS, Denga FGO, Abwao P, Kitheka JU (1993a) Impacts of floods and drought on the development of water resources of Kenya: case studies of the Nyando and Tana catchments. Hydrol Warm Regions 216:117–123

Osore MKW, Daro N, Tacks MLM (1997) The effect of rainfall and tidal rhythm on the community structure and abundance of the zooplankton of the Gazi Bay, Kenya. Hydrobiologia 356:117–126

Petts GE (1984) Impounded rivers: perspectives for ecological management. Wiley, Chichester, 326 pp

Ruwa RK, Mwaguni SM (2002) Waste collection, handling and treatment system: Port of Mombasa environment impact appraisal. A report to the East African Marine & Environmental Management Company Limited, Mombasa, Kenya, 36p

Saha SK (1982) Irrigation planning in the Tana Basin of Kenya. Water Supply Manag 6:261–279

Toner M, Keddy P (1997) River hydrology and riparian wetlands: a predictive model for ecological assembly. Ecol Appl 7:236–246

UNEP (1998) Eastern Africa Atlas of coastal resources 1: Kenya. UNEP and BADC (Government of Belgium), 119p

UNEP (2001) Eastern Africa atlas of coastal resources: Tanzania. UNEP and BADC (Government of Belgium), 111p

UNEP (2006) GIWA, Challenges to international waters –regional assessment in a global perspective

Vanden Bossche JP, Bernacsek GM (1990) Sourcebook for the inland fishery resources of Africa, vol 1. CIFA Technical Report No.18.1. FAO, Rome, 240 p

Wakibia JG (1996) The potential human induced impacts on the Kenya Seagrass, UNESCO Reports in Marine Science No. 66

WRMA (2009) Tana water catchment management strategy