4.18 The Tana River Basin and the opportunity for research on the land-ocean interaction in the Tana Delta

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Introduction

The Tana River basin is one of the five main drainage basins in the Republic of Kenya. In terms of river discharge, it is one of the largest and also one of the most important drainage basins. It occupies about 23% of the total land area and contributes 32% of the total river runoff in Kenya. The basin is composed of the vast eastern plateau forelands, which sprawl between the Central Kenya Highlands to the west and the coastal strip on the east. The river flows down a gentle slope towards the Indian Ocean. The government of Kenya has initiated a number of significant water resources development projects in the basin. These include agricultural projects, particularly large-scale irrigation and hydroelectric power development schemes. As the river drains into the Indian Ocean, it passes through a mangrove-fringed estuary at Kipini. Apart from discharge of freshwater and terrigenous sediments into the Indian Ocean, the river also supplies a large quantity of dissolved and particulate nutrients, which makes Ungwana Bay and the Tana Delta one of the most productive fishery grounds in Kenya. Most previous studies have focussed on the Upper Tana Basin and very few studies have been implemented for the Lower Tana Basin and the Tana Delta. This paper examines the hydrological and geographical characteristics of the basin and discusses the need for studies on land-ocean interaction at the Delta.

Hydrology and climatic conditions

The Tana River Basin has a spatial extent of approximately 132,000 km^2 which is equivalent to about 23% of the total area of the Republic of Kenya (Table 1) (Ojany and Ogendo 1985). The main catchment area of the river is Mount Kenya (5199 m) and the Aberdare Ranges in the Central Highlands of Kenya. The snow-covered peaks of Mount Kenya provide continuous replenishment of the river, making it one of the few perennial river systems in East Africa. However, despite the high rainfall in elevations greater than 1800 m, the Tana River displays marked seasonal variations in river flow. As a result of rainfall pattern, the river usually has two distinct periods of high flow of three months total duration, separated by dry seasons when the flow frequently drops to one-fifth of the long-term average.

The total length of the river is about 1,102 km, from the Central Kenya Highlands to the Indian Ocean. The river takes a north-easterly course as it flows from the Kenya Highlands and then plunges over the Gtaru Falls (134 m) into the semi-arid landscape that constitutes the middle course. It forms a wide arch, then veers south and opens into a wide valley where it meanders through a floodplain into the Lower Tana Basin. The most important tributaries in the Kenya Highlands include the Sagana, Chania, Thika, Saba Saba, Maragua, Ruamuthambi and Mathioya rivers. In the Lower semi-arid zones, the river receives contributions in the rainy season from several ephemeral tributaries such as Tiva, Hiriman, and Kokani.

The Upper Tana catchment area in Central Kenya covers an area of 7,950 km^2 (Schneider 2000) which is about 6% of the total basin area, but it contributes more than 70% of the river runoff. The Upper Tana Basin has been the focus of a number of studies geared toward understanding soil erosion and sediment transport dynamics (Dunne and Ongwenyi 1976; Ongwenyi 1983; Schneider 2000).

Table 1. The main drainage areas in Kenya.

Drainage basin	Area (km^2)	% of the total area of Kenya
Lake Victoria	49,000	8.4
Rift Valley	127,000	21.8
Athi River	70,000	12.0
Tana River	132,000	22.7
Ewaso Ngiro	205,000	35.1

Rainfall in the Upper Tana Basin is controlled by the Indian Ocean monsoons in combination with pronounced orographic effects of the inland hills and mountains (Ewbank and Partners 1974). The Aberdare and Mount Kenya regions receive heavy rainfall (>1800 mm/year). Between 1800 and 1200 m ASL, rainfall is high, 1000-1800 mm yr^{-1}. However, in the Lower semi-arid regions, rainfall is much Lower ranging 500-750 mm yr^{-1}. This is particularly so in semi-arid zones of the basin such as Embu, Kitui, Mwingi and Tana River districts. Evaporation in these areas is about 1800 mm yr^{-1}, but there are significant seasonal variations.

The basin in general experiences two rainfall seasons controlled by the south-east (between March and September) and north-east (between October and early March) monsoons (Ojany and Ogendo 1985). The southe-east monsoon is associated with the long rains, which occur between March and June, with maximum rainfall in May. The north-east monsoon is associated with the short rains (November and December) with peak rainfall in November. However there are often great inter-annual variations in rainfall, partly due to *El -Nino* and *La Nina* southern oscillation cycles.

Rainfall in the Upper Tana Basin is more important than snow melting on Mt. Kenya in increasing the river runoff, with a good relationship between rainfall in the Central Kenya Highlands and river runoff in the basin. The maximum river discharge at Garsen in the Lower Tana Basin is experienced in June and December, implying a time lag of about one month between peak rainfall and peak river discharge in the Lower Tana Basin. The river discharge varies from less than 10 $m^3 s^{-1}$ in the dry seasons to over 2,000 $m^3 s^{-1}$ during flood flow conditions (UNEP, 1998). During normal rainfall years, river discharge ranging 100-500 $m^3 s^{-1}$ is common in the Lower Tana Basin. The mean annual river runoff has been estimated to be 4,700x10^6 m^3 per year, or about 32% of the total mean river runoff in Kenya estimated to be 14,836 x10^6 m^3 per year (Ojany and Ogendo 1985). Due to rainfall anomalies in the Western Indian Ocean which result in exceptionally high rainfall in Central Kenya, the Lower Tana Basin experienced extreme floods in 1937, 1947, 1951, 1957-8 and 1961 (Ojany and Ogendo 1985). However the severity of these floods has been reduced since the construction of Masinga high dam in the Upper Tana Basin (Otieno and Maingi 2000).

Land use and water resources programmes

The Upper Tana catchment area in Central Kenya covers an area of 7,950 km^2 (Schneider 2000) which is about 6% of the total basin area. ample rainfall and good volcanic soils have favoured maximum exploitation of the agricultural potential of the highlands and heavy human population settlement (Ojany and Ogendo 1986), predominantly encompassing the Central Kenya administrative districts of Kirinyaga, Murang'a, Nyeri, Thika, Meru and Embu. The main urban centers include Thika (also an important industrial center), Murang'a, Embu and Meru.

The soils of Central Kenya are well-covered with dense evergreen forests. There are mainly deeply weathered loams with high infiltration rates and low erodibility despite the steepness of the land (Ewbank and Partners 1974). Between 1800 and 1200 m ASL, rainfall is high (1000-1800 mm per year) and slopes are steep with loamy soils. However, where the former woodland vegetation has been removed and replaced with cultivated agricultural crops such as tea and coffee, bananas, vegetables, maize and beans, continuous tillage has reduced the natural fertility of the soil and this has necessitated the use of industrial fertilizers to boost crop production. Most of the crops grown in the region do not provide adequate ground cover, so the rate of erosion is greatly accelerated despite the generally low erodability of the soils

(Otieno and Maingi 2000). Major sediment-contributing areas are the densely populated and intensively cultivated foothills of the Aberdares, rather than the semi-arid lowlands (Schneider 2000). In the Murang'a and Nyeri districts the steep, intensively cultivated slopes are the main contributors of sediment into the Masinga Dam and the Tana River (Dunne 1974).

The main hydroelectric power-(HEP) generating dams constructed across the Tana River are in the Upper Tana Basin. These include Masinga, Kamburu, Gtaru and Kiambere HEP dams. Masinga Dam, the Uppermost reservoir, has impounded 45 km of the 1,102 km long Tana River and created a body of water covering 25 km^2, one of the largest artificial lakes in East Africa. Masinga Dam acts as a high dam, controlling water storage and discharge for the turbines of the dams downstream (Kamburu, Gtaru and Kiambere). Data showing the contribution of the main Tana River tributaries to the total sediment discharge into Masinga Dam is shown in Table 2. In addition to these reservoirs, Sasumua reservoir provides much of the water used in the Kenya's capital city, Nairobi.

Table 2. Mean annual discharge and sediment inflow into Masinga reservoir.

Tributary	Water Discharge (m^3)	Suspended sediment inflow (t yr^{-1})	Bedload discharge (t yr^{-1})
Tana	2239	3,890.000	390,000
Maragua	412	2,290,000	230,000
Saba Saba	120	990,000	100,000
Chania	205	870,000	90,000
Thika	252	420,000	40,000
Total	**3228**	**8,460,000**	**850,000**

Source: Otieno and Maingi (2000).

Poor land-use practices in the rich agricultural Upper Tana basin have increased soil erosion and a large quantity of sediments enters the reservoirs annually (Dunne and Ongwenyi 1976; Ongwenyi 1983). The long-term sustainability of these dams is in doubt due to reduction of their design capacities from heavy siltation (Schneider 2000; Otieno and Maingi 2000). The Tana River sediment load is 1-7 million t yr^{-1} during high-flow conditions (Schneider 2000). However, the mean annual discharge of water-suspended sediment into Masinga reservoir is 8.46 million tonnes against a mean annual water discharge of $3{,}228 \times 10^6$ m^3 (Otieno and Maingi 2000). This means that the sediment discharge downstream of the Masinga Dam is slightly less than 8 million tonnes per year, because the reservoirs trap a large portion of sediments from the Upper Tana Basin which is the main source of sediments carried by the river.

Various studies have yielded different sediment load estimates (Table 3). This is due to differences in the accuracy of the river runoff data, varying periods of data analysis and differences in techniques applied in the computation of sediment fluxes. Quantitative sediment yield estimates are difficult to produce with any degree of certainty. Prediction of the future rates of sediment yield is even more problematic given the variation in the annual discharge of the river. Most of the previous studies have extensively relied on the use of historical river discharge and suspended sediment concentration records to determine the sediment yield in the Upper Tana catchment (Schneider 2000). River and sediment discharge records include large gaps in some of the data and inaccurate analytical and river-gauging approaches result in erroneous estimates. There is a need to improve on the river and sediment discharge monitoring through regular maintenance of river gauging stations and regular collection of suspended sediment concentration data at representative river gauging stations.

Table 3. Sediment yield for the Upper Tana River basin.

Source of data	Sediment yield (t yr^{-1})
Gibb (1959)	280,000
ILACO (1971)	250,000
Dunne (1975)	1,283,000
Dunne and Ongwenyi (1976)	568,547
Edwards (1979)	334,730

the Lower Tana Basin is mainly semi-arid with rainfall of 500-750 mm yr^{-1}. Low rainfall, hot climatic conditions (30-35°C) and poor soils have resulted in low agricultural potential and therefore low human population densities. The human population is concentrated along the floodplains of the river, particularly in Tana River district, where the annual influx of floodwater during rainy seasons deposits fertile silt on the floodplains which in turn sustains the cultivation of rice and bananas by the riverine tribal communities. In the more arid zones of the basin, the main land-use activity is livestock grazing.

The Lower Tana Basin also has relatively flat coastal plains, which have encouraged the development of large-scale irrigation schemes such as the Bura, Hola and Tana Delta schemes. These development ventures were initiated by the Kenya government with generous bilateral and multilateral financial assistance from donor countries. However, these schemes have proved uneconomical and have failed. The main crops grown in these irrigation schemes were cotton and rice. As a result of the low nutrient status of soils in the Lower Tana Basin, there was heavy application of industrial fertilizers to improve production. At present, the only surviving large-scale irrigation project is Mwea-Tebere Irrigation and Settlement scheme in the Upper Tana Basin.

The Tana Delta dynamics

Despite being the largest deltaic system in Kenya, the Tana River delta and its associated estuaries has not been targeted for comprehensive research studies. Thus the hydrological and ecological dynamics within the delta are poorly known. The processes within the delta can be discussed only on the basis of very limited field investigations and reconnaissance surveys that have been carried out in the area.

The Tana River in its lower reaches forms a complicated drainage pattern of braided channels and meanders, with ox-bow lakes formed as a result of the interlocking erosion-deposition events. Downstream of Garsen, the river starts to break up into several distributaries which combine to form what is loosely referred to as the Tana Delta. In fact these distributaries are thought to be former channels of the river that have since been abandoned when the river shifted its course as it headed towards the Indian Ocean. The Tana River has changed its course over different time-scales (Ojany and Ogendo 1985), but the reasons for doing so are poorly known. The present main course of the river is to the north of the delta, where it enters into the Indian Ocean through a mangrove-fringed estuary at Kipini. Its former outlet is about 32 km south-west of Kipini.

The flow of nutrient-rich freshwater to the Indian Ocean has led to the formation of a rich fishery at Ungwana Bay, which is regularly targeted by large-scale commercial fishing companies because of the abundance of prawns (UNEP 1998).

The tidal influx from the Indian Ocean penetrates approximately 2-7 km into the estuary at Kipini, taking saline water into the inner portions of the delta. As evidence of the outflow of river water into the Indian Ocean, there is no coral reef complex in Ungwana Bay. Within the bay, circulation is driven by the river discharge, tides, monsoon winds and the coastal current systems, particularly the seasonally reversing Somali Current and the East African Coastal Current. Unfortunately, there are no studies detailing the degree of influence of these forcing factors on water circulation in the bay and delta. There have also been no hydrological studies geared at examining the main circulation patterns in the delta, including also the patterns of material (nutrient and sediment) transport and exchange. This is unfortunate since the Tana

Delta is one of the most important riverine systems in Kenya and is regarded as an important wetland for wildlife conservation by the Ramsar convention, of which Kenya is a signatory. Lack of studies in the area seem to have mainly been due to insecurity and inaccessibility. The delta is located in a remote part of the Coast Province with a poor transport network and facilities. Encroachment by armed bandits has also compromised security and development in the area.

The Tana Delta is certainly different from the Mwache, Mida and Gazi creeks (Kitheka 1998; Kitheka *et al.* 1999; Kitheka 2000), but there are certain fundamental aspects that could be similar given that these systems are fringed with mangroves and all receives freshwater discharge. Mangrove wetlands have been known to modify water and sediment circulation patterns and their presence along the estuary is certain to alter sediment transport dynamics.

Anthropogenic impacts and synergies

In the absence of any reliable data on anthropogenic impacts in the Tana Delta, it is difficult to offer a concrete synthesis of the likely relationship between man and the biophysical system at the delta. However, experience in similar systems helps us to understand the possible connections between the two (Kitheka 1998; Kitheka *et al.* 1999; Kitheka 2000).

There is no doubt that soil erosion in the Central Kenya highlands is impacting negatively on hydroelectric power reservoirs in the Upper Tana Basin (Ongwenyi 1979; Ongwenyi 1983; Schneider 2000; Otieno and Maingi 2000). The design capacities of these dams declinedover the years with the result that the Masinga reservoir cannot hold enough water for the generation of electricity. The reservoir also cannot hold enough water in periods of high river discharges and therefore its role in flood mitigation is being reduced steadily. In periods of severe droughts, there is rationing of electricity throughout the country, which severely constrains the industrial sector since industrial production in Kenya is highly depended on power supplied from the Tana River HEP dams.

Reduction in the design capacities of the Upper Tana River reservoirs has also complicated water supply schemes in both rural and urban areas due to heavy expenditure required for water treatment particularly in the removal of silt. This has increased the cost of treating water for domestic and industrial uses. Low storage capacities of the reservoirs has also reduced the volume of water available for rural and urban water supply, large and small-scale irrigation schemes.

In irrigation schemes located in the Lower Tana Basin, siltation of irrigation channels has necessitated expensive irrigation canal maintenance works, and irrigation water pumps constantly break down as a result of clogging due to high silt content of the river water.

In the Tana Delta, the main impact of heavy siltation has been the destruction of large hectarage of mangrove forests, which are important coastal ecosystems. Mangroves are thought to be nursery grounds of fishes and crustaceans of high commercial value, so their destruction affects the fisheries sector. This will definitely impact negatively on the socio-economic status of the local population. However, apart from destruction due to high sediment supply, destruction of mangroves also occurs through extensive uncontrolled cutting by local inhabitants. The destruction of the mangrove wetlands through these processes reduces the sediment-trapping role of the mangroves, allowing more terrigenous sediment to enter directly into the Indian Ocean where the resulting highly turbid water may be detrimental to marine ecosystems.

Research needs in the Tana Delta in the context of LOICZ

A comprehensive hydrological study should be initiated under the auspices of the Land-Ocean Interaction in the Coastal Zone (LOICZ) project, to examine the main circulation and material transport (both sediments and nutrients) patterns in the delta, and the influence of the mangrove forests in trapping terrigenous sediments from Tana River with a view of advising on their management. The project should also aim at determining the dynamics of sediment and nutrient transport along the Ungwana Bay coast, taking into account the patterns of the south-east and north-east monsoons as well as the dynamics of the coastal current systems. The project should run for two to four years, targeting both high and low river flow conditions, with time-series measurements of tides, tidal flow, tidal current velocities and directions, river discharge, suspended sediment concentrations, salinity, temperature and nutrient concentrations particularly silicates, nitrite-nitrogen, nitrate-nitrogen and orthophosphates. These parameters should be measured with reliable and accurate scientific equipment, including Orbital Backscatter turbidity sensors, MicroTide pressure gauges, Aanderaa Recording current meters (RCM-9), Atomic Absorption Spectrometer (AAS) and Auto-Analyser. Some of this equipment is currently available at the Kenya Marine and Fisheries Research Institute (KMFRI) at Mombasa. KMFRI is a government of Kenya research organisation with the mandate of conducting all aspects of aquatic research in Kenya.

Conclusions

Although the Tana River is one of the largest and most important river system in Kenya, its linkage with the Indian Ocean is at present poorly known. There have never been comprehensive studies on the hydrology of the Tana Delta. Variations in material concentrations and fluxes to the Indian Ocean are only poorly known. Most studies have been concentrated in the Upper Tana Basin but, because delivery ratios of different materials transported by the river have not been established, it would be scientifically inappropriate to use Upper Tana data to compute water and material fluxes to the Indian Ocean. The Tana River Basin, including the Tana Delta, offers a good location for determining how changes in the coastal system may feed back on the human system. It is recommended as perhaps the best case study site in Africa for studying Land Ocean Interactions in the Coastal Zone.

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