Freshwater inflow requirements for Wami River Estuary, Saadani National Park, Tanzania



Tanzania Integrated Water, Sanitation and Hygiene (iWASH) program

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Funding for the Freshwater inflow requirements for the Wami River Estuary, Saadani National Park, Tanzania was provided by the American people through the U.S. Agency for International Development (USAID). The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Agency for International Development, the United States Government or Florida International University.

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For bibliographic purposes, this document should be cited as:

FIU-GLOWS. 2016. Freshwater inflow requirements for Wami River Estuary, Saadani National Park, Tanzania, 104 p.
ISBN 978-1-941993-14-9

This report has been written to present information on the Wami River Estuary ecosystem and the freshwater inflows required to sustain the ecosystem. It is meant for multiple audiences - from policymakers, water/natural resource managers and national park administration to hydrologists, ecologists and social scientists.

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Acknowledgements

We are extremely grateful to the Saadani National Park authorities for permission and for full cooperation in conducting fieldwork in the Wami River Estuary, especially to the Chief Park Warden, Mr. Hassan, to Mama Rukya and to Angela. Park rangers Ismail Omary, Tumaini Magesa aand Kanji provided continual assistance and knowledge of the park ecosystems and history in a very cheerful manner despite the long hours worked on successive days.
We thank the District Water Eng. Juliana T. Msaghaa and Eng. Jason N. Raphael for their support in data collection. We thank the Wami Ruvu Basin Water Office (WRBWO), Morogoro for their participation in the fieldwork and the flow-setting workshop. In particular, we thank Praxeda Kalugendo, the Basin Water Officer for her wholehearted support.

Our heartfelt appreciation goes to different groups of people who surrendered their time to share their knowledge during group discussions and key informant interviews. Thanks go to villagers at Saadani and Kitame villages, fishermen at the fishing camp, public relations and owners of the Sanctuary Saadani Safari Lodge and Saadani River Lodge and Managers from Sea Salt LTD and Utondwe salt work.

This report and maps have been prepared by Amartya Saha with contributions from Japhet Kashaigili, Fredrick Mashingia, Halima Kiwango, Ernest Lema, Mathias Igulu, Michael Kimaro and Pendo Hyera. Rashid Tamatamah led the Environmental Flows Workshop based upon his long experience with environmental flows assessment and familiarity with aquatic ecology in East Africa. Elizabeth Anderson shared her expertise in environmental flow assessment in East Africa and her suggestions have enhanced the readability of this report. Vivienne Abbott and Maria Donoso have contributed their perspectives and along with Trymayne Hodge, have assisted with editing the report. Photographs have been provided by Michael Kimaro, Halima Kiwango, Ismail Omary, Tumaini Magesa and Amartya Saha.

This work has been coordinated and facilitated by the Tanzania iWASH Program led by Vivienne Abbott and Leodgard Haule, under the Global Water for Sustainability Program at Florida International University (FIU) led by Maria C. Donoso. The study would not have been possible without the financial support and the commitment of USAID to sustainable natural resources management.

Abbreviations and Acronyms

ANN	Annual
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DWR	Directorate of Water Resources
EC	Electrical Conductivity
EF	Environmental Flow
EFA	Environmental Flow Assessment
FDC	Flow Duration Curve
FIU	Florida International University
GEV	Generalized Extreme Value
GLOWS	Global Water and Sustainability Program
IUCN	International Union for Conservation of Nature
iWASH	Integrated Water and Sanitation Hygiene Programme, Tanzania
IWRMDP	Integrated Water Resources Management Development Plan
JF	January and February
JJAS	June, July, August and September
MAM	March, April and May
MK	Man- Kendall Statistical Test
MoW	Ministry of Water, Tanzania
OND	October November and December
RTK	Real Time Kinematic (survey equipment receiver)
SAGCOT	Southern Agricultural Growth Corridor of Tanzania
SANAPA	Saadani National Park
TAFIRI	Tanzania Fisheries Research Institute
TANAPA	Tanzania National Parks Authority
TDS	Total Dissolved Solvent
UDSM	University of Dar es Salaam
WSDP	Water Sector Development Programme
WRBWO	Wami-Ruvu Basin Water Office, Tanzania

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Executive Summary



The Wami Estuary – setting and importance

The Wami River arises in the biodiversity-rich Eastern Arc Mountains of Tanzania and flows into the Indian Ocean north of Bagamoyo. The last 20 kilometers of the river until its confluence with the sea constitutes the estuary, that witnesses a tidally and seasonally varying mix of freshwater and seawater. The Wami Estuary is situated within Saadani National Park (SANAPA) and is one of the very few estuaries on the Eastern coast of Africa to have the protection of being part of a National Park; thereby still provides habitat to a large and diverse wildlife population. The seagrass beds, mangroves and nutrients in the estuary constitute a the main nursery for numerous marine fish and prawn species on which coastal fisheries depend; thee fisheries are the main income source for coastal villages as well as a major protein source for Tanzania. The Wami River is the only perennial water source in SANAPA; human communities around the estuary also depend upon the river for water. As human needs for water rapidly escalate in the Wami Basin, sizeable water abstractions especially for large irrigation projects can significantly decrease this freshwater availability, thereby endangering the survival of these communities and the ecosystem services provided by the estuary.

Freshwater inflows - lifeblood of an estuary

A river's ecological health and viability is dependent on its natural flow-regime that creates and maintains hydrological, biogeochemical and ecological connectivity between the channel, floodplain, wetland and estuary. Ecosystem function and biodiversity has evolved under this natural variation in river flow. Rivers with highly altered flows lose their ability to support natural processes of maintaining water quality and supporting a healthy diverse ecosystem; this in turn vastly diminishes the services provided by a healthy river ecosystem to mankind – water, fisheries, flood control, to name a few. Large departures in freshwater inflows from the natural seasonal cycle can lead to abrupt changes in salinity in estuaries, with detrimental effects on the early life cycle stages of fish and other aquatic organisms. Sediment and nutrients brought in by the river contribute to the significantly higher productivity of the estuary as compared to the open ocean. Freshwater being the lifeblood of an estuary, the Wami Estuary and SANAPA are thus extremely susceptible to large upstream freshwater abstractions and land cover change. It is therefore essential to understand the linkages between seasonal freshwater inflow and the estuarine ecosystem. This understanding can help develop a set of inflow guidelines in wet and dry seasons, in years with low and normal rainfall. Furthermore, ensuring minimum inflows to SANAPA and the Wami

estuary automatically ensures minimum flows throughout the Wami River system, thereby benefitting the entire Basin.

Objectives and components of this study:

The main objective of this study is to establish environmental flow recommendations (reserve flows) into Saadani National Park, in order to sustain the estuarine ecosystem, ecological services and the wildlife in the Park. The continually changing mix of freshwater and seawater in both time and space within an estuary makes this kind of assessment very complex. Data on ecosystem links to water flow/depth and salinity in the Wami Estuary are extremely limited. A multidisciplinary team of experts was formed to obtain the best possible level of ecohydrological information and understanding via a combined approach of literature review, fieldwork and modeling. This team was drawn from Saadani National Park (SANAPA), Wami/Ruvu Basin Water Office (WRBWO), University of Dar Es Salaam (UDSM), Tanzania Fisheries Research Institute (TAFIRI), Sokoine University of Agriculture (SUA), Nelson Mandela Arusha Institute of Science and Technology (NM-AIST), Tanzania iWash Program/Florida International University (GLOWS-FIU) and the Ruaha Carnivore Project, Ruaha National Park.

The study has the following components:

1. Characterizing the ecological links of various communities within the Wami Estuary with water flow/level and water quality, in particular, with salinity. These communities include fish, invertebrates, seagrasses, mangroves, riparian vegetation and terrestrial wildlife. Ascertaining human use/demand of freshwater in the Estuary and upstream from SANAPA.
2. Investigating the historical flow data of the Wami River into the estuary, so as to understand the seasonal and interannual variability in flow that the estuarine ecosystem has witnessed since the 1950s.
3. Setting up a hydrological model to relate water depth to flow at the upriver end of the estuary.
4. Developing freshwater inflow guidelines (provided in this report) that replicate the natural inherent seasonal and interanual variability in inflows together with the flow/depth requirements for various faunal and floral communities.
5. Installing instrumentation at three sites along the Estuary in order to continually measure water level, flow and quality. This aims to develop the first continuous data time series to capture both diurnal and seasonal variability in these parameters, for at least an entire year. This data can then be input into a model relating salinity with freshwater inflows in different parts of the estuary in different seasons; such a model, if developed can form an independent management tool for Basin water managers to provide freshwater inflows to maintain the estuarine ecosystem.

Following two weeks of fieldwork in SANAPA, a flow setting workshop was held over two days at Bagamoyo, where team members presented the current level of knowledge about ecosystem-water links from literature/data review and fieldwork. This understanding then underpinned the discussion in identifying multiple water use needs and finally to set flow guidelines in wet and dry seasons for high and low flow conditions in normal rainfall and drought years. Other stakeholders were also present in this workshop from the Wami Ruvu Basin Water Office, Saadani National Park and Bagamoyo District Water Engineer's Office.

Freshwater depth/flow requirements for critical ecosystem processes

By adapting the Building Blocks Methodology (BBM) for Environmental Flows Assessment (EFA), a detailed assessment was performed on the seasonal minimum depth/flow/quality requirements for the vegetation, terrestrial and aquatic wildlife and human communities dependent on the Estuary. The depth requirements (depth averaged across river channel) were assessed for both drought years as well as 'maintenance' years with normal rainfall; corresponding discharges were obtained by a hydrological model (HEC-RAS) that was developed for the river channel at Gama Gate. The recommended flows were seen to be well within historically occurring flows. However given the rapidly increasing demand for water, coupled with the reduction in water storage in the basin from deforestation and wetland loss, it will be critical to ensure that these minimum flows are present. Without these minimum flows, essential ecosystem services to the people of Tanzania (fisheries, water quality, mangrove forest resources and wildlife/tourism) will be in jeopardy.

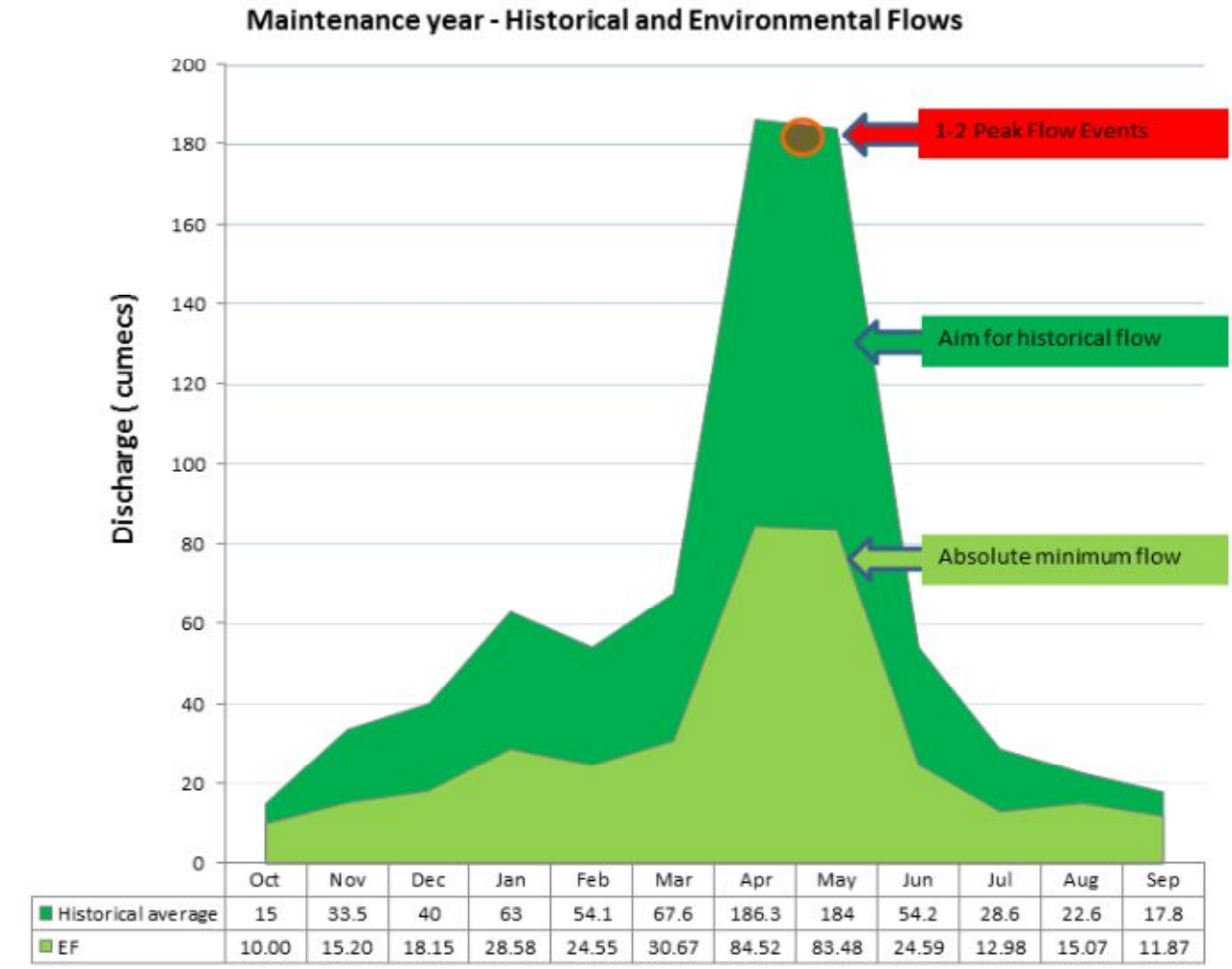
The minimum depth (averaged across river channel) and discharge values (at Gama Gate) for critical ecological processes are presented in the following table, along with ecological justification. Drought years are shown in orange coloured rows.

Season, flow, normal/dry year	Average Water Depth (m)	Discharge At Gama (m^3/s)	Motivation for depth/flow requirement	Consequences of not providing minimum flow/depth
Dry season, LOW flow, DROUGHT year	1.5	6.6	SURVIVAL of organisms; critical importance of maintaining flowing water and to avoid the river becoming a set of pools (that leads to large drop in dissolved oxygen levels, algal blooms and drastic change in water quality).	Mortality, possibly local extinction of organisms; dry conditions in riparian zone allows fires to spread from inland – very destructive for riparian vegetation that typically is not adapted to fire
Dry season, LOW flow, MAINTENANCE year	2.4	16	SURVIVAL, maintenance of dry season organism function (health) for growth and reproduction in following wet season; river habitat connectivity, critical importance of maintaining flow	Mortality; lower water levels create stress that affects growth and reproductive fitness in the following season; fires
Wet season, LOW flow, DROUGHT year	3	25	Wet season is the main period of water and nutrient availability; thus the major growth and reproduction season for almost all organisms	Species survival is at risk; Inadequate water flow/availability limits nutrient uptake, habitat connectivity, impaired water quality and fish spawning.
Wet season, LOW flow, MAINTENANCE year	4	46	Maintenance years allow reproduction at normal levels compared to drought years which can see very low reproduction	Same as above row; fish migrations from channel to floodplain or upstream along channel depend on adequate connectivity and flow.
Wet season, HIGH flow pulse, DROUGHT year	6	150	Flushing of sediments and salts from river channel; replenishment of nutrients and water to floodplain and oxbow lakes; suppression of invasive herbaceous vegetation along riverbanks; cues for fish spawning and migration.	Inadequate flushing of channels and floodplains, invasive herbaceous vegetation gets established; migration of fish and wildlife affected; oxbow lakes and floodplain become nutrient impoverished
Wet season, HIGH flow pulse, MAINTENANCE year	7	200	1-2 Flood pulses (peak flow) needed for replenishing nutrients and water to floodplain and oxbow lakes; spawning cues for fish; clearing channel of sediment and salt.	Same as above row. Normal years require 2-3 flood pulses to flush the system.

Environmental Flow Recommendations for the Wami Estuary at Gama Gate

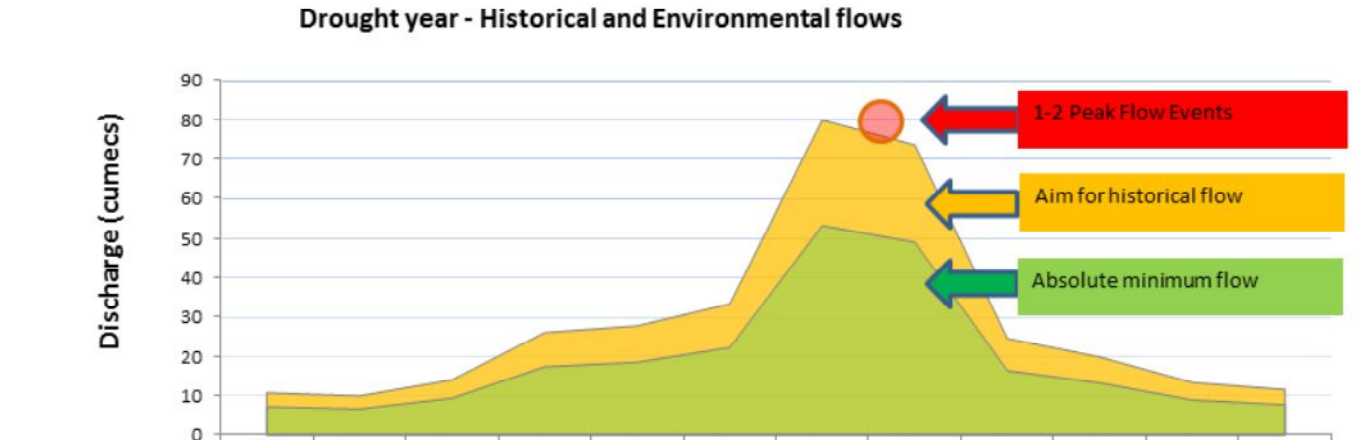
The depth and flow values in the above table reflect the minimum water needs to enable critical ecosystem processes to function for the current year. However, these flow values are LESS than naturally occurring flows in the lower Wami River as seen over the past fifty years (of available data). It is very important to note that the ecosystem has evolved with and is attuned to the magnitudes of naturally occurring flows (as shown in the monthly discharge graphs for maintenance and drought years below).

The figures below illustrate the monthly minimum freshwater inflows as measured at Gama Gate. In addition, pulses or high flow events of 100 cumecs are recommended twice a year, in April, as well as a 500 cumec flow once in five years, as such high peak flow events has been seen to occur with this approximate frequency in the historical flow data.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical average	15	33.5	40	63	54.1	67.6	186.3	184	54.2	28.6	22.6	17.8
EF	10.00	15.20	18.15	28.58	24.55	30.67	84.52	83.48	24.59	12.98	15.07	11.87

In the figure above, the dark green plot shows the historical monthly flow in cubic meters per second (~1950-2010) averaged for years with normal rainfall (ecosystem maintenance year). Light green plot depicts the minimum environmental flow (EF) necessary in Wami River at Gama Gate to maintain estuarine ecosystem for a given year.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical Average	10.7	9.9	14	26	27.7	33.3	79.8	73.5	24.5	19.8	13.3	11.5
EF	7.13	6.60	9.33	17.33	18.46	22.20	53.19	49.00	16.33	13.20	8.87	7.67

In the figure above, the yellow plot shows the historical monthly flow in cubic meters per second (~1950-2010) averaged for drought years (years with rainfall lower than one standard deviation below the average rainfall). The lime green plot depicts the minimum environmental flow (EF) necessary in the Wami River at Gama Gate to maintain estuarine ecosystem for a drought year.

Environmental flow guidelines indicate the MINIMUM flows

The environmental flows shown in the figures above were obtained from the ecosystem water needs (in the above table). However, if river flows (as measured at Gama Gate) are maintained at these minimum EF levels for multiple years, that would mean lower than historically normal flows over the period, which will stress the ecosystem. While a minimum set of flows as assessed in the workshop represents conditions for survival. However, in order to maintain ecosystem function in its natural state (the state in current and recent past), the historical flow magnitudes and patterns are necessary. However, providing the full amount of historical flows every year could be a challenge on account of increasing water demand and human impacts throughout the basin. Hence the EF concept has emerged to avoid catastrophic change in the ecosystem.

Hence, the EFs are just a guideline for minimum flows for a year, and river basin water management efforts should strive to allow more flow than the minimum EFs, whenever possible.

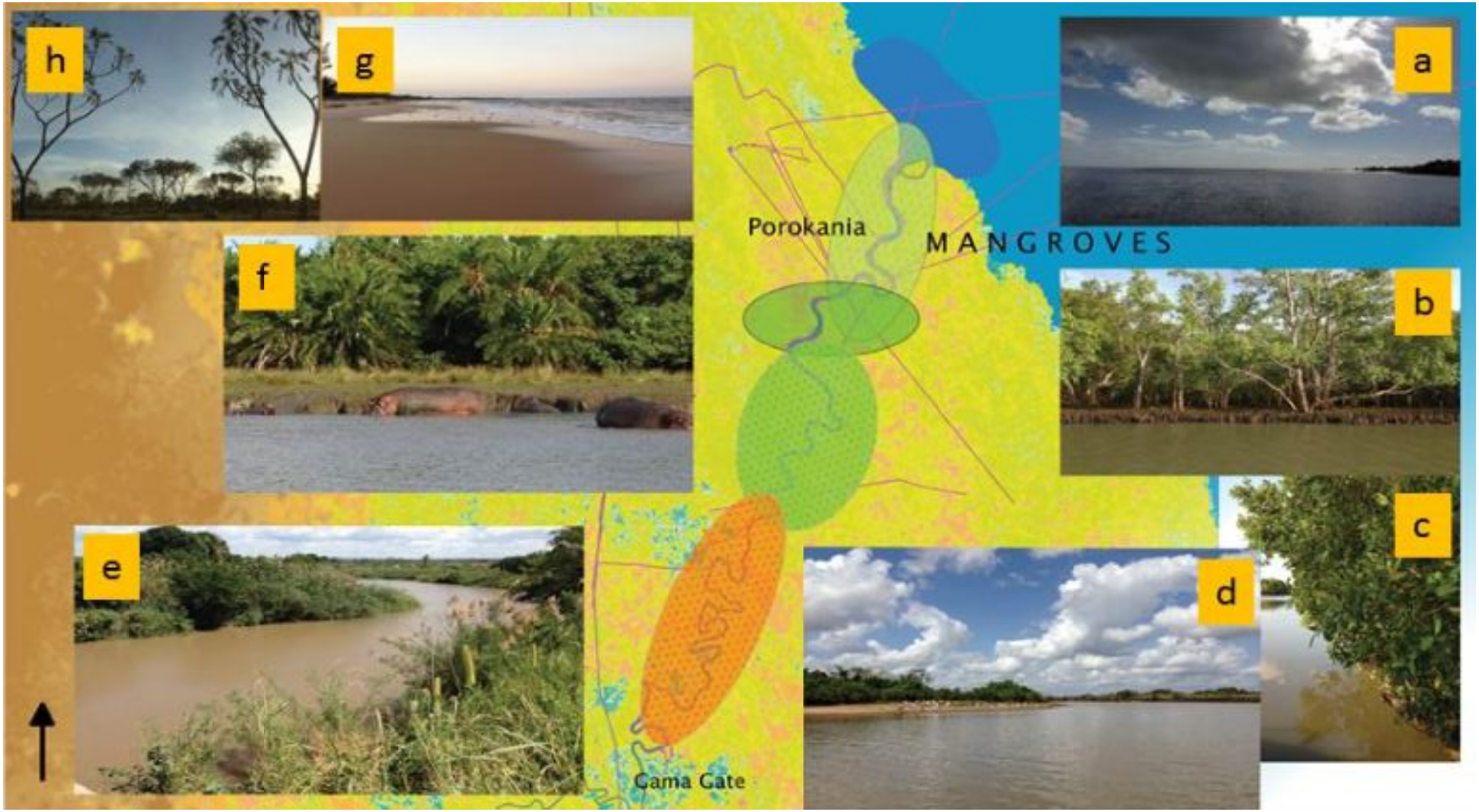
Future steps:

A hydrological and water quality model will be necessary to calculate the magnitude of freshwater inflows necessary at the upstream Park boundary (Gama Gate) in order to maintain the seasonally-varying salinity regime. Developing the hydrological model would require high-resolution elevation data of the floodplain along the estuary. Calibrating this model would necessitate, at the minimum, a year of salinity data. In order to obtain a continuous time series of data, which is not available as yet, instrumentation has been placed that meausres and logs salinity, water level, flow and DO data in three zones in the Estuary – (i) Porokanya, near the mouth of the river, (ii) Kinyonga camp, past the mangrove-palm transition zone and (iii) upstream at Gama Gate where freshwater conditions exist, but where estuarine fish have been observed. This will hopefully provide the critical data necessary for modeling the estuary to relate salinity and flow, as well as the first real-time data for the National Park for monitoring purposes. The model can then be used to refine the initial set of recommendations that resulted from the September 2015 Flow Setting Workshop. Finally. EF processes are part of an adaptive management strategy, using available data and knowledge to make preliminary assessments, and then updating and improving these with time and additional research.

Report contents

The Executive Summary summarizes the importance of providing adequate freshwater inflows to maintain the estuarine ecosystem and the services provided to mankind. It also presents the initial set of guidelines for freshwater inflows in different months as measured at Gama gate, near the upstream end of the Wami estuary.

In the main report, the first chapter introduces the Wami Estuary within the broader Wami River Basin. Chapters 2-8 describe the existing knowledge of the hydrology, water quality, the various ecosystem components and human resource use in the Wami Estuary. This knowledge was obtained from literature/data surveys and fieldwork in the estuary. Chapter 9 details the Environmental Flows Assessment (EFA) process and the recommended guidelines for freshwater inflows while Chapter 10 specifies potential future actions and the way forward.



Diverse ecosystems and landscapes in the Wami River Estuary. Starting from top right in clockwise order: (a) Wami River mouth on the Indian Ocean; (b) mangrove bank at low tide; (c) mangrove-dominated vegetation for the first 4 km; (d) freshwater vegetation further upriver with aquatic birds on beach; (e) freshwater vegetation at Matipwili; (f) hippos and palms near the mangrove-palm interface; (g) a beach on the Indian Ocean and (h) hyphaena palm and acacia forest. The coloured ellipses along the river signify vegetation communities: from top to bottom, mangroves, mangrove—palm transition zone, freshwater riparian forests and acacia savanna.

Chapter 1: The Wami River Estuary

The Wami River starts in the biodiverse-rich Eastern Arc Mountains of Tanzania and flows into the Indian Ocean north of Bagamoyo (Figure 1) through Saadani National Park. The last 20-25 kilometers of the River until its confluence with the Ocean forms the Estuary (Figure 2), with a tidal and seasonally varying mix of freshwater and seawater. Out of all the major estuaries in Tanzania (ie, Pangani, Wami, Ruvu and Rufiji), the Wami Estuary is the only estuary that is protected by being partially included in a National Park. The small and shallow deltaic estuary provides shelter to a diverse wildlife population that depends both on the river as well as the surrounding riparian forests. The wildlife and riparian vegetation depend upon the seasonally varying freshwater availability, and their life cycles and migration patterns have evolved in response to natural variations in freshwater inflows. The Wami River is also the only perennial water source in Saadani National Park; human communities around the estuary also depend upon the river for water. As human needs for water rapidly escalate in the Wami Basin, including plans for commercial irrigated agriculture and the proposed Southern Agricultural Corridor (SAGCOT), large water abstractions will significantly decrease this freshwater availability, thereby endangering the water security of these communities. In addition, seagrass beds, mangroves and nutrients in the Estuary constitute an important nursery for numerous marine fish species on which depends coastal fisheries, the main income source for coastal villages as well as an important protein source for Tanzania (20-30% -FAO 2007).

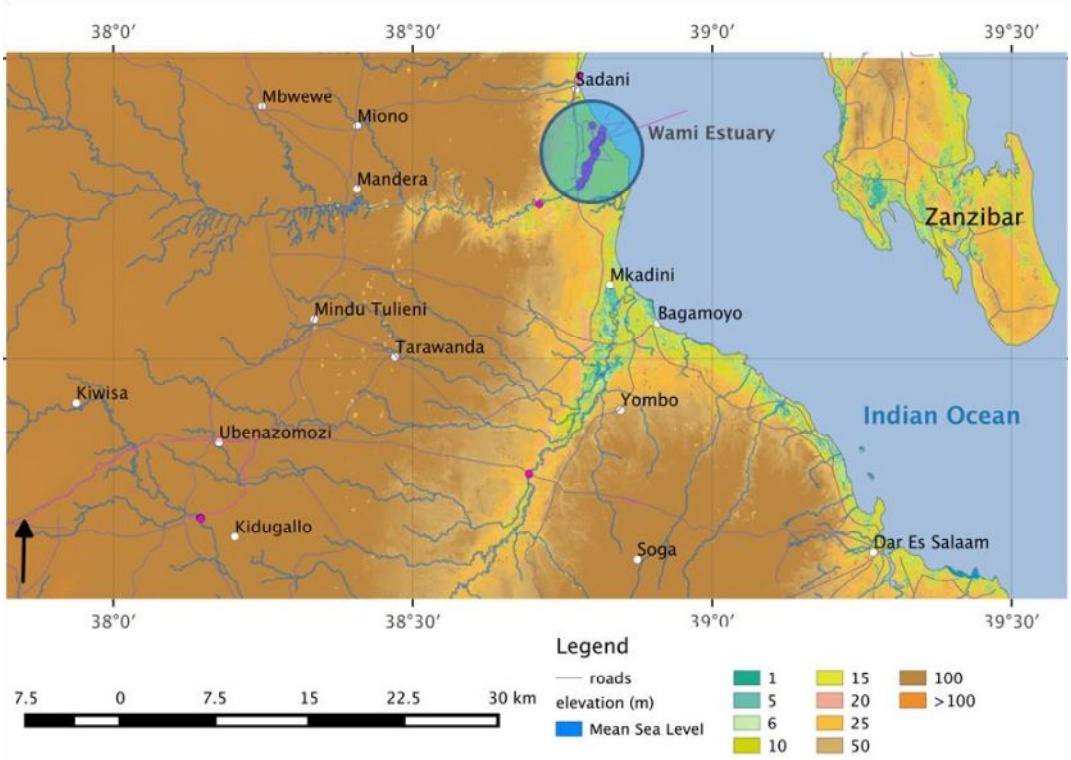


Figure 1: Location of the Wami Estuary in Tanzania

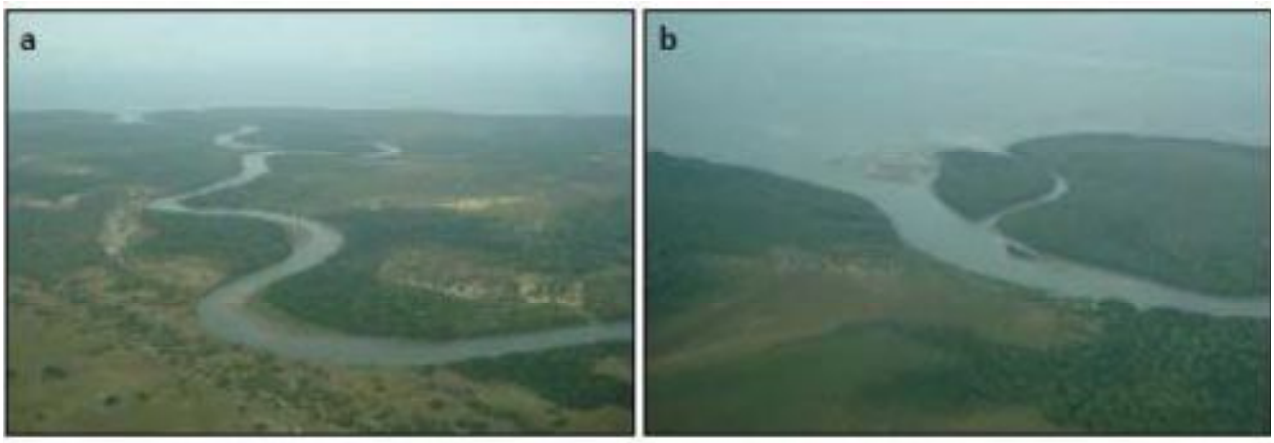


Figure 2: Wami Estuary entering Indian Ocean through Sadaani National Park. Right - deltaic feature of the estuary. Source: Kiwango 2011

Estuaries – highly productive ecosystems sensitive to freshwater inflows

An estuary is defined as a partly enclosed body of brackish water with at least one freshwater river flowing into it and having a free connection to the sea (Pritchard 1967). Estuaries have a unique environment with a constantly varying mix of freshwater and seawater. In the Wami Estuary, this mix varies seasonally from a pulse of freshwater flowing far out to sea during the rainy season, to very saline conditions in the estuary during the dry season when the freshwater flow in the river decreases (Anderson & McNally 2008, Kiwango *personal observation*). The mix of freshwater and saline seawater also varies diurnally with tides; at high tide, the seawater opposes the freshwater and moves into the river as a wedge of denser water flowing in under the freshwater that is flowing seaward in the opposite direction. This is typically seen from increasing salinity values with depth, such as in the Ruvu estuary (FIU-GLOWS 2014 b).

This ever-changing environment of fresh and saline water along with the nutrients brought by both water flows provides some of the world's most productive ecosystems - the estuarine and coastal ecosystems. In the tropics, seagrass beds cover the estuary and coastal offshore muddy/sandy bottom, where marine fish come to breed, the seagrass and mangroves providing both shelter for juvenile fish from larger marine predators of the open sea, as well as food in the form of submerged aquatic vegetation and marine invertebrates (Bwathondi & Mwamsojo 1993). About 90% of global fisheries occur in estuaries and their associated near shore and continental margin systems (Wolanski *et al.,* 2004). Many species of mangroves frequently are found growing along the river banks and coasts of tropical and subtropical estuarine environments. Their roots protect the coast from erosion and from tropical storms, and also slow down flow thereby facilitating sedimentation and nutrient deposition (Semesi 1991). Mangroves and seagrass beds are critical nursery areas for marine fish, and coastal fisheries depend on these habitats remaining in a healthy condition. Semesi *et al.*(2000) describe in detail the natural resources in the mangrove forests and the seagrasses and their uses by the local communities. The livelihoods of local human populations are often largely dependent on these resources such as fish and mangrove poles that have been exported for centuries throughout Tanzania and across the Indian Ocean (Martin 1978). Furthermore estuaries provide habitat for wildlife and migratory oceanic species, play a key role in flood and erosion control, sediment retention, absorption of pollutants and protection of water quality (Uncles *et al.,* 2002).

Freshwater inflows influence the physical, chemical and biological properties of water, circulation and mixing characteristics, habitat structure and other geomorphological features such as channel morphology and sediment depositions. Thus changes in freshwater inflow may have an impact on the general functioning of the estuary. Many estuaries in the world are suffering from decreasing freshwater inflow to the lowest level of their natural regime. This result in degradation of aquatic habitats, increasing salinity intrusion upstream, reduced sediment and nutrient loading, and affect distribution, composition and abundance of estuarine organisms. In some cases, extreme increase of freshwater inflow may also impact the estuarine functioning by interfering with residence times and aquatic life.

Rainy and dry seasons in the river basin cause a seasonal fluctuation in freshwater inflows into the estuary to which local ecosystems have adapted. However a decrease in freshwater inflow to levels lower than the natural seasonal flow regime results in increased seawater intrusion into the estuary (Nguyen & Savenije 2006). Prolonged exposure to high salinity reduces water uptake in mangroves by stressing the salt-exclusion mechanisms in roots and leaves (Parida & Das 2000). Even though mangrove species differ in their tolerances to salinity, high levels of flooding with saline water can stress even the most salinity-resistant species, resulting in eventual mangrove dieback. Similarly, hyper-saline conditions in bays stress seagrasses, as well as the various organisms that reside in these habitats. Not much is known about the impacts of prolonged high salinity on biogeochemical decomposition cycles, or the growth and metabolism of juvenile crustaceans and fish. Decreased river inflows into estuaries also lead to decreased nutrient and sediment inputs; decreased sediment inputs can lead to accelerated erosion of the estuary by ocean waves as has been observed in the Pangani river estuary (Sotthewes 2008). At the same time, very high aseasonal freshwater flows can also disrupt lifecycle process of estuarine ecosystems (Powell *et al.*2002, Tolley *et al.*2012). Keeping all this in mind, there is an optimal range of freshwater inflows into estuaries necessary to maintain estuarine ecosystems; this range should typically follow the natural seasonal flow variation as seen from longterm historical flow data (where available).

Freshwater flows to the estuary thus balance seawater coming in with the tide. Hence, any large decrease in freshwater inflows leads to seawater intrusion into the estuary, and possibly into coastal aquifers near the estuary in areas where the estuary and underlying aquifers are hydrologically connected, or in low elevation flat areas along riverbanks where seawater floods in overland during low tide. Once shallow well water gets saline, wells often have to be abandoned. This is already happening in Bagamoyo district, Tanzania, as evident from coastal village wells that had to be relocated on account of salinization (Tobey 2008). While coastal salinization is reportedly occurring over a wider section of the coastline in Tanzania, maintaining the seasonal freshwater flows into estuaries can resist the salinization of aquifers in the vicinity of the estuary. Sotthewes (2008) notes increasing saltwater intrusion occurring in the Pangani estuary over the past several decades and attributes it to two major factors: decreasing freshwater discharge on account of irrigation and hydropower

reservoir abstractions and increasing erosion at the marine end on the account of less deposition of river sediment. In spite of the importance of estuaries, they remain one of the most negatively impacted ecosystems on the earth mainly due to increasing anthropogenic impacts such as excessive abstraction of water in the catchment, pollution, habitat alterations, eutrophication and overfishing. As a result, the natural functioning of these ecosystems continues to be altered causing significant impact on productivity and provision of ecosystem services.

Sustainable estuary/coastal management and freshwater inflows

Physicochemical characteristics, biological structure, and productivity of estuaries are closely linked to seasonal changes in timing and volume of freshwater inflow (Drinkwater and Frank 1994, Sklar & Browder 1998, Alber 2002, Powell *et al.*2002, Estevez 2002). Maintaining an adequate freshwater inflow regime is critical for maintaining fisheries, the ecosystem and surrounding connected environments. Policymakers thus are faced with the difficult task of developing water resource management programs that allocate freshwater between changing human and ecosystem needs in a sustainable manner (Pielou 1998). The challenge is to assess what constitutes an 'adequate freshwater inflow regime', and to translate that into a tool or a set of guidelines that river basin water management can implement.

An Environmental Flow Assessment, as related to an estuary, aims to determine the quality, quantity, and timing of freshwater flow required to maintain the estuarine ecosystems in a desired state. It must foremost be kept in mind that the ecosystems in rivers and estuaries have evolved under naturally varying flows and water quality. Hence, the determination of these freshwater inflow requirements would need to consider the following questions:

- What are the ranges of water flow, depth and quality (particularly salinity and turbidity) associated with the various plant and animal communities, human resource use and ecosystem services in the estuary?
- What have been the historical (last 30-50 years) flows entering the estuary?
- How does the salinity profile in the estuary and upriver vary with freshwater river flows, tides and seasons?

Issues and challenges in the Wami Estuary: water flow and quality

The Wami River drains approximately 43,000 sq km across an area of widely diverse climate, topography and land use, ranging from the Mkondoa headwaters in arid Dodoma to the Mkata plain and Dakawa wetlands adjacent to the Ukaguru and high rainfall Nguru Mountains that contribute considerably to the Wami River (IUCN 2010). Chapter 2 of this report details the historical seasonal variation in river flow, and the findings from the environmental and aquatic biodiversity assessments in 2007 (FIU-GLOWS 2014 d) show that many parts of the Wami River still supported high diversity. However, surface water demand in the Basin has sharply increased in the past decade. Large scale irrigation projects in Mkata and Dakawa for water-hungry crops such as rice and sugarcane carry high potential water demand from the river; in addition, there are increasing river water abstractions for village water supply and small scale irrigation in the dry season, many of which are unauthorized. At the same time, the ongoing loss of native forest cover in both mountains and lowlands as well as wetland loss has led to the earlier drying up of springs and consequent reduction of baseflow into streams and the river (IUCN 2010, FIU-GLOWS 2014 a). Water quality is another issue – the rates of sedimentation in the river have gone up sharply over the past decade (Yanda & Munishi 2007, IUCN 2010, FIU-GLOWS 2014 a-c, authors personal observation), as a consequence of extensive deforestation, cultivation on riverbanks and increasing livestock access. Increasing agrochemical inputs in runoff, industrial effluent and other human waste further impair water quality. The estuary and Saadani National Park are at the receiving end of the river, and hence are most susceptible to flow decreases and water quality deterioration. The critical role freshwater plays in estuary ecosystem function, and the services that estuaries provide mankind are not widely known amongst the urban public in general across the globe, that is evident from statements often heard, such as "letting the freshwater in the river go to waste in the sea". Furthermore, Saadani National Park ("where the Bush meets the Beach") is a one of a kind, unique park having a stunning variety of both terrestrial and aquatic ecosystems, from savanna grassland and dry forest to estuarine river and coastal beaches. The Wami River is the only perennial water source in the Park, and hence there are strong, multiple reasons for ensuring a flow regime that is as close to the natural regime as possible.

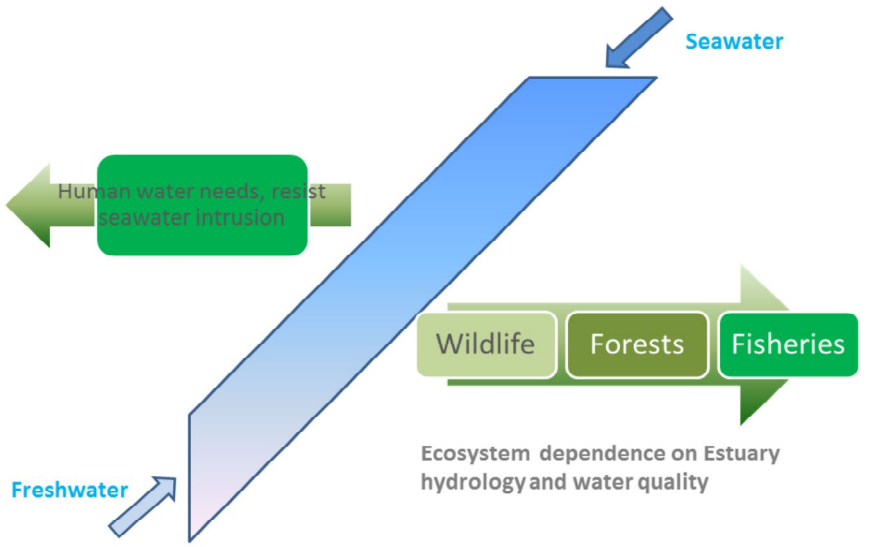


Figure 3: The estuary with freshwater and seawater inputs provides several ecosystem services.

The purpose of this report is three-fold:

1. To compile in one document the current state of knowledge of the Wami estuarine ecosystem, with specific reference to the connection with water flow and quality
2. To lay down the initial recommendations for environmental flows for the Wami Estuary and Saadani National Park along wth a description of the process of obtaining these recommendations, and
3. To serve as a scientific reference for justifying the need for reserving minimum freshwater inflows to the estuary, in order to sustain the services it provides Tanzania.

Study approach

The study had the following components:

1. Characterizing the ecological links of various communities within the Wami Estuary with water flow/level and water quality, especially salinity. These communities include fish, invertebrates, seagrasses, mangroves, riparian vegetation and terrestrial wildlife.
2. Ascertaining human use/demand of freshwater in the Estuary and upstream
3. Relating salinity to freshwater inflows in the Estuary via modeling and data analysis. Longterm flow data at Mandera along with existing salinity data from various surveys in the estuary were used.
4. Flow setting workshop involving all stakeholders in the region, to discuss the understanding of the ecosystem gained from survey and data analysis, consider multiple use needs and then set flow guidelines.
5. Installing instrumentation at three sites along the Estuary in order to continually measure water level, flow and quality and thereby aimiing to develop the first continuous data time series to capture both diurnal and seasonal variability in these parameters.

Study Sites

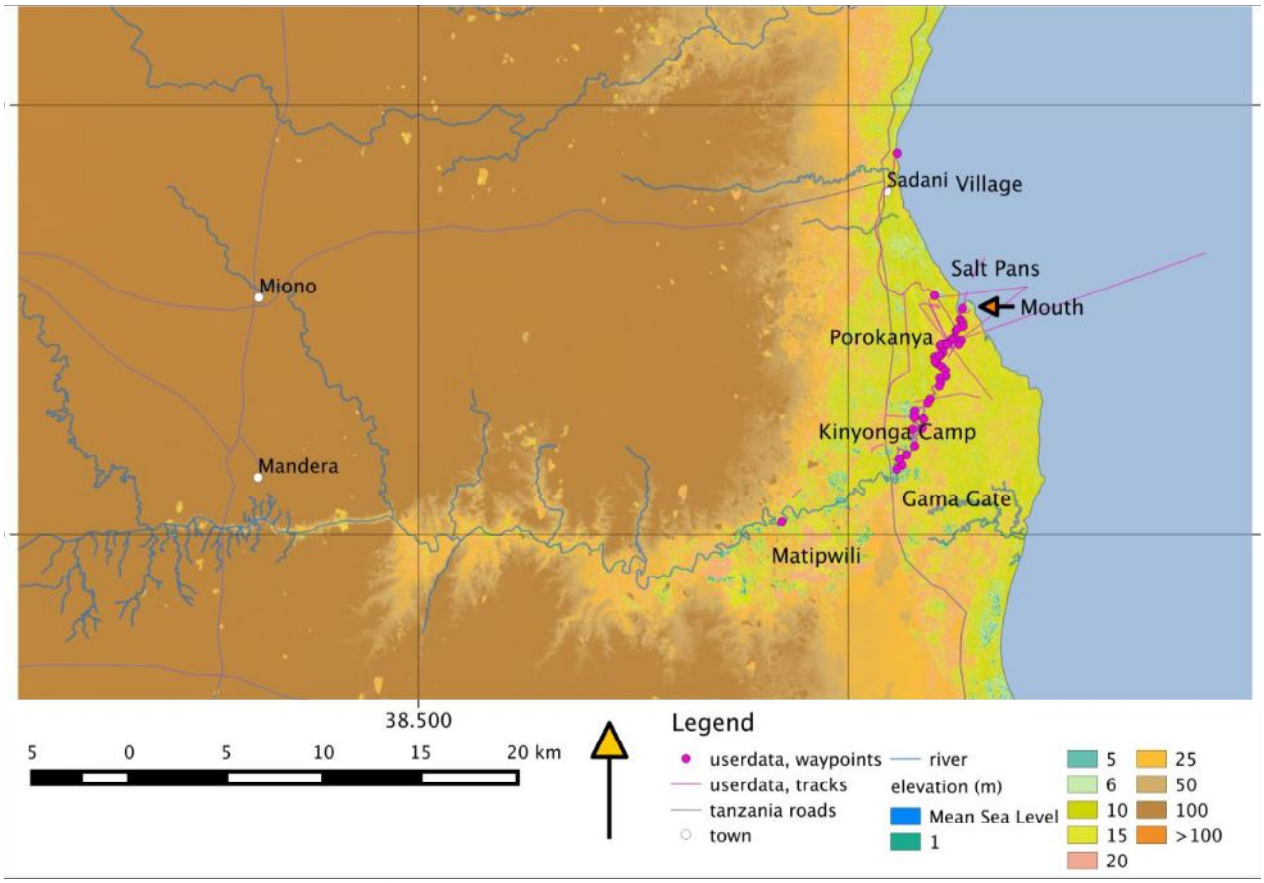


Figure 4: Field sites along the Wami Estuary from the mouth to Matipwili

The study took place throughout the estuary, from the river mouth going upstream to Gama Gate, situated close to the park boundary on the road from Bagamoyo to Sadaani village. Hydrological and hydraulic investigations went further upriver to Matipwili and Mandera. Instrumentation was set at Gama Gate, Kinyonga Camp and Porokanya (boat ramp). Water quality, riparian vegetation, aquatic and terrestrial wildlife observations as well as human water use assessments were carried out from Gama Gate downsteam to the mouth of the river. In addition, human use (water, wood, fisheries) was also assessed in settlements outside the National Park that are dependant on the estuary.

Chapter 2 – Hydrology

Contributors – Japhet Kashaigili, Amartya Saha

This chapter details the hydrology and climate of the Wami Estuary scaling up to the Wami Basin. Given that there is no historical flow data within the estuary, flow regime data is obtained from Wami-Mandera gaging station and extrapolated to the estuary after accounting for water abstractions and inputs. The data is presented to provide an understanding of the magnitudes of flow along with seasonal and interannual variation that the estuarine ecosystem has experienced since the 1950s. A basinwide perspective on hydrology helps to understand the factors affecting the amounts and timing of freshwater flowing into the estuary.

Background: Drainage and Climate of the Wami River Basin

The Wami is one of the major rivers draining the Eastern Arc Mountains. Located within 5°S-7°S and 36°E-39°E, its basin area extends from the upper catchments in semi-arid Dodoma Region through the humid inland swamps in the Morogoro Region. The Wami discharges into the Indian Ocean at Saadani north of Bagamoyo, Coast Region (Figure 5). The basin covers an area of approximately 43,760 km^2. The river originates from the following mountains: Chenene Hills, north to north-east of Dodoma (2000 m.a.m.s.l.), Ukaguru Mountain north of Wami (400-1000 m.a.m.s.l.), Rubeho Mountain west of Kilosa (400-1000 m.a.m.s.l.), Nguru Mountains north of Kilosa (altitude 400-2500 m.a.m.s.l.). The following main tributaries form part of the Wami system: Kinyasungwe River, Lumuma River, Mkondoa River, Miyombo River, Kisangata River, Mkata River, Tami River, Rudewa River, Lukigira River, Diwale River and Divue River (WRBWO 2007). More details on hydrological zonation, tributary discharge and wetlands ecosystems can be found in (IUCN, 2010; Valimba, 2007, FIU-GLOWS 2014c).

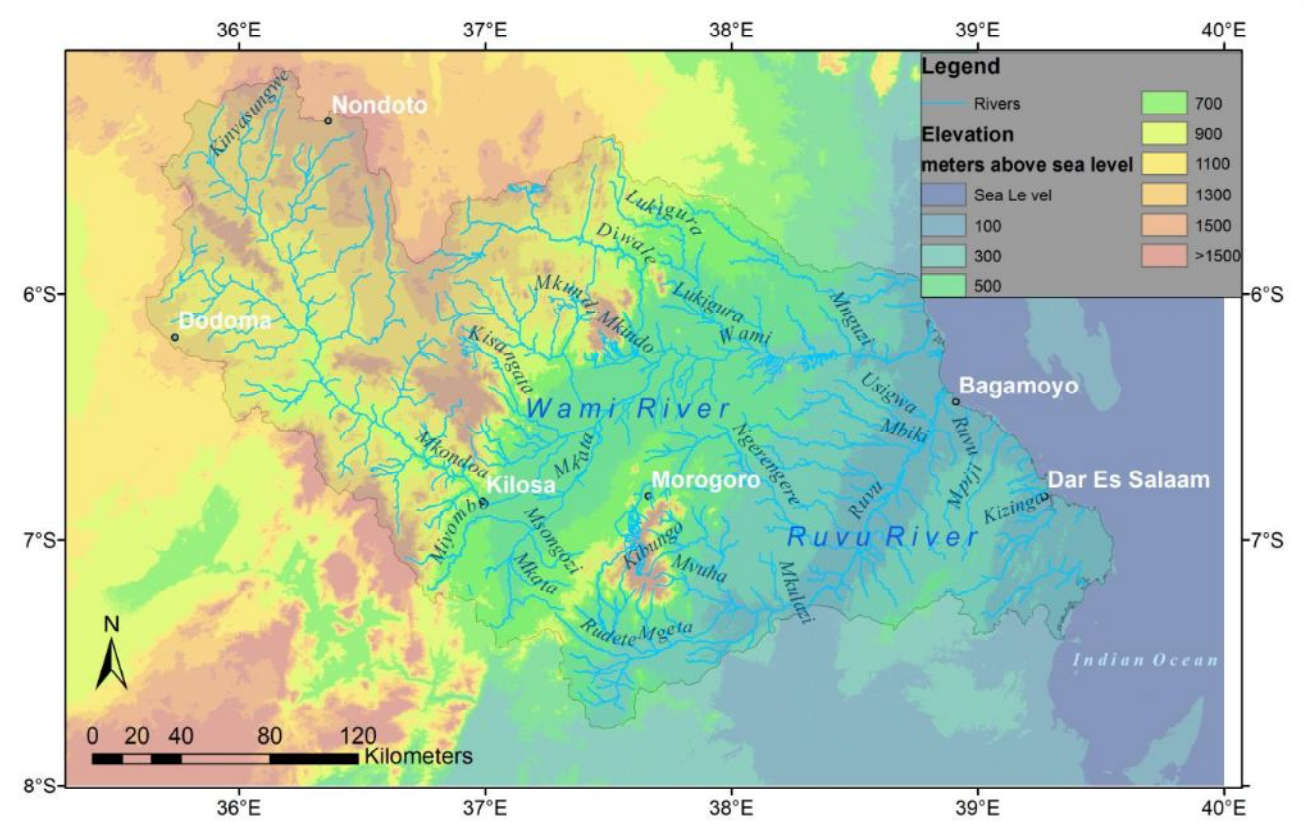


Figure 5: Map of Wami Ruvu River basin

Rainfall

Average annual rainfall across the Wami sub-basin is estimated to be 550–750 mm in the highlands near Dodoma, 900–1000 mm in the middle areas near Dakawa and 900–1000 mm at the river's estuary (IUCN, 2010), with the highest rainfall

(> 2000 mm) occurring in the Nguru Mountains. Most areas of the Wami sub-basin experience marked differences in rainfall between wet and dry seasons. Although there is some inter-annual variation in timing of rainfall, dry periods typically occur from July to October (monthly rainfall under 50 mm) and wet periods from November to December (vuli rains) and from March to June (masika rains) (WRBWO, 2007). August is the driest month in the basin while the highest rainfall amounts are mainly experienced in March and April (Valimba (2007).
As regards interannual variability, Valimba (2007) provides results of linear trend analysis on seasonal and annual rainfall amounts for the 1964-1993 periods. The general results indicated predominant decreasing trends in seasonal rainfall amounts in both the long and short rainy seasons, as well as over the dry season. This was spatially uniform across the basin. There were no clear trends over the intermediate period between the two rainy seasons, ie: January and February.

Streamflow

The results from long term analysis of flows and rainfall indicate existence of transition pattern of intra-annual flow variation between the bimodal (double peaks) regime and the unimodal (single peak) regime within the sub-basin with a defined peak during the long rains (Figure 6). Such occurrence of well-defined peak reflects the influence of rainfall peaks during the long rains. However, a slight peak during the short rains is sometimes apparent in the higher elevation gauging stations with large catchments. The low flows in rivers in the Wami River sub-basin are experienced during the dry period, namely July to October.

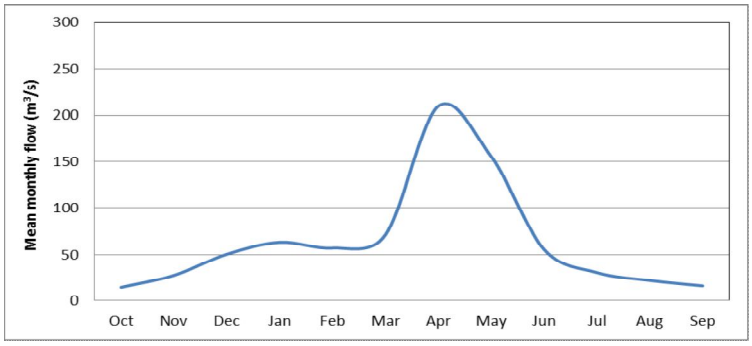


Figure 6: The average seasonal flow pattern in lower Wami River Basin, with the wettest period during March-April, and the driest period in September and October (Note: Hydrological year is October to September)

River stage and discharge data – what is available

Available information on hydrometric observations in the Wami sub-basin indicates existence of flow gauging stations that have been operational in different periods (Valimba, 2007). Most of the stations were established between the 1950s and 1960s and operated up to between the late 1970s and early 1990s. The majority of available records cover the period from the 1970s to the early 1980s. There is no reliable information to enable concrete assessment of the present flow situation in most of the stations. Recent efforts to revive the river flow gauging network have rehabilitated some non-operational gauges and water level observations are now available since September/October 2006 at 12 stations (Valimba, 2007). Despite these advances, there are no reliable rating equations to enable conversion of water levels to discharge. Also, for most of the gauging stations, there is a large gap of missing information between the early 1980s and mid 2000 in addition to other gaps existing within the observation periods. Details on data availability and gaps can be found in Valimba (2007).

Study approach and methodology

Gama Gate – the upstream gateway to the Wami Estuary

The main study site for the hydrological assessment was Gama Gate which is located just upstream of the saltwater – freshwater interface in the Wami River (Figure 4, Figure 7). Although seawater does not reach Gama Gate (as evident from the freshwater riparian vegetation and water quality measurements), there is possibly a tidal backwater effect, as observed from the drop in water levels over the course of the morning by ~30 cm and a rise again in the evening (data shown at the end of Chapter 3). Hence, measurements were also carried out further upstream at Matipwili and Mandera, sites where there have been WRBWO staff gauges with data records since 1955 but with data gaps as mentioned in the previous paragraph.



Figure 7: Panoramic view of Wami River at Gama Gate, upstream left to downstream right.

The literature review aimed at collecting and collating all existing relevant information and hydrological data for the Lower Wami and Wami Estuary, including historical records, and any additional water managements concerns or threats relevant to this study. The main source of the information was the previous EFA studies for the Wami River in 2007 and 2014; a Rapid Ecological Assessment of the Wami River Estuary carried out in 2007; Report on the Impacts of Fire on Wildlife Habitats and Population Abundances, Densities and Diversities of Introduced Mammalian Species in Saadani National Park, Tanzania of 2015; and the WamiRuvu IWRMDP documents. The results of the literature and data survey along with fieldwork are presented below.

Results and Discussion

Hydrological fieldwork was conducted from 19th to 25th August 2015. Discharge measurements were carried out the three sites using a Q-Liner tool (Table 1; illustration in Chapter 3).

Table 1: Summary of measured discharges at three locations in August 2015

Station Name	Date	Mean Depth (m)	Width (m)	Mean Velocity (m/s)	Max Velocty (m/s)	Cross-sectional Area (m^2)	Discharge (m^3/s)
Gama Gate	22 - 08 - 2015	1.34	36.5	0.105	0.329	62.92623	6.598
Matipwili Village	22 - 08 - 2015	1.53	30.0	0.121	0.375	59.15303	7.131
Wami Mandera	22 - 08 - 2015	2.10	45.0	0.059	0.109	118.7769	7.013

Estimation of historical flows at Gama Gate

The Gama site in the Wami River is currently ungauged: a set of staff gauges exists but is not operational. Therefore, the flows at this station had to be estimated based on neighbouring stations. The nearest station with good historical records is the Mandera station at Wami River Bridge. The missing values of the flow observations at Mandera station were previously reconstructed and infilled for the period 1955 to 1984 (Valimba, 2007), hence, the reconstruction process was not repeated. The previous reconstructed time series data was used in estimating flows at Gama after accounting for seasonal flow contributions from the intervening catchment between Mandera and Gama and the water uses/abstractions especially in the dry season (Table 2). The intervening catchment was delineated from an ASTER Digital Elevation Model (Table 3).

Table 2: Estimated Water Uses

Water User	Village	Type of use	Type of Infrastructure	Date established	Amount (m^3/d)	Amount (m^3/s)	Remarks
Saadani village Water supply project	Saadani village	Domestic	Intake	10/1/2013	163.3	0.0019	
Sea salt industry	Saadani village	Domestic	Dozer	1977	24.0	0.0003	
Saadani National Park	Saadani village	Domestic	Dozer	2005	342.3	0.0040	
Kitame village water supply project	Kitame village	Domestic	Intake	10/1/2013	140.6	0.0016	
Zakaria Musa Farm	Gama -Kitame	Irrigation	pump	1997	40.0	0.0005	Based on estimates

Sabina Nyoni Farm	Gama -Kitame	Irrigation	pump	2014	60.0	0.0007	Based on estimates
Hamis Makenza Farm	Gama -Kitame	Irrigation	Pump	2015	60.0	0.0007	Based on estimates
"Mchugaji" Farm	Gama -Kitame	Irrigation	pump	2015	60.0	0.0007	Based on estimates
Sanctury River lodge	Gama -Kitame	Domestic	pump		15.0	0.0002	
H.J Stanley & Sons LTD (Utondwe solt work)	Kitame village	Domestic	Bulzers		25.0	0.0003	
Chalinze Water Supply	Chalinze area				9600.0	0.1111	
Total water used/abstracted					10530.2	0.1219	

Source: This study (Socio-economic study, Saadani NP, Pumping house at Wami and Ecologist)

Table 3: Estimated Catchment Areas

Catchment	Estimated area (km^2)
Wami River at Mandera, 1G2	40030.802
Intervening catchment area between 1G2 and Gama	1297.130
Total Catchment – Wami River at Gama Gate	41327.932

Two considerations were taken in estimating flows for the Wami River at Gama Gate:
(i) The flow contributions from the intermediate catchment during wet season: the period from November to May in the following year was considered to be relatively wet, constituting the short rains (October-December), the intermediate period/ transition period (January-February) and the long rains (March-May). In this case, a catchment ratio of 1.0324 was used to scale flow from Wami River at Mandera to Gama for the respective periods.
(ii) Dry season abstractions for different uses: It was assumed that most of the water abstractions for different occur during the dry season (June-October). Hence the total daily water abstraction rates were subtracted from the dry season flows at Mandera station and routed to Gama station. Note that the estimated water uses does not include 'illegal' water extractions, such as those seen in the field and mentioned in Chapter 8.

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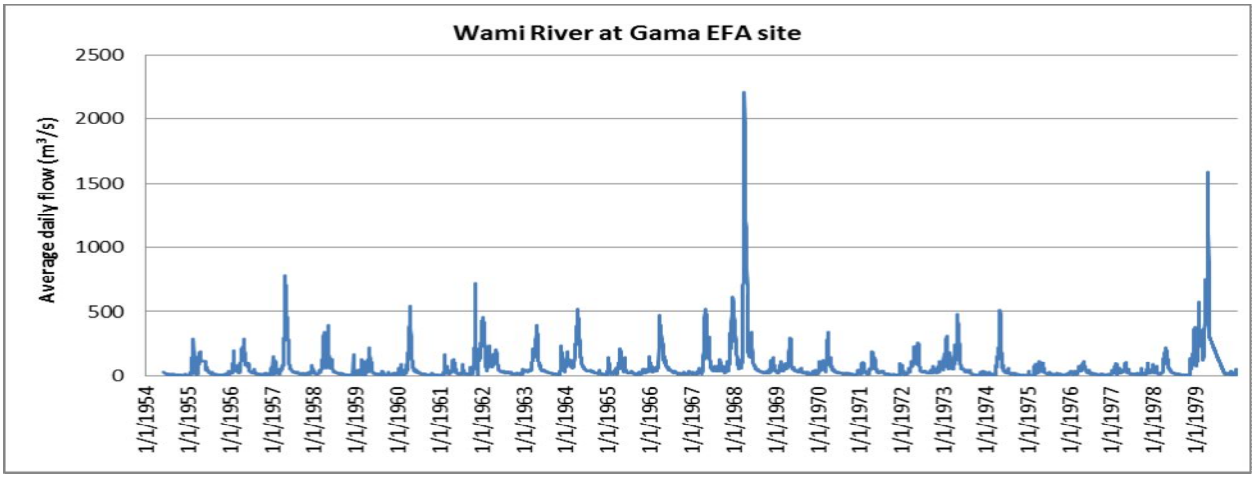


Figure 8: Estimated daily flow time series for Wami River at Gama Gate

Figure 8 presents the average daily flow time series for Wami River at Gama Gate, while
Figure 9 presents the average monthly and annual volumes. From the available records, the maximum ever recorded flood was 2209.13 m^3s^{-1} in 1968. The maximum average monthly flow is 209.4 m^3s^{-1} while the minimum average monthly flow is 14.21 m^3s^{-1}.

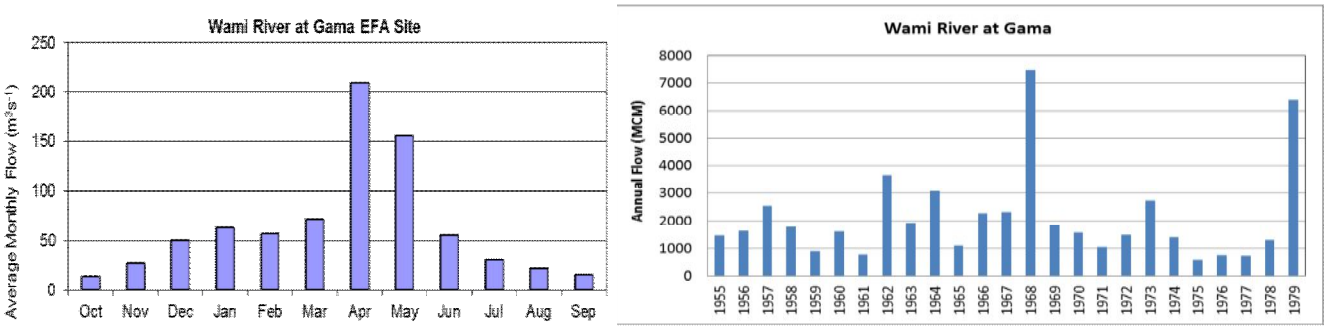


Figure 9: Average Monthly Flows (left) and Annual flow volumes (right) for Wami River at Gama Gate (1955-1979)

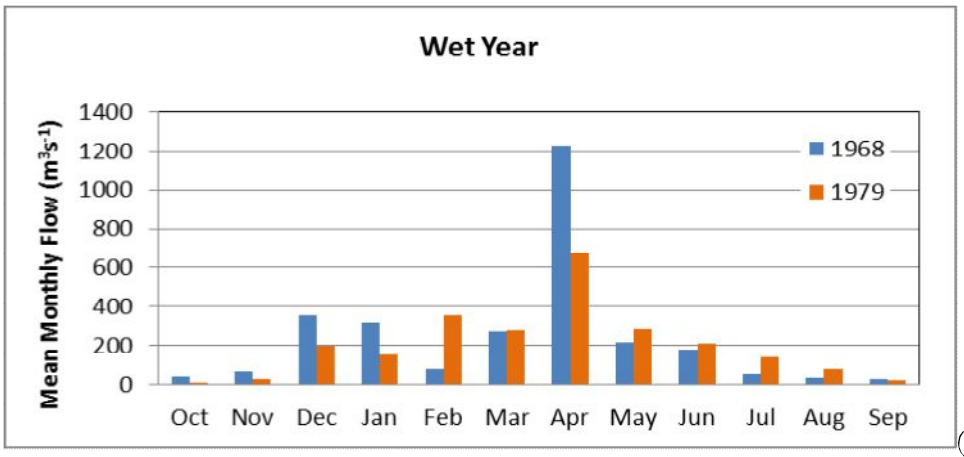
Table 4: Summary of average monthly flows in cumecs for wet, normal and dry year at Gama EFA site (1955-1979)

Month	Year		
	Wet	Normal	Dry
Oct	22.1	15.0	10.7
Nov	49.0	33.5	9.9
Dec	277.3	40.0	14.0
Jan	235.8	63.0	26.0
Feb	217.0	54.1	27.7
Mar	274.5	67.6	33.3
Apr	948.8	186.3	79.8
May	251.4	184.0	73.5
Jun	190.5	54.2	24.5
Jul	98.5	28.6	19.8
Aug	56.1	22.6	13.3
Sep	23.9	17.8	11.5
Annual	**220.4**	**63.9**	**28.7**

Wet, normal and drought years

A wet year is defined as a year with annual rainfall being one standard deviation greater than the average rainfall for the entire period. Similarly a drought year has annual rainfall lower than one standard deviation from the mean annual rainfall over the period.

The expected average monthly discharges in a normal year were computed using all years in which discharges were normal. Similarly, expected discharges in drought and wet years were computed using dry and wet years (Figure 10 a, b, c). The results indicate that, in a normal average year, monthly average discharges vary from as low as 15 m^3s^{-1} usually recorded in October to as high as 186.3 m^3s^{-1} in April. In dry years, average monthly discharges ranges from 9.9 in November to 79.8 m^3s^{-1} in April. It is worth noting that the flow observed in August 2015 during the field visits (~ 6 m^3/s – Table 1) was far lower than the average in August for dry years (13 m^3/s) from Table 4.



(a)

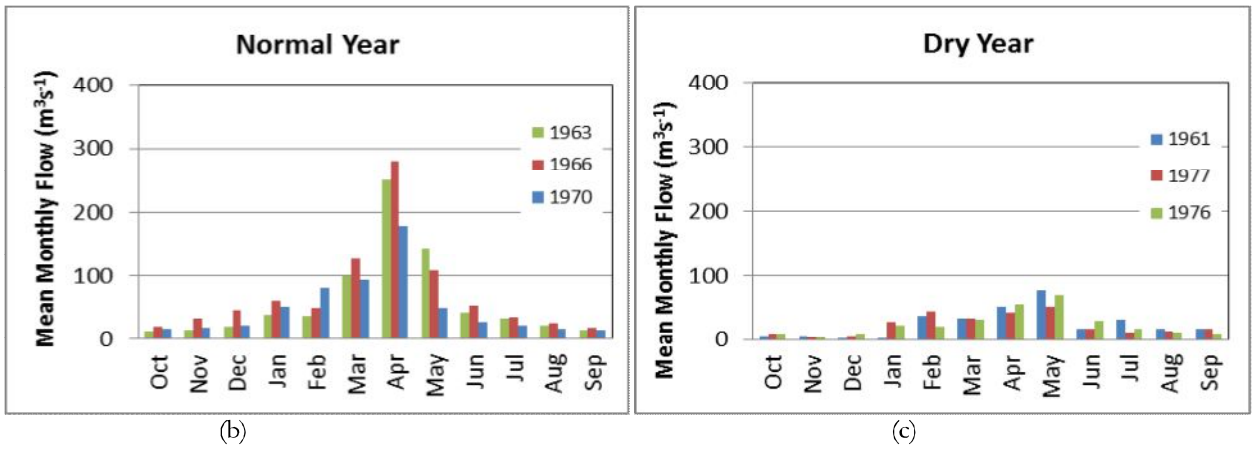


Figure 10: (a, b, c) Mean Monthly Flow for Wet, Normal and Dry years at Gama EFA site

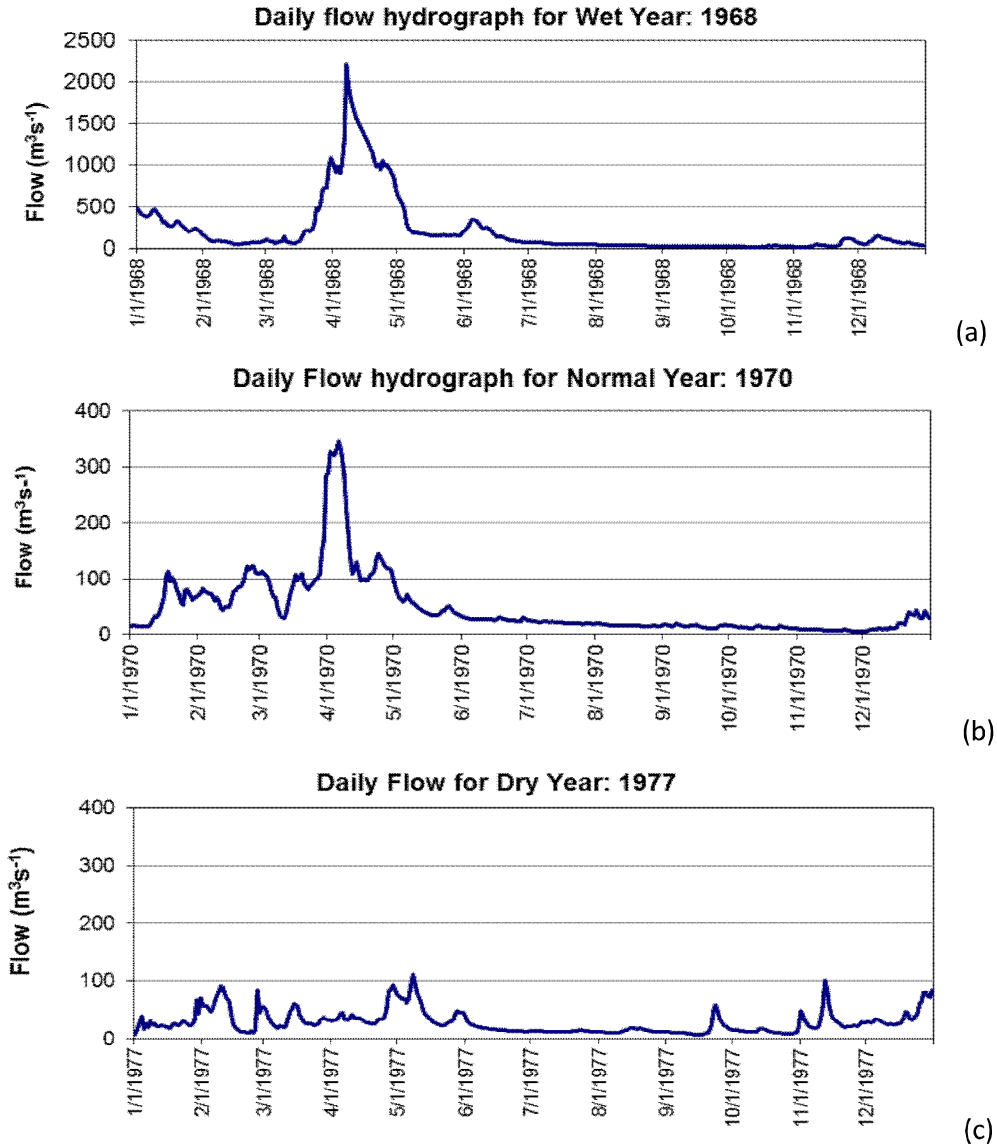


Figure 11: (a, b, c) Average daily flow for Wet, Normal and Dry years at Gama EFA Site

The daily flow hydrographs for wet, normal and dry years (Figure 11) indicate high flows during April – May as well as a fair amount of variability or flashiness as a response to rainfall in the Wami Basin. The ecosystem in the river and estuary has evolved with this large variability of flow within a typical year, which is a very important aspect to be kept in mind while managing water abstractions and maintaining flow within the river.

Inter-annual flow variability: declining flows

To statistically assess if there is an upward or downward trend in seasonal and inter-annual flows over time, a Mann-Kendall (MK) test was performed (Mann, 1945; Kendall, 1975; Gilbert, 1987). A monotonic upward trend means that the variable consistently increases through time, but the trend may or may not be linear. The results of trend analyses on annual and seasonal flows for Wami River at Gama gate are as follows. The Mann-Kendall test statistic (Z) on annual flows (value: -1.43) indicates a decreasing trend in river flows in the sub-basin as revealed at the far downstream site at Gama gate. This decreasing trend is seen over the various seasons - the Z statistic for the short rainy season over October-December (-0.42), intermediate dry season over January-February (-1.38) and long rainy season over March-May (-0.71) indicate declining flows. The same trend was also reported in Valimba (2007) at the various gauging stations in the upstream of Gama site. However, the Z statistic for dry season flows at Gama (0.35) did not reveal a negative trend at 95% of confidence, indicating that the dry season flows have not changed significantly over the time. Despite this present case, the increasing dry season human activities along the river banks and water abstractions from the river for agricultural activities may result in a decreasing status of water availability in the future.

Flow Duration Curves

The shape of flow duration curves (FDCs) is related to the interactions of climate, catchment size and morphology, vegetation cover, and the properties of the subsurface domain, which together control the various runoff components (Castellarin *et al.*, 2007). The shape of FDCs is largely governed by both precipitation and evapotranspiration variability and how water moves through the catchment (Castellarin *et al.*, 2007). The FDC can be partitioned into three distinct parts (Yokoo and Sivapalan, 2011), each of which is governed by different mechanisms or process controls:

(i) the upper part, which represent high flows, is governed by flood processes for which the dominant control is the interaction of extreme rainfall and fast runoff processes;

(ii) the middle part, relates to the mean runoff and its seasonality, for which the dominant control is the competition and seasonal interaction between available water, energy and storage, and

(iii) the lower part, is governed by base flow recession behaviour over dry periods for which the dominant control is the competition between deep drainage and riparian zone evaporation.

In this study the FDC percentage points were calculated from the average daily flow data at Gama Gate. A substantial amount of uncertainty is expected in the quality of data used, since this data was extrapolated from Mandera as mentioned earlier; hence the FDC estimations are subject to the availability of data. The daily flow duration curve at the Game EFA Site is presented in Figure 12. The general outlook reveals gradual sloping indicating stable flows in the river. For most of the time (between 40-60%), the flow is around the mean.

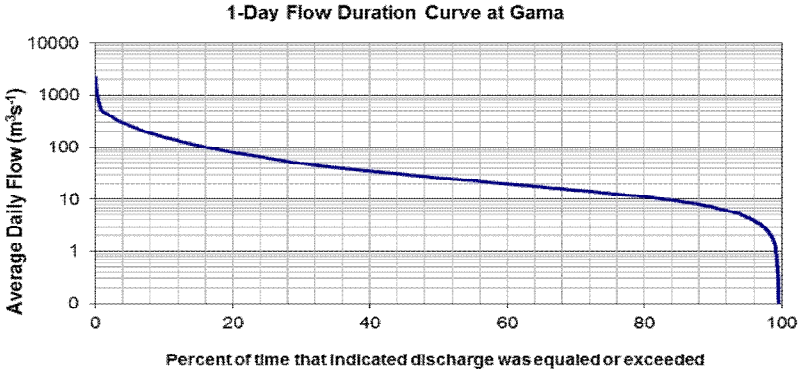


Figure 12: 1-Day Flow Duration curve for Wami River at Gama EFA Site

Flood Frequency Analysis

Frequency analysis was carried out for annual maximum extracted from available daily data. The Generalized Extreme Value type 1 (GEV-1) and the Log-Pearson Type III probability distributions were fitted to the data. The best fit probability distribution was Log-Pearson Type III. The results of frequency analysis using the best fit probability distribution at the EFA sites are presented in Figure 13 while Table 5 presents a summary of flood quantiles. It is important noting that substantial amount of uncertainty is expected in the quality of data used, based on the unreliability of the higher flows estimates at gauging station (high flows not normally recorded at gauges) and also are subject to the availability of data (ca.27years), which may not reflect present conditions as records end in the 1980s. The increase in

deforested areas in the Basin since the 1980s (Yanda & Munishi 2007, FIU-GLOWS 2014a) suggests the possibility of a corresponding increase in high flows responding to large rainfall events because of lower rainfall interception by forests; however the existence of large discharge data gaps since the 1980s, together with the absence of the collection of high flow data by manual staff gage readings suggests an underestimation of flood frequency.

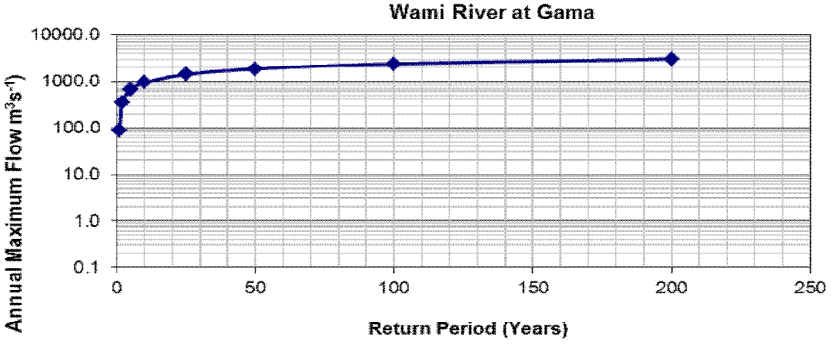


Figure 13: Annual Flood Frequency Analysis for Wami River at Gama EFA Site using Log-Pearson Type III (Analysis using Annual Maximum Flow: 1955-1981)

Table 5: Summary of maximum flow quantile for the Wami River at Gama

	Q_T							
River Name	1.0101	2	5	10	25	50	100	200
Wami River at Gama	86.4	346.8	654.3	936.8	1399.6	1835.1	2359.1	2989.3

Conclusion and recommendations

The amount of water used from the Wami River between Mandera and Gama is variable along the reach but the major abstraction currently is by the Chalinze water supply. Overall, the estimated amount of water abstracted from the river for different uses is about 0.122 m^3s^{-1} -- comparatively low when compared to long term flow average in the dry season of 9.9 m^3s^{-1}. However, increased water abstractions to meet the growing demands for agricultural expansion will pose a threat to the existing flow condition especially in drought years; for example, the pumping capacity at Wami Dakawa is around 6 m^3s^{-1}

Paucity of Hydrological data: monitoring needs are critical

The available streamflow data at the neighbouring station (Mandera) are not recent, spanning between 1950s to 1980s. There is no reliable information to enable concrete assessment of the present flow situation in most of the stations apart from the few spot discharge measurements. The hydrologic data paucity at the hydrometric stations in the basin calls for interventions aimed at improving the hydrological monitoring in the catchment. The Gama site is important for the characterization of the inflows into the estuary and hence should be gauged to enable better understanding of the inflows into the estuary. It is also important underscoring the fact that most of the discharge measurements at Mandera gauging station have been undertaken during the period of low and intermediate flows thereby missing the high flows. Owing to this, the rating curves better represent low and intermediate flow regimes and cannot be depended on for estimating high flows. Besides, every high flow has the potential to alter channel geometry by scouring and deposition thereby necessitating revision of a rating curve developed at a particular place on the river. It is also imperative to install and monitor weather stations. The available climatic stations are located in the highlands areas with very few in the lowlands area. To better understand the climatic contributions to flow in the lowland including Saadani area, installation of climatic stations is indispensable. The daily observations at the monitoring stations have always been carried out by the gauge readers who are lowly paid and sometimes with delays. The accuracy of the measurement relied on the trustworthiness and accuracy of the gauge readers, who cannot always be relied upon. In trying to overcome the problem and also improve the quality of the data, automatic loggers have been installed in some large rivers. Although this has been the case, most of the automatic stations are poorly maintained and data infrequently downloaded. The lack of funds to enable regular monitoring has been usually cited as a major limitation. To establish a reliable hydrological and climatic monitoring network will require adequate human and financial resources; low-cost possibilities are described in Chapter 10.

Chapter 3 – Channel Hydraulics, Flow and Bathymetry



Figure 14: A Q-liner in operation at Gama to obtain flow speeds at various channel depths

Contributors – Fredrick Mashingia, Amartya Saha, Roman Evarist, Mercy Asha Mohamed

The main objective of the hydraulic survey was to define the cross-sectional profile of the river channel at selected EFA sites in sufficient detail to enable hydraulic measurements, modeling and analysis to be undertaken at the required levels of accuracy. The final product of the hydraulics component comprises a series of relationships between streamflow and other flow parameters (hydraulics) that would be used by experts to arrive at Environmental Flow Recommendations. These parameters include water depth, flow velocity, wetted perimeter and water surface width. Channel bathymetry measurements give an idea of the channel geometry and depths along the course of the river.

Background: Channel Hydraulics

The methodology in this assignment entails literature review, fieldwork on flow discharge sampling and geometric data survey and hydraulic analysis/modeling.

HEC-RAS Model overview

Hydrologic Engineering Center-River Analysis System (HEC-RAS) Version 4.1, a widely-used hydrodynamic model for natural channel networks has been used as a modelling framework. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS system contains four components for i) Steady flow water surface profile computations; ii) Unsteady flow simulation; iii) Movable boundary sediment transport computations; and iv) Water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines.

In steady flow water surface profiles component, water surface profiles are calculated for steady gradually varied flow. The system can handle a single river reach, a dendritic system, or a full network of channels. The steady flow component is capable of modelling subcritical, supercritical, and mixed flow regime water surface profiles. In model set up, it is necessary to divide the cross sections into parts that have homogeneous hydraulic properties, in the direction of the flow (Figure 15). These are usually the left/right overbanks and the main channel. It is assumed that there is no exchange of energy across the boundaries. Both the water surface elevation and the total energy head are assumed to be constant at the whole cross section. Such an assumption partly helps to reduce data requirements on observed water surface for calibration. Besides, in the field practice, it is difficult to capture the small changes in water surface elevation between the inner and out banks at the meander as theoretically idealized.

The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning Equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges, levees, culverts, weirs, spillways and

other structures in the flood plain may be considered in the computations.

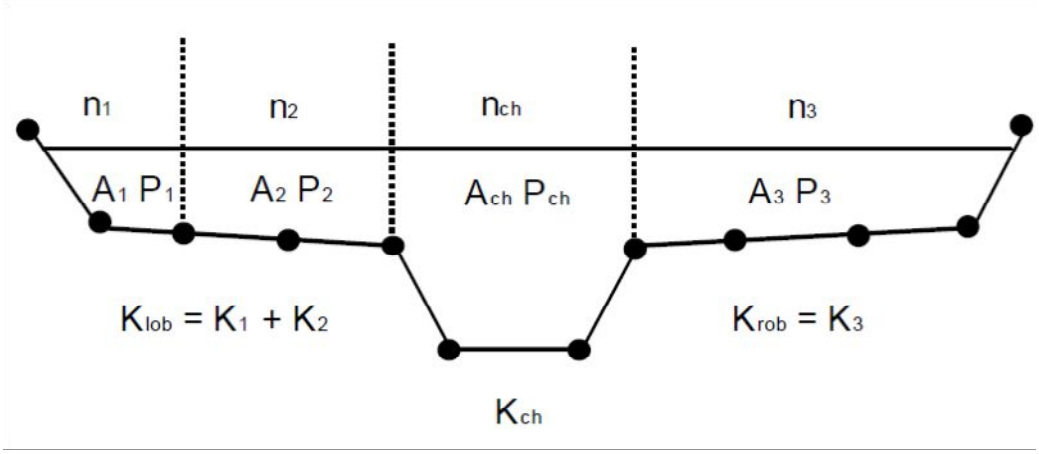


Figure 15: HEC-RAD model cross secrion subdivided into parts that have homogenous hydraulic properties

Note: K_i is conveyance factor; n_i is Manning's roughness number; P_i is wetted perimeter; A_i is flow area; lob, ch, and rob signify left overbank, main channel, and right overbank, respectively.

Study Approach and Methodology

Study Area

Mandera and Matipwili sites were studied in the previous EFA (Ndomba, 2007). In this study, EFA was extended to Gama site (BBM2) and Matipwili site (BBM1) was revisited. **Table 6** shows the physical characteristics of these two EFA sites.

Table 6: Physical Description of the EFA sites

Site Name	Site ID	Coordinates (WGS 1984)	Locality	Physical description
Matipwili	BBM 1	E 468513.17 N 9311004.92 UTM Zone: 37	It is located in Matipwili village, at the pump house of the irrigation scheme	Freshwater; ungauged; meandering with a short straight reach; low lying vegetated right bank; elevated and collapsing left bank; sand and gravels are material forming the channel bed; runs, pools and sand bars are present
Gama	BBM 2	E 475213.32 N 9314427.88 UTM Zone: 37	It is located at the Saadani National Park gate in Gama	Sea water backflow upstream limit; Abandoned gauging station; meandering with a short straight reach; elevated vegetated stable banks with isolated collapsing banks; bridge could be used as platform for flow sampling; runs, pools and sand bars occur instream

Fieldwork data were collected during the low flow season in August but it should be noted that the driest month in the study area is October/November. It is important to accurately capture the low flows as they are the lifeline of the ecosystem and human communities in the dry season. Four river cross sections/transects were surveyed at both EFA sites. Given the complexity of the study area, more transects would have been ideal in order to capture high spatial variability of habitats, cross-section geometry and bed roughness. But it was not possible due to limited resources (time and funding). Hydraulic data collected at each EFA site include cross-section geometry, reach lengths, water surface profile elevations, streamflow, flow velocity and roughness conditions.



Figure 16: Transect map and ground photo of EFA site 1 at Matipwili village



Figure 17: Transect map and ground photo of EFA site 2 at Gama Gate

Data collection methodology

Geometric surveys

The geometric survey entailed accurately locating riverine mesohabitat (riffle, pool, run, etc.), survey of bed elevation, and establishment of survey control points. A geometric survey at each EFA site was carried out at all channel cross sections using dumpy levels, staff and an 100 m steel measuring tape. The cross sections were placed perpendicular to flow. The geometry of the cross section within the main channel, below the water line, was surveyed using the manual water depth sounding approach. The measuring tape stretched across the channel width was supported from steel pegs (survey reference points) anchored on the banks. The cross section transects were located in sections of the river where the mesohabitat is homogeneous across the channel. The study river reaches began with a downstream hydraulic control or riffle. The right bank and left bank was designated when looking downstream, with the left bank designated headpin and right bank designated tailpin. Verticals used in depth measurements were spaced at 1m interval along the transect. Since the surveys were conducted during the low flow season, it was possible to access the river bed and hydraulic controls.

The conducted surveys provided information such as distance between transects, water-surface elevation, bed-elevation profiles, stage of zero flow elevation, water depths, and benchmark locations and elevations. The cross section transect extends beyond the Highest Flood Marks (HFM) to the cross section freeboard. Existing survey bench marks in the EFA sites, were used as Temporary Bench Mark (TBM) for this study. All heights were reduced to elevation of the established TBM. In all the EFA sites reduced level of the TBM was 100.0 metres above site datum (masd). The benchmark used for the transect headpin and tailpin elevation surveys served as benchmarks for water-surface elevation (WSL) measurements during hydraulic data collection. Additional cross sections were identified and surveyed (positioned at changes in water slope and channel geometry and along the bridges axis – Figures 16, 17). The river longitudinal profile was required to determine the channel slope. Ideally this was supposed to be determined as the ratio of the difference between thalweg (deepest point) elevations to river reach length. However, considering the uncertainty involved in capturing the cross section deepest points, water surface elevation difference was surveyed and used with the assumption that a nearly normal uniform flow condition prevails. A survey of the left overbank (LOB) and right overbank (ROB) reach lengths was carried out using 50 m tape measure. The transects and general locations of the EFA sites were recorded using a handheld GPS.

Flow measurements

Flow discharge measurements were carried out in the river cross sections using a Qliner. The QLiner features a 2-dimensional (3 beam) acoustic Doppler current profiler without bottom tracking. The measurement is done using the classic verticals process. The Qliner was operated from the edges to measure both the vertical velocity distribution and the water depth at every 1m vertical positions. All measured data were transferred to the PDA via Bluetooth.
It should be noted that the QLiner's depth limit range is between 1.2 - 20m. Since the flow sampling campaigns were conducted during the low flow season, the water depth was shallower than 1.2m in some transects. This has contributed to huge uncertainty in discharge measurements. A current meter or the smaller Qliner with a depth limit range between 0.35 - 10m would have been ideal for this assignment. Figures 16 and 17 show the ground photos of discharge measurement in the transects at BBM1 and BBM2 sites respectively. Since the flow depth was shallow during the fieldwork, the roughness condition was assessed visually. Chow (1959) was referred to for estimating the roughness number.

Data analysis

The hydraulic river reaches of EFA sites capture the variability in habitat types and hydraulic regimes. The width of the macro channel ranged from 34m to 40m. The longitudinal water surface profile slopes are 0.0003 and 0.001 for BBM2 and BBM1 respectively. This result indicates that two sites are situated in distinct geomorphologic zones and/or hydraulic regimes.
With reference to streamflow sampling results the following key remarks could be deduced:
The Coefficient of variation, Cv, for Total streamflow, Q, as computed for all the EFA sites is less than 20 %.
In most practical applications the Cv values are reasonably low to assume Mean streamflow as Best discharge for individual EFA site. Therefore, the mean streamflow was used as steady upstream boundary condition in the hydraulic model for simulating the hydraulics.

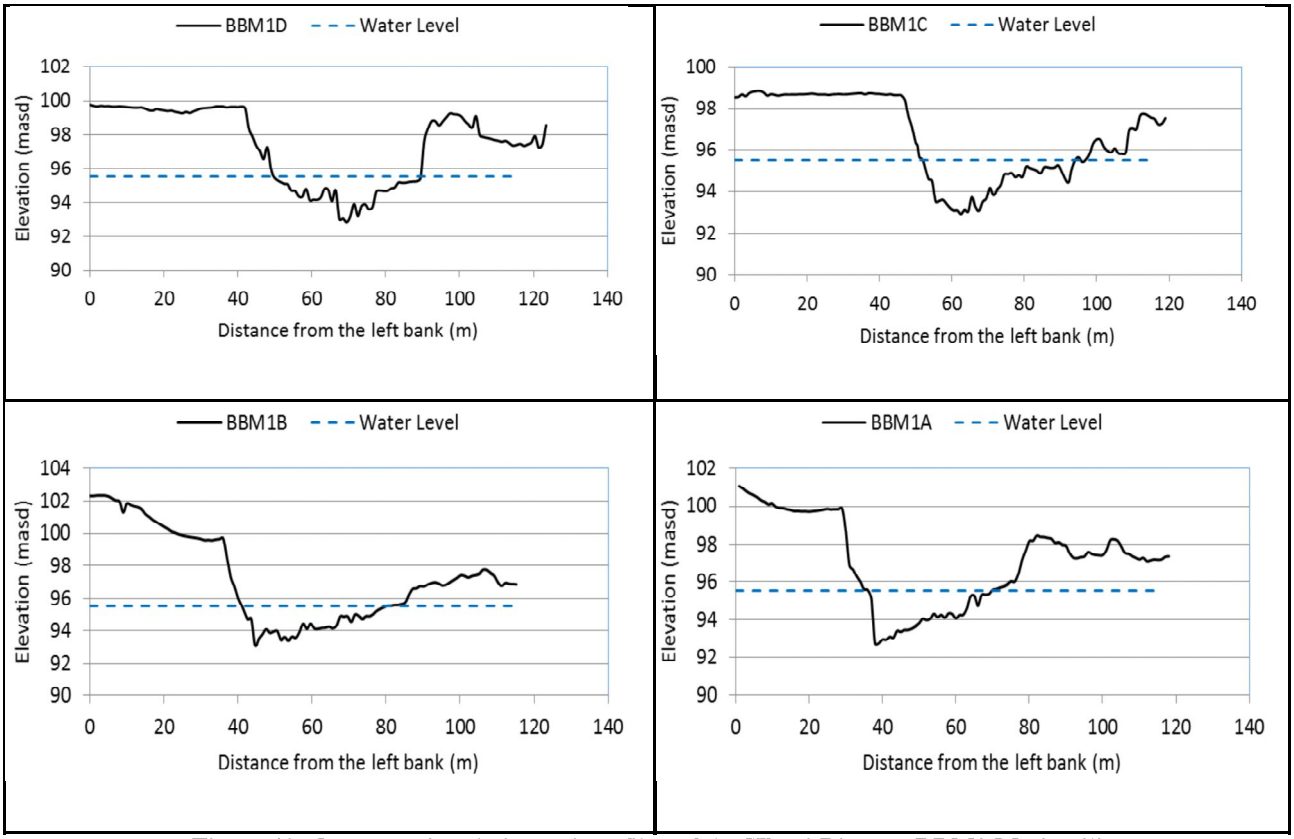


Figure 18: Cross-sectional channel profiles of the Wami River ar BBM1-Matipwili

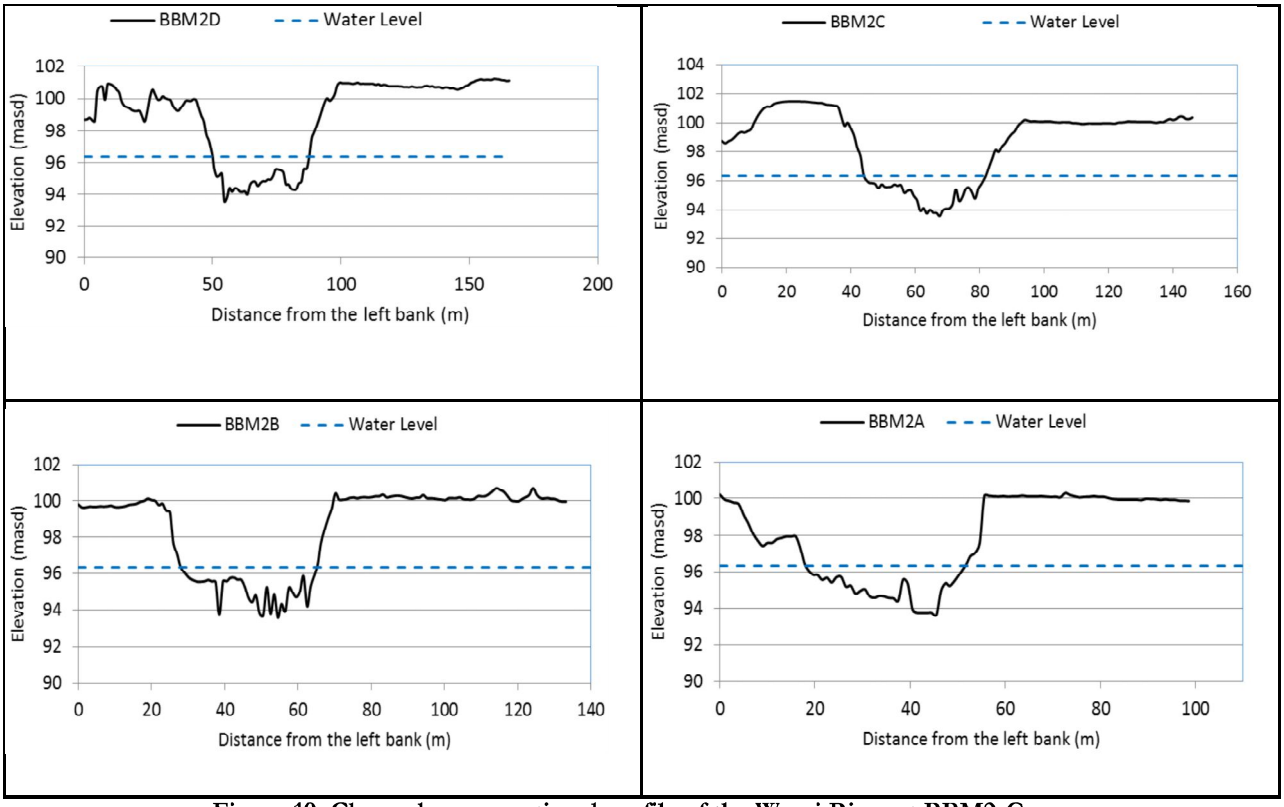


Figure 19: Channel cross-sectional profile of the Wami River at BBM2-Gama

Hydraulic modeling

King et al. (2000) suggests that an ideal data set for EFA would be six data points of stage measurements over a wide distribution of discharges, plus the stage of zero discharge and some flood-related data. The EFA sites were assessed for only one sampling event conducted in August, 2015. Therefore, in order to interpolate or extrapolate hydraulic parameters other than the measured ones, a reach based HEC- RAS hydraulic model was set up for the two EFA sites. The model uses Manning and energy equation (s) to simulate river hydraulics. Quantitative and field observation data were used to calibrate and validate, respectively, the flow parameters (hydraulics) simulated by the hydraulic model. The parameters include maximum water depth, flow velocity, flow area, wetted perimeter and top water surface width. The model was calibrated by matching the simulated and observed water surface profiles as they are considered most reliable. Model performances for other pertinent simulated hydraulics such as velocity, wetted width, flow area, etc., were evaluated qualitatively and quantitatively. A relative error in percent (%) criterion was used to qualify the performance of the calibrated model quantitatively. Professional judgement or expert knowledge was also be explored to qualitatively assess the model performance. Quantitatively, the model performance was considered satisfactory for Relative error less than 20%. Then the validated model was used to simulate the hydraulics in a range of stream that mimic drought, medium, and bankfull flow conditions.

RESULTS AND DISCUSSION

Hydraulic model performance

The model performance for the 5 flow parameter - mean velocity, water surface profile elevation, flow area, water surface top width and maxim water depth was evaluated quantitatively based on the relative error in percentage criterion (Table 12 & 13). Generally, model performance was found to be satisfactory in most of the transects. The transects with very good performance are recommended for use in the EFR workshop (Table 14). The results from other transects need to be used with caution as professional judgment is critical for meaningful application.

Table 7: Performance of hydraulic model at BBM1 site - Matipwili

Data Type	Transect	Mean Velocity (m/s)	Water Surface Elevation (masd)	Flow Area (m^2)	Flow Top Width (m)	Max. Water Depth (m)	Average Depth (m)
Observed	BBM1D	0.13	95.45	76.68	38.50	2.59	1.00
Simulated		0.16	95.42	38.21	39.12	2.53	0.98
Relative Error in %		**20.6**	**0.03**	**50.2**	**1.6**	**2.3**	**2.0**
Observed	BBM1C	0.17	95.50	82.16	40.00	2.54	1.23
Simulated		0.12	95.50	50.72	42.96	2.54	1.18
Relative Error in %		**27.4**	**0.00**	**38.3**	**7.4**	**0.0**	**4.1**
Observed	BBM1B	0.16	95.55	65.08	39.20	2.43	1.20
Simulated		0.13	95.52	45.06	39.07	2.41	1.15
Relative Error in %		**16.8**	**0.03**	**30.8**	**0.3**	**0.8**	**3.9**
Observed	BBM1A	0.13	95.60	72.74	35.00	2.88	1.48
Simulated		0.12	95.55	50.15	34.92	2.82	1.44
Relative Error in %		**9.5**	**0.05**	**31.1**	**0.2**	**2.1**	**2.9**

Table 8: Performance of hydraulic model at BBM2 site - Gama

Data Type	Transect	Mean Velocity (m/s)	Water Surface Elevation (masd)	Flow Area (m2)	Flow top width (m)	Max.Water depth (m)	Average depth (m)
Observed	BBM2D	0.12	96.33	67.39	37.50	2.73	1.48
Simulated		0.12	96.28	55.18	36.86	2.67	1.50
Relative Error in %		**3.7**	**0.05**	**18.1**	**1.7**	**2.2**	**1.2**
Observed	BBM2C	0.11	96.33	72.04	37.80	2.77	1.31
Simulated		0.18	96.29	35.87	36.59	2.38	1.00
Relative Error in %		**63.3***	**0.04**	**50.2**	**3.2**	**14.1**	**23.8**
Observed	BBM2B	0.12	96.34	60.24	37.20	2.74	1.22
Simulated		0.19	96.31	34.81	36.00	2.44	0.98
Relative Error in %		**57.7***	**0.03**	**42.2**	**3.2**	**10.9**	**19.9**
Observed	BBM2A	0.15	96.35	58.21	33.60	2.71	1.38
Simulated		0.14	96.34	45.66	33.63	2.72	1.36
Relative Error in %		**4.8**	**0.01**	**21.6**	**0.1**	**0.4**	**1.2**

**Large velocity errors at the bridge approach and exist cross sections may be attributed to the ineffective flow areas.*

Table 9: Global summary statistics of hydraulic model performance and performance rating for both EFA sites

EFA Site	Relative error (%)				Remarks	Recommended transects	Performance rating 1-5
	Minimum	Maximum	Mean	Median			
Matipwili	0.00	50.17	10.51	2.58	Simulated hydraulics matched well with field data/observations in most of the transects. The spotted errors in some of the transects could be attributed to both uncertainty in discharge measurements and complexity of the river geometry. The hydraulic model is based on only one sampling event.	BBM1A	3
Gama Gate	0.01	63.3	14.32	3.48	Simulated hydraulics matched well with field data/observations in most of the transects. The bridge approach and exit transects did not perform well. The spotted errors could be attributed to uncertainty in discharge measurements, lack of bridge design data, influence of the sea water backflow and complexity of the river geometry. The hydraulic model is based on only one sampling event.	BBM2D	2

Simulated water surface profiles

The hydraulic model simulations developed a series of relationships between streamflow and other parameters such as maximum water depth, flow velocity, flow area, wetted perimeter and water surface width. Figures 20 & 21 show the water surface profile plots for selected transects.

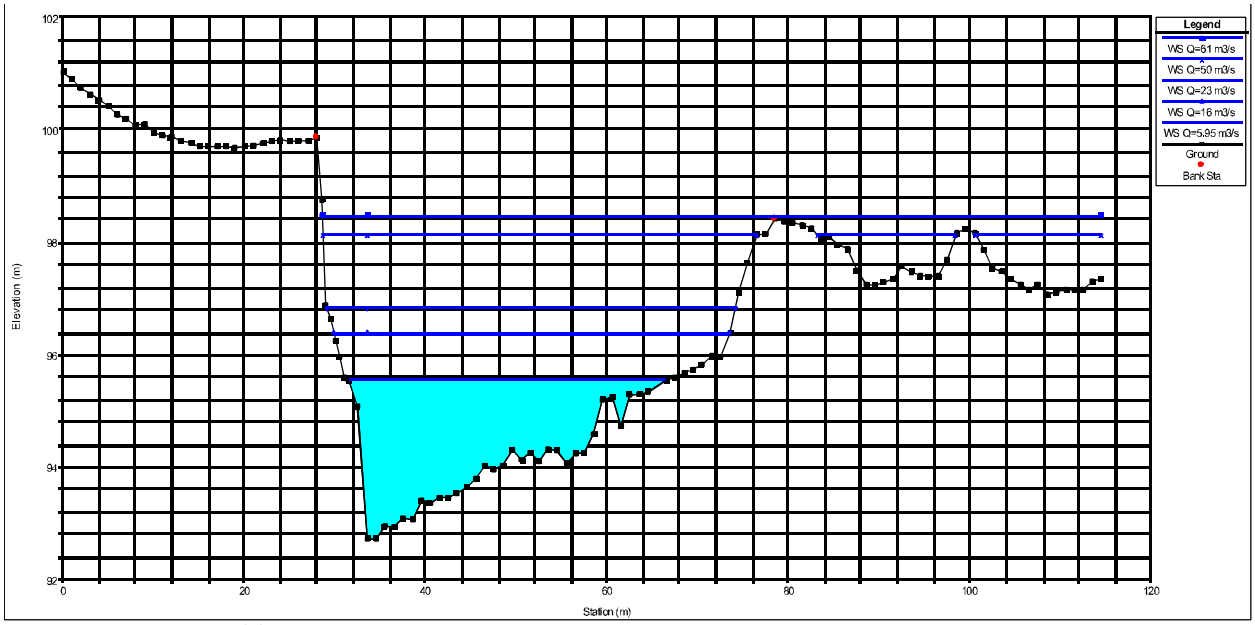


Figure 20: Transverse Water surface profiles at various streamflow at BBM1A in Matipwili

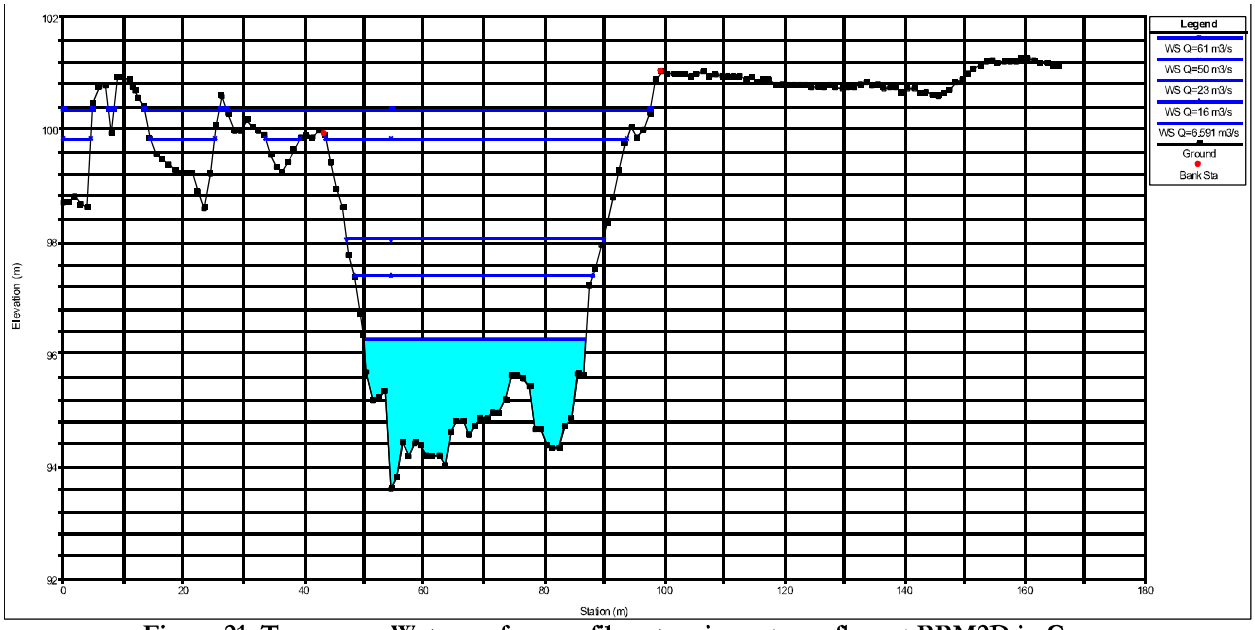


Figure 21: Transverse Water surface profiles at various streamflow at BBM2D in Gama

Channel Hydraulics - conclusion and recommendations

The product of this component comprises of a series of relationships between streamflow and other flow parameters such as maximum water depth, flow velocity, flow area, wetted perimeter and water surface width. Transects with best simulated relationships at Matipwili and Gama Gate (BBM1A and BBM2D respectively) are herein recommended for further analysis during the Environmental Flow Recommendations (EFR) workshop.

The errors spotted in hydraulic simulations are attributed to uncertainty in discharge measurements, lack of the original bridge design data, complexity of the river geometry and the influence of backwater flow from the sea at BBM2 site in

Gama. Furthermore, fieldwork data were collected during the low flow season in August but the driest month in the study area is November. The hydraulic model is based on only that one sampling event. It is therefore recommended that the hydraulic model be validated with high flow season data. Also, the low flow data may be revisited during the driest month with the use of current meter or smaller version of the Qliner.

The river reach between Gama and the mouth at Porokanya should be modeled as a two - dimensional unsteady state flow to define the backwater curve. This would require spatially detailed river bathymetry and floodplain topographic data alongwith time series data of sea level at river mouth and river discharge at the upstream end of the estuary.

Channel Bathymetry

A bathymetry unit was attached to the stern of a boat which then travelled along the river downstream from Kinyonga campsite in a zigzag manner to get as many channel cross-sections as possible, given the need to traverse the entire estuary under similar tidal conditions. The unit consists of a submerged depth finder sensor connected to a Goldilocks microprocessor board that recorded the depth to the river bottom at 1 second intervals and records the data on an SD card. The system is powered by a 12V motorcycle battery. The map generated by a GIS is shown in Figure 22.

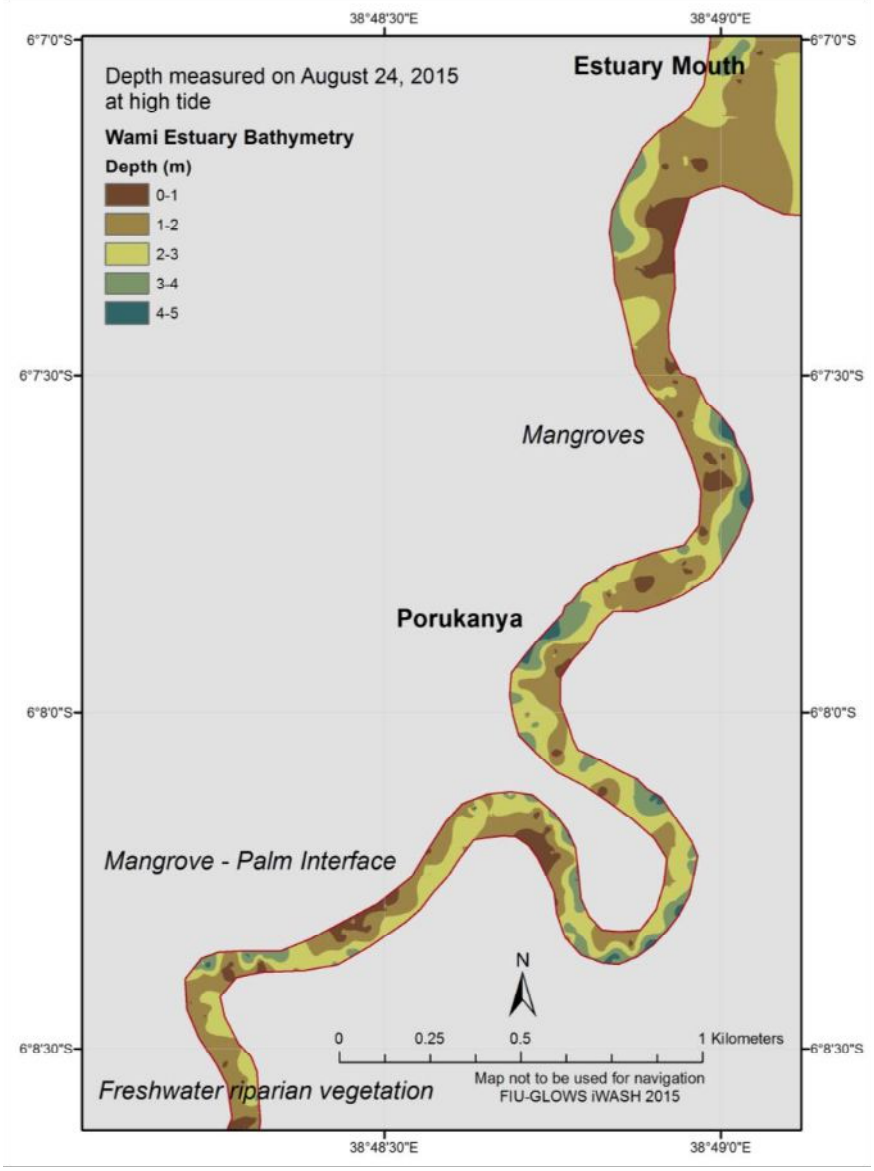


Figure 22: Wami Estuary Channel bathymetry upto freshwater vegetation section.

Backwater tidal effects at freshwater end of estuary

The water level in the river at both Gama and Kinyonga was observed to be falling from mid-morning through the early afternoon, leaving a moist band of 25-30 cm on the riverbank. The river level rose again early evening onwards. This periodic rise and fall was likely an effect of the freshwater flow backing up during high tide.

Flow measurements were made periodically (about every 5-10 minutes – Figure 23) between 10 am and 5 pm on the surface at Gama Gate and Kinyonga on two separate days using a General Oceanics 2031 mechanical current meter. Additionally, at Gama, water depth was also recorded.



Figure 23: Measuring flow speed with a mechanical current meter

The plot for Gama Gate (Figure 24) shows that the flow speed dropped from 10 am to around 2 pm, and thereafter began to increase once again. The higher speeds occur when the water level is low, and as the water level rose from midmorning to mid afternoon, most probably as a consequence of being backed up by the incoming high tide at the estuary mouth, the speed of flow slackens.

At Kinyonga, only the flowspeed was recorded between 11.30 am and 5 pm (Figure 24). Unlike the situation at Gama Gate (11.7 km upstream), the flow velocity appeared to increase from noon until mid afternoon. This was perhaps due to the river at Kinyonga experiencing low tide effects earlier than at Gama Gate. To understand the effect of tides on water level and flow in the estuary, it is clear that locations differed in tide conditions at an instant in time, and that there are lag effects that vary with distance upriver.

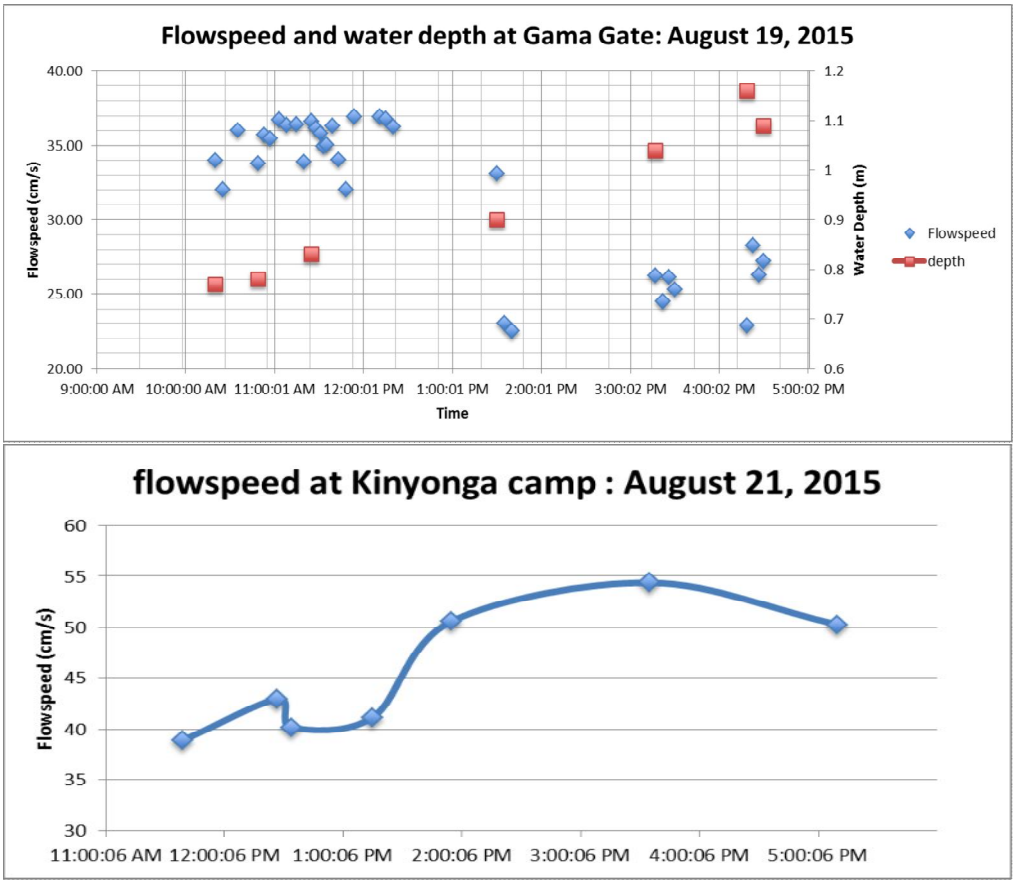


Figure 24: Flow speeds differed along the estuary at the same time due to lag of tidal backwater

Chapter 4 – Water quality



Figure 25: water quality measurements at the estuary

Contributors – Halima Kiwango, Ernest Lema, Amartya Saha, Mercy Asha Mohamed

Background

Estuaries provide the most important habitat to a lot of freshwater and marine wildlife, and are especially important as nurseries for numerous marine fish. Hence estuarine water quality is of critical importance in maintaining life. The primary water quality parameters of significance in estuaries are salinity and turbidity. In addition, the presence of anthropogenic disturbances in the watershed could lead to changes in pH, dissolved oxygen and conductivity, as well as include excess nutrients (fertilizers), pesticides and industrial organics, heavy metals, oil and grease. Water quality is also directly impacted by the quantity of freshwater inflow into the estuary, where higher inflows increase dissolved oxygen in the upstream reaches as well as bringing in nutrient, sediments and pollutants from upstream.

Study Approach and methodology

The objectives of the present study were to:

- Characterise the estuary based on water quality (salinity and turbidity) in relation to riparian vegetation; Add to the very sparse baseline data on water quality in the Wami Estuary;
- Compare if there is any change in eco-hydrological trends documented in the past (especially in Anderson *et al.,* 2007) and observed during the fieldwork.

In situ measurements of water quality parameters were done in neap tide season between 20th -24th August 2015 from outboard engine fibre boat during flood and ebb tides. Water temperature, salinity, dissolved Oxygen, electric conductivity and total dissolved solids (TDS) were measured by using handheld EC and DO probes (YSI EcoSense EC300A and YSI EcoSence DO200A, YSI, USA). Cables with EC and DO sensors were tightly tied in a calibrated pole for easy measurement of parameters at depths of 1 and 2 meters. Water clarity was measured by using a 30 cm diameter Secchi disk while pH was measured using BANTE 900P portable multi-parameter meters. Water from 1 and 2 meters for pH measurement was collected by a small water sampler of 400cc.

On 20th August, measurements were taken during ebb tide from the surface every 500m starting from the upstream site (Kinyonga) towards river mouth. Unfortunately when we reached the river mouth it was already flood tide so measurements could not be taken. On 21st August, the same sampling procedure was done during ebb tide but it was after every kilometer and measurements stared from upstream of Kinyonga site towards river mouth. On 23rd August measurements were taken during flood tide from the Ocean going upstream to Kinyonga. Since we noted the rapid change of tides within few hours before we complete sampling of the whole estuary, we decided to sample in four sites that were already established by Halima Kiwango (SANAPA staff) for consistency and comparison (Figure 1). The following day we did the same with exception of the ocean site. Site 1 represented the river mouth (the lower estuary), site 2 and 3 represented the mid estuary whereby site 2 was characterised by a very sharp corner/meandering, and site 3 was the transition zone of mangroves to palms. Site 4 represented the upper estuary at the extent of the tidal limit.

Results

Salinity

During the sampling period, the lower estuary (5 km from mouth upriver, corresponding to the mangrove zone) was mainly freshwater-dominated (0.1- 0.3 ppt) at ebb tide and saline water-dominated at flood tide (Figure 26, Map panel). Salt water intrusion extended up to the area of mangrove/palm transition zone during flood tide, showing different patterns of mixing and stratification through the water column (see maps in Figure 26, 27 and 28).

Salinity – spatial profiles during flood and ebb tides

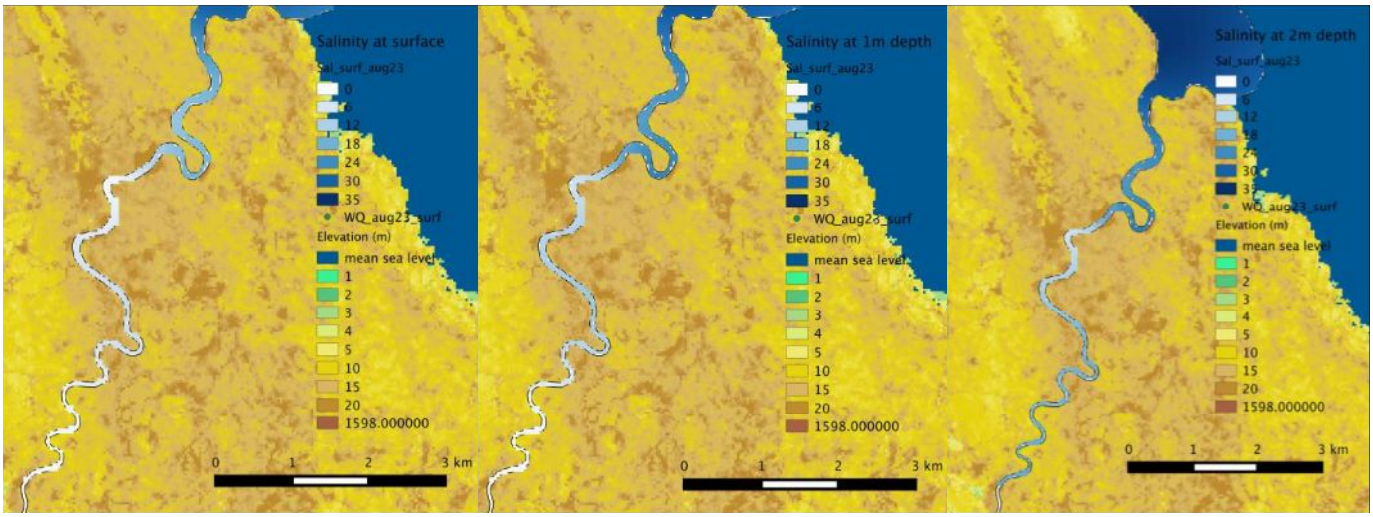


Figure 26: Salinity in the Wami Estuary at flood tide on August 23, 2015 at surface (left), 1 m (or bottom) depth (middle) and 2 m or bottom depth (right). Salinity is depicted in a graduated blue colour scale, where freshwater is depicted in white while seawater (~35ppt) is in dark blue.

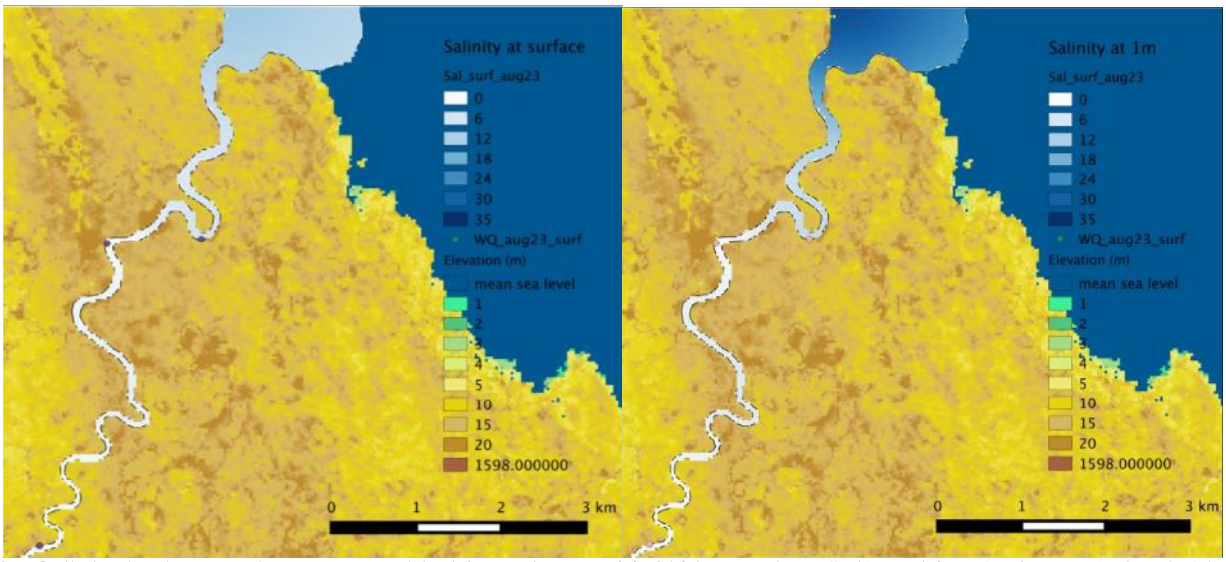


Figure 27: Salinity in the Wami Estuary at ebb tide on August 24, 2015 at surface (left) and 1 m (or bottom) depth (right).

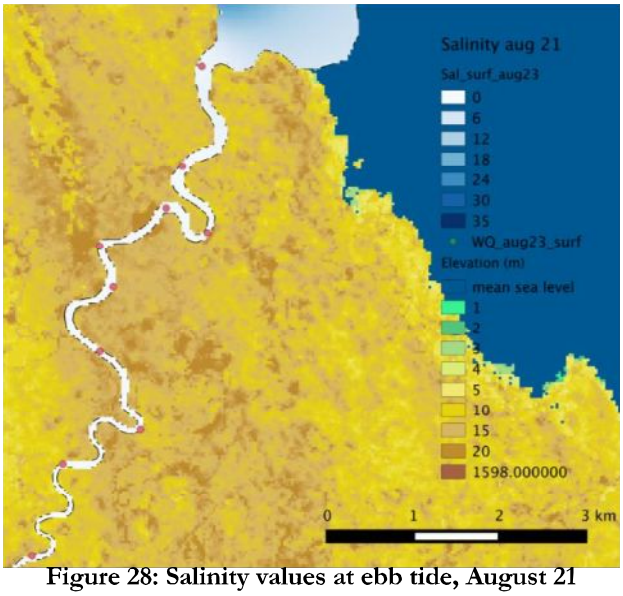


Figure 28: Salinity values at ebb tide, August 21

Homogeneous mixing occurred at site 1 and site 4 on 23-Aug-15 while the mid estuary showed partial stratification through the water column with surface salinities of 17.1 and 1.1 ppt and bottom salinities of 25.6 and 7.3 ppt at site 2 and 3 respectively (Figure 29, 30). On 24-Aug- 15, strong stratification was observed at site 1 with surface salinity of 13.1 ppt and bottom salinity of 31.7 ppt (Figure 30). Partial stratification occurred at site 2 with surface salinity of 6 ppt and bottom salinity of 10.4 ppt, while the other sites were homogeneously mixed with salinity of 0.4 and 0.1 ppt throughout the water column at site 3 and 4 respectively. Normally surface salinity at the estuary tend to decrease from the estuary mouth towards the upper estuary and the bottom salinity increase towards the estuary mouth, this was also the case for Wami River estuary (see maps – Figures 26-28).

Since we sampled the ocean site only once, we did not observe a clear demarcation of freshwater plume at low tide as it was observed in August, 2007. The Ocean had salinities of 34.1ppt at the surface and 34.2 ppt at 1 and 2 m depths. Salinity recorded after site 3 towards the upper estuary during both ebb and flood tide were similar to salinity recorded in August 2007 i.e 0.1 ppt. The rest of the river from site 4 to Gama Gate was mainly freshwater with salinity of 0.1 throughout the water column during flood and ebb tides. However, in times of very low freshwater flows particularly in October, salinity intrusion extends beyond the site 4 and sometimes up to the newly constructed water supply pump for Saadani village. For example in October 2007 during high tide, salinity at site 4 was 10 ppt at the surface and 17 ppt at the bottom (Kiwango's data, ongoing PhD study). The villagers of Saadani also have been complaining about having saline water from the water supply tank during high tides, especially during spring tide which is undrinkable.

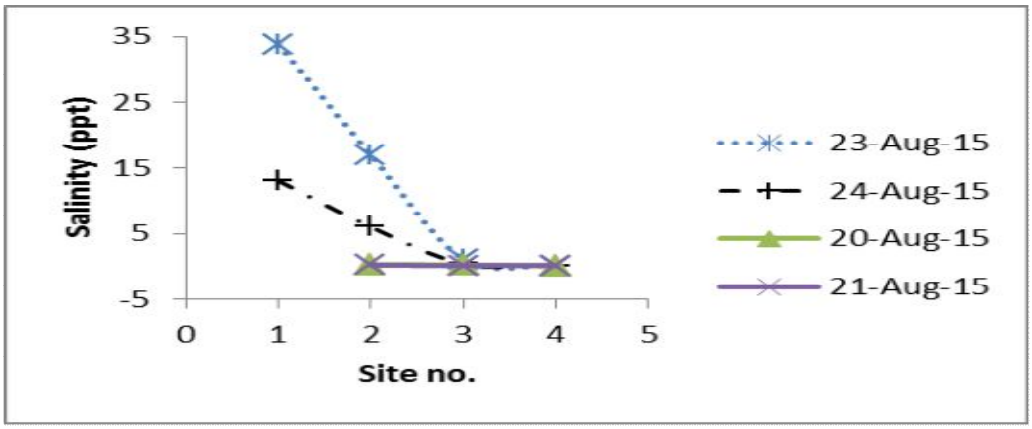


Figure 29: Longitudinal profile of salinity during flood tide (23 & 24 Aug 2015) and ebb tide (20 & 21 Aug 2015)

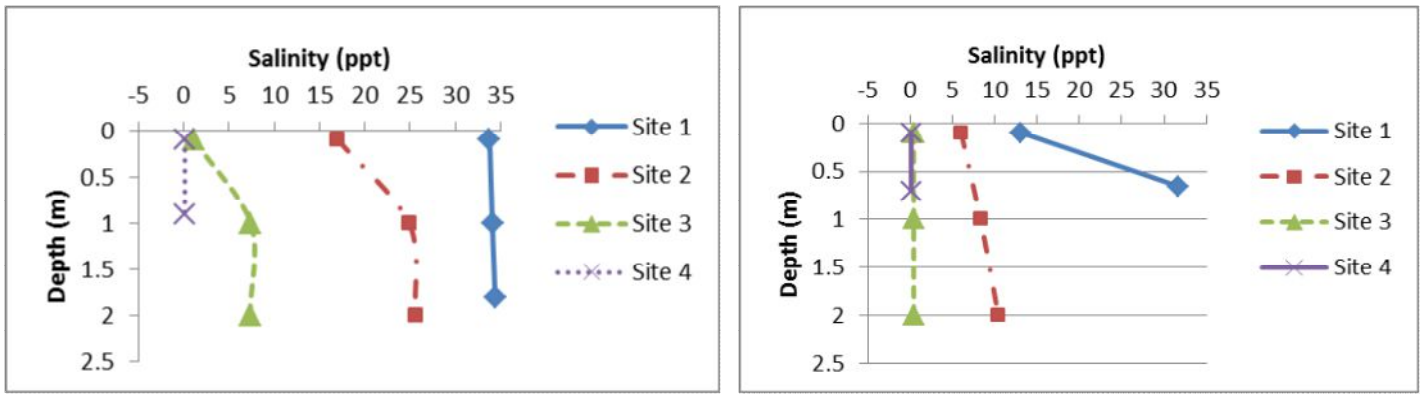


Figure 30: Vertical profile of salinity during flood tide (23 Aug-15 - left) and (24 Aug-15 - right)

Turbidity

Wami Estuary is generally a turbid system because; first, it is tide- dominated estuary where strong tidal currents re-suspend fine sediments; second it has large population of hippopotami which re-suspend bottom sediments through their movements in water and; third, the high erosion from weak river banks add sediment to the river. During survey, turbidity was measured using a Secchi disk. The Secchi depth indicates the depth of the water column through which light can penetrate and the disk seen clearly. Hence, higher turbidity results in smaller values for Secchi depth. Values varied from 0.26 to 0.87 m with lowest value recorded at site 3 and highest value at site 2 (Figure 31). Site 3 was more turbid that other sites because of presence of large group of hippo and significant river bank erosion. Also it is a place where elephants cross the river, swim and drink water (Visual observation by Kiwango). The similar pattern of water clarity was observed during both flood and ebb tides. However in shallow depths of less than 1 m. the water was clear enough to see the bottom of the river.

On a later visit to the estuary (September 13-14, 2015), the water level at Gama Gate had dropped by 25 cm when measured, and was much clearer.

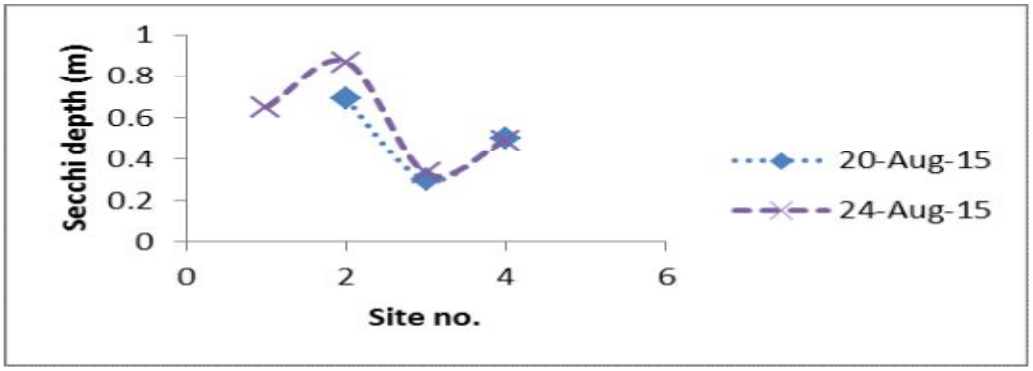


Figure 31: Water clarity during ebb (20 -Aug-15) and flood (24- Aug-15) tides.

Dissolved Oxygen (DO)

DO concentrations varied between 6.28 - 7.57 ppm (78.1 and 93.7 % saturation) and 6.74 - 7.66 ppm (80.7 - 95.4 % saturation) during flood and ebb tides respectively. High DO levels were detected at the surface and low level at the bottom. Moreover, values recorded during ebb tide were relatively higher than flood tide values, possibly a consequence of faster freshwater flows at ebb tide. Site 2 and site 3 which had hippopotami had lower values compared to site 1 and 4 at both flood and ebb tides. This could be because of high consumption of oxygen by microbial activities for decomposition of hippo feces. Generally the DO concentration is similar to that recorded in August 2007.

pH

pH in Wami Estuary throughout the sampling survey varied between 8.23 - 8.54 and 7.67 to 8.54 during ebb and flood tides respectively. Though the normal pH within estuaries may vary from 7 - 9, for Wami Estuary it appears as this parameter has more fluctuations compared to other parameters. For example in October 2003 at high tide pH was between 7.9 and 8.7, January 2004 at high tide it was between 8.3 and 8.6, October 2007 was 7.1 - 8 and 7.8 - 8.1 at low and high tide respectively (Kiwango unpublished). Factors that may cause pH fluctuation include salinity, freshwater and groundwater inflows and primary productivity. However, it is difficult to pinpoint the reasons for pH change in Wami Estuary since there are no detailed studies of ecological and biogeochemical factors affecting pH in the system.

Temperature, Total Dissolved Solids and Electrical Conductivity

Other water parameters such as water temperature, TDS and electric conductivity may provide some additional physicochemical properties of water. For instance, electrical conductivity (EC) of water indicates the presence of ions that are charged. Salt dissociates into sodium anions and chlorine cations; similarly many other inorganic chemicals from agriculture, industrial discharge and runoff also dissociate. Hence a higher EC indicates the presence of more ions in water. In this case, higher EC in flood tide, correlated with higher salinity readings stems from higher salt ions. Similar values of temperature and TDS were also recorded in August 2007. A summary of these water quality parameters observed during our sampling survey is indicated in the table below:

Table 10: Water quality parameters

Date	Tide	Water temperature (°C)	TDS (mg/L)	Electric conductivity (µS)
20-Aug- 15	Ebb	26.2 - 27.2	105.7 - 439.4	162.7 - 677
21-Aug-15	Ebb	25.6 - 27.4	112.2 - 287.1	172.2 - 443
23-Aug-15	Flood	25.2 - 26.4	126 - 33940	197.8 - 52100
24-Aug-15	Flood	24.4 - 26.4	138 -90000	211 - 47450

Agrochemical and Industrial pollutants

Water samples were taken in 1 liter Nalgene plastic bottles along various sites (Table 16) in the Wami Estuary, kept in a thermally insulated cooler and sent for analysis to the Morogoro Water Quality Laboratory, WRBWO.

Table 11: Agrochemical and Industrial Pollutants in the Wami Estuary

Location	Date	Temp °C	TSS mg/l	Sulphate mg/l	Chloride Mg/l	Nitrate Mg/l	Iron Mg/l	Manganese Mg/l	Phosphorus Mg/l
Gama	14.09.15	27.1	17.50	12	17.02	2.22	0.02	0.30	0.06
Gama	18.08.15	27.1	93.33	8	9.93	3.54	0.49	0.40	0.12
Kinyonga	15.09.15	27.4	50.00	19	50.34	9.74	0.05	0.30	0.04
Kinyonga	24.08.15	27.1	130.00	11	23.40	1.77	0.25	0.20	0.08
Porokania	15.09.15	27.1	170.00	260	1481.81	2.66	0.10	0.70	0.10
River mouth	24.08.15	27.1	63.33	1100	8933.40	8.86	0.05	0.40	0.05
Site 3-sharp corner	24.08.15	26.8	62.50	500	3452.00	5.32	0.01	0.50	0.05
Site 4	24.08.15	26.9	62.50	33	187.89	0	0.30	0.40	0.09

Heavy Metals

Water quality samples taken at the same sites as above and at the same times were analyzed for heavy metals at the SEAMIC laboratory, Dar es Salaam (Table 17).

Table 12: Heavy metals in the Wami River measured at Gama gate

Location	Date	Pb	Cu	Cr	Hg
Gama	18.08.15	< 0.01	< 0.01	0.25	< 0.01
Gama	14.09.15	< 0.01	< 0.01	0.17	< 0.01

Chromium (Cr) readings were higher than the safe recommended maximum limit (0.05 mgl) for aquatic ecosystems (Wami EFA report, FIU-GLOWS 2014). Possible sources could include metal and electroplating industries, leather tanneries, paint as well as through the incineration of domestic waste that has chromium from many sources. In natural waters, the concentration of Cr is very low, typically 0.2-0.6 ppb in seawater, and 1 ppb in river water; however rivers subject to industrial pollution and non-point pollution from urban areas can have higher levels, such as 5-20 ppb in the River Rhine and 10-40 ppb in the River Elbe (LennTech 2015). It is interesting to note that, as of 2007, Wami River water quality showed no significant presence of either agrochemicals or industrial pollutants (Anderson et al 2007).

Primary producers, water quality and water flow

Phytoplankton are primary producers in aquatic ecosystems. The estuary supports fewer species compared to other transitional water bodies due to high variability of water flow. In the Wami Estuary, there are three main dominant groups of Phytoplanktons; Diatoms (Bacillariophyta), Cyanobacteria and Dinoflagellates (Kiwango 2011). Their composition, abundance and distribution in the estuary are mainly influenced by hydrological variations (particularly tidal flow during dry season) rather than changes in physico-chemical properties of water. In wet season very few phytoplankton can be found in the estuary compared to dry season because of high turbidity which limit their productivity and high freshwater inflows with high velocities which tend to flush them quickly to the sea (Kiwango's data, ongoing PhD study).

Sediment

Sediments are the most significant form of nonpoint pollution, and certainly holds true for the Wami river in recent decades. The volume of sediment load transported along Wami River depends mainly on the management of the land use activities and water use in the upper catchments, with higher sediments in the wet season. Major activities on the watershed of Wami Basin comprises of agriculture, livestock farming and fishing activities in the streams and rivers that make up Wami River. The nature of the soils and any other elements to be found on the surface and underground, in catchments of these areas may be considered the determining factors of the water quality for this particular river. The soils include loam soils, clays and sandy soils. By nature most of the soils of these areas are unconsolidated especially on the surface, due to the nature of human activities such as farming without any soil conservation measures on recently cleared steep slopes, or the movement of large heads of livestock along the catchments. Mining is another activity, along with wildfires that are frequently lit and further loosen the soil by removal of vegetation. Generally, the water in the dry season as observed was nowhere as turbid as in the wet season. At least four livestock watering points were noted along the river banks. These watering points were seen to be sources of erosion adding to the sediment load in the river. Building and farming within the restricted 60 meters from the river bank was also recorded. The structures were well established with concrete fence posts. The movements of the backwater have effects also in sediment load by its violent movement causing erosion along the river banks. As a result the water is turned to be turbid. These hydrodynamics are experienced frequently along these areas.

Conclusion and recommendations

The above study details water quality information from specific dates. In order to understand seasonal variation in water quality, and thereby the links between ecosystem processes, communities and water quality, a continuous water quality monitoring program is necessary. Key sites for such a monitoring program could be the existing sites 1-5 established by Halima Kiwango for her PhD research, as these sites were selected at important ecosystem transition sites, such as river mouth, palm-mangrove interface and freshwater zone. In addition, Porokania, Kinyonga Camp and Gama Gate have ranger stations, are accessible by road and hence are also convenient water quality monitoring stations. More information on current initiatives towards generating continuous water quality data at these locations are presented in Chapter 10.

Chapter 5 – Riparian Plant Communities

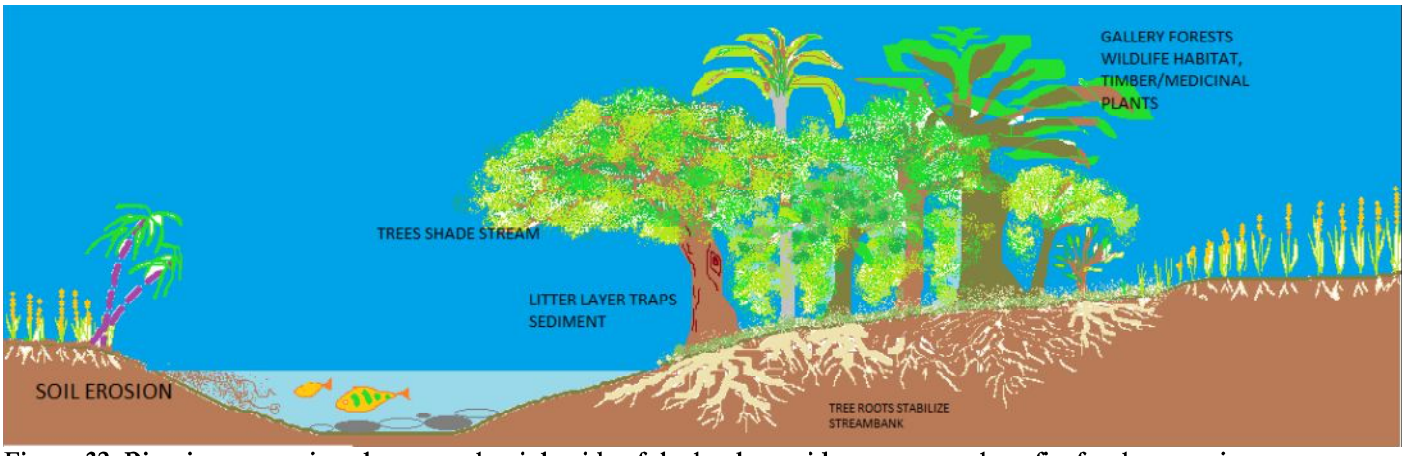


Figure 32: Riparian vegetation shown on the right side of the bank provides numerous benefits for the aquatic ecosystem

Contributors – Amartya Saha, Halima Kiwango, Michael Kimaro

Background:

Riparian vegetation – ecological characteristics and ecosystem services

Riparian vegetation refers to the trees, shrubs, herbaceous plants and grasses growing on riverbanks and floodplains (Figure 32). In any landscape, riparian vegetation differs markedly from the natural vegetation further away from the river on account of higher water availability over a longer period of the year; this is usually seen as a green vegetation belt alongside river courses. For instance, in Sadaani National Park, savannah woodlands with deciduous trees occupy much of the area away from the river, indicating seasonally dry areas, while the natural vegetation bordering the Wami River is more evergreen in nature. Since plant species differ in their tolerance ranges of flooding and salinity, the composition of a natural riparian forest is tightly coupled to the seasonal flow regime of the river, and gives clues on the extent of flooding of banks, soil water availability and salinity occurring in the root zone (rhizosphere).

Canopy heights of riparian trees can be higher than vegetation further away on account of not only higher water availability but also higher nutrient availability in the riparian zone. The soils in riparian zones are biogeochemical hotspots where fluctuating water levels, nutrients brought in through overland runoff, downstream transport and fauna (monkeys and birds resident in the trees), and a thick leaf litter layer gives rise to high microbial activity. This active nutrient cycling, coupled with the addition of leaves, flowers and fruits into the stream also constitutes important nutrient inputs into the aquatic ecosystem, sustaining invertebrates, reptiles and fish. Mangrove roots submerged in the river provide shelter to fish fry from predators and hence serve as nursery grounds and breeding sites for fish and prawns. The aquatic ecosystem in turn sustains the wide diversity of birds and wildlife as well as fisheries for coastal villages. Trees shade streams and rivers, thereby keeping the water temperature cool which results in higher dissolved oxygen (DO), crucial for many fish species of flowing water (lotic) systems. Riparian forests also provide many other ecosystem services, such as their roots stabilizing riverbanks and by functioning as buffers intercepting sediment and nutrients from overland runoff, thereby protecting water quality at source. These forests provide a host of timber, fruit, fodder, fuelwood and medicinal plants for local human communities.

Study approach:

Vegetation on riverbanks was observed on all boat trips along the estuary. Species were recorded with GPS points and mapped, notes taken in reference to salinity and water level, as well as riverbank morphology (whether erosional or depositional, that also indicates vegetation succession and extent of flooding in wet season). Special attention was given to the locations and nature of transitions of major vegetation types, such as palm-mangrove. No shore landings were made (except at Porokania, Kinyonga and Gama). Onshore transects were not possible on account of the presence of hippopotami and crocodiles.

Results:

Riparian vegetation composition in the Wami Estuary

The Wami River estuary is located in the southern part of Saadani National Park (SANAPA). It is a small and shallow deltaic estuary, dominated by salt-tolerant mangrove forest for the first 4-5 kilometers upstream from the river mouth. Thereafter lies the transition zone over a kilometer, with a mix of mangrove species and palms, followed by a greater abundance of trees on the river bank that do not tolerate salinity. Mangroves disappear altogether after around 6 kilometers upriver; even though mangroves grow well in freshwater, they get outcompeted by other vegetation that is entirely freshwater dependant. Inland, ie away from the riverbank lies *Acacia* woodlands and open grasslands. Presence of many hippopotami in the estuary and crocodiles along the riverbanks led us to sample and identify riparian vegetation from the boat. GPS coordinates and photographs were taken continually (every 15 meters) as well as whenever there was a change in vegetation. Figure 33 indicates the main vegetation zones (on basis of salinity tolerance), Figure 35 displays species locations while Figure 39 includes photographs of the dominant vegetation zones.

Vegetation, Flooding and Salinity tolerance

As mentioned in earlier reports on the Wami Estuary (Anderson et al 2007, McNally 2008) river bank vegetation throughout the estuary was grouped into three dominant plant communities (Figure 33) on the basis of salinity tolerance:

(i) Saline water vegetation - dominated by mangroves
(ii) Brackish water vegetation - dominated by palms (*Nypa fruticans*/*Phoenix reclinata*) and some mangrove species
(iii) Freshwater vegetation - dominated by *Ficus-Kigelia-Terminalia* in the canopy with herbaceous annuals and wetland vegetation on sandbanks that are inundated over the wet season.

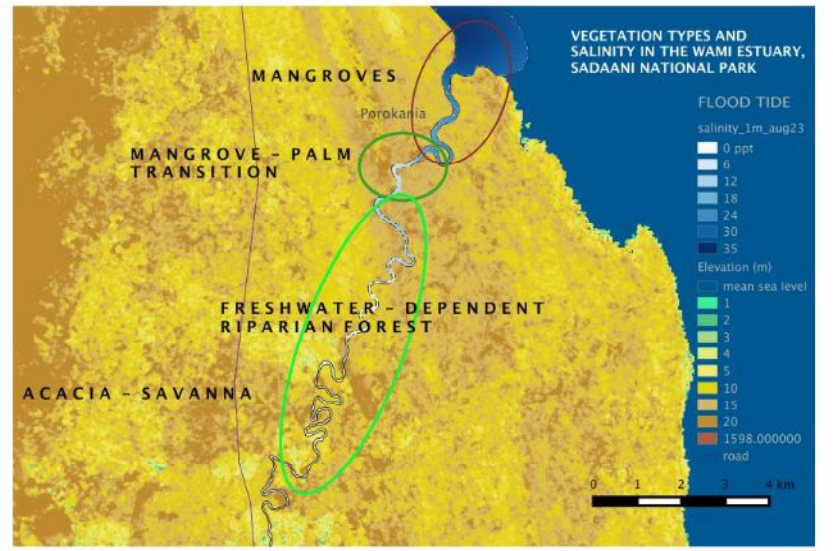


Figure 33: Vegetation communities in the estuary with varying degrees of salinity-tolerance

Mangrove composition and zonation

The term mangrove represents a group of woody species that can tolerate salinity over the entire range from seawater (35 ppt) through brackish to freshwater. In the Wami Estuary, there exists mangrove species zonation both along the river course from estuary mouth to upstream, as well as with distance inland from the bank.

Seven mangrove species were observed in the Wami Estuary; they differ in their salinity tolerance range (Table 13). *Sonneratia alba (SA)* and *Avicennia marina (AM)* are the most salt tolerant of the mangroves; in addition, amongst the mangroves, SA can tolerate continual inundation in seawater for the longest period. Both SA and AM have pneumatophores as anb adaptation to prolonged immersion in waterlogged soils. Hence monodominant stands of SA grace the river mouth, closely followed by AM. *Rhizophora mucronata* (RM) also tolerates full-strength seawater, as seen by occurrance of RM with stilt roots along banks that are inundated at high tide. *Ceriops tagal* (CT) and *Xylocarpus granatum* are less salinity-tolerant and grow on banks that are higher. At the lower end of the tolerance scale lies *Brugeria gymnorhiza* (BG) and *Hereteria littoralis (HL)*. More information on mangroves in Tanzania can be obtained in (Semesi 2001, Richmond 2011, FIU- GLOWS 2014c).

At the river mouth, *Sonneratia alba* dominated the coastal margin, including sandbanks with lone individuals. Close behind the shore were monospecific stands of *Avicennia marina*. These banks get tidally inundated. In addition, the extent and duration of inundation is larger during spring tides as compared to neap tides, as well as in the rainy season when higher freshwater flow in the river leads to higher water levels overall. A slightly higher bank (< 1 m at high tide) had individuals of *Rhizophora mucronata* inundated at high tide, with few *Bruguiera gymnorrhiza* and *Ceriops tagal* higher on the bank (not inundated). Thereafter follows a zone of *Xylocarpus granantum* with curly ribbon roots on the mudbank which dominates a large part of the estuary before giving space to *Heritiera litoralis* close to the transition zone. While *Xylocarpus* and *Heriteria* are dominant canopy species, the bank shore and sand depositional areas at river bends were dominated by stands of

Avicenia, and at times *Sonneratia*. Difference in mangrove species composition on either bank of the river is likely a result of the differences in bank height.

Table 13: Mangrove species occurring in the Wami Estuary

Species Name	Family	Local Name	Availability in Wami	Salinity tolerance
Avicennia marina	*Verbenaceae*	Mchu	Yes	seawater
Bruguiera gymnorrhiza	*Rhizophoraceae*	Msinzi	Yes	brackish (low)
Ceriops tagal	*Rhizophoraceae*	Mkandaa	Yes	brackish (medium)
Heritiera littoralis	*Sterculiaceae*	Mkungu	Yes	brackish (low)
Rhizophora mucronata	*Rhizophoraceae*	Mkoko	Yes	seawater
Sonneratia alba	*Sonneratiaceae*	Miliana	Yes	seawater
Xylocarpus granatum	*Meliaceae*	Mkomafi	Yes	brackish (medium)

This is especially noticeable at river bends, where the convex bend has sand deposits and thereby much lower than the opposite bank, which is scoured and hence steep. The lower bank gets flooded more frequently and for longer periods than the higher bank, resulting in flood-tolerant mangrove species (*Avicennia*) on the sandbanks. Figure 35 indicates the occurrence of different species of mangroves as well as other species, whose locations were recording using a handleld GPS.

Palm-mangrove transition

At the transition zone, the mangroves *Xylocarpus, Avicennia and Sonneratia* give space to palms on the river banks (either *Nypa fruticans* or *Phoenix reclinata*, or perhaps both) which dominate further upstream about 1.5 km. While *Nypa fruticans* is the common estuarine palm in the Asian Indo-Pacific region, no literature was found suggesting that their native range includes East Africa (although they have been introduced to West Africa where they are becoming an invasive exotic). In contrast, several publications mention the presence of *Phoenix reclinata* as being present along with mangrove communities in both East and West African estuaries (Nicole 1994, Saenger 2013). These palms can tolerate flooded soils, and slightly brackish water. In August, salinities at flood tide were less than 5 ppt at the river bottom in this zone. Hence the mangrove-palm transition zone has been widely held to demarcate the extent of seawater intrusion on average (eg Anderson et al 2007, FIU-GLOWS 2014).

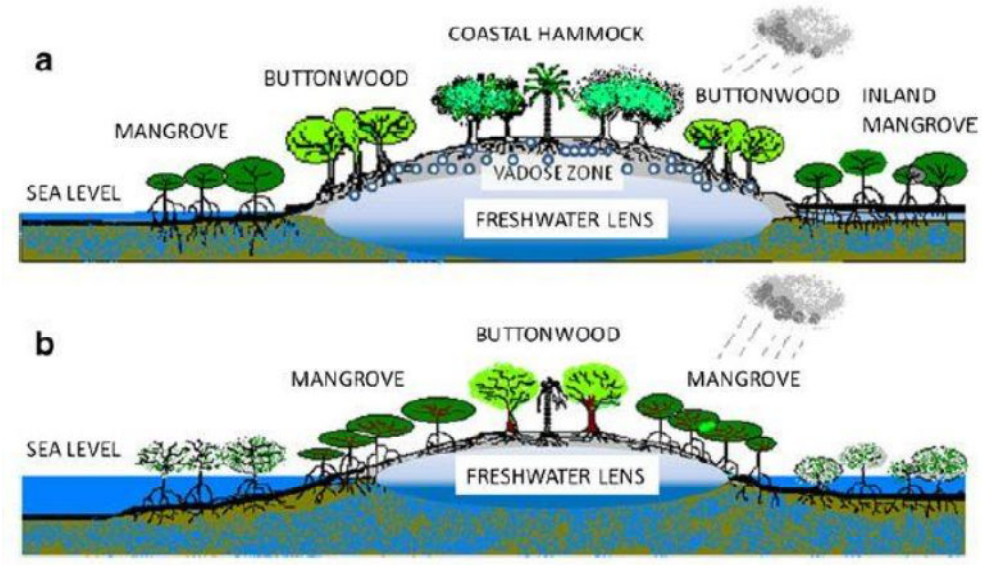


Figure 34: Pools of freshwater created from collected rainwater allows freshwater dependant vegetation to exist in a saline water table in coastal forests

While there are episodes when seawater intrudes further upriver (as noted by the Sadaani village water supply project situated another 4-5 km upstream that could pump water only at low tide), the seawater would be flowing in along the bottom, overlain by freshwater which is what the plants would be accessing. In addition, relatively less salt tolerant mangroves on high banks would also be likely utilizing a soil rainwater pool in the rhizosphere. For instance, in the estuarine section of the Florida Everglades, a perched rainwater pool allows salinity-intolerant trees (such as *Conocarpus erectus, Eugenia fetida, Bursera simarouba, Swetenia mahagoni*) to coexist with mangroves over the regional saline groundwater, albeit on slightly higher locations on the order of as little as 10-15 cm (Figure 34 - Saha *et al.* 2011). In addition, high freshwater inflows over the successive wet season can flush out some of the salt that might remain in the soil pores.

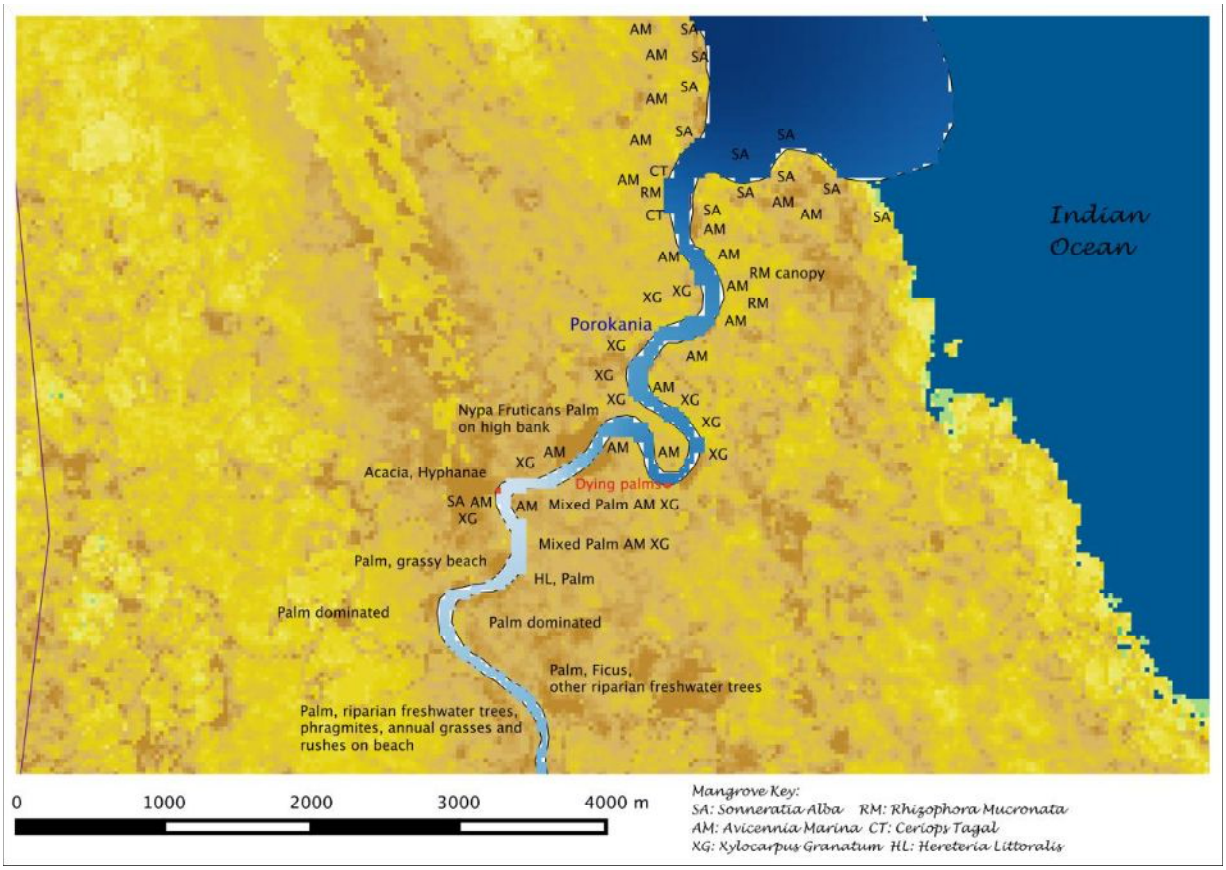


Figure 35: Mangrove species and other vegetation noted alongside the banks.

Freshwater riparian forest

At the upstream end of the transition zone, about 6 km upriver from the mouth, the mangroves disappear and are replaced by palms and salinity-intolerant trees dominated by *Ficus sycomorus*, *Salvadora percica*, *Kigelia* and *Terminalia* species, reaching canopy heights up to around 10 meters. Other palm species, *Hyphaene compressa* and *Borasus sp* were seen in this zone, however these palms occurred inland, and not on the river bank. Several species of climbers were commonly seen in Palm trees, at times forming thickets. Along river bends, the beaches are colonized by herbaceous annuals and wetland vegetation (rushes, reeds, *Cyperus papyrus* and grasses including *Phragmites*) - indicators of seasonal flooding that do not allow woody vegetation to establish. The herbaceous annuals die back every year when continuously flooded by high water

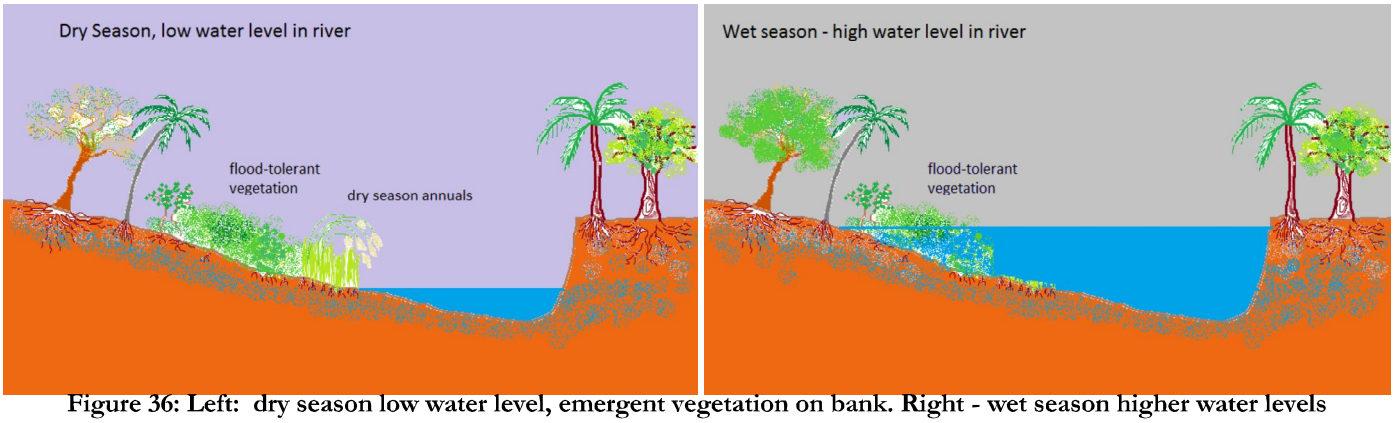


Figure 36: Left: dry season low water level, emergent vegetation on bank. Right - wet season higher water levels

levels for several months in the wet season (Figure 36, 39 bottom). Wetland vegetation have root and stem adaptations to withstand saturated soils. Woody vegetation, such as mature trees occurs beyond this belt of herbaceous plants, thus indicating the extent of flooding on average over the past decade at least (Figure 36). Further inland, away from the river exists savannah woodland dominated by *Acacia zanzibarica along wth A. nilotica, A.melifera and Dichrostachys cinerea* interspersed with open grassland dominated by *Sporobolus sp.* mixed with few unidentified shrubs.

Table 14: Estimated distance for ranges of different vegetation cover from the river mouth to the Gama Bridge

Habitat	Distance (km)
Mangrove forest	4.72
Mangrove-Palm ecotone	0.73
Palm forest	2.71
Palm-Riparian ecotone	0.51
Riparian vegetation	14.57
Total distance covered	23.24



Figure 37: Golden weaver birds nesting on grassy vegetation growing on beaches along river

Conclusion and recommendations:

Challenges facing riparian forests in the Wami Estuary

Riparian forests provide critical habitat for wildlife, promote favorable in-stream conditions for fish, resources for humans, bank stability and water quality, by being the last defense of the riverine ecosystem from adverse land use impacts such as nonpoint pollution. In the Wami Estuary, riparian forests face the following challenges:

1. Deforestation: Large sections of the banks, especially the southern bank of the Wami River within SANAPA are currently devoid of riparian gallery forest. Trees were cut down in the past and have not been allowed to regenerate; likely causes for which include indiscriminate livestock grazing, firewood collection and cultivation on riverbanks. This is a serious issue, as in many cases the banks are being destabilized and falling into the river (Figure 38), adding to siltation as well as decreasing channel depth (that increases extent of wet season flooding). Furthermore, the loss of riparian forests also leads to loss of the numerous valuable ecosystem services such forests provide. The ongoing uncertainty



Figure 38: Banks destabilized with trees falling in the Wami river

2. Reduced inflows in the future: this is a very likely consequence of increasing water demand further upstream in the Wami basin can lower the water table in the riparian zone, leading to water stress in riparian forest plants, and under extended periods, create drier conditions that can allow fires from inland (commonly set by people) to spread and destroy the existing forest. Riparian trees are not adapted to fires. The black and white colobus monkey lives only in these forests. Reduced freshwater inflows also would lead to increasing seawater intrusion upriver, together with increasing salinity in the root zone. This can lead to mortality of mangrove species that are only partially tolerant to salinity (such as *Xylocarpus, Brugeria, Hereteria* and *Ceriops*). While in theory mangroves could migrate inland, there is not much land remaining that is not under some human use.

Recommendations:

It is absolutely essential to include both banks of the Wami River inside SANAPA, in order to protect the riparian forests and thereby the estuary and its services. Tanzanian law prohibits farming along riverbanks to about 60 meters inland from the bank; this law has to be enforced. Definite livestock access points can be maintained to restrict the damage caused by livestock access anywhere along the riverbanks.







Figure 39: Plant communities along the river from mouth (saline/brackish water) to upstream (freshwater): mangrove diversity at the mouth, mangrove palm interface, palm-riparian freshwater forest, riparian forest on both banks of river

Chapter 6 – Aquatic ecosystem



Figure 40: Sampling for fish at the estuary mouth

Contributors – Mathias Igulu, Patroba Matiku, Amartya Saha

Background: critical fisheries habitat and freshwater inflows

Estuarine habitats (*e.g.* main channel, mangrove forest creeks, tidal channel, mud and sand flats) and their adjacent areas (*e.g.* seagrass beds, coastal reefs and sandy beaches), provide a series of ecological services to coastal waters, including protection of the shoreline, circulation of nutrients, maintenance of fisheries productivity (nursery, shelter and food supply) and connectivity to other habitats (Sheaves 2009). Mangrove habitat is not only important as a source of nutrients to adjacent areas but also as a feeding and nursery ground to many species of finfish, shellfish, prawns and crabs (Igulu et al. 2013). These are also important environments for protection, feeding and reproduction of a considerable number of species of vertebrates and invertebrates. Studies in estuaries have linked the seasonal fluctuation of salinity and water temperature to the seasonal and spatial fluctuations of distribution and abundance (density and biomass) of fish assemblages in the estuarine ecosystems (Barletta et al. 2005). Seagrasses are a group of rooted flowering plants belonging to the monocotyledon group that occur in shallow bays and lagoons in the tropics and subtropics. Seagrass beds provide shelter and food for numerous species of aquatic invertebrates, fish, juveniles of larger marine fish, sea turtles and dugongs (Semesi 2001).

In estuarine ecosystems, the maintenance of a balance between freshwater and marine inputs is essential for proper ecosystem function. For instance, seagrasses are sensitive to flow alterations, hypersalinity, turbidity increases and nutrient reductions (Doehring 2002, Fourqurean *et al.*2003) and are globally threatened ecosystems on account of changes in water quality and introductions of invasive species. Increased sediment can increase turbidity, thereby decreasing sunlight penetration, as well as eventually smother seagrass beds. Habitat degradation through disruption of this hydrologic connectivity (Pringle 2001), e.g., by altering the magnitude or dynamics of freshwater flow into estuaries, may be the primary cause of ecosystem imbalance and in most cases will affect estuarine fisheries (Layman et al. 2011). Juvenile fish of many species have narrow salinity range tolerances, and thus are sensitive to changes in freshwater inflows. Therefore, it is important to maintain the seasonally varying freshwater inflow for co-existence of estuarine species in the ecosystem.

Study approach and methodology

There is a dearth of literature on the fish and associated species of the Wami River estuary, with a few reports (Tamatamah 2007) and (FIU–GLOWS 2014) describing previous fish surveys.

Survey methods

A rapid field survey was conducted for five days (August 19-24, 2015). Two methods were employed: boat-based fishing in the estuarine part of the Wami River and visiting nearby fishermen's landing sites. During fishing, a 2 m wide and 100 m long gillnet with stretched mesh size of 1.5 inch was used to sample fish species. The net was set in the deeper part of the channel while making a cycle; fish were then trapped, collected and identified to the species level. Prior to fishing, environmental parameters (salinity and temperature) were measured in the estuary. Two landing sites were visited - these

were Kajanjo and Saadani fishing village. During visits, we observed fish landings (catch) from fishermen and conducted discussion with fishermen on the trends of the fishery. Species caught from fishers was identified to species level, other information noted were type of the gear and vessel used. Findings from the literature search, field survey and catch landings from fishermen were used to assess the water needs for fish and associated aquatic organisms in the Wami Estuary.

Results:

Coastal habitats

The estuarine environment contains important terrestrial and aquatic habitats that support rich biological diversity and valuable assortment of natural resources. These include tidal creeks, river channel, mangrove and coastal forests (palms) and sand flats. These ecosystems provide essential nursery, feeding areas and shelter for a large variety of terrestrial and marine biota, from crocodiles and hippos to marine fish, crustraceans, molluscs, annelids and echinoderms. For instance, mangrove roots provide shelter to an array of marine fish (Figure 41). The lower salinity in estuaries attracts large numbers of juvenile prawns, with different species preferring different habitats. For example, *Peneus indicus* is found on muddy and mangrove-lined regions while *Peneus latisulcatus* appears to prefer sandbanks with seagrass growth (Silas 2011).



Figure 41: Banded porcupine pufferfish swimming along mangrove roots

There are no coral reefs in the Wami River mouth, probably due to lack of a firm seabed and excessive discharge of fresh water and sediments inputs. Similarly, the presence of 10-30 cm mud layer in the mouth of the river suggests that any seagrass beds that may have been there have been smothered in sediment. Sediment cores can reveal whether this may have happened. Seagrass beds were observed a half kilometer away from the river mouth along the coast, with seagrasses of several species regularly washed up on beaches either side of the Wami estuary.

Fish and crustaceans

The most common fish species that inhabit the Wami Estuary are *Arius africanus, Hilsa kelee, Liza macrolepis*, *Chanos chanos*, and *Thryssa* spp. Crustaceans includes *Scylla serrata*, hermit crabs, and prawns. Molluscs include *Saccostrea cucullata*, *Terebralia palustris*, *Cerithidea decollata*, and *Strombus* spp. Moreover, there are a number of freshwater fish species that inhabit the fresh water part of the Wami basin (Figure 42). These species can potentially move downstream during rainy season (for detail see Tamatamah 2007). The most common fish species caught during this survey includes: *Arius africanus, Valamugil buchanani* and *Thryssa baelama*. Crustaceans include *Scylla serrata* and hermit crabs (Figure 43). At the river mouth the dominant species was African catfish (*Arius africanus*); same species was observed in large number at Fungu Maboko. Few kilometers away from the river mouth upstream at Saadani River Lodge, the catch was mainly dominated by *Valamugil buchanani*, the same species came second at Fungu Maboko (Figure 43 c&d). The situation was different few kilometers offshore, where there was large variation in species caught with puffer fish (Tetraodontidae) being the dominant fish.



Figure 42: fish of Labeo genus caught in the freshwater section of the Wami estuary

There were 18 different types of fish species observed at Kayanyo landing site and 10 species at Saadani. The catch was mainly dominated by prawn species (*Paneus monodon*) in Kayanyo and Indian pellona fish species (*Pellona ditchela*) at Saadani landing sites (Figure 44). This could potentially indicate diversity and abundance of fish species decrease as the distance from river mouth increases. However, the opposite situation could possibly occur during large floods in the rainy season as fresh water inputs pushes away marine water. Year-round sampling of fish catches can yield more information as to the

abundance and diversity of fish species in the estuary and surrounding coastal and upriver areas.

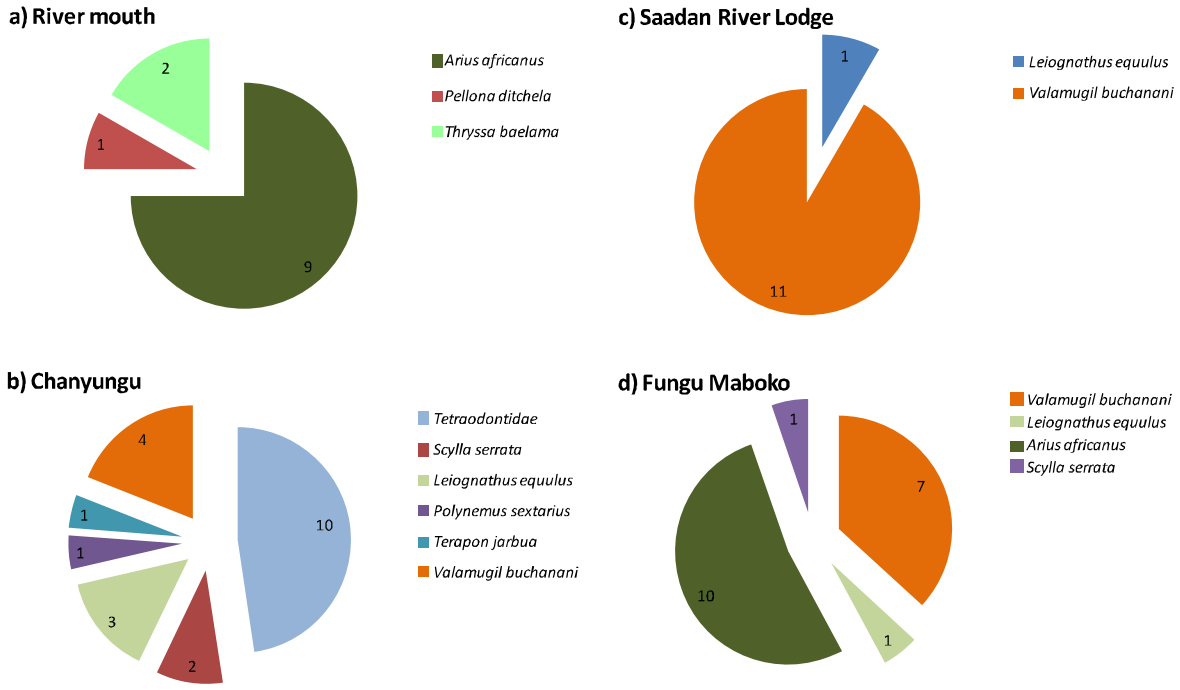


Figure 43: Catch composition of fish species at different locations in the Wami River estuary and within 2 kilometer offshore (Chanyungu). Numbers indicate number of individual fish species caught.

Fisheries

Availability of muddy deposits and mangrove habitat at the river mouth forms an excellent ground for various species of fish including prawns. The area around Wami Estuary is one of the famous fishing grounds for prawn fishery in Tanzania. Together with fishing ground around Bagamoyo, they are commonly known as fishing area Zone I as per TAFIRI classification (Silas 2011). The prawn fishery was closed in 2007 following the decline in the industrial catch, however, artisanal fishing is still operating (Tumbo et al. 2015). The dominant fishery in Saadani area was and still is prawn fishery with peak season from March to April (Mosha & Gallardo 2013). The fishery around Saadani is artisanal dominated. In most cases, artisanal fishers are characterised by the use of multi-gear, targeting multi-species, the target fish species of one gear could be bycatch for another gear. Most common gear used is gill net. Some gear such as gillnets have a wide range of mesh sizes, several setting techniques and capture different categories of marine organisms including prawns.
Discussion on the status of the fishery, trends and seasonality came into the conclusion that there have been changes on the catch and abundance of fish species in the estuary. Overall good agreement between fishermen's perception was that Saadani used to be the ground for prawn fishery but changes in the water flow and other environmental parameters has resulted into the collapse/decline of/in prawn fishery. This decline over the past three decades has also been noted by Silas (2011) in his review of Tanzanian prawn fisheries. Fishermen had an accurate perception on the seasonality of the prawn fishery that concedes with scientific evidence for the peak period between March to April.





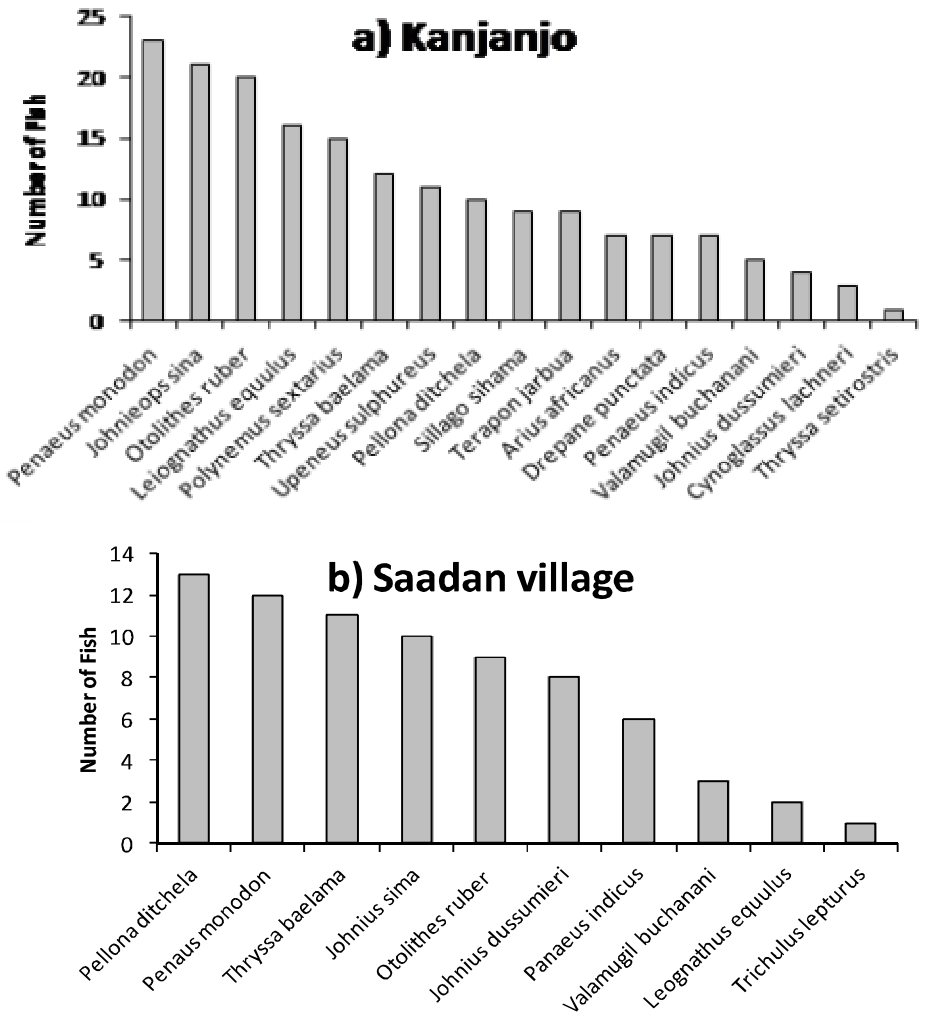


Figure 44: Number of fish caught in one day (August 2015) by fishermen at Kajanjo and Saadani landing sites

Table 15: Common fish with local names in the Wami coastal region

Swahili name	Common English name	Swahili name	Common English name
Taa	stingray	Msusa	Pickhaudle
Mkizi	mullet	Kolekole	Tille Trevally
Mkunga	Africa lungfish	Chewa	Grouper serranidae
Koazi		Ngogo	Squeaker Mochokidae
Papa	Shark	hongwe	Sea catfish
Kanda		Kamba	Prawns
Changu		Kalamamba	Cock grunter
Kungu	Two spot re snapper	Perege	Nile Tilapia
Mkunga	African longfineel	Kambale	Catfish
Pweza		Ngogo	Squeker
		Kurufi	Minnow

Conclusions and recommendations:

Threats and issues

Despite firewood collection and the need for mangrove trees for timber, salt production seems to be the largest threat to mangrove forest of the Wami Estuary. Clearing of mangroves for solar salt farms will have profound influences on the mangrove-associated fish and prawn species as density and diversity are expected to decline and fish community structure will change over a long term. This in turn can negatively affect fish populations in the surrounding coastal areas.

The use of small mesh size fishing nets as observed during this survey negatively impacts the abundance of many juvenile fish species including prawns. Intensive fishing of juvenile fish can lead to lower population sizes in future. Industrial prawn fishery had collapsed, with recovery taking time since 2007, therefore, there is potential for artisanal prawn fishery to collapse too, if juveniles are not protected (Silas 2011).

The large increase in silt loads in the river has led to thick (10-30 cm) deposits of mud all across the mouth of the estuary, covering seagrasses. These mud deposits, together with the increasing turbidity (pers comm SANAPA park staff) in the river are harmful for seagrass beds, which are the foundation of the estuarine food web. In addition, thick mud deposits on the seabed reduce habitat heterogeneity for economically important marine invertebrates such as sea cucumbers, molluscs and crsutaceans, along with other organisms that constitute the coastal marine ecosystem.

Water needs for fish and other aquatic organisms in the estuary

Trying to determine appropriate environmental flows using fish community is the big question to ask. However, individual fish species have specific requirement for water flow, temperature and salinity, and not much is known about these requirements. In the current study we assessed the fish community present in the estuary at this time of the year (dry season) and tried to link this with the current flow at Matipwili, Kinyonga and River Mouth. There is need to consider the variability of flow velocity (discharge) as this will determine the structure and composition of fish species at any particular time in the estuary. The effects of river flow on the fish species depend not only on the magnitude of discharge but also on its timing, to which species-specific breeding cycles are linked with. Data is sparse and longer duration time series data is needed to gain a more accurate overview of the flow regime and seasonal variations. Moreover, it would be convenient to perform field surveys before and after extreme events (i.e., large floods and long lasting droughts) in order to establish relationships between the fish community structure and the flow regime. This would allow, for instance, undertaking studies on fish behavior during floods and droughts of different magnitude and duration, which would definitely improve the planning capacity for the allocation of environmental flows in river basins with scarce water resources.

Challenges on sampling fish community in the estuary

It is possible that this survey may not have encountered many of the fish species present in the Wami Estuary due to:

1. Strong currents in the river channel and at the river mouth making it difficult to use either beach seine or gill net.
2. The presence of large populations of crocodiles and hippos leads to difficulty in locating landing sites for beach seine or gill net in the mangroves.

Electrofishing is recommended as an appropriate sampling technique for the estuary. An electrofisher mounted on a boat can be a viable method for sampling fish, whereby a nonlethal electric current stuns the fish for < 2 minutes, they float up and are netted, identidified, weighed and measured and then released.

The complexity of the estuarine ecosystem with tidal and seasonal variation indicates the need to sample in different times of the year to observe the life cycles of estuarine fishes.

Chapter 7 – Terrestrial and aquatic wildlife

Contributors – Michael Kimaro, Ismail Omary, Amartya Saha

Background: Wami - a globally unique estuary



Estuaries throughout the world have been altered for human activities, especially for transport, commerce and settlement, since river mouths allow navigational entry into the country from the ocean (Wilson 1988). The Wami Estuary is one of the very few estuaries in the world that still supports a large and diverse wildlife population along with the forests and river that supports them. The Wami River approaches Indian Ocean through Saadani National Park - the only national park established along the coast in Tanzania. Various wildlife species together with people living aside depend on this river especially during dry season and during migration such as Water bucks, Wildebeest, Hippo, Crocodiles and water birds.

The Wami River estuary integrates the natural and anthropogenic influences on the landscape of the large river basin and changes of flow, water, salinity and water depth creates heterogeneity of habitat on terrestrial and aquatic species. Within approximately 5 kilometres of the ocean shore, the tropical forest and acacia plant species inhabit the bank and give way to mangroves which indicates the boundary between freshwater and brackish environment. Characterized by a mixing of freshwater and seawater, the wildlife and riparian vegetation of the estuary depend upon the seasonally varying freshwater availability, and their life cycles and migration have evolved in response to the natural variations in freshwater inflows (FIU-GLOWS 2011). The tidal and seasonal variation in the fresh and brackish reaches of the river affects the distribution of wildlife; for example, colobus monkeys, hippos, crocs, wildebeests and bucks use water from the river along different points, since these animals differ in the degree of brackish water they can tolerate. The abundance and diversity of bird species are due to the heterogeneity of habitat in the estuary, as some birds are usually found on sandy beaches, others on edges and in mangroves, palm trees, grasslands and wooded grasslands upstream the river. Therefore, the aim of this study is to estimate the freshwater inflows to maintain ecosystems and assess the water need for wildlife. Wildlife assessment in the Wami Estuary provides the distribution, abundance, water consumption, habitat preference and the linkage with water availability and quality. The analysis relies on literature review, the more than ten years field experience of the SANAPA staff and field work in the current study.

Study approach and methodology

A transect of about 24 km was covered from the river mouth passing through mangrove forest (4.72km), mangrove-palm transition zone (0.73km), palm forest dominated by wild date palm – *Phoenix reclinata* (2.71km), palm-riparian transition zone (0.51km) and freshwater riparian vegetation (14.57km). The aim was to record the habitat changes and wildlife species found in Wami Estuary. The habitat type and dominant plant species were recorded and its location marked and distance (in kilometres) by using Geographical Positioning System (GPS). On account of the rapid nature of the field assessment, there were no exact time used for recording wildlife species on the field; instead observations were made while travelling up and down the estuary during both high and low tides. Wildlife species (birds, large reptiles and mammals) were recorded based on area observed followed by location, habitat type and number of individuals found at that point but small reptiles, amphibians and invertebrates were not possible to be recorded on this boat-based survey. Amount of water consumption required by each species and population was estimated based on the body size of the animal and by using literature available showing the amount required per individual for some species also used to estimate to other species corresponding to those sizes.

Results and discussion

Habitat types and distribution of birds, reptiles and mammals along the estuary

The distribution of birds, reptiles and mammals were influenced by habitat type and water conditions. Habitats along the Wami River estuary has been identified and categorized into five areas, namely; mangrove forest, mangrove-palm

transition zone, palm forest, palm-riparian transition zone and freshwater riparian vegetation.

Birds

About 28 bird species have been identified (as shown on appendix) and figure 45 shows the increase in abundance and species diversity of birds with respect to habitat upstream, with the largest and most diverse assemblages in the freshwater riparian environment. In freshwater riparian environment (salinity 0.08 ppt as measured), some birds such as Golden Weavers build nests hanging over the river, some kingfisher species excavated holes in high cliffs at points where water level cannot reach even during spring tide and on top of this steep sandy river bank mostly topped by *Acacia zanzibarica* species. Woolly-necked storks, Little bee-eaters, Intermediate Egrets, Pink-backed pelican, African Golden Weaver, African Spoonbills and Pied kingfisher were observed in every habitat of the estuary except weavers as they inhabited at the tall grasses found in riparian environment (see appendix).

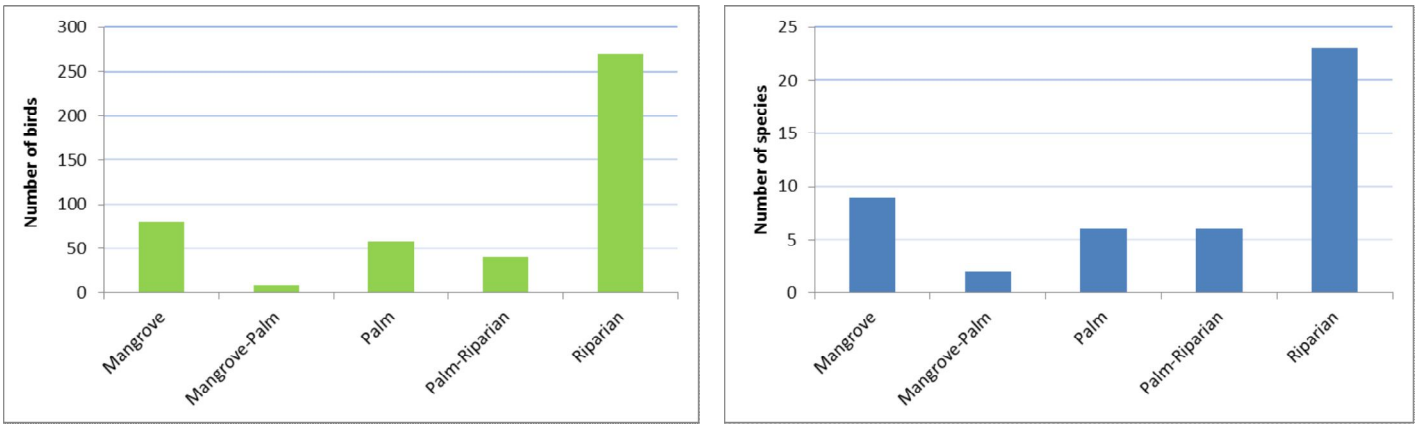
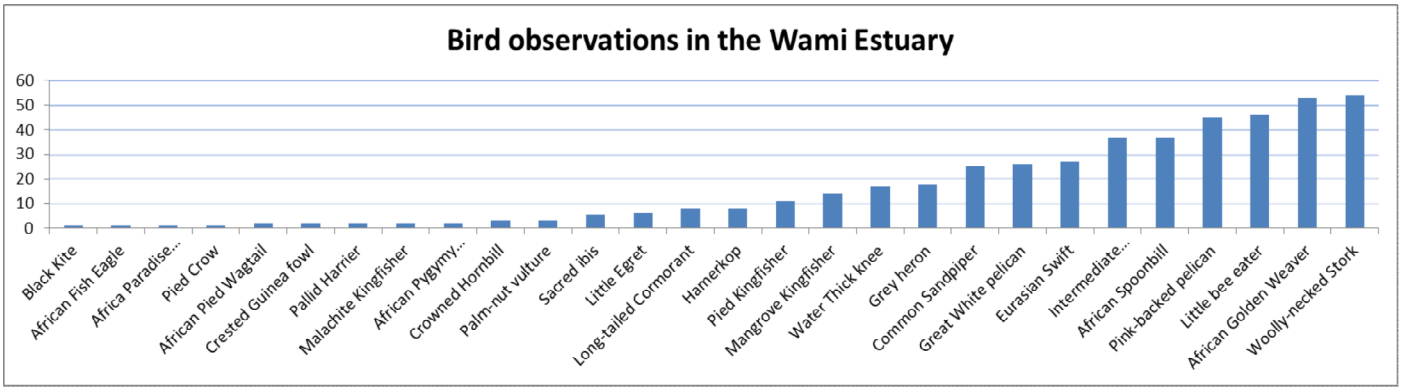


Figure 45: Number of individuals and number of bird species encountered in different habitat types



Large Reptiles

During this study, the Nile crocodile (*Crocodilus nilotica*) was the dominant reptile throughout the Wami Estuary, and was the most abundant in the freshwater section, from palm-riparian transition zone to riparian forests. About 47 % of crocodiles were sighted in the freshwater riparian environment, followed by 24% in palm-riparian transition zone, thus indicating a preference for riparian and palm environment (Figure 46). As salinity increased in the river, the number of crocodiles decreased: the palm zone (salinity, 0.1 ppt) and mangrove-palm transition zone held 11.77% while mangrove (salinity, 0.26 ppt) held 6% of all sighted crocodiles.

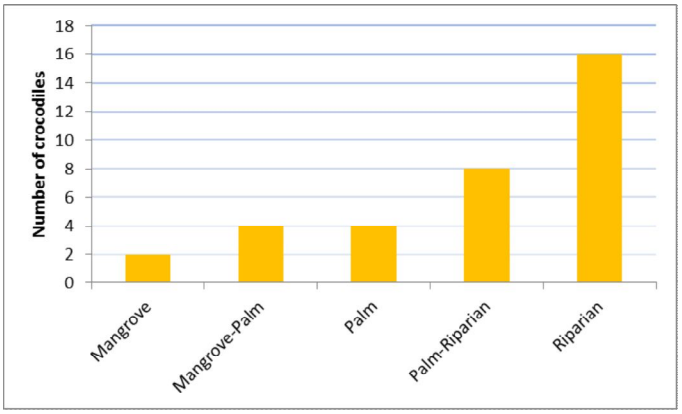


Figure 46: Number of Nile crocodiles in each habitat type

A few green monitor lizards were seen in palm habitat along the river bank (salinity, 0.1 ppt). This study being boat-based was able to observe only large reptiles, hence, lizards and snakes were not seen, apart from a green mamba in the riparian forest at Kinyonga Camp. It is likely that far more crocodiles were seen than monitor lizards, as crocodiles are more

exposed to view as compared to monitor lizards that are smaller and more likely to be in the riparian forest.

Mammals

Hippos are the most abundant mammal in the estuary (N=153) and constitute around 66% of all mammals observed while yellow baboon, black and white colobus monkey and blue monkey comprised 20%, 8% and 5% respectively, see appendix). Mammal distribution is influenced by habitat type and water quality. Primates appeared to avoid mangrove and seawater environments. Most primates were found in palm and freshwater riparian forests. The majority of individuals of Black and White Colobus monkeys and Blue monkeys appeared to prefer palm forest environment while yellow baboons were seen in the more open Acacia-savannas alongside the river.

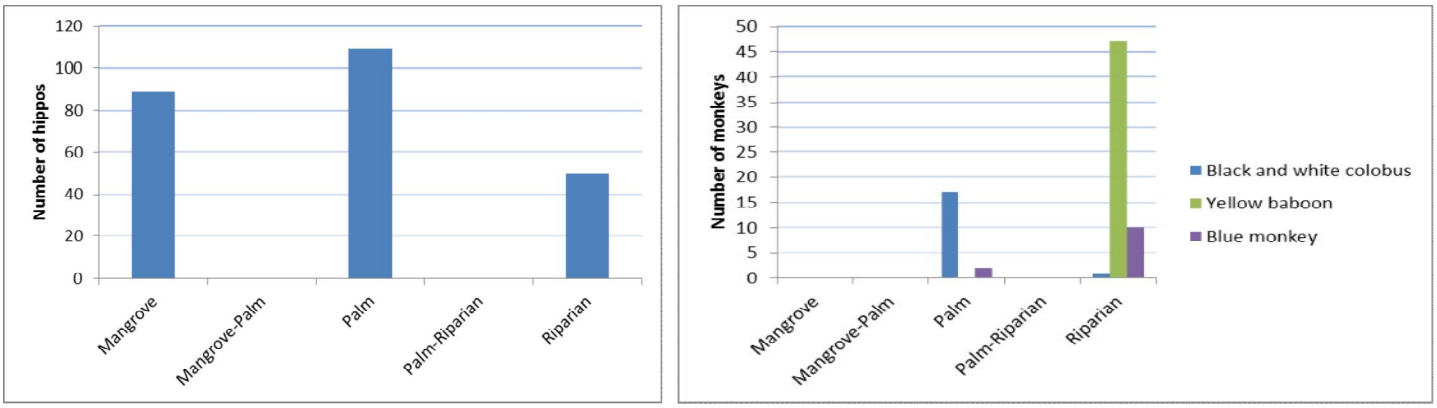


Figure 47: Number of hippos (left) and primates (right) in different habitats. Errata: left graph should read 59, 51, 4 and 39 individuals of hippopotami.

The majority of hippos were observed in freshwater, although a family was observed in brackish water on two days, where the salinity ranged from 2 ppt at the surface to 10 ppt at the bottom. That hippos prefers fresh water environment rather than sea water has been specified in the literature, showing hippos are greatly depends on freshwater environment which makes them susceptible to drought, agricultural and industrial developments (Lewison and Oliver, 2008). Hippos observed were ranging from 5-31 individuals; two large groups were seen in mangrove forest environment were of 31 and 25 individuals, palm had two large groups as well of 28 and 23 individuals, palm-riparian group has 4 individuals and 15 individuals group at riparian environment. Although small groups of hippos observed ranged from 1-5 individuals, the normal range is from 20 to 100 individuals (Barklow, 2004). Several trails have been seen along the river channel; these trails also constitute sub-channels during high tide and wet season, when they provide lagoons and side pools that small fish retreat during drought (Eltringham, 1999; Mosepele, et al., 2009). Other wildlife in the park, such as elephants, giraffes, lions, warthogs, ungulates and antelopes were encountered in the savanna part of SANAPA on our way to the estuary; however, since our observations were largely restricted to the estuary, we do not have any direct observation of these animals in the short time frame of the study.

Water depth and salinity relationships to wildlife

Each habitat type supports certain species of animals. Downriver from Gama gate, tall grasses dominate along the river bank that provide habitat for weaver birds to build their hanging nests. Little bee eaters were very common on both sides of the river searching for food. Behind these grasses are the trees that are dominated by sycamore fig *(Ficus sycomorus)* and when combined with climbers become thick riparian forest. However in some areas the forest is cleared, leading to grassland where yellow baboons are the dominant primates in those areas.

Pastoralists use areas with shallow water for their cattle to drink; these shallow areas are also preferred by Nile crocodiles. When water tide is very low, they bask on the river banks on sand beaches and short small patches of grasses but when water surface level increases they return in river channel to feed on fishes coming from the ocean. The salinity changes of water in riparian to palm forest environment is low (0.1 ppt) compared to mangrove forest environment (ranging from 0.2-5 ppt) and at river mouth is very high up to 20 ppt during medium tide level and crocodiles preferred to stay on 0.1 to 0.2 ppt as observed in the field.

The range of water depth at Gama gate in the mid dry season (August 20-22, 2015) was from 0.76 metres at low tide and 1.18 metres at high tide while the favourable depth range for hippos is 1.5 metres to 14 metres (Estes, 1992). Therefore, at low tide, hippos tend to migrate down the stream and when high tides, they avoid too much salt water and move upstream areas with moderate depth from palm forest upstream up to about 2.5 kilometres after Kinyonga camp site. When water

depth is below 0.15 metres, hippos dessicate (West *et al.,* 2013) and hence migrate to deeper areas. This could be the reason for hippos to not reach Gama gate that often (where it is shallower than downstream) although their trails going to and from grazing are visible on the bank. Behaviourally, male hippos select females who are on heat, chasing the females back to water with high depth for mating; the female has to be totally submerged (de Magalhaes and Costa, 2009), hence, if the depth of Wami River continues to decrease downstream, hippos will lose mating sites thus affecting their reproduction. More than three large water abstractions have been observed along Wami River just within a few km from the Gama gate downstream (as described in Ch 8). The literature points out that combination of natural and human disturbances to hippos population can cause them to disappear within 60 years and it has been simulated per year and found that even relatively minor human disturbance combined with realistic natural disturbance cause hippos to decline dramatically of more than half of the population (Lewison, 2007). It has also been pointed out that hippos are declining on the range of 7 to 20% over past 10 years while the estimated population of hippos in the world is about 125,000 to 148,000 individuals in 29 countries (Lewison and Oliver, 2008), hence, hippos are very sensitive to human disturbances like water level changes due to large abstractions, erosion caused by cattle, habitat loss due to grazing and cultivation near the Wami River. These disturbances have the potential to eventually cause disappearance of hippos within short period of time. Hippos are very territorial, and an increase in humans crossing hippo territory leads to fatal encounters on both sides. Hippos stay on shallow water for mating and child raising and in the evening emerge from the river to the land for grazing for a distance of not less than 1.6 km along the river banks the river (Estes, 1992; Lewison and Oliver, 2008; Roomer, 1872; Stevenson-Hamilton, 1912) but cattle grazing, cultivation and water abstractions affect their livelihood as they compete with cattle on feeding grasses which will make cause them to migrate.

Water requirements for wildlife

The Wami River is the only perennial source of water for both terrestrial and aquatic wildlife in Saadani National Park, apart from a few pools constructed by the Park Authority. The river is the main water source for drinking, bathing and shelter for wildlife, and also supports vegetation, which in turn provide the only habitat for birds, reptiles and primates. Figure 48 below indicates the estimated amount of water required per population found in Saadani National Park.

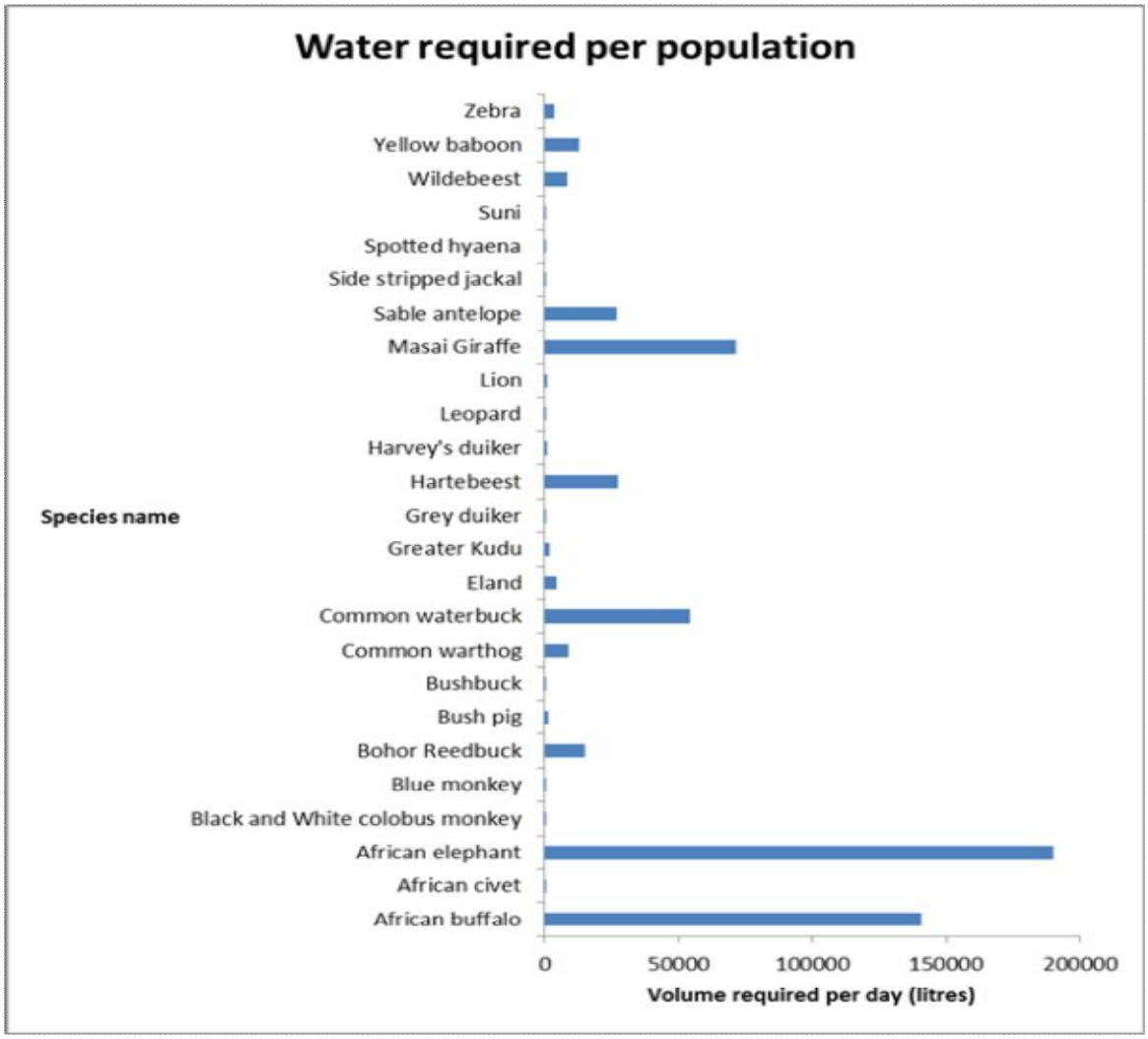


Figure 48: Water required per population of terrestrial wildlife species in Sadaani National Park

The abundance of large bodied mammals such as African elephant, African buffalo and Masai giraffe in the park is relatively low; howeve the volume of water required per day by these large mammals is high compared to small and medium size mammals of (Figure 48). In Saadani National Park, the elephant population requires the most water (189,900 litres) while buffalo population consumes 140,800 litres and the giraffe population around 71,520 litres per day. The movements of African buffaloes are influenced by water availability especially during dry season, when they are never found very far away from water sources. Some elephants and buffaloes are often seen crossing the Wami River and drink water during dry season in the upper regions of the river between Matipwili area and Gama Gate. Giraffes are mostly found in acacia savanna browsing leaves and they prefer to be close to water sources as well. Common waterbucks and Hartebeests are also very common around water sources and their consumption of water is intermediate as shown on Figure 48.

Yellow baboons need a high amount of water compared to other primates; most of the time they are found on the open grassland eating stems of palatable grasses with high sugar content which in turn causes baboons to drink water. Despite individual baboons drinking infrequently, their large population has a high cumulative demand for water - around 32,730 litres per day. Although they are small in body size, they are the largest population in the park, and even their water requirement is still high compared to some large-medium bodied mammals.

Some animals consume relatively low amounts of water due to low population and small body size but they are highly influenced by habitat type. For instance, blue and black and white colobus monkey has been occasionally sighted drinking water from the river, and more commonly from water trapped in hollows in trunks and flowers in the riparian vegetation. These arboreal monkeys also feed on invertebrates trapped in these water pools. Hence the palm and riparian forests, so dependant on the river water levels as well as intolerant of salnity as described in Chapter 5, are critical for shelter, food and water for these primates. Palm forests also provide nesting sites for numerous bird species as well as supporting reptiles and insects, which are part of the gallery forest food web.

Hippos are very unique large bodied mammals that require a minimum depth of water for reproduction as mentioned earlier. The current levels of water in the mid dry season in the Wami are insufficient for this. Hippos usually mate in the wet season, however the females can conceive year round. Only the dominant male in the group can mate, and hence the restriction of mating opportunities due to low water levels can significantly affect reproduction. A female generally only has one offspring every two years. Another concern of low water levels is sunburn and peeling skin for female and baby hippos that happens in shallow water. Crocodiles move along the river foraging for food.

Challenges facing wildlife and habitats of Wami River estuary

- It has been shown that the increase in sea water flowing upstream is due to removal of water from the river for irrigation activities upstream (Beck, 2005). Large water abstractions which reduce freshwater inflow required by wildlife species and affect the migration of hippos and crocodiles. Hippos need a depth of surface a minimum of 1.5 metres but prefers freshwater or low brackish water while crocodiles prefer shallow waters of fresh or brackish waters but not in sea water or area with high salinity and mostly they very close to hippos by staying to similar areas with little distance of each other.
- Human encroachment by pastoralists and crop cultivators. Water use for large herds of livestock in the dry season pose competition for scarce water. Pastoralists were observed with large herds starting from the bank opposite ro Kinyonga camp, which bring more concern on the freshwater inflow needed to keep wildlife species alive.
- Nile crocodile is classified as threatened species due to trade and habitat loss, retaliatory killing due to human-crocodile conflicts and illegal cultural harvesting makes crocodile close to extinction (Beck, 2005). Pastoralists use riverbanks with shallow water for their cattle, where also live crocodiles. The resulting crocodile attacks upon livestock create further man animal conflict. Several local fishermen have seen along the river at banana farms after Kinyonga camp site upstream, and the challenge is to control these fishermen for not using gill nets when fishing as it can drown baby crocodiles. This has been seen in Kenya, where young crocodiles entrapped due to the use of gill nets (Beck, 2005).
- Tree mortality in palm and freshwater riparian forests caused by increasing sea water intrusion will in turn lead to a loss of critical habitat for primates, especially black and white colobus monkeys, as well as birds and other wildlife supported by these gallery forests.
- Increasing turbidity from soil erosion affects sea grass photosynthesis and thereby the base of the food web, on which crocodiles also depend on.

Conclusions and recommendations

The varied habitat within the Wami River estuary supports an abundance of wildlife species. About 28 bird species were observed with woolly-necked stork, little bee-eaters and golden weavers being most commonly along the river. Only large reptiles (Nile crocodiles and green monitor lizards) observed on this boat-based survey study. Hippos are living under their minimum water depth level due to low freshwater inflow in the river channel and they aggregate to small parts of high depth and entirely rely on fresh water although few groups tolerate low salinity maximum of 5 ppm at the mangrove environments during high tides. Primates such as the Black and White Colobus monkey and Blue monkey rely on freshwater specifically to palm and riparian environments, which are threatened by both invading salinity and human disturbances such as clearing riparian vegetation for cultivation. Increasing large freshwater abstractions from Wami River in the estuary endangers hippos and crocodiles as it decreases the surface water required for these species to survive during dry season. Large herds of cattle accelerate soil erosion along the riverbank. The high wildlife diversity in the Wami River estuary and SANAPA depends upom adequate freshwater inflows in the Wami River, as well as the protection of the riparian vegetation along both banks of the Wami river estuary.



Chapter 8 – Human resource use in the Wami Estuary

Contributors – Pendo Hyera, Leodgard Haule

Background

The Wami estuary is populated by people from diverse ethnic groups, the dominant being the Wadoe, Wazaramo Wakwere and Wazigua while others are the Maasai, Mang'ti, Sukuma and Wagogo. Major livelihood activities of the community within the Estuary include fishing, tourism, cultivation, livestock keeping, salt making and business. There are big investments including big Tourist hotels, large salt work industries as well as large agricultural activities. The Sanctuary Saadani Safari Lodge in one of the famous tourist hotels located by the ocean within Saadani village. Coastal fisheries have been and are currently the main economic activity of the villages in the vicinity of the Wami Estuary, as well as coastal villages in general. The fact that most of the marine fish, prawns and crabs depend upon the estuary as a nursery and the major source of food makes preserving the estuary of utmost importance to sustaining coastal fisheries. Fish caught here not only provide the main protein source for coastal villages, a lot of the catch is sent on ice to cities, or dried and sent far inland. Apart from fisheries, coastal villages have always depended upon the estuarine forests for timber for boat building and other structural purposes, for fuelwood and other non-timber forest products such as molluscs, honey, fruits and medicinal plants. This report highlights results from the fieldwork conducted on 20th – 24th August 2015 and data from review of relevant literature on human use/demand of freshwater in the Wami Estuary.

Study approach and methodology

The social economic component of the Wami Estuary study aimed at documenting the human uses of ecosystem services in the Wami Estuary. It further assessed community perception on future existence of these resources.

Study sites were two villages, Kitame and Saadani, within the Wami Estuary. Saadani village, located inside the Saadani National Park, has a population of 1,606 people, while Kitame village, located south of the estuary, has a population of 1,452 people. The interviewed population was around 90 people. Data was derived from extensive review of literature, key informant interview, focus group discussions and field observation. With assistance from staff of the Saadani National Park, the social scientist spent some time with communities, conducting focus group discussions with different groups of men, women, youth and elders. She also interviewed key informants, namelyrepresentatives from the Saadani National Park, Sanctuary Saadani Safari Lodge, Saadani River Lodge, salt industries, farms along the Wami River, village leaders, fishermen, and wise elders.



Figure 49: Focus group discussions with fisherfolk

Results

Human use/dependence on ecosystem services

Ecosystem services include both direct and indirect services and provide an important livelihood to local communities and the national economy. The direct services include freshwater, fish, wildlife, and recreation, while indirect services are water quality, water storage, flood control and nutrient cycling. Other services include option service (agriculture, leisure, industrial) and non use values such as cultural, heritage and bequest (IUCN 2007).

Freshwater is critical for human survival - domestic, irrigation, industrial, navigation, and recreation, and food, cultural and aesthetic purposes. Because of the big impact of water withdrawal on freshwater ecosystems, ecosystems require effective

management in order to regulate and protect them. In Tanzania the main consumption of water resources are for irrigation and livestock (89.5 %), while 10.1% is for domestic consumption, and much less for industry (0.4%).

The Wami River Basin has abundance of riparian and in-stream natural resources such as fish, animals, trees and medicinal plants that are important to the surrounding communities. Most of these resources have been reported to decrease in number due to various reasons, including unsustainable overexploitation, climate and environmental factors.

Domestic water use

Freshwater is the most important commodity within the Wami River estuary for communities living within the estuary and surrounding areas. Domestic needs such as drinking, cooking, bathing, washing, and cleaning depend on freshwater. Two water supply projects have recently been established by the Bagamoyo District Council to supply water at Saadani and Kitame villages, but are not yet complete. Since then communities within the area have been collecting water direct from the Wami, filling drums or water tanks. Water bowser's were used to supply water at Saadani National Park for the Rest House and communities working for sea salt industries. Four salt industries were located at within and nearby the Estuary; Stanley Salt Works, Shangha Salt and Wami Salt Works at Kitame village and Seasalt LTD at Saadani village respectively. In addition to the Wami, villagers at Saadani reported to be using water from hand dug wells which are open to contamination, though not many households would boil water for drinking, despite the ongoing public health campaign.
The Wami is also a very important source of water for tourist hotels located within the estuary. According to interview with hotel owners, 99% of domestic water consumption depends on the Wami River. The Sanctuary River Lodge, located along the river, has a water infrastructure to pump water in storage tanks for their domestic use including gardening.



Figure 50: Water uses in the Estuary

Water for irrigation

Apart from domestic use, the Wami River is also widely used for large and small scale irrigation. Cultivation is an important livelihood activity for communities with the estuary planting variety of vegetables and fruits including tomatoes, watermelon, spinach, green papers, and bananas. It was however noted that the majority of farms extend to the edge of the river bank, which is against the law that restrict human activities within 60m of the river banks. Irrigation was common practice by all farmers, using portable water pumps (5.5 hp). More water was being pumped from the river for irrigation purpose.

Water for livestock

Several large herds (300-500 heads in each herd) of cattle have recently been migrating to the estuary from other regions of Tanzania. This was noted at Kitame village. The village chairperson at Kitame claimed to have not received any official document from pastoralists although he was aware of their existence within the village. Pastoralists mainly depend on the Wami River and nearby ponds as sources for providing water for their cattle. According to studies, highland dairy cattle use about 36 m3/head/yr, upper basin dairy and beef cattle use 27 m3/head/yr, and lowlands cattle use 18 m3/head/yr.

(Tobey, 2008)

Fisheries

Fishing is the major livelihood activity within the estuary and the main source of protein for the majority of the people in Saadani village and coastal areas. According to interviewed fishermen, fishing is mostly done in the ocean and not the river, because the river is under protection. However, the river is the central breeding site for fish. Shrimps and prawns can be sold at a higher price than any other fish. One kilogram of shrimp is sold at Tshs. 4,000 – 20,000. Other available fish included: *kaa* (crabs) *Changu, papa, kolekole, and Sulusulu*. The list is provided in Table 15 in Chapter 6. This study revealed that recently, there has been a drop in catch size, amount and types of fish in the coastal area around the Wami estuary. Besides, fish species caught back in the 1990s have either disappeared or barely exist, as per individuals interviewed in Saadani village. It was learnt that the average maximum fish catch is 10 kgs during high season. A striking question would be *what has happened that caused the depletion of fish populations*. Although there are many arguments specifying *climate change* being a contributing factor for major environmental tragedies, communities admitted that some of their actions, such as overfishing, fishing during the spawning season, fishing of juveniles and destructive practices such as dynamiting coral reefs may have considerably contributed to the decline. According to fishermen at the fishing camp, changes in water temperature is another factor, where they now witness the water being hotter than in the past. They also suggested that a decrease in fish is caused by a decrease in freshwater in the Wami River.

Fish farming or aquaculture is also another emerging activity which requires pumping of water to fill the ponds. This was noted at Gama and Kitame village.

Forest resources

Mangroves have long been harvested and used as poles for housing, firewood and charcoal for fuel, medicine, boat building and raw materials for fishing gears. According to interviewed individuals, *Rhizophora mucronata* and *Sonneratia alba* are good for poles and *Xylocarpus granatum* is used to cure stomach problems. The high demand for resistant wood from mangrove has lead to its overexploitation, making management and protection of these forests even more important. Over-harvesting is driven by mangrove usage for firewood, charcoal, building timber, poles, tannin and traditional medicines. In Tanzania this threat from community utilization has been reduced through sensitization towards moderate harvesting and allowing for recolonization. Construction of evaporation ponds for solar salt production is another threat to mangroves. This is said to be the greatest threat to mangrove resources in Tanzania, where 75% of salt is currently produced via solar production (Tamatamah 2007). Despite their ecological importance of stabilizing shorelines from wave and storm erosion as well as habitat for the fish and invertebrates, human utilization of mangroves is very high, with the most destructive activities being clearing of mangrove for salt pans and charcoal production. The study noted about four established salt work industries with more than 1,000 ha, under production. It further observed another form of destruction which is the cutting of mangroves for temporally housing. Not many initiatives have been taken to restore and manage mangrove forests in the area, although SANAPA has been trying to patrol and provide some protection.



Figure 51: Temporary houses at the fishing camp within the mangroves

Wildlife tourism

The Wami River is the only reliable source of water for wildlife in Saadani National Park. Animals such as hippos, crocodile, giraffe, lions, wildebeest, zebra and elephant are found in the Estuary. There are also blue monkeys, bush pigs and various types of birds including mangrove king fishers, little egret, sand piper, white pelican and flamingo. To a greater extent the life of these animals depends on the Wami River for their survival. Wildlife attracts a huge number of tourists from all over the world. The Saadani National parks is among 14 National parks that provide revenue to the Nation.

Boat safari is the most loved tourist attraction at the Estuary. International tourists visiting the Saadani National Park are also attracted to drive along the Wami River. Saadani Safari Lodge, located just north of Saadani Village and the Saadani Safari Lodge offers a suite of activities to guests, ranging from game drives to beach excursions, to boat trips on the Wami

River. Guests list the Wami River trip as their favorite activity (McNally, 2007). According to hotel owners, the cost per trip per guest was 40$. While in boat drive, tourists enjoy bird watching along the river.

Seasonality of resources in relation to flow regime

Discussions with communities revealed that some river resources are only abundant during the wet season while others are rarely available during dry seasons. Some resources are, however, available throughout the year. Two peak shrimp catch seasons were mentioned by fishermen at Saadani, the highest season from March-May which corresponds to high fish catches mainly shrimps. September – December was reported to be the lower fishing season with lesser fish catches.
Generally, there has been a decline in almost all riparian resources in recent years as reported by interviewed communities. The major reason as mentioned by villagers was climatic change being linked by unpredictable rains, increased temperature and the raise in sea water level. The decrease in water level in the Wami River was also associated with climate change. Human activities such as tree cutting for timber and charcoal making, land clearing for agriculture, illegal fishing, bush fire, illegal mining, and unsustainable use of water irrigation activities were reported to be the contributing factors.

Major threats to the estuary and its ecosystem services

- Clearing of mangroves for salt pans, charcoal, timber, settlements (fishing camp)
- Increased water abstraction upstream/ downstream - decreasing water flows
- Increase migrating livestock
- Inefficiency use of water or irrigation
- Cultivation along the buffer zone
- Use of pesticides
- Siltation due catchment degradation
- Sea water intrusion at increased rate
- Huge investments along the river; hotels etc
- Climate change

Sustainable utilization and management of resources at the Wami Estuary should be emphasized to avoid future catastrophe. The currently situation in resources utilization positions the basin at great risk due to escalating emerging threats at the Estuary and surrounding areas. The growing population, increased abstraction, and clearing of mangrove are some of the detected threats as discussed below:

Increased population growth

With rapid population increase, there is also an increased demand on environment services. As people struggle to improve their livelihood much pressure is invented to exploitation of natural resources. Studies indicate that there has been a rapid population growth over past two decades, between 1988 -2002, the growth rate was 6.1% compared to that of 1.0% in past 10 years (URT, 2004). This has been due to the influx of people migrating to the area mainly for fishing. However, the increase has been escalating by the presence of salt industries employing large number of workers and pastoralist migrating to adjacent villages with large number of livestock. Increasing human populations result in increased pressures on resources of the Wami River Estuary to support their livelihoods.

Clearing of mangroves

McNally et al (2011) describe the effects of prohibiting indiscriminate mangrove treecutting in the Sadaani National Park upon resources availability to local communities. While firewood costs increased, as this had to be sourced from further away, the newly granted protection to the mangrove forests benefitted prawns, molluscs, crabs and fish populations, with subsequent increases in fish catch across all economic groups in the villages. The clearing of mangrove was noted back in 1990s, caused by destructive activities happening along the coast. The establishment of salt pans largely involves clearing of vegetation, and has an impact on mangroves. The current expansion of salt pans within the estuary and coastal areas has greatly reduced mangrove coverage along the coast of Bagamoyo. While the existing salt works provide revenue benefits to SANAPA, and income to the local community, they also constitute a very important permanent habitat for a wide variety of aquatic birds including several species of flamingoes (Omary 2015). A balance is necessary between the benefits from salt pans and the loss of benefits resulting from the destruction of mangroves.

The following human activities have also been mentioned by interviewed communities; illegal cutting of mangroves for firewood, charcoal and timber. It was revealed that Zanzibar has been a good market for charcoal and firewood. Establishment of settlements at the fishing camp within the mangrove forest in Saadani village was another noted threat calling for an immediate sustainable Environmental Management strategy.

Increased human activities upstream/ downstream the Wami

Water abstraction in the Wami is largely for irrigation, domestic and industrial use. Of recent, there has been an increase in the number of users abstracting from the Wami River both upstream and downstream leading to management challenges for the Wami/Ruvu Basin Water Board, Many are unlicensed water abstractions. The largest water users in the Wami include, Mtibwa Sugar Company, Chalinze Water projects, Dakawa Irrigation scheme and the recently established Eco-Energy project just upstream if the Sadaani National Park. A decrease in water flows in the Wami was cited as a result of increased water abstraction although further studies are required to assess the validity of this argument.

The present study revealed that despite of the presence of the WRM Act 2009, the component of enforcement is still a challenge. This was also observed at the Wami Estuary, where the buffer zone has been encroached by human activities, including cultivation within 60 meters from riverbanks. It was also noted that water is inefficiently used for irrigation purposes, as users do not pay the real value of the water and abstractions are not monitored. The widespread use of pesticides also impacts the quality of water and on living organisms depending on the river.



Another issue of concern is increasd sedimentation due to catchment degradation and soil erosion, resulting from deforestation, poor agricultural practices, livestock, encroachment of river banks and wetlands.

Of great interest was the increased rate in sea water intrusion impacting on water quality. According to interviews with communities in Saadani, salt water intrudes further compared to the past. The impact was felt after the establishment of a water project where they claimed to have been pumping salt water during high tides. Another significant environmental threat would be the expansion of salt pans which impacts the sustainability of mangroves.

Figure 52: Threats in the Wami Estuary

Conclusion

The socioeconomic component of the study highlights the major human uses of resources offered by the Wami estuary – freshwater as well as fisheries, forest resources and wildlife tourism-based economic opportunities. The report provides a baseline overview to integrate information already available through other studies. It further points the major environmental threats to the estuary. Human water use is dominated by irrigation and domestic uses which account for about 90% of the water withdrawn from water sources within the basin. With increased population growth and socioeconomic development, the demand for water is likely to double in a few years. A sustainable approach to water management is sought to be achieved through an integrated water resources management. Such an approach is also necessary for maintaining the ecosystem that has provided the basic services supporting the lives and livelihoods of local communities, as well as resources for people living further away from the Wami estuary, by providing assets such as mangrove poles and others, as well as benefiting fisheries and tourism activities.

Table 16: Water uses by human communities around the Wami Estuary

Water User	Village	Ward	Location (Gps)	Population	Type Of Use	Water Source	Amount	Water Use Permit	Type Of Infrastructure	Major Production	Year Established	Remarks
Saadani village Water supply project	Saadani village	Mkange	S 06° 10.779" E 038° 47.258"	1,609	Domestic	Wami River	163.3m3/day	No	Intake	NA	Oct. 2013	
Sea salt industry	Saadani village	Mkange	S 06° 01.556" E 038° 46.654"	500	Domestic	Wami River	24m3/day	No	Water Bowser	Salt	1977	
Saadani National Park	Saadani village	Mkange			Domestic	Wami River		No	Water Bowser	NA	2005	
Kitame village water supply project	Kitame village	Makulunge	S 06° 10.779" E 038° 47.529"	1452	Domestic	Wami River	140.6m3/day	No	Intake	NA	Oct. 2013	
Zakaria Musa Farm	Gama - Kitame	Makulunge	S 06° 12.465" E 038° 46.841"	Aprox. 5 ha	Irrigation	Wami River	40m3/day	No	Pump	Vegetable farmining	1997	Based on estimates
Sabina Nyoni Farm	Gama – Kitame	Makulunge	S 06° 12.465" E 038° 46.840"	Aprox. 7 ha	Irrigation	Wami River	60m3/day	No	Pump	Vegetable farmining/ Fishing	2014	Based on estimates
Hamis Makenza Farm	Gama - Kitame	Makulunge	S 06° 10.779" E 038° 47.529"	Aprox 2 ha	Irrigation	Wami River	60m3/day	No	Pump	Water melon Fruits	2015	Based on estimates
"Mchugaji" Farm	Gama - Kitame	Makulunge		Aprox 10 ha	Irrigation	Wami River	60m3/day	No	Pump	Vegetables	2015	Based on estimates
Sanctury river lodge	Gama - Kitame	Makulunge		60	Domestic	Wami River	15m3/day	No	Pump	Hotel		
Santuary Saadani Safari Lodge	Saadani village	Makulunge		90	Domestic	Borehole		No	Borehole	Hotel		Not applicable
H.J Stanley & Sons LTD (Utondwe solt work)	Kitame village	Makulunge		100	Domestic	Wami River	25m3/day	No	Water Bowser	Salt	1960s	

Chapter 9 - Environmental Flow Assessment of the Wami Estuary



Contributors: Rashid Tamatamah, Amartya Saha, Elizabeth Anderson, Vivienne Abbott and the Flows workshop team

Background

The importance of maintaining the natural flow regime for sustaining the ecosystem integrity of rivers and estuaries has been recognised worldwide, which led to development of the environmental flows (EF) concept. According to the Brisbane declaration of 2007 (http://www.watercentre.org/news/declaration) EF has been defined as "the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems". EF assessments are now considered globally as important tools used for ecosystem restoration and management of water resources. Legal frameworks and water policy in Tanzania support Environmental Flow Assessments (EFAs) where it indicates the water allocation for environment as the second priority and that water for environment is required to maintain the health and variability of riverine and estuary ecosystems. More information on this is included in earlier EFAs for the Wami and Ruvu rivers (FIU-GLOWS 2014 d & e). However, the extent to which environmental flows are incorporated into water allocation plans remains a challenge in Tanzania and worldwide.

The EFA approach

Environmental Flow Assessment processes are part of an adaptive management strategy, using available data and knowledge to make preliminary assessments, and then updating and improving these with time and additional research.
Over the past several decades there have been various approaches to determine the magnitudes of environmental flows; Arthington et al 2004 provides a review of major methodologies. A widely used methodology is the Building Blocks method (Tharme and King 1998) where the magnitudes and necessity of flows in a river during different seasons are linked with the various processes in the aquatic ecosystem in that river. The range of water flow necessary to maintain a certain ecological process is thought of as a 'building block', with blocks added over each other across seasons in order to visualize the flow necessary in a river for various ecological needs. To illustrate, the first building block (Figure 53) represents the low flows necessary in each month to maintain species and the conditions for life in flowing waters (such as adequate dissolved oxygen, carrying nitrogenous wastes away, bringing in nutrients). The second building block illustrates the higher flows

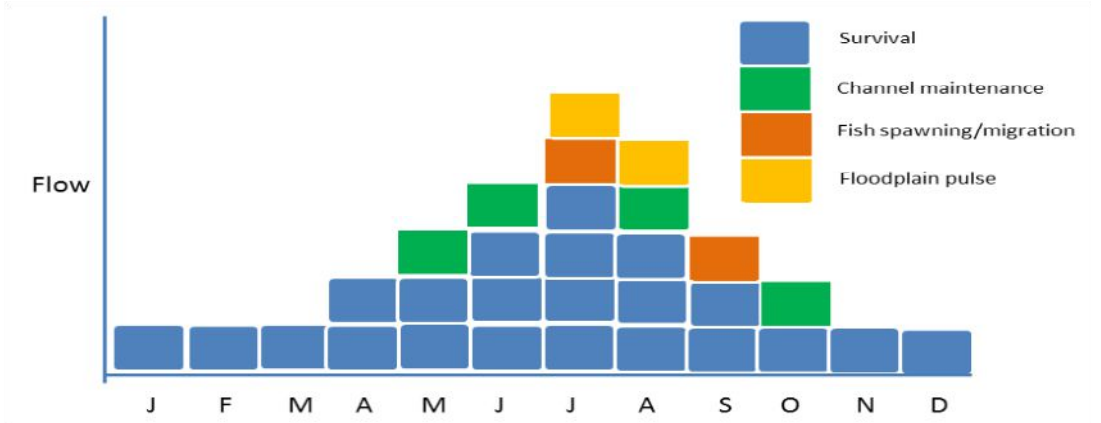


Figure 53: The building blocks approach for EFA with four examples of building blocks

necessary for channel flushing and habitat maintenance. The third building block involves even higher flows to trigger spawning and migration cues in fish. A fourth block could represent periodic flood pulses necessary to connect floodplains to the river channel for species migrations and nutrient rejuvenation. The approach for the Wami estuary EFA was based upon this methodology, whereby the flows necessary for different ecosystem processes were identified by the experts to the best of their knowledge, given the paucity of data relating flora and fauna communities to flow and salinity in the Wami estuary, or coastal East Africa in general. The approach was similar to the EFAs carried out for the Wami and Ruvu rivers by some of the team members (FIU-GLOWS 2014 d & e). The EFA process and approach has been described in detail in these earlier reports. Below the proceedings of the three main parts are described.

Part 1. Characterizing the state of the ecosystem

At the 2-day flow setting workshop, experts from each the component disciplines were asked to evaluate the overall situation in the estuary pertaining to their area of expertise. Specifically, the following three aspects were considered:

(i) the current status is given a grade between A through F, A referring to a pristine condition and F for an irreversibly degraded situation (Table 17);
(ii) the trajectory of change (positive, neutral, negative – Table 18); and
(iii) the desirable status from the perspective of ecological sensitivity (Table 19)

On the basis of these three conditions, each expert offered a suggested Ecological Management Category (EMC) for each site, scored between A through D (Table 20). A thorough discussion ensued, in which the experts were asked to explain their recommendations for present state, trajectory of change, and importance or ecological sensitivity for the Wami Estuary. SANAPA staff and director, WRBWO staff and particularly the Basin Water Officer as well as the Water Engineer from Bagamoyo District contributed information on the management challenges they face at each site, historical conditions and on potential developments—such as dams or irrigation projects—that might be on the horizon. On the basis of these discussions, a consensus recommendation for Ecological Management Category (EMC) was made for the estuary ecosystem.

Table 17: Summary of the ecological categories used in determination of the present state and for the recommended ecological management class.

Category	Description
A	Unmodified, natural.
B	Largely natural with few modifications.
C	Moderately modified. Changes have taken place but the ecosystem functions are largely unchanged.
D	Largely modified. Large changes have occurred and the resource base reserve has been reduced.
E	Seriously modified. Seriously reduced resource base reserve.
F	Critically modified. Changes may be irreversible.

Part 2. Linking ecosystem with hydrology

Flow recommendations to achieve the suggested EMC in the estuary were made using a combination of information from the published scientific literature, field data and professional judgment. The process for setting flow recommendations generally followed that outlined in BBM (King *et al.,* 2008) and in the Wami and Ruvu river EFA processes (FIU-GLOWS 2014 d&e). The experts were asked to consider the flow needs as related to ecosystem structure or ecosystem function in six different scenarios:

- low flow in the dry season of a drought year;
- low flow in the wet season of a drought year;
- low flow in the dry season of a maintenance year;
- low flow in the wet season of a maintenance year.
- High flow in the wet season of a drought year
- High flow in the wet season of a maintenance year

They were also asked to consider the ecological role of, the magnitude, and the timing of floods or peakflow. All of the flow suggestions were backed up with detailed, written descriptions of the objectives of different kinds of flows—for instance, a high flow in the wet season—and the experts' professional motivations—based on field data or knowledge

from the literature—for recommending these different flows during different seasons. Standardized flow objectives and motivations forms were completed by the respective scientists during the workshop. In some cases, for instance for the aquatic ecologist and riparian ecologist, it was easier to identify the habitat conditions associated with indicator species—such as velocity or depth—rather than try to recommend flows in cubic meters of water per second (cms or m^3/s); in these instances, the hydraulic engineer provided the corresponding flows for these parameters from a hydrological model created and configured for the channel at Gama Gate. The hydrologist looked back in the historical record to verify whether these recommended flows were within the range in the historical data, and thereby, possible.

Part 3. Determining environmental flows for the ecosystem

A consensus decision was thus reached for a recommended environmental flow for the dry and wet season conditions in drought and maintenance years, and for floods. Each expert presented her/his suggested flow recommendations by discipline, and was asked to defend the reasoning behind those recommendations. Each expert also estimated his or her level of certainty that the recommended environmental flow would actually satisfy the needs for species or important ecosystem processes, like sediment transport. The discussion for each site was concluded only once a consensus for flow recommendations had been met, a facilitated process that typically lasted about two-three hours. The hydrologist then took the recommendations for the dry, wet, drought, maintenance, and flood conditions and extrapolated them across the year, following the BBM (King *et al.,* 2008). The resulting information constituted a prescribed environmental flow regime for the estuary, taken at Gama Gate.

The Wami Estuary EFA process therefore has relied on a combination of historical records, modern field data, and professional judgment of those with years of experience working in Tanzanian and international rivers and estuaries. The fact that the process is carried out as a team effort, in which all experts are together making decisions about sites for study, working side-by-side in the field, and then debating flow recommendations as a group, provides opportunities for team members to learn from each other and also question results. The involvement of the Tanzanian Ministry of Water and especially the WRBWO was a critical component of the Wami Estuary EFA process, given their leadership role in implementation of the flow recommendations made and also their broad knowledge of the Wami Basin's resources. The Wami Estuary EFA process was directed and carried out entirely by team members who had gained earlier experience from prior EFAs carried out in Tanzania (FIU-GLOWS 2014) and thereby represents the result of capacity building within Tanzania for EFA and the increasing recognition of a team of local experts in ecohydrology, aquatic sciences and their management applications.

Environmental Flow Assessment for the Wami Estuary: the process

The 3-part process of determining the environmental flows (freshwater inflows) for Wami Estuary followed these steps:

1. Presentations on the state of knowledge and fieldwork results for different components of the study – ecosystems (aquatic, riparian, terrestrial), human resource use and hydrology of the estuary.
2. Decision on the present ecological state of each ecosystem component, the trajectory of change, and the desired target for restoration/maintenance with the assignment of Grades A-F.
3. Determining the minimum depth necessary to prevent disappearance of various ecosystem components. This was done for dry and wet season. Apart from minimum depths, the role of flood pulses along with their magnitudes was also noted.
4. Confidence estimates for each EFA component.
5. Obtaining discharge values from corresponding minimum depth values using a hydrological model developed for relating depth to discharge at Gama Gate.
6. Extrapolation of these values for other months, to obtain a minimum set of environmental flow recommendations for each month, as measured at Gama Gate. This was done in a manner that replicates the seasonal variation inherent in the historical flow average data.
7. Comparison of the recommended EFs with the historical flow data, to see whether the magnitudes of the recommended minimum flows lie within the historical flow range.

These steps are described in detail.

Setting Ecological Objectives for Environmental Flows

Current status of ecosystem

This is where experts evaluated the current state of their ecosystem component, assigning a grade and explaining the reasons for their assessment. The lowest grade assigned is taken to be the overall state of the ecosystem. In the case of the Wami Estuary ecosystem, the current status is C. The table below indicates the assessments for different components of the ecosystem.

Table 18: Current status of various ecosystem components in the Wami Estuary

Component	Class	Reason
Water Quality	C	High sedimentation and turbidity; decreasing freshwater inflows; other physicochemical water quality parameters fluctuate seasonally and tidally within the normal ranges for the estuary.
Riparian Vegetation	C	Freshwater riparian forests have been partially or completely cleared from many sections of the riverbanks; Mangroves still show signs of tree-cutting, although most of the species are still present, and appear to be recovering from earlier deforestation, given the different stages of succession
Aquatic Communities	B	Patches of seagrass beds are no longer present at the river mouth on account of heavy sedimentation; mangrove cover on riverbanks is patchy in places, which decreases habitat for aquatic organisms; fish catches in the wider coastal area have been stated to be significantly declining
Terrestrial Wildlife	C	Considerable human disturbance – cattle grazing, farming on riverbanks, poaching, fishing within the river (SANAPA), lack of scientifically managed fire regimes
Human communities	C	Uncontrolled water abstraction from river; reduced freshwater inflows; increase in sedimentation that decreases channel depth thereby leading to flooding over wider areas; increasing livestock encroachment; presence of hotels.

Trajectory of change

Experts assessed the direction of ongoing change (options are positive, no change and negative). Changes over the past decade as well as the present trajectory were seen to be negative. For instance, in the mid-2000s, there was much less turbidity and sedimentation in the estuary as compared to the present. Furthermore, as the basinwide demand for water, together with increased agriculture, deforestation and soil erosion occur, if not controlled or managed effectively, the outlook is lower freshwater inflows coupled with higher sediment and agrochemical loads.

Table 19: Trajectory of change in various ecosystem components

Component	Direction	Reason
Water Quality	Negative	Increasing water abstractions upriver; increasing agrochemical use and runoff leading to eutrophication; increasing sediment loading due to deforestation; uncontrolled livestock grazing bank erosion and agriculture
Riparian Vegetation	Negative	Decreasing inflows and increasing water abstractions will water stress vegetation; increasing pressure on gallery forests and mangroves for wood; bank clearance for agriculture, uncontrolled livestock access deters natural regeneration of riparian forest; species loss; riverbank not yet legally protected by being inside SANAPA
Aquatic Communities	Negative	Abundance and diversity of fish species has decreased and is still decreasing according to fishermen; sedimentation increasing smothering seagrass beds; mangroves not fully protected as yet, therefore declining habitat quality for nursery of crustaceans and marine fish
Terrestrial Wildlife	Negative	Declining population densities of some animals like zebra, wildebeest, hartebeest, eland, kudu. Rhino, Ostrich and oryx are locally extinct. Decreasing inflows can cause seawater intrusion further upstream, thereby decreasing the freshwater zone where hippos and crocodiles live. Loss of riparian forests mean loss of the only habitat for black and white colobus monkeys, other primates and the rich birdlife, many of which use gallery forests as migrational corridors.

Human communities	Negative	Population growth and increasing demand for resources – land clearing, irrigation, livestock that will also increase sedimentation and pollution, leading to resource conflicts. Many resources are also exported to other regions in Tanzania, while people from farflung regions are still immigrating to the area to settle and farm.

Desirable ecosystem status – the extent to which the ecosystem can be restored and maintained

While establishing a minimum set of freshwater inflows that are needed to sustain the estuarine ecosystem, it becomes necessary to decide what state the ecosystem should be maintained. The goal is to understand what level of ecosystem structure and function is absolutely essential to maintain critical ecosystem services such as marine fish nurseries, wildlife habitat and maintaining riparian forests. The following table summarizes the assessments from the team. Ideally the goal would be to restore the ecosystem to the pristine state, pre human disturbance, ie grade A. However such a state is impractical given the considerable human presence in the Basin. The challenge is to maintain critical ecosystem functions amidst increasing human resource demand and impacts. The team's decision was to strive for a grade better than a B, is B +, which is also reflective of the tremendous ecological importance attached to the only protected estuary in Tanzania as well as regionally along the eastern coast of Africa.

Table 20: Restoration goals

Component	Status	Motivation
Water quality	B+	Maintain sufficient freshwater flow during dry season to prevent increases in salinity intrusion further upriver; less turbid water for allowing light penetration, for both phytoplankton and seagrass productivity and for fish predator-prey visibility; reduce nutrient loading to prevent eutrophication and consequent decrease in dissolved oxygen leading to fish mortality
Riparian vegetation	B+	Only national park in Tanzania/coast of East Africa with estuarine, marine and terrestrial biomes; estuary is critical nursery for marine fish/crustaceans and wildlife; the only protected estuary in Tanzania. Riparian forests the only habitat for the black and white colobus monkey, and considerable birdlife, else whose habitat is declining regionally.
Aquatic community	B	It is difficult to restore the ecosystem to its pristine state; however specifying B can at least ensure the provision of ecosystem services. Fisheries are declining due to coastal pollution, overfishing and changes in ocean currents, hence protecting the estuary protects nurseries and habitat.
Terrestrial wildlife	B	The aim is to achieve a largely natural system with few modifications; there is a presence of high abundance and diversity of species, including rare and endangered species like green sea turtle, sable antelope, elephant, for which the Wami River is the only permanent perennial water source. A corridor can connect to Wami Mbiki Conservation Area to allow wildlife migrations, greater habitat extent and geneflow.
Human community	B	Importance of SANAPA for local and national economy from tourism (proximity to Dar, Bagamoyo, Zanzibar, Tanga); also coastal fisheries require a healthy estuary as the nursery.

Assessing minimum water depths/flows required in different seasons in both drought and maintenance years

The dominant concern is that freshwater inflows into Saadani National Park will decrease over time. This is because of increasing water demand as well as decreased landscape water storage capacity as a consequence of deforestation across the Basin. Hence, guidelines need to incorporate the natural seasonal variability of water flow and depth in the estuary, as well as upstream of Saadani National Park (upto Mandera). Plant and animal communities and various ecosystem processes have evolved under seasonally varying water availability, from gushing flows flooding river banks to just a trickle at the end of the dry season. Life cycles of different organisms have developed in tune to this seasonal rhythm in flow. For instance high flows in the rainy season are when fish and prawns spawn in estuaries. Yet, drought conditions in the preceding dry season can affect fish fitness thereby negatively affecting spawning. Apart from seasonal flow changes, there is considerable amount of inter-annual variation in rainfall and flow as well – years are classified as wet, normal and dry (Chapter 2). From the perspective of water availability to communities, a dry year is termed a drought year, while a normal rainfall year is termed as maintenance year. Periodic and episodic high flow events are also associated with ecological processes such as fish migration through hydrologically connected floodplains, or the replenishment of nutrients and suppression of invasive vegetation in floodplains, or channel scouring of accumulated sediment and dead vegetation.

Ideally, maintaining the natural seasonal variation in river flow and level that has existed for at least the past several hundred years (free of major human alterations of catchment forest cover and water demands), would ensure ecosystem flow needs. We mention 'past several hundred years' as the present-day plant and animal communities have been defined by the hydrological regime with considerable inter-annual variability (more information on this is available in a climate study of the Wami Basin (FIU-GLOWS 2014a). However, given the increasing anthropogenic impacts on the catchment, locally and regionally, striving for pre-disturbance era flows is unfeasible. Hence the team deliberated upon what minimum flows or water depths are necessary for maintaining plant and animal communities along with ecosystem processes such as habitat provision, water quality maintenance, nutrient cycling and decomposition, to name a few. Each ecosystem component was considered, and a minimum water depth value was suggested. This drew upon the team's professional knowledge and experience along with the 5-9 days spent on the estuary.

Response variable: Why water depth

Water depth was chosen instead of water flow, as for most ecosystem components, it is easier to relate numerically or quantitatively to water depth as opposed to flow (whose values are not known if not measured, and besides flowspeeds change with depth). Furthermore, for riparian vegetation, water depth or river water level controls the depth of the water table and unsaturated soil zone that dictates water availability to plant roots. The hydraulic engineer then obtained the flow value corresponding to a given water level from a hydrological model set up with the channel cross-section geometry at Gama Gate (as detailed in Chapter 3).

Table 21: Maintaining the DRY season LOW flows for DROUGHT years (November)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	0.5	1	SURVIVAL, maintain habitat within channel, *P. Indicus* sensitive	Lose juveniles as November is beginning of spawning period, loss of critical habitat, lifespan 2 years, multiyear drought = population disappearance
Wildlife	1.5	6.6	SURVIVAL, only source of freshwater in SANAPA, hippos, crocs and water birds; water source for other wildlife	Lower diversity and abundance, chance of local extinction of water-dependent wildlife, fishkills resulting from very low oxygen in hippo pools, if flow is very little.
Riparian vegetation	1	3.3	SURVIVAL of trees, prevent cavitation and mortality, maintain annual vegetation on river bend beaches	Tree mortality from extreme water stress, dry soil + understory promotes fires in riparian zone from inland farms
Water quality	1.5	6.6	Maintain sufficient mixing and circulation of water for survival of estuary species, particularly phytoplankton; maintain water residence time < 10 days	Hypersaline water inhibits survival of estuarine organisms; eutrophication and harmful algal blooms can occur; anoxia due to decomposition of hippo dung leads to fishkills
Social	1.5	6.6	Water supply projects to be able to pump water (at low tide); insuring water security for domestic use; also ensures fishing downstream (estuary) for food and income; provision of water for livestock; sufficient flow for water quality; flushing pollutants and salt dilution	Watersecurity and availability negatively impacted; livelihood, health, revert to unimproved sources, and income negative impact; Increased potential for conflict between groups over access to water
Geomorphology			Keep water flowing	Prevent pools and excess sedimentation
Agreed Hydraulics	1.5	6.6	0.5 is disastrous as large part of estuary saline, saltwater intrusion far upriver, while 2 m3/s is sometimes unattainable from inflows; maintain water quality, enough for hippos, fish, water uptakes	

Table 22: Maintaining the WET season LOW flows for DROUGHT years (April)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	2	11	Spawning for marine fish; catadromous fish (live in ocean and come to spawn in freshwater – eels, hilsa); to inundate more bank area where aquatic vegetation grows, more habitat, shelter and feeding, leading to greater productivity	Loss of hydrologic connectivity; water remains in channel and adjacent vegetation covered banks are not inundated, so fish do not have access to prey and shelter
Wildlife	3	24	More breeding activities, training juveniles how to defend themselves, gather prey; increased foraging, hippos can get more food closer to river channel and not have to wander further offshore, in competition with livestock; Elephant and buffalo movements in corridors during wet season; migration route crossing river; Black and white colobus monkeys feed on invertebrates in riparian trees	Reduced abundance and diversity of aquatic biodiversity because of breeding being impaired; riparian gallery forest habitat
Riparian vegetation	2	11	Maintain water and nutrient uptake for photosynthesis and growth	Growth of trees can be interrupted ot hampered if insufficient water is available in soil (capillary and root uptake of groundwater from river source)
Water quality	3	24	Maintain normal ecosystem function and adequate flushing of materials (particularly nutrients and sediment) to the sea	Inadequate flushing can lead to increase in sediment and nutrient loading to the estuary
Social	3	24	Guarantee water security for domestic use; river condition for fishing (fish spawning for instance) for food and income; not concerned with water for livestock and irrigation; sufficient flow to maintain water quality	Water security may be negatively impacted, as also incomes and health; *Peneus indicus* (marine) prawn catch is related to good freshwater inflow
Agreed Hydraulics	3	24	9.1 is available, max available is 80 cumecs (historical data – natural flows)	

Table 23: Maintaining the DRY season LOW flows for MAINTENANCE years (October)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	1.5	6.6	Dry period, survival, more nutrient uptake, better growth, hydrologic connectivity between diff parts of estuary, more flushing	Fitness of fish can be affected, especially if following year may be a drought; also
Wildlife	2	11	Hippos need particular amount of water for reproduction (males and females need to be submerged, so below 1.5 m cannot submerge; april – nov is mating season, gestation 8 months), crocs and water birds (prey availability – fish); maintaining water quality and quantity is needed for aquatic biodiversity	Low reproduction;
Riparian vegetation	1.5	6.6	Support leaf flush, flowering and fruiting in some woody species; food source for wildlife using riparian habitat; herbaceous/graminoids on bank	Plant water stress; dry conditions promote fires spreading from interior adjacent farms; pest outbreaks possible under dry conditions
Water quality	2.4	15	Maintain adequate water to support primary and secondary productivity; maintain salinity intrusion within the tidal limit area (Kinyonga)	Decreasing estuary primary/secondary productivity; saline instrusion may exceed tidal limit area and affect composition and abundance and distribution of estuarine biota
Social	2	11	Same as dry low in drought year – ensure water supply, fishing (major occupation for people), livestock, irrigation (vegetables), tourism (boating); guarantees suffiucuient flow to maintain water quality (dilutuion and flushing of pollutants	Water security negatively impacted; livelihoods health and income may be impacted negative; tourism negatively affected
sediment	2	11	Minimize excess deposition of sediments on convex bank	
Agreed Hydraulics	2.4	15	5.5 is available from historical data	

Table 24: Maintaining the WET season LOW flows for MAINTENANCE years (April)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	3	24	Spawning period; excess freshwater provides reproductional cues for freshwater fish that spawn in the sea (catadromous);	Affect reproductive success and recruitment for next season; loss of migration corridors and less fish abundance
Wildlife	4	45	Diversifying aquatic habitats; diversity of foraging and grazing grounds; maintains adequate depth for boat safari; migration and immigration happens in wet season; enhancing mangrove community ecosystem productivity and dependant wildlife	Reverse of motivations elements; animals would be constrained for foraging, reducing genetic variation on account of inhibited ranging;
Riparian vegetation	3	24	Wet season = season of growth because of high water and nutrient availability.	Suboptimal growth during wet season reduces fitness (for flowering, fruiting) in ensuing dry season; if drought follows, trees do not have adequate storage of nutrients and carbohydrates
Water quality	3.5	33	Same as wet season low flow in drought year	Same as wet season low flow in drought year
Social	3	24	Ensure water security for domestic, fisheries, water quality (dilution and flushing of pollutants)	Water security and availability and livelihoods will be impacted negatively
Agreed Hydraulics	4	45	18.2 is available, max available from historical naturalized flows is 96 cumecs.	

Table 25: Maintaining the WET season HIGH flows for DROUGHT years (April)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	6	147	Spawning; especially for marine fish; isolated peaks as this is a drought year; at least one peakflow for a week; inundating floodplain transports nutrients from the floodplain to the river	Affects successful recruitment of floodplain spawners such as clarias
Wildlife	5	88	Same as wet season low flow in drought year; moving of drowned trees downstream, flushing the most tolerant invertebrates that have established during prior dry season, allowing for recolonization of greater aq. invertebrate diversity	Same
Riparian vegetation	5	88	Adequate nutrient uptake; suppressive invasive herbaceous vegetation; not more than a weeklong consecutive flooding period, replenish soil moisture that can be low in a drought period	If floodplain not inundated, less nutrients and sediment comes in (for trees) .But, if more than a week, 2 weeks, then trees get flood stressed.
Water quality	5	88	Maintain flushing of materials; enhance nutrient cycling between mangroves/vegetation and adjacent waters; few days to a week of continual inundation	Low productivity; turbidity and sedimentatikon increases; reduces light penetration for photosynth and predator-prey visibility
Social	5	88	Floods required for moisture within floodplain, recharging water table (boreholes and ponds); duration: 1 week	Livelihoods, health and income negatively impacted if flood event does not occur that replenishes water and nutrients in floodplain
Agreed Hydraulics	6	147	available	

Table 26: Maintaining the WET season HIGH flows for MAINTENANCE years (April)

Component	Depth (m)	Flow at Gama Gate (m^3/s)	Motivation	Consequences of not providing this flow
Fish	6	147	Spawning; removal of excess sediment/mud in channel; Two peaks – one in march/april, other in may/june of duration 2 weeks each (for spawning of labeo and repeated spawners)	Affects spawning, same as above
Wildlife	7	200	Actually Recommends 10 m because – oxbow lake (garuka) is filled only when this level of flooding happens (in good years, wet years); but 10 m will flood the bridge at gama gate. So 7m once every two years.	No oxbow lake (hippo and elephant and other wildlife incl fish and birds)
Riparian vegetation	6	147	Sediment and nutrient transfer to floodplain via inundation and transport; suppress invasive herbaceous vegetation. Flooding duration NOT exceeding 2 weeks at a stretch. Two flood events preferable.	Impoverished floodplain in terms of nutrients and soil; invasive vegetation establishing;
Water quality	6	147	Same as above	Same as above
Social	6	147	Same as above; inundation over wider areas (max 100 m away from bank); a week of continual flooding; only in the long rains (march-may)	
Agreed Hydraulics	7	200	6m depth twice per year AND 7 m depth once every alternate year. This also flushes river of deposits on scouring bank	

Consolidating these assessments

For each season-flow-year combination, the minimum depth values necessary were evaluated by the team, and the largest value for the minimum depth was selected as the critical ecosystem MINIMUM depth value. Going below this minimum will lead to mass mortality and the rapid, catastrophic failure of key ecosystem processes, from species reproductions to food web cascading effects to biogeochemical cycling.

Table 27: Summary of minimum discharges and minimum water depths required at Gama Gate for the 6 different hydrological conditions to avoid ecosystem collapse

Season and normal/dry year	Discharge At Gama (m^3/s)	MIN Depth (m)	Motivation	Consequences of not providing minimum flow
Dry season, LOW flow, DROUGHT year	6.6	1.5	SURVIVAL of organisms; critical importance of maintaining flowing water and to avoid the river becoming a set of pools (that leads to drastic change in water quality and oxygen levels).	Mortality, possibly local extinction of organisms; dry conditions in riparian zone allows fires to spread from inland – very destructive for riparian vegetation that typically is not adapted to fire
Dry season, LOW flow, MAINTENANCE year	16	2.4	SURVIVAL, maintenance of dry season organism function (health) for growth and reproduction in following wet season; river habitat connectivity	Mortality; lowered water levels create stress that affects growth and fitness; fires
Wet season, LOW flow, DROUGHT year	25	3	Wet season is the main period of water and nutrient availability; thus the major growth and reproduction season for almost all organisms	Inadequate water flow/availability limits nutrient uptake, habitat connectivity, impaired water quality and fish spawning.
Wet season, LOW flow, MAINTENANCE year	45.5	4	Same as above, plus maintenance years allow reproduction at normal levels compared to drought years which can see very low reproduction	Same as above; fish migrations from channel to floodplain or upstream along channel depend on adequate connectivity and flow.
Wet season, HIGH flow, DROUGHT year	150	6	flushing of sediments and salts; replenishment of nutrients to floodplain; suppression of invasive herbaceous vegetation along riverbanks; cues for fish spawning	Inadequate flushing of channels and floodplains, invasive herbaceous vegetation gets established; migration of fish and wildlife affected; restoring water in floodplain oxbow lakes
Wet season, HIGH flow, MAINTENANCE year	200	7	1-2 Flood pulses (peak flow) needed for replenishing nutrients to floodplain, spawning cues for fish, clearing channel of sediment and salt.	Same as above. Normal years require a couple flood pulses to flush the system.

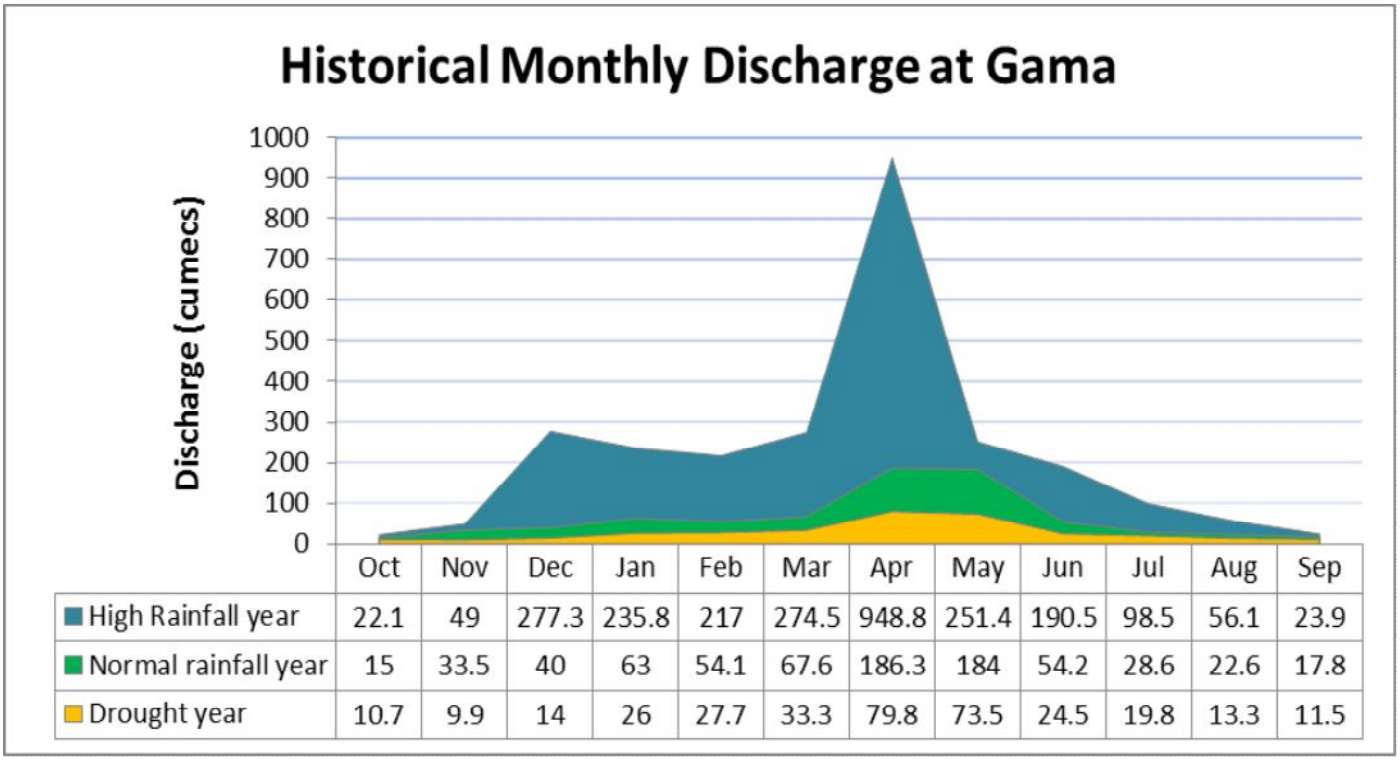
Results: Environmental Flow Recommendations for the Wami Estuary

Environmental flows: a subset of historical natural flows?

The concept of Environmental Flows (EFs) has been defined as "the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems". Inherent in this is the compromise between sustaining the ecosystem and meeting the increasing human demand for water. This indicates that environmental flow recommendations will usually be less than the historical flows. This is due to the decreasing availability of water in the river driven by an increasing water demand alongwith a decreasing natural ability of catchment ecosystems to regulate water flow on account of the loss of native forests and wetlands. **Hence it is important to realize that Environmental Flows are a guideline to prevent catastrophic or drastic changes in the ecosystem; however efforts should be made to provide flows greater than the environmental flows whenever possible.** This is usually not an issue in years with high rainfall, when plenty of water is available for all uses. The utility of environmental flows guidelines is in years with normal rainfall, and is enhanced in years of lower than normal rainfall, when water managers have to make the increasingly difficult decisions of water sharing between diverse stakeholders.

Characterizing natural flows to which ecosystem has been accustomed

Before looking at the Environmental Flow recommendations, it is instructive to look at the natural flows that have been occurring in the river upstream of Gama Gate since the 1950s (Figure 54) . These are the flows that the estuary has been receiving, and ecosystem processes are attuned to these magnitudes and seasonal variations. The historical data for Gama Gate (as explained in Ch 2) is shown for high rainfall years, normal rainfall years and drought years, in order to provide a visual idea of the seasonal variability as well as the relative magnitudes of flow in different months.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
High Rainfall year	22.1	49	277.3	235.8	217	274.5	948.8	251.4	190.5	98.5	56.1	23.9
Normal rainfall year	15	33.5	40	63	54.1	67.6	186.3	184	54.2	28.6	22.6	17.8
Drought year	10.7	9.9	14	26	27.7	33.3	79.8	73.5	24.5	19.8	13.3	11.5

Figure 54: Historical monthly average discharge at Gama Gate in wet, normal and dry years

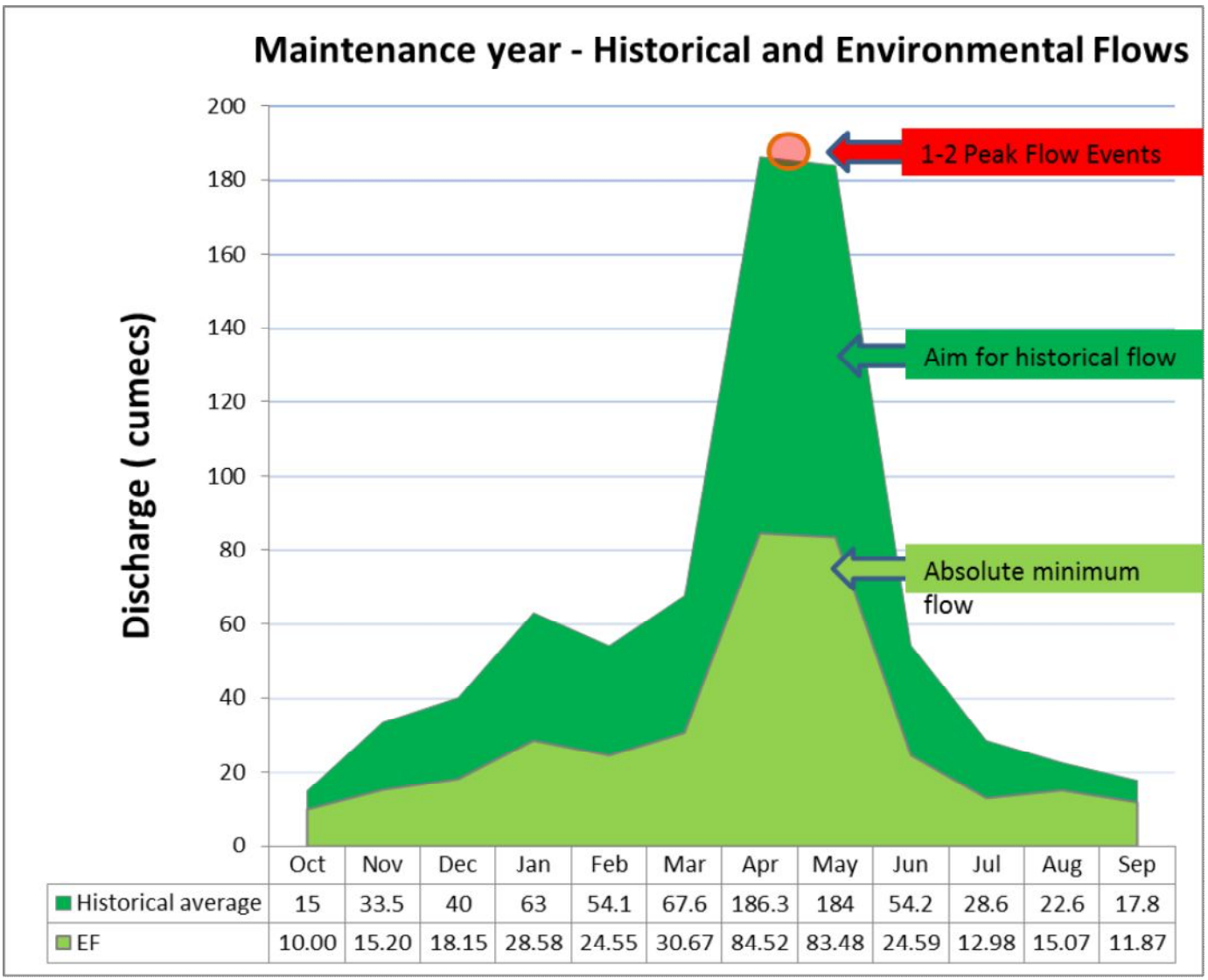
Environmental Flows at Gama Gate

The process of obtaining the EFs was carried out as a two step process:

1. The hydraulic engineer obtained the discharge value corresponding to a given water level from a hydrological model set up with the cross-section geometry at Gama Gate (as detailed in Chapter 3). Values for six flow conditions were obtained in the EF workshop.
2. These values were extrapolated for other months in accordance with the seasonal pattern present in the historical flow data.

In the two graphs below (for normal/maintenance years and drought years), the colour scheme for the historical flows has been maintained. Note that in these graphs, the EFs are less than the historical flows. These EFs are the minimum required flows for a year, or at most, for a couple consecutive years (in case of a prolonged drought). However, if the flows are maintained at EF levels for longer, say over 5 years or more, that would mean lower than normal flows over the period, which will stress the ecosystem. This is because the ecosystem has evolved under historical flow conditions, which as can be seen from the graphs below, are greater than the EFs. While a minimum set of flows as assessed in the workshop represents conditions for survival, in order to maintain ecosystem function in its native state (the state in current and recent past), the historical flow magnitudes and patterns are necessary. However, given the unfeasibility of provision of historical flows, on account of increasing water demand and human impacts throughout the basin, the EF concept has emerged to avoid catastrophic change in the ecosystem. Hence, the EFs are just a guideline for minimum flows for a year, and river basin water management efforts should strive to allow more flow than the minimum EFs, wherever possible.

Maintenance year

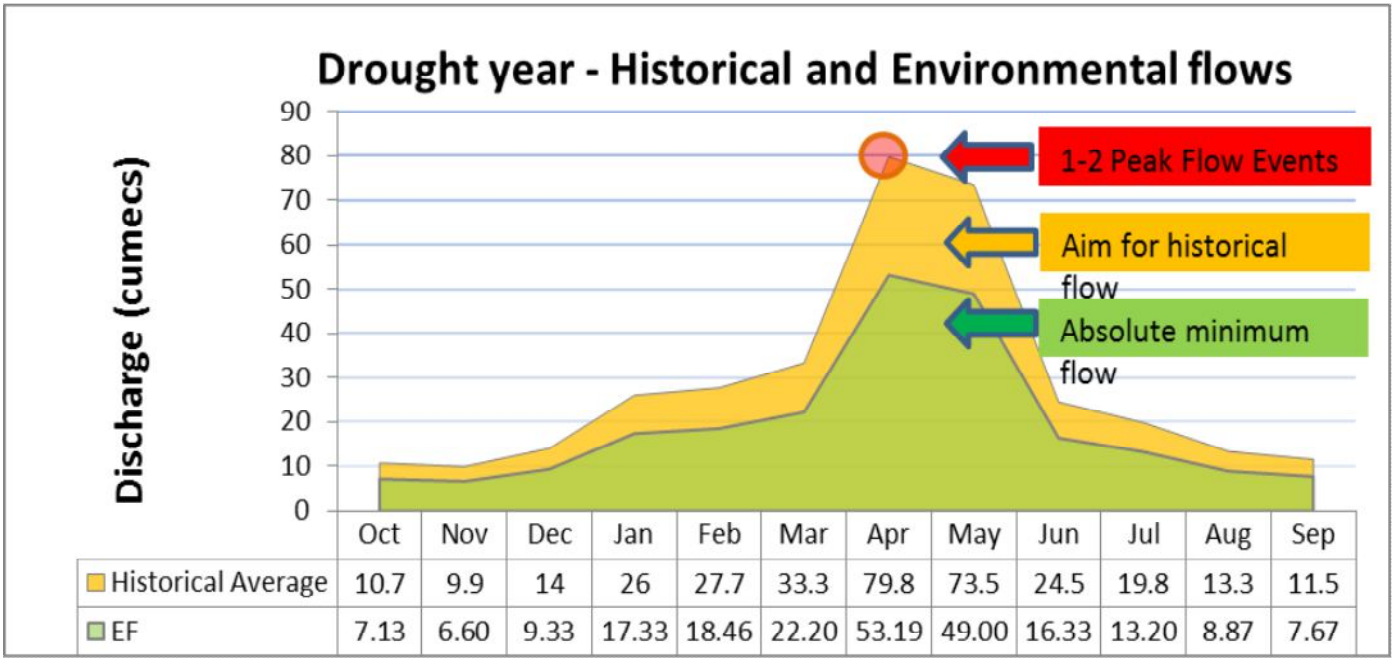


	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical average	15	33.5	40	63	54.1	67.6	186.3	184	54.2	28.6	22.6	17.8
EF	10.00	15.20	18.15	28.58	24.55	30.67	84.52	83.48	24.59	12.98	15.07	11.87

Figure 55: Historical average monthly flow in a year with normal rainfall (dark green) and recommended minimum environmental flow at Gama Gate along with 1-2 pulse events (high flows) per year.

For a year with normal rainfall (Figure 55), two data series are shown – the historical monthly flow data (dark green) and the recommended Environmental Flow (light green) that has to be maintained in the river at Gama for survival of the ecosystem. Note that the recommended flows also follow the seasonal maxima over the March-May high flow period. It is critical to remember that the EFs specifies the minimum flow in the river as measured at Gama in order to prevent the mortality of large numbers of organisms and ecosystem failure. Hence water management should strive for flow values higher than the EF, with the EF signifying minimum values to be maintained. On the higher side, the availability of flows higher than EF data series are beneficial, as long as they follow the seasonal historical flow pattern. Indeed, the ecosystem and communities have evolved under the historical average flow conditions – what has been existing in the river, and not under the environmental flows (which is a subset, a guide to ensure critical ecosystem processes are maintained in a particular year). Sudden releases of water, however are usually detrimental to communities which get washed away; sudden water releases can also erode streambeds.

Drought year



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical Average	10.7	9.9	14	26	27.7	33.3	79.8	73.5	24.5	19.8	13.3	11.5
EF	7.13	6.60	9.33	17.33	18.46	22.20	53.19	49.00	16.33	13.20	8.87	7.67

Figure 56: Historical monthly average flow and recommended minimum environmental flow in a drought year along with 1-2 pulse events (high flows) per year.

A similar visual is shown for the environmental flow recommendations for a drought year (Figure 56), ie a year with rainfall one standard deviation or lower than the average annual rainfall. The historical monthly average is shown in yellow while the recommended EF in. As with the earlier visual, the EF values indicate critical freshwater inflows at Gama gate that are required to prevent mass mortality due to the river drying up, and vastly increasing seawater intrusion. As a thumb rule, the EF recommendations are targeted towards maintaining the ecosystem longterm; however, it is worth repeating that the ecosystem has evolved over historical flow conditions, of which the EF is a subset, and any flows greater than the EF are beneficial, as long as they are not an artificial sudden release of water.

Sporadic high flow / flood pulse events

The EFs take into account the peakflows necessary during the wet season. In addition, very high flows that happen about once in 5 years can be important for the ecosystem. For instance, in the Murray-Darling Basin in Australia, a 1-in-5 year flood event in the Barmah-Millewa Forest was created through releases from a major storage in the Basin, leading to the great egret breeding for the first time since 1979 along with nine species of frogs and native fish (Dyson et al. 2003). In the Wami Estuary, high flows of at least 10 m water depth at Gama Gate are thought to be necessary to flush out and replenish water and nutrients in the oxbow lakes (garuka) which are important wildlife habitat apart from the river. However, as that amount would also flood the ranger station, a 7 m water depth once in two years has been recommended. The 1-day flow duration curve for Gama Gate (Ch 2) indicates that 100 cumecs of flow occurs or is

exceeded 16% of the time in a year. This is also seen in the Flood Frequency Assessment graph that shows a flow of 100 cumecs has a return period of less than a year. Hence 2 pulses of 100 cumecs are recommended in addition to the EFs. A flow of 500 cumecs has a return period of about 5 years; hence a flow of 500 cumecs is recommended once in 5 years – this typically can occur during a year with high rainfall.

Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical average (m^3/s)	15	33.5	40	63	54.1	67.6	186.3	184	54.2	28.6	22.6	17.8
EF	5	12	15	23	20	25	68	55	20	10	8	6
% average	36.50	36.50	36.50	36.50	36.50	36.50	36.50	36.50	36.50	36.50	36.50	36.50
Pulse												
Magnitude (m^3/s)							500	100				
Return Period							5 years	< 1 year				

Table 28: Environmental Flow (EF) Recommendations at Gama Gate: Maintenance Year (year with normal rainfall). Also shown are the peak flow pulse magnitudes and return periods.

For a drought year, while water demand is very high for human activities, one peakflow event of around 100 cumecs should be allowed or created during the main rainy season (Table 29).

Table 29: Environmental Flow (EF) Recommendations at Gama Gate for a Drought Year (year with rainfall < 1 standard deviation). Also shown are the peak flow pulse magnitudes and return periods.

Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical average (m^3/s)	10.7	9.9	14	26	27.7	33.3	79.8	73.5	24.5	19.8	13.3	11.5
EF	6	6	8	15	16	19	45	42	14	11	8	7
% average	56.89	56.89	56.89	56.89	56.89	56.89	56.89	56.89	56.89	56.89	56.89	56.89
Pulse												
Magnitude (m^3/s)							100					
Return Period							< 1 year					

Confidence estimates of the assessments

The assessments were made from a combination of literature findings, the professional knowledge of the experts, the experience of the SANAPA staff, field observations over the 5-10 day period and interviews with local village communities. It thus represents an attempt to collect the best available knowledge, both technical and anecdotal about the estuarine ecosystem, its interconnections with hydrology and the services it provides to wildlife and local communities, and thereby add to the scientific knowledge base for the region. As mentioned before in various chapters, there is very little in-depth scientific literature for the ecosystem, nor is there any time series data on water quality and hydrology in the estuary. Furthermore, the fieldwork was carried out in the mid dry season only, missing out on the ecosystem responses to different flow conditions in other periods of the year. In some cases, professional experience can be relied upon to infer ecosystem structure and function with respect to hydrology; for instance, the boundary between herbaceous annual / wetland vegetation and woody trees can indicate the usual extent to which the river level reaches in most years. Hence, a confidence assessment was carried out for the team's EFA recommendations. The results are expressed as a confidence rating from 1 to 5, with 1 being the highest level of confidence and 5 the lowest. The motivation for a particular expert's self-assessment is also included in Table 30.

Table 30: Confidence levels of the different ecosystem component assessments

Component	Confidence Rating: 1 (highest) – 5 (lowest)	Motivation	Research gap/proposed future research
Aquatic community	2	Observations in only mid-dry season (low flow), as species distribution and abundance changes during the wet season (experience in Tanzanian rivers and wetlands) when the area of inundation and connectivity between different water bodies increases. Flow guidelines for species were determined elsewhere in tropical Africa and not for the conditions prevalent in the Wami River.	Additional sampling during the wet season; using electrofishing is recommended; species and community studies understanding the life cycle and foodweb positions.
Riparian Vegetation	2	Knowledge of phenology (leaf flush and fall, flowering and fruiting) with respect to water availability is needed to better understand the fate of riparian forests, as well as to manage them to preserve biodiversity (given that they are degraded or absent in many areas).	Study water level-plant ecophysiology and phenology; mapping species composition of gallery forests to enable monitoring; riparian-aquatic ecosystem interactions
Terrestrial wildlife	2	While Park staff have 10 year + continuous knowledge, understanding wildlife water use requires year-round focused studies; many animals are hard to monitor or regularly observe, such as chameleons, also population sizes of big mammals refer to that in the whole park and not just those near the river	requiring other observation methods such as traps for reptiles, camera traps, scat studies along transects; settle the uncertainty about the southern boundary; both banks of the river must be included within SANAPA
Water quality	2	Data collected just for few days, at neap tide, that too, some days in flood tide, other days in ebb tide.	Continous sampling can yield time series data at a fixed location, to infer both tidal and seasonal changes; turbidity meter; seasonal and tidal observations of biological properties like phytoplankton, the base of the estuarine foodweb; sediment and nutrient budgets related to discharge
Hydrology	2	Missing climate aspect and sea level rise effects; Data time series at mandera, upriver of the estuary had to be extrapolated to the estuary head; and this data too had gaps; amount of abstractions all along the estuary, and between mandera and matipwili is not known;	Need endpoints of driest and wettest times of the year. Propose gauging station at Gama.
Hydraulics	2	Limitations of Q-liner tool: minimum operating depth is 0.5 m but in many places the river channel had depths < 0.5, even 0.1-0.2 m, so this can cause error in flow readings.	Developing an accurate hydrological model requires the use of RTK for elevation measurements in the floodplain, especially because being inside a national park, vegetation cannot be cleared for the line of sight required by traditional survey methods; besides more time spent onshore increases danger of attack by hippos and crocs.
Human communities	2	Interviewing local communities, officials and other stakeholders is a long and time consuming process taking more than the allotted 5-8 days	Socioeconomic valuation of ecosystem services; estimate amount of unauthorized water abstraction; effects of increasing livestock in area; longer study period;

Chapter 10: Recommendations for monitoring and management



Figure 57: Water level recorder (extreme left by margin) and water quality instruments mounted on a buoy at Porokania.

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This has been the first ecohydrology study to develop minimum freshwater inflows to the Wami Estuary and SANAPA. However, the process of understanding the ecohydrology of the Estuary has just begun. The collection of continuous data together with hydrological modeling can refine and increase confidence in the Environmental Flow estimates provided here. Ensuring these flows are provided, in turn, requires a tremendous coordinated effort by the Wami Ruvu Basin Water Office, the central authority in charge of water management in the Basin. Key to the success of that endeavor is the cooperation of all stakeholders affecting water use and quality. This can happen only if all stakeholders understand the importance of the estuary (ecological services and SANAPA), how freshwater inflows maintain the estuary and how each stakeholder's actions can contribute towards preservation of this priceless natural asset of Tanzania. This chapter details (1) the needs for further data/modeling and (2) general recommendations for actions necessary to protect water availability and quality to maintain the estuarine ecosystem.

Areas for technical engagement

1. The need for continuous data collection

The recommendations for freshwater inflows into SANAPA have been based upon expert assessment of how different ecosystem components are linked with the magnitude and seasonality of freshwater flow in the Wami River. As mentioned earlier, the flow data has been extrapolated from the nearest available station to the estuary, ie Mandera. Given that the data spans a relatively long period (from the 1950s), there is good confidence in capturing both the seasonal and the interannual variability in the river. However, gaps in the data, and the lack of information on water abstractions introduce uncertainty.

Decreasing this uncertainty would require time series data from the estuary, specifically water level, salinity and flow. This data can then be input into a hydrological model of the entire estuary, from Gama Gate or Matipwili to the mouth. The only data so far available for the estuary is some water quality data taken for 3 days in 2007 (wet season – Anderson et al 2007), 3 days in 2008 (dry season – McNally 2008) and now for 4 days in 2015 wet season, included in this report.

Instrumentation installed in this study – data for the future

To address the need for continuous measurements in order to capture both tidal and seasonal variation, we have installed low-cost instrumentation to measure water level, water flow and water quality at three locations along the estuary:

- Gama Gate - to know inflows and water quality at the upstream end of the estuary, where the river enters SANAPA. Water is entirely fresh, although backwater effects caused by high tide are seen.
- Kinyonga Campsite – water at the bottom of the river is brackish at high tide, as reported by the water supply project for Sadaani Village
- Porokania Boat Ramp – close to the mouth of the river and dominated by mangroves, the water varies from salty to brackish to fresh depending on tide and season.

These three sites were chosen, not only because they lie at three different points along the salinity gradient, but also for logistical reasons, as they have park rangers stationed in these places. Vandalism is often a major issue with instrumentation installed in the field. Frequent maintenance of these instruments, such as cleaning of algae off water quality probes and flow meter is also essential, and can be practically achieved at these three sites that are accessible by road. However, safeguarding instruments on a buoy still has challenges of tree branches coming down sudden high flows in the river and ensnarling or knocking the buoy.

Water level

The unit is placed above the river surface, mounted under a bridge, or on a pole, or on a tree branch. This system comprises of an ultrasonic distance ranger (Maxbotix) that sends an ultrasonic beam vertically down, which reflects off the water surface and returns to the sensor. A microprocessor inside (Sodaq mbili, SODAQ) records the time taken for the beam to travel and then calculates the distance from the sensor to the water surface. As the total distance from the sensor to the river bottom at that point is known, the water depth is calculated. Data is stored on an SD card; in addition there is the facility of transmitting the data via mobile phone network using the included SIM card and hardware; however the mobile phone signal was not reliable at the sites. The entire system is encased in a watertight weatherproof box (Pelican), powered by a 6 W solar panel and charged by a 3.7 V Lithium Polymer battery. The microprocessor is programmed via Arduino IDE software on a computer (USB connection). Data is recorded hourly or every 2 hours.
Being outside the water surface, the unit does not have issues with biofouling. However, the mobile phone reception is weak to unavailable at the sites, and hence periodic visits for downloading the data are necessary. The unit may not work under very stormy conditions (high waves and choppiness that can scatter the beam).



Figure 58: Water level logger installation at Porokania (left) and Kinyonga Camp (right)

Water flow

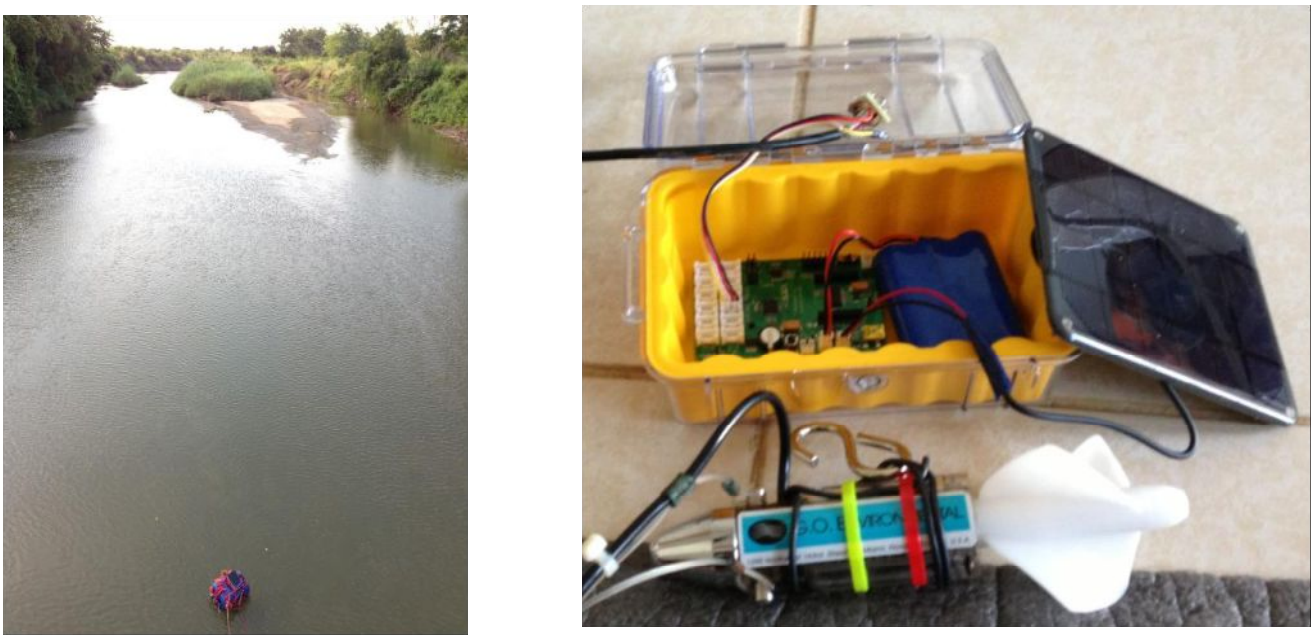


Figure 59: Buoy in the river at Gama Gate on which the flowmeter assembly (right) is mounted

An electronic flowmeter (General Oceanics 2031H) measures flowspeed by counting the frequency of propeller revolutions. A Hall effect sensor inside the flowmeter generates 2 pulses per revolution. By tracking the number of revolutions, the microprocessor (Sodaq mbili) calculates flowspeed using a frequency-velocity calibration curve specific to the flowmeter. Data storage and transmittal, power and box are similar to the water level recorder. The unit is housed on a buoy so that flow speed is recorded at the same height relative to the surface, independent of rise and fall of river level. The flowmeter is positioned 10 cm below surface. The buoy is made from an empty sealed petrol can made of heavy plastic and available in any town. It is anchored to the river bed with rope and a heavy stone, and is also tied to a tree or bridge piling. Hourly data recorded. Challenges with instruments immersed in the river are biofouling and destruction by wildlife or by incoming tree branches accompanying sudden high flows.

Water quality

pH, Dissolved Oxygen (DO),Electrical Conductivity (EC) and temperature probes (Atlas Scientific) were connected to a microprocessor board (Sodaq mbili). The rest of the installation is similar to the flowmeter on the buoy. However, unseasonal high river flows in December with branches overturned the buoy, and led to stationing the box with electronics on shore, and the probes kept in the water by means of a PVC pipe. However this raises the challenge of measuring salinity at the same relative depth. A future refinement can be to keep the electronics on shore and place only the probes on a buoy; however the challenge of entanglement in floating branches and being carried away remains, even if the site is frequently monitored. Such are the challenges inherent in continuous monitoring when the instrument is placed within the water.

2. Hydrological modeling

Data collected by the above instruments at least for a year can be input into a hydrological model that can be developed for the estuary, as described in Ch 3. Field data for developing the model would in addition require obtaining accurate elevation data on selected locations on the floodplain and river banks using an RTK. These points can then be used to adjust the vertical accuracy of a Digital Elevation Model (ASTER 30 DEM, NASA/JSRO), which then is used in combination with river channel bathymetry to obtain the volume and geometry of the estuary channel. This model can then be utilized to relate discharge and water level. Given that the estuary has both freshwater and seawater inputs from opposite ends that continually vary with tide, upstream abstractions, weather and season, the model would be a 2 dimensional unsteady state model. This hydrological model can then be used to fine-tune inflows as a response to required salinity regimes within the estuary, and thus can be a refinement of the historical discharge-derived flow recommendations developed.

Recommendations for management – local and basinwide

WRBWO (2007b) had concluded that maintaining the integrity of the Wami River Estuary in the future will depend on the sustainable use and management of natural resources in areas within and adjacent to the estuary as well as over the entire Wami River Basin. Furthermore, it was noted that emerging threats to the estuary include human population growth in the region, mangrove cutting, increased fishing pressure, changes in land use and increasing water withdrawals from the Wami river in upstream areas. New concerns and threats have emerged around the boundary of SANAPA. There is presently political pressure to degazzete the park boundary in favour of village communities and investors such as Eco-Energy Ltd (Ismail, 2015). According to SANAPA, the degazzetement of the park boundary will leave the Wami River Estuary out of the park, including a large part of the mangrove forest. Aside from the threat to the integrity of SANAPA, this plan will likely result into more estuary pollution and complicate water management in the estuary as a result of increased anthropogenic activities. There are a number of interventions necessary within SANAPA in order to restrict degradation and promote restoration and maintainance of the ecosystem and its services. At the same time, since the estuary lies downstream of the entire Wami basin, actions in the Basin can impact the estuary. Hence a combination of local and basinwide perspectives and management actions are necessary, the salient points are mentioned below.

1. Inclusion of South bank of Wami River inside SANAPA

Given that the riparian gallery forests constitute essential habitat for wildlife and are instrumental in maintaining the estuarine ecosystem, the southern bank of the Wami needs to be wholly contained within the SANAPA boundary. Doing so will enable protection and restoration of the riparian forest and thereby the ecological services provided by the forest towards the estuarine ecosystem. This will also enable the enforcement of national riparian buffer law prohibiting cultivation on river banks upto 50 m.

2. Protection of river banks within SANAPA from encroachment

The prevention of encroachment (removal of gallery forest cover, establishing houses, farms and uncontrolled livestock access) is necessary to restore habitat for wildlife and the ecological services rendered by gallery forests to the river ecosystem. This is already showing results in areas where mangroves are being protected and thus allowed to regenerate. The protection requires inclusion of both banks of the river, ie the river banks inside the National Park, as mentioned earlier; this can then facilitate law enforcement by Park Personnel. The question of livestock movement needs to be addressed by establishment of community watering points. This is to restrict uncontrolled water access that erodes the river banks. Participatory approach if practiced can have positive results.

3. Soil erosion control – local and basin

The control of sediment loads in the river is both a local and a basinwide issue. Locally inside SANAPA, banks should be stabilized with restoration of native riparian gallery forest, prohibiting cultivation and grazing on riverbanks as well as controlled livestock access points.

Basin-wide, it is a far more challenging issue requiring the collaboration of farmers, water user associations and the government. The Wami basin has witnessed an enormous amount of deforestation over the past 2 decades (FIU-GLOWS 2014), creating large areas denuded of protective vegetation cover. A sediment fingerprinting approach can be utilized to indicate areas in the catchment contributing the largest amount of sediments, to help prioritize targeted soil conservation. Moreover, long term plans for the conservation of the upstream catchments including the plains on downstream catchments should be considered. Emphasis should be put on conservation approaches; this needs proper planning on the best options. Agroforestry can promote soil stability and water conservation by controlling erosion and surface runoff. Restoring native forest is ideal, however a mix of native and non-invasive exotic plant species (such as *Grewalia*) can also provide income to local people. In order to develop a perennial vegetation cover, planted saplings will have to be protected from animal destruction or fire by fencing and protective fire breaks and warning posters. Agroforestry has proved to be effective for the restoration of degraded catchments, such as in Kibosho Village in Kilimanjaro Region and Lushoto district in the West Usambaras (Johansson 2001). Another example is Gansu Province in China where degradation had devastated very extensive land mass so much that the soils was left completely barren, but much efforts have made recovery of the soils by the application of contour ridges, terraces and agro forestry (People's Republic of China - UNEP Rainwater Harvesting Training Course for Africa, May 2009). These processes have controlled surface runoff to a great extent.

4. Ensuring adequate freshwater inflows - basinwide

The adoption of the recommended environmental flows (as included in this report) into basin hydrological models can indicate the amount of minimum discharge necessary in the major tributaries of the Wami, in order to ensure that the minimum freshwater inflows are being provided to Saadani National Park and the Wami Estuary.

The frequent and accurate monitoring of large water users ensures they return the specified amounts of water to the Wami River system as stipulated in water law and as mentioned in their water permits. The water returning mechanisms should be improved to allow significant returns of high quality water into the rive, thereby augmenting flow. Water quality monitoring is equally important in these points of return flows.

The wetlands at Mkindo, Mkata and other regions along the Wami River should be studied, monitored and protected because of their hydrological functions of water storage and water quality improvement. Wetlands are areas of land that are permanently or temporarily flooded and support a huge biodiversity. Typical examples are swamps, mangrove forests, and river flood plains. The objective is to allow more water storage underground for future stream and river flows that can maintain ecological balance of these areas.

Water quality must be sufficient to maintain the ecological integrity of the river, wetlands and the estuary in order to sustain ecosystem structure and function.

The creation of a network of small reservoirs situated in the floodplain alongside the river can ensure water storage during the wet season for release downstream in the dry season if needed. Such steps have been taken elsewhere, such as in Australia (Dyson et al 2003). Local storage is an adaptive measure to deal with increasing water demands, decreasing watershed storage capacity due to loss of native forest and wetlands, and uncertainty in rainfall from climate change (FIU-GLOWS 2014 a). At the same time, since the reservors are filled via channels from the main river that can also be controlled by gates and locks, the flow in the river is not affected, unlike the effects of placing dams across the river channel.

Bush fire has contributed to massive catchments degradations; this is another area which should be taken care of, to ensure effective catchments conservations. It is understandable that at the end much water will be stored underground for future use.

Eventually, a coordinated approach involving all stakeholders and led by the Wami/Ruvu Water Board is essential to ensure the provision of sustainable water flows in this river from source to mouth. This is necessary on a daily time scale, as even a few weeks of uncharacteristically low flows can alter the environment for the plant and animal communities living in the Wami River Estuary.

Appendix:

1. Fish encountered in the Wami Estuary Study

Area	Lat	Long	Species	Number
River Mouth	-6.11694	38.81704	*Arius africanus*	9
			Pellona ditchela	1
			Thryssa baelama	2
Chanyungu	-6.13457	38.83628	*Tetraodontidae*	10
			Crabs (Scylla serrata)	2
			Leiognathus equulus	3
			Polynemus sextarius	1
			Terapon jarbua	1
			Valamugil buchanani	4
			Jellyfish	1
Saadani River lodge	-6.15968	38.80814	*Leiognathus equulus*	1
			Valamugil buchanani	11
Fungu Maboko			*Valamugil buchanani*	7
			Leiognathus equulus	1
			Arius africanus	10
			Scylla serrata	1
Kajanjo(Morning Fishers Catch)	-6.09474	38.79898	*Otolithes ruber*	6
			Pellona ditchela	8
			Thryssa baelama	11
			Polynemus sextarius	15
			Leiognathus equulus	16
			Johnius dussumieri	4
			Johnieops sina	21
			Penaeus indicus	5
			Upeneus sulphureus	11
			Penaeus monodon	7
Kajanjo (Evening- Fishers Catch)	-6.09474	38.79898	*Penaeus indicus*	2
			Penaeus monodon	16
			Arius africanus	7
			Pellona ditchela	2
			Thryssa baelama	1
			Cynoglassus lachneri	3
			Otolithes ruber	14
			Terapon jarbua	9
			Drepane punctata	7
			Valamugil buchanani	5
			Sillago sihama	9
			Thryssa setirostris	1
SaadaniVillage Landing Site	-6.04534	38.78051	*Trichulus lepturus*	1
Fishers Catch			*Otolithes ruber*	9
			Penaus monodon	12
			Pellona ditchela	13
			Leognathus equulus	2
			Panaeus indicus	6
			Thryssa baelama	11
			Johnius sima	10
			Johnius dussumieri	8
			Valamugil buchanani	3

2. *Estimated population size of terrestrial mammals, their maximum water consumption per day per individual species and per whole population*

EPS=Estimated Population Size (Source: Ismail *et al.*, 2015); EWC=Estimated Water Consumption

Terrestrial mammal Name	EPS	Maximum Estimated Water consumption per species/Litre/day	Amount required per population/day (Litre)
Yellow baboon	6546	2	13092
Common waterbuck	2710	20	54200
African buffalo	2560	55	140800
Masai Giraffe	894	80	71520
Bohor Reedbuck	753	20	15060
Hartebeest	683	40	27320
Sable antelope	673	40	26920
African elephant	633	300	189900
Common warthog	442	20	8840
Wildebeest	210	40	8400
Eland	90	50	4500
Lion	90	10	900
Harvey's duiker	80	10	800
Bushbuck	70	10	700
Zebra	70	50	3500
Bush pig	70	20	1400
Greater Kudu	60	30	1800
Suni	30	10	300
Grey duiker	20	10	200
Side stripped jackal	20	5	100
Spotted hyaena	20	5	100
African civet	10	2	20
Leopard	10	10	100
Blue monkey	12	2	24
Black and White colobus monkey	18	2	36
Total	**16774**	**843**	**14140482**

3. Name, composition and habitat of water birds observed in Wami Estuary

Avians	*Scientific name*	Number observed	%	Mangrove	%	Mangrove-Palm	%	Palm	%	Palm-Riparian	%	Riparian	%
African Pied Wagtail	*Motacilla aguimp*	2	0.4376368	0	0	0	0	0	0	0	0	2	0.7407407
Little bee eater	*Merops pusillus*	46	10.065646	0	0	0	0	0	0	0	0	46	17.037037
Long-tailed Cormorant	*Phalacrocorax africanus*	8	1.750547	8	10	0	0	0	0	0	0	0	0
Crested Guinea fowl	*Guttera pucherani*	2	0.4376368	0	0	0	0	0	0	0	0	2	0.7407407
Woolly-necked Stork	*Ciconia episcopus*	54	11.816193	19	23.75	7	87.5	8	13.793103	16	39.02439	4	1.4814815
Black Kite	*Milvus migrans*	1	0.2188184	0	0	0	0	0	0	0	0	1	0.3703704
Little Egret	*Egretta garzetta*	6	1.3129103	6	7.5	0	0	0	0	0	0	0	0
Intermediate Intermediate Egret	*Mesophoyx intermedia*	37	8.0962801	8	10	1	12.5	11	18.965517	3	7.3170732	14	5.1851852
Eurasian Swift	*Apus apus*	27	5.9080963	16	20	0	0	0	0	0	0	11	4.0740741
African Fish Eagle	*Haliaeetus vocifer*	1	0.2188184	1	1.25	0	0	0	0	0	0	0	0
Pallid Harrier	*Circus macrourus*	2	0.4376368	0	0	0	0	0	0	0	0	2	0.7407407
Grey heron	*Ardea cinerea*	18	3.9387309	8	10	0	0	5	8.6206897	2	4.8780488	3	1.1111111
Hamerkop	*Scopus umbretta*	8	1.750547	0	0	0	0	0	0	2	4.8780488	6	2.2222222
Crowned Hornbill	*Tockus pallidirostris*	3	0.6564551	0	0	0	0	0	0	0	0	3	1.1111111
Malachite Kingfisher	*Alcedo cristata*	2	0.4376368	0	0	0	0	0	0	0	0	2	0.7407407
Mangrove Kingfisher	*Halcyon senegaloides*	14	3.0634573	8	10	0	0	6	10.344828	0	0	0	0
Palm-nut vulture	*Gypohierax angolensis*	3	0.6564551	0	0	0	0	0	0	1	2.4390244	2	0.7407407
Africa Paradise Flycatcher	*Terpsiphone viridis*	1	0.2188184	0	0	0	0	0	0	0	0	1	0.3703704
Pink-backed pelican	*Pelecanus rufescens*	45	9.8468271	0	0	0	0	0	0	0	0	45	16.666667
Great White pelican	*Pelecanus onocrotalus*	26	5.6892779	0	0	0	0	0	0	0	0	26	9.6296296
Pied Crow	*Corvus albus*	1	0.2188184	0	0	0	0	0	0	0	0	1	0.3703704
Pied Kingfisher	*Ceryle rudis*	11	2.4070022	6	7.5	0	0	0	0	0	0	5	1.8518519
Common Sandpiper	*Actitis hypoleucos*	25	5.4704595	0	0	0	0	25	43.103448	0	0	0	0
African Pygymy Kingfisher	*Ispidina picta*	2	0.4376368	0	0	0	0	0	0	0	0	2	0.7407407
Sacred ibis	*Threskiornis aethiopicus*	5	1.0940919	0	0	0	0	3	5.1724138	0	0	2	0.7407407
African Spoonbill	*Platalea alba*	37	8.0962801	0	0	0	0	0	0	17	41.463415	20	7.4074074
Water Thick knee	*Burhinus vermiculatus*	17	3.7199125	0	0	0	0	0	0	0	0	17	6.2962963
African Golden Weaver	*Ploceus subaureus*	53	11.597374	0	0	0	0	0	0	0	0	53	19.62963
Total birds		**457**	100	**80**	100	**8**	100	**58**	100	**41**	100	**270**	100

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Notes

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