Project Study Series

Wami River Sub-Basin, Tanzania
Hydrology Component of EFA Study

Environmental Flow Assessment Study

Dr. Patrick Valimba

Wami River Environmental Flows Initiative

ENVIRONMENTAL FLOW ASSESSMENT (EFA), WAMI RIVER SUB-BASIN, TANZANIA: THE WAMI HYDROLOGY

VOLUME 1 – GENERAL DESCRIPTION

Prepared by:
Dr. Patrick Valimba

Executed by:
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ACRONYMS AND ABBREVIATIONS

ADF	Average Daily Flow
EFA	Environmental Flow Assessment
FDCs	Flow Duration Curves
NRCS	Natural Resources Conservation Services
RWH	Rainwater Harvesting
USDA	United States Department of Agriculture
WRED	Water Resources Engineering Department

1 INTRODUCTION

1.1 BACKGROUND

Freshwater ecosystems provide a range of goods and services for humans (including fisheries, flood protection, wildlife, etc) which worth huge sums of money annually. Owing to their dependence on freshwater, water needs to be allocated to these ecosystems and therefore they should be considered an additional user to currently known agriculture, power generation and municipal/town users. Balancing the requirements of the aquatic environment and other uses is becoming a challenging issue in many river basins such as Wami River Sub-basin as population and its associated water demands increase. Moreover, the establishment of water requirements for ecosystem uses is an additional challenge.

Ecological and geomorphological maintenance of the health of the river requires a day-to-day management of flows in that particular river. This requires specification of environmental water requirements (discharges) for almost the whole spectrum of ecosystems within the particular river reach in relation to lateral and longitudinal connectivities. The estimation of environmental requirements of freshwater ecosystems for their conservation is commonly related to natural variability of the flow regime, which is the main determinant of ecosystems composition, diversity, productivity and resilience.

Therefore, one of the major inputs into an appropriate environmental flow management is the best knowledge of the hydrology and precise characterisation of hydrological regime in relation to geomorphological and ecological observations. This report presents the general hydrology of the sub-basin and results of preliminary spatio-temporal variability of flow regime as indicated by analyses on available hydrological information.

1.2 OBJECTIVES

This report forms a basis of understanding the hydrology of the Wami River Sub-basin and is a supplemental report to sub-basin environmental flow assessment (EFA) report. The main objective of the report is to provide background to the sub-basin hydrology and details the upstream-downstream linkages across the sub-basin so that decisions can be made with an informed knowledge of the impacts of upstream water use changes on downstream reaches, estuary and marine ecosystems.

1.3 REPORT ORGANISATION

This report comprises seven (5) chapters organised in such a way to provide a flow that brings towards better understanding of the issues presented in the report. The first chapter provides a background information related to this report including its objectives while the second chapter presents a general description of the surface water resources and the availability of hydrological data for characterisation of sub-basin hydrology. Chapter 3 discusses the historical evolution of water abstraction situation in the sub-basin while chapter 4 provides spatio-temporal hydrological variability across the Wami River sub-basin. Conclusions and recommendations are provided in the last chapter 5 which is followed by a list of cited references.

2 SURFACE WATER RESOURCES OF WAMI

2.1 INTRODUCTION

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 Morogoro region to discharge into the Indian Ocean at Saadani in Bagamoyo, Coast region (Fig 1). The sub-basin (as it is commonly referred in country's hydrological divisions) covers an area of approximately 40,000 sq km.

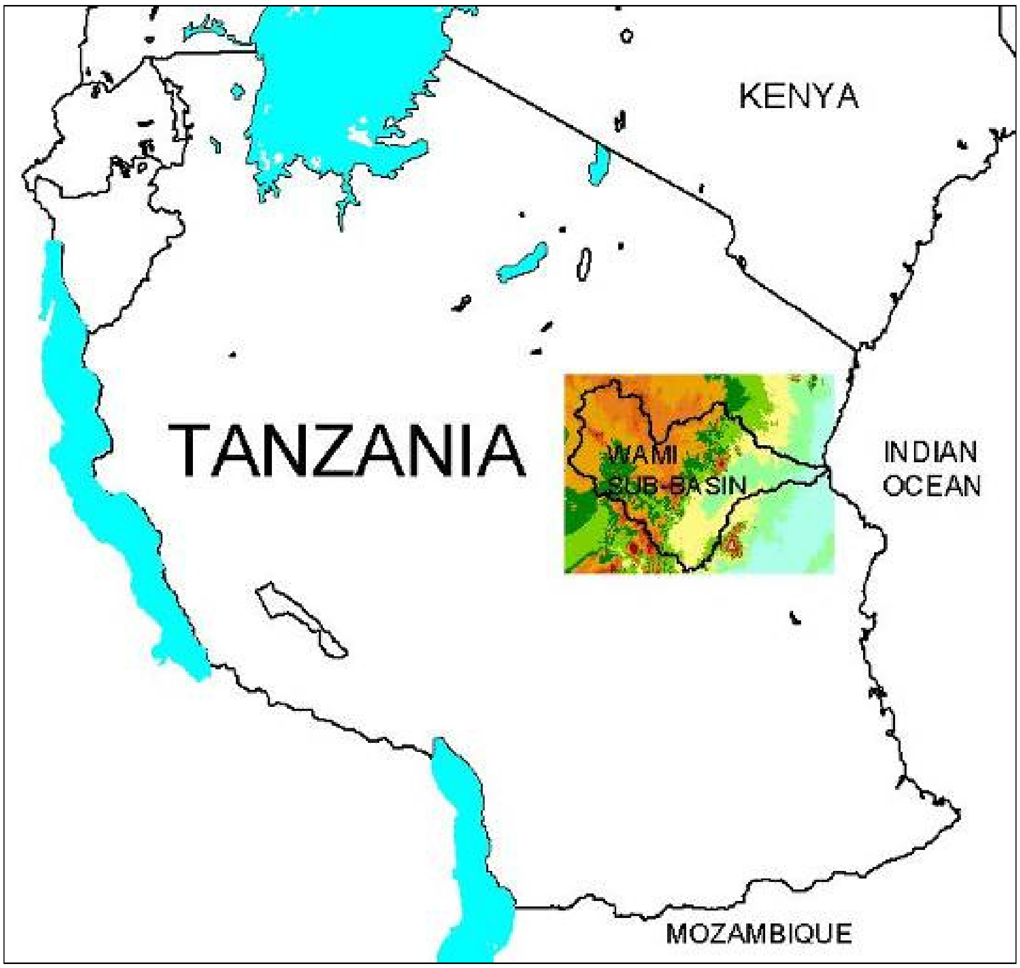


Fig 2.1: Location of the Wami River sub-basin.

2.2 WETLANDS OF WAMI

Wetlands are broadly defined as areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions[1]. Or in simple terms, wetlands are areas containing much soil water due to the presence of water at or near the soil surface. The Natural Resources Conservation Services (NRCS) of the

[1] Definition of wetlands as used by the U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA).

United States Department of Agriculture (USDA) defines wetlands as areas inundated for 7 days or saturated for 14 days during the growing season at least once every 2 years. Inundated and saturated mean respectively standing water on the surface and a wet surface sustained by capillary action in the soils.

Wetlands are often characterized by hydric soils and hydrophytes. Hydric soils have characteristics that are unsuitable for the growth of most plants except hydrophytes such as marsh grasses. It should be noted however that the presence of water by flooding, ponding or soil saturation does not necessarily constitute a wetland. Further, wetlands fluctuate seasonally due to their determining variables such as rainfall, groundwater, etc. From the definition of wetlands and their characteristics, four (4) different wetlands systems are distinguished in the Wami River Sub-basin. They include palustrine, riverine, lacustrine and estuarine systems. These are shown in Fig 2.2 and described below.

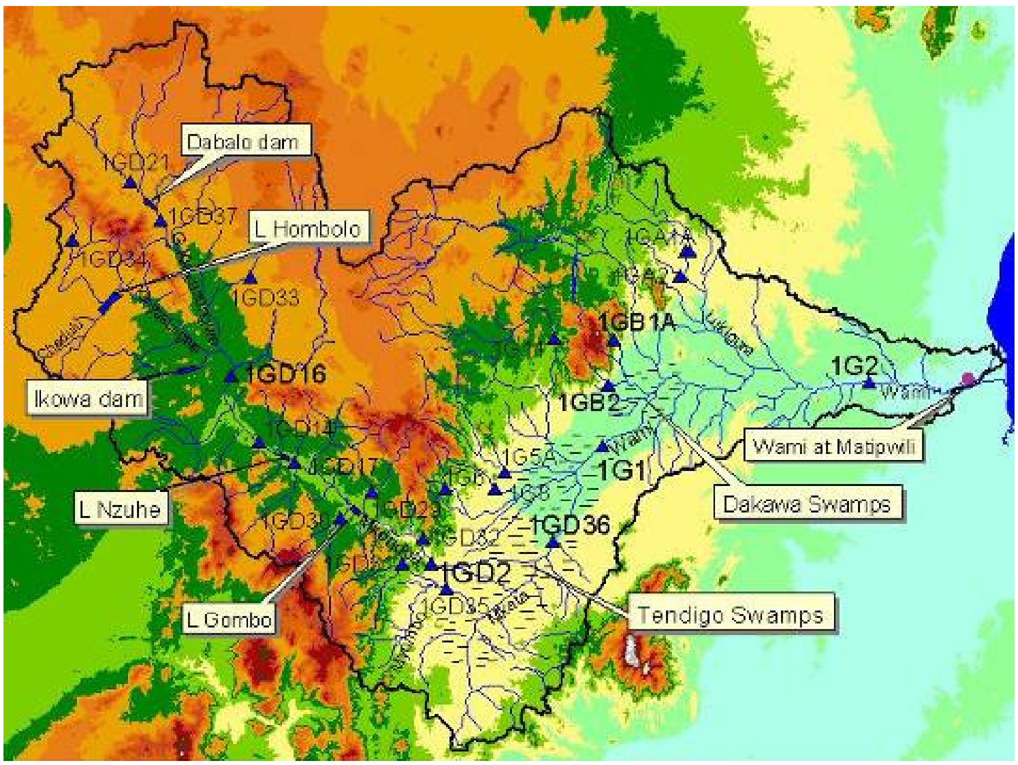


Fig 2.2: Wetlands systems of Wami.

2.2.1 Riverine wetlands

Riverine system is the largest wetlands system in Wami River sub-basin and comprises mainly rivers and floodplains. Many large rivers in the sub-basin such as the Wami, Mkata and Mkondoa and a few small rivers are perennial while others like the Kinyasungwe as well as many small rivers are ephemeral. Within the Wami sub-basin, floodplains are found along the widest channel sections of the rivers and are of different width depending on the locations. It is commonly observed that, for the same river, some sections expand into floodplains while in other floods are completely missing. The largest riverine swamps are found along the long Mkata-Wami-Diwale reach.

The river network in the Wami sub-basin drains mainly the arid area of Dodoma, the central mountains of Rubeho and Nguu and the norther Nguru mountains (Fig 2.2). The River Kinyasungwe with its headwaters in the arid areas of Dodoma is the major river that drains the upper catchments of the sub-basin. It flows southeast to discharge into River Mkondoa (Fig 2.3) with its headwaters in the southern Ukaguru mountains. Similarly, Mkondoa flows southeast, joined by its major tributaries of Lumuma and Mdukwe which drain the Rubeho mountains, to discharge into River Mkata (with its headwaters in the eastern Rubeho). Mkata flows northeast through the Tendingo swamps and joined by River Tami and Kisangata (which drain the eastern Ukaguru mountains) to form the main Wami, about 16 kilometres from Wami Dakawa. The main Wami continues flowing northeast and is joined by a Diwale tributary, which drains the Nguru mountains through Dakawa swamps, after which it flows easterwards towards the Indian Ocean. The only tributary, River Lukigura draining the Nguu mountains, joins the Wami some 47 kilometres downstream of the confluence with Diwale.

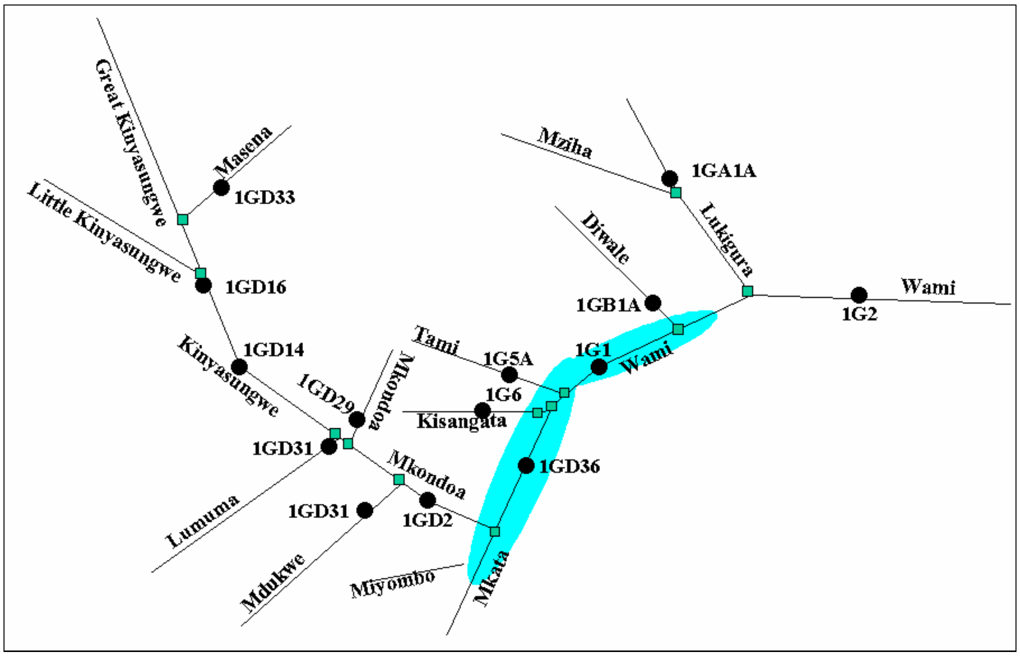


Fig 2.3: Schematic representation of the Wami river network.

2.2.2 Palustrine wetlands

Palustrine include generally all vegetated wetlands from marshes to springs to other forms including lagoons, ponds, pans, swamps and dambos (which is a spongy-like land area that stores substantial amounts of water during wet seasons and releases it gradually during the dry season). The Tendingo and Dakawa swamps are the major vegetated wetlands in the Wami sub-basin extending almost the whole length of the inland plain zone (Fig 2.2). The swamps are perrenial and seasonally expand during the rainy season between November and May and shrink during the dry season to the smallest spatial extent in late October.

2.2.3 Estuarine wetlands

Estuarine wetlands are found near river mouths and are characterized by mixed-origin volumes of water. This type of wetlands system in Wami sub-basin is found along the coastline of Bagamoyo at Saadani where River Wami discherges into the Indian Ocean.

2.2.4 Lacustrine wetlands

Lacustrine wetlands are lakes found in depressions or dammed river channels. They are either natural or manmade lakes and perennial mostly perennial although some may be seasonal. In the sub-basin, there are a few natural lakes such as Lakes Hombolo, Nzuhe and Gombo as well as several manmade lakes (reservoirs) including Lakes Ikowa and Dabalo. Most of these lakes are small and found mainly in the upper dry catchments.

2.3 HYDROLOGICAL DATA AVAILABILITY

2.3.1 River flows

2.3.1.1 Hydrographic observational network

The riverine wetlands in the Wami River sub-basin indicates that the river network comprises the main River Wami, its 5 major tributaries (Lukigura, Diwale, Tami, Mvumi/Kisangata and Mkata). The Mkata tributary is the largest comprising two major subtributaries, the Miyombo and the large Mkondoa. Mkondoa itself includes a major Kinyasungwe tributary with its two Great and Little Kinyasungwe draining the dry upper catchments in Dodoma. Consequently, the number and spatial distribution of flow gauging stations is related to the size of the drainage areas. The inventory of available information on river gauging observations network indicate that there have been 32 primary and secondary flow gauging stations in the sub-basin, two of which are locally managed (Table 2.1).

Table 2.1 Status of flow gauging stations in the Wami River sub-basin.

SNo	Station Code	River	Location	Gauge Range	Status
1	1G1	Wami	Dakawa	0 - 10m	Operational – rehab in Sep 2006
2	1G2	Wami	Mandera	0 - 5m	Operational – rehab in Dec 2006
3	1G4	Mkundi	Mkundi		Non-Operational
4	1G5A	Tami	Msowero	0 - 5m	Operational – rehab in Oct 2006
5	1G6	Kisangata	Mvumi	0 - 6m	Operational – rehab in Oct 2006
6	1G8	Wami	Rudewa		Non-Operational
7	1G10	Mkundi	Matale		Non-Operational
8	1G11	Chogoali	Difulu Village	0 - 3m	Non-Operational
9	1GA1A	Lukigura	Kimamba Rd.Br	0 -5 m	Operational – rehab in Sep 2006
10	1GA2	Mziha	Mziha (Kimamba)	0 -4 m	Operational – rehab in Sep 2006
11	1GB1A	Diwale	Ngomeni		Operational – rehab in Oct 2006
13	1GB2	Mkindu	Mkindu		Non-Operational
14	1GB3	Chazi	Chazi		Non-Operational
15	1GD2	Mkondoa	Kilosa	0 – 6m	Operational – rehab in Oct 2006
16	1GD5	Mkombola	Lukando		Non-Operational
17	1GD6	Miyombo	Ulaya		Non-Operational
18	1GD14	Kinyasungwe	Gulwe		Non-Operational
19	1GD16	Kinyasungwe	Kongwa/Dodoma	0 - 5m	Operational
20	1GD17	Kinyasungwe	Godegode		Non-Operational
21	1GD21	Kinyasungwe	Itiso		Operational
22	1GD29	Mkondoa	Mbarahwe	0 - 5m	Non-Operational
23	1GD30	Lumuma	Kilimalulu	0 - 4m	Non-Operational
24	1GD31	Mdukwe	Mdukwe	0 - 4m	Non-Operational
25	1GD 32	Mkondoa	Railway Brg.	0 - 4m	Non-Operational
26	1GD33	Masena	Ibumila		Non-Operational
27	1GD34	Kinyasungwe	Mayamaya		Non-Operational
28	1GD 35	Miyombo	Kivungu	0 - 6m	Operational – rehab in Oct 2006
29	1GD36	Mkata	Mkata	0 - 6m	Operational – rehab in Oct 2006
30	1GD37	Kinyasungwe	Ikombo	0 - 4m	Operational – rehab in Sep 2006
31	Local	Kinyasungwe	Ipala	0 - 4m	Non-Operational
32	Local	Kinyasungwe	Chihanga	0 - 4m	Operational – rehab in Sep 2006

The stations were established in various periods since the 1950s through to 1970s and have been operational in various periods between the early 1950s and 2007 (Table 2.1). Spatially, there have been a few (usually one) gauging stations in small catchments or tributaries such as Miyombo, Tami and Lumuma (Fig 2.4) and several gauging stations in large catchments of large and long rivers such as Rivers Kinyasungwe, Mkondoa and Wami. The existed dense network (Fig 2.4) has significantly declined since the early days due to several factors including necessary closure from unfavourable site conditions (e.g. closure of 1GD6), poor maintenance and replacement of measuring equipement, etc. Currently, only a few (14) gauging stations are still operational with some receiving major rehabilitation in 2006 (Fig 2.4).

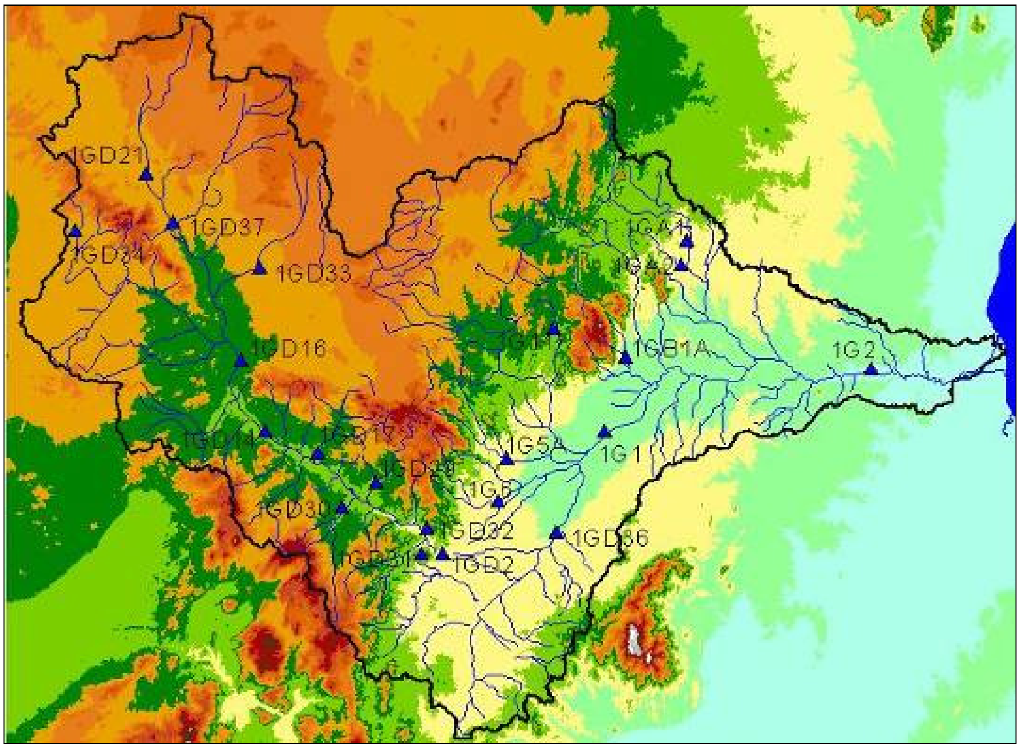


Fig 2.4: Spatial distribution of flow gauging stations ever operated in the Wami River basin.

2.3.1.2 River flow data

The spatial distribution of these river flow gauges (Fig 2.4) indicates that most of the rivers have been measured although in different observational periods (Table 2.2) related to their establishment and operation. Consequently, available flow data have different length, period of observation (Table 2.2) and quality (related to the size of missing observations). Most of the available records span the period 1970s to early 1980s (Table 2.2). Only 6 records have started in the 1950s and only 4 span through early 1980s. Recent effort to revive the river flow gauging network has rehabilitated some non-operational gauges and water level observations are available since September/October 2006 at 12 stations (Table 2.1). This therefore indicates that at many gauging sites, there is a large gap of missing information between the early 1980s and 2006 apart from other gaps existing within the observation periods.

Table 2.2: Availability of daily river discharge data in the Wami River basin.

Sno	Station	River	Location	Lat	Long	Established	Area (Sq. km)	Data availability			
								Water levels		Discharges	
								From	To	From	To
1	1G1	Wami	Dakawa	-6.43	37.53	14/11/1953	28488	Nov 1953	Dec 2006	Nov 1953	Mar 1983
2	1G2	Wami	Mandera	-6.23	38.40	09/06/1954	36450	Jan 1954	Aug 2003	Jan 1954	Mar 1984
3	1G5A	Tami	Msowero	-6.52	37.21	20/10/1964	907.0	Oct 1964	Jul 2007	Oct 1964	Dec 1983
4	1G6	Kisangata	Mvumi	-6.62	37.18	13/10/1955	140.3	Oct 1955	Mar 2007	Oct 1955	Dec 1969
5	1G8	Wami	Rudewa	-6.62	37.18		63.2	Jul 1958	Aug 1969	Jul 1958	Aug 1969
6	1G11	Chogoali	Difulu Village	-6.10	37.36	24/03/1973					
7	1GA1A	Lukigura	Kimamba Rd. Br.	-5.80	37.80	01/11/1964	1060	Oct 1964	May 1987	Oct 1964	Dec 1981
8	1GA2	Mziha	Mziha-Kimamba	-6.90	37.78	15/10/1964	178.0	Oct 1964	Jul 2007	Oct 1964	Mar 1990
9	1GB1A	Diwale	Ngomeni	-6.17	37.62	10/09/1964	173.8	Nov 1964	Jul 2007	Nov 1964	Nov 1989
10	1GB2	Mkindu	Mkindu	-6.25	37.55		90.7	Sep 1953	Aug 1969	Sep 1953	Aug 1969
11	1GD2	Mkondoa	Kilosa	-6.83	37.00	13/03/1952	17560	Apr 1952	Mar 1991	Apr 1952	Dec 1981
12	1GD14	Kinyasungwe	Gulwe	-6.43	35.42	28/11/1956	11103	Jan 1957	Dec 1977	Jan 1957	Dec 1977
13	1GD16	Kinyasungwe	Kongwa/Dodoma	-6.20	36.28	26/02/1958	9570	Feb 1958	Jul 2003	Feb 1958	Dec 1984
14	1GD17	Kinyasungwe	Godegode	-6.50	36.62	01/11/1960	12500				
15	1GD21	Kinyasungwe	Itiso	-5.59	36.00	17/11/1971	900				
16	1GD29	Mkondoa	Mbarahwe	-6.60	36.78	02/03/1969	475.3	Apr 1969	Dec 1982	Apr 1969	Dec 1982
17	1GD30	Lumuma	Kilimalulu	-6.68	36.67	10/03/1969	502	Mar 1969	Mar 1989	Mar 1969	Dec 1975
18	1GD31	Mdukwe	Mdukwe	-6.83	36.93	29/03/1969	460	Mar 1969	Jun 2003	Mar 1969	Dec 1989
19	1GD32	Mkondoa	Railway Bridge	-6.75	36.95	13/03/1973					
20	1GD33	Masena	Ibumila	-5.90	36.40	24/12/1972	240		Jun 1976		
21	1GD34	Kinyasungwe	Mayamaya	-5.78	35.80	28/02/1974			Mar 1983		
22	1GD35	Miyombo	Kivungu	-6.91	31.03	21/03/1973					
23	1GD36	Mkata	Mkata	-6.76	37.37	20/03/1973	20974.4	Mar 1973	Jun 2007	Mar 1973	Dec 1978
24	1GD37	Kinyasungwe	Ikombo	-5.75	36.12	30/10/1971	930		Mar 1990		

Despite recent restart of flow measurements since the early 1980s, the rating curves at various gauging need revision before used to estimate discharge from available water levels. Details of any gauge relocation and cross section changes must be used with a few recent rating observation to assess the suitability of existing rating curves and consequently establish some modifications to account for the changes. Therefore, no attempts are made to use available water levels until the rating curves are verified and/or modified.

2.3.2 Rainfall

According to available compiled information on rainfall observations, there have been more than 120 rainfall stations in the basin with a rather uniform spatial distribution (Fig 2.5). The inventory indicates different starting dates of available records related to different observational periods. Some of these stations are still operational while others have been closed due a multiplicity of factors. As a result, available rainfall data have different length, period of observation and quality (related to the size of missing observations).

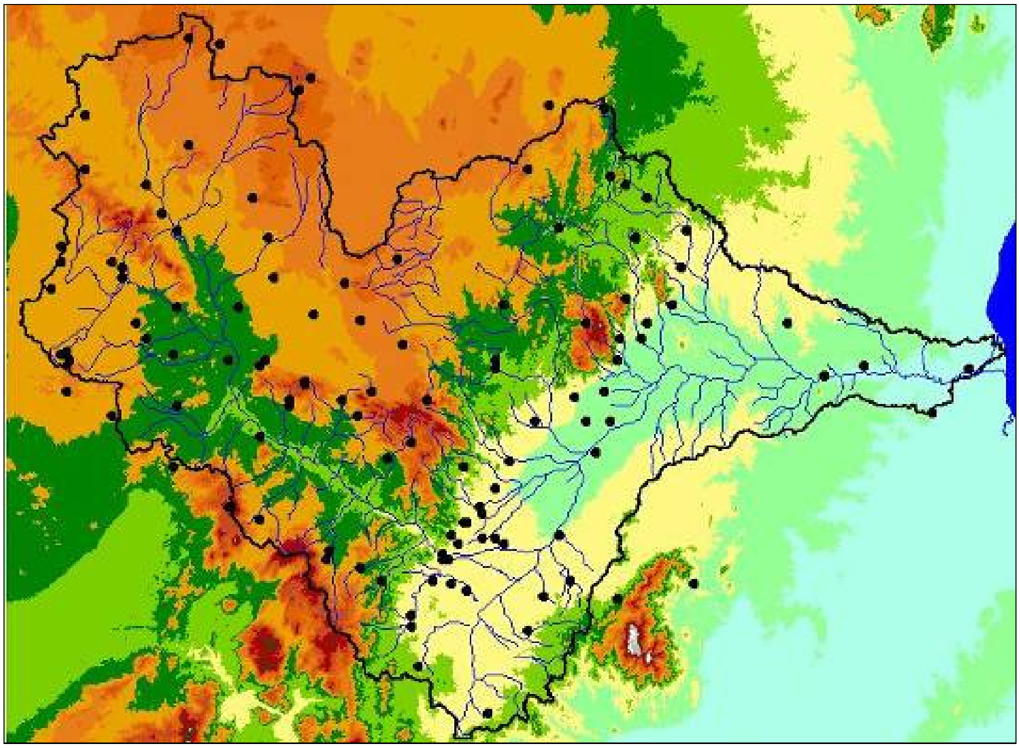


Fig 2.5 Spatial distribution of operational rainfall stations with monthly data in the Wami River basin.

Of the 120 stations with available rainfall data, only 28 were established before 1950 while 60 (including the 28 stations) were established before 1970. However, the available unupdated records indicate that only 12 stations have monthly rainfall data until 1990 while 88 have records extending at least to 1985 (Appendix 9.1). Moreover, analysis of available rainfall records in the basin indicates that only 40 out of the 120 stations have records at least 25 years long. In general, the available rainfall information therefore indicates that at many stations, there is currently a large gap of missing information between the mid 1980s and 2007 apart from other gaps existing within the observation periods.

3 WATER ABSTRACTIONS SITUATION

3.1 INTRODUCTION

This chapter presents the historical water abstraction situation in the Wami River Sub-basin that facilitates the establishment of naturalised flow series. The general situation of existing water abstractions is presented followed by a detailed discussion of water in each hydrological zone.

3.2 BASIN WATER ABSTRACTION SITUATION

Among the important factors which determine the amount of water that is available in downstream reaches of the river is the level of water abstraction to cater for various uses such as agriculture and municipal water supplies. Throughout the Wami river sub-basin, water abstractions are spatially non-uniform and the amount abstracted depends on the total requirement which is somehow affected by the local climatic conditions. Water abstractions in the sub-basin either withdraw water from the groundwater table or surface river network (including springs). The available information on legal water abstractions by August 2007 indicates that there are about 296 licenced water rights in the basin with 99 abstracting water from different surface rivers and 14 from springs (Table 3.1).

Table 3.1: Summary of registered water abstractions in the Wami River basin by August 2007.

Water source	No of registered water rights
Boreholes and wells	176
Rivers	99
Springs	14
Reservoirs	7
Total	296

Two type of surface water abstractions are therefore distinguished in the sub-basin, the dammed and direct-from-river abstractions. The former is widely practiced in the arid climate in upper catchments of Wami in Dodoma where several reservoirs storing river water are operational. They include Lake Hombolo resulting from empoundment across Little Kinyasungwe, Dabalo reservoir on Great Kinyasungwe and Ikowa reservoir behind a dam erected across River Majenjeule. These reservoirs store considerable amounts of flow that could otherwise be available to downstream reaches through to the Indian Ocean.

The number of licenced surface water abstractions is spatially variable with concentrations in some rivers like Lumuma while other rivers have 1-3 licenced abstractions (Table 3.2). Most of these licenced abstractions, however, are uniform throughout the year irrespective of seasonal and multi-year river flow variations. The investigation of registration dates indicates that most of large water abstractions were issued as early as in the 1960s in River Kibakwe, early 1980s in Rivers Lumuma and Diwale to recent issue in River Wami. However, currently, the coordinates of exact locations of almost all these licenced water abstraction have not been established.

According to available information, a number of licenced surface water abstractions are issued in ungauged rivers making it difficult to actually establish what could be the state of the rivers once the grantees are fully exploiting the granted abstractions.

This is illustrated by cummulative licenced water abstractions in some rivers when compared to a common measure of hydrological drought (Q70) (Table 3.2). The Q70 flow established from records in River Lumuma prior to 1980 (1969-1975 data), for example, indicates that issued water abstraction licences are far higher than the flow that is usually available during the drought years. The total licenced abstractions in this river (2,587.6 l/s) are still higher than the average daily flow (ADF) (820 l/s) since almost all abstractions licences were issued between 2002 and 2003 except that of DDD Kilosa which was granted in 1980 and which exceeds ADF (Table 3.2).

Table 3.2 Illustrative registered water abstractions in rivers within the Wami River basin.

River	Q70 (l/s)	ADF (l/s)	Total abstraction (l/s)	No of abstractions	Highest abstraction (l/s)	Date of issue
Chamkoroma	Ungauged	Ungauged	220.0	2	110.0	Jun 1994
Diwale	2,800	9,660	1,784.2	6	1,500	Nov 1981
Dizungwi	Ungauged	Ungauged	90.7	5	80.0	Mar 2003
Ilonga	Ungauged	Ungauged	544.6	7	300.0	Sep 1986
Kibakwe	Ungauged	Ungauged	470.0	2	470.0	Mar 1960
Kinyasungwe	900	4,730	411.6	1	411.6	Jan 2005
Kisangata	1,200	2,760	72.8	2	56.6	
Kizunguzi	Ungauged	Ungauged	80.0	1	80.0	Apr 1981
Lufusi	Ungauged	Ungauged	57.4	6	44.0	Nov 2002
Lumuma	400	820	2,587.6	14	930.0	Sep 1980
Mkata	3,100	7,640	154.1	8	50.0	May 1990
Mkindu	10,800	32,710	620.0	1	620.0	Nov 2001
Mvumi	Ungauged	Ungauged	90.0	1	90.0	
Myombo			3,839.1	6	1,132.0	Sep 1980
Wami	7,000	25,780	8,549.1	10	5,000	May 2007

3.3 ZONAL WATER ABSTRACTION SITUATION

3.3.1 Kinyasungwe

Surface water abstractions in the Kinyasungwe include largescale rainwater harvesting (RWH) reservoirs and direct abstractions from rivers and springs. A number of dams have been constructed between 1920s and 1980s, particularly in the between 1920s and 1960s (Table 3.3) for flood protection and community and agricultural water supply. The majority of these reservoirs are located in the dry Dodoma region across major tributaries of River Kinyasungwe, the Little and Great Kinyasungwe tributaries and their sub-tributaries such as River Majenjeule and Chadulu (Fig 3.1).

Table 3.3 Inventory of dams in Kinyasungwe.

SNo.	Reservoir	River/stream	Lat	Long	Alt (m)	Comm. date	Capacity (m^3)
1	Ikowa	Majenjeule	-6.16667	36.20000	900	1957	3,107,000
2	Dabalo	Gt Kinyasungwe	-5.78333	36.13333	1007	??	??

3	Hombolo	Lt Kinyasungwe	-6.80000	39.28333		??	??
4	Imagi	Imagi stream	-6.20000	35.73333	1185	1929	174,000
5	Msalatu	Msalatu stream	-6.20000	35.75000	1190	1944	388,000
	Total:	**Assumed**					**11,669,000)**

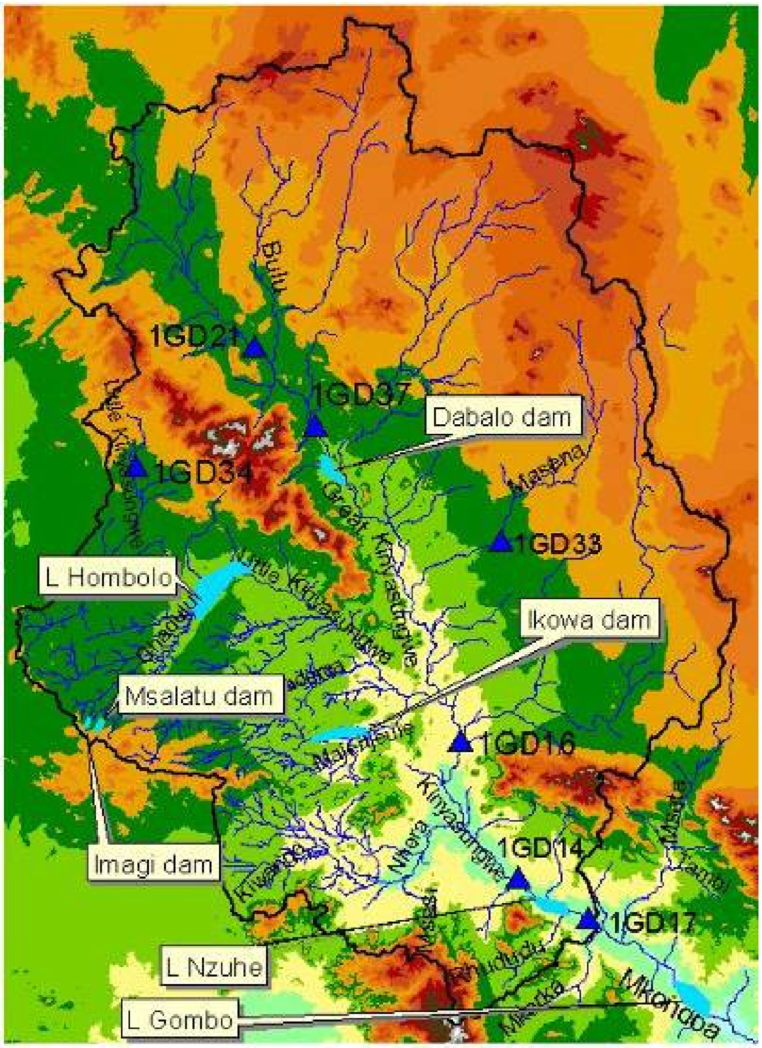


Fig 3.1: Reservoirs and lakes in the Kinyasungwe zone.

The reservoirs have variable capacities ranging from as low as 0.15 Mm^3 for minor Imagi and Msalatu reservoirs to over 3 Mm^3 for medium Ikowa and Hombolo reservoirs (Table 3.3). Being built across upper tributaries of the Kinyasungwe, they retain much of the flow that would otherwise reach the downstream reaches and eventually ends in Indian Ocean. Their total volume of 11.669 Mm^3 suggests that they can equivalently retain about 0.74 m^3/s if this volume is equally distributed over the six flow months (December – May, 182 days). This amount constitutes about 14% of ADF, ranges between 11 and 3700% of average flows in each day between mid November and end of May and only 11-148% of average flows in the medium/high flow period between mid December and end of April.

It was estimated that about 50 – 70% of reservoir storage is lost by leakage and evaporation each year (Rapp et al., 1972; Christiansson, 1979) while high annual sedimentation rates contribute to annual loss of reservoir capacity of 0.8 - 6% (Hatibu et al., 19??; Christiansson, 1979). The amount of flow being abstracted from reaching the downstream gauge at 1GD16 must have considerably modified seasonal flow regime from this gauging station (1GD16) downstreams although the amount retained is declining due to decreasing reservoir capacities. Despite the availability of a few rainfall records at various locations since the early 1930s (e.g. Dodoma met), there are no flow records before the mid 1950s within the catchment and this lack of reliable hydrological records (rainfall, discharge) and the fact that these reservoir exist since the 1920s might complicate the analysis of the impacts of flow retention by reservoirs on flow regime changes.

Another potential source that might contribute to flow regime changes in the Kinyasungwe zone is direct withdrawal of water from the rivers both legally and illegally. Illegal water abstractions are difficult to quantify while several water rights have been issued to allow withdrawal from various rivers within the zone. The largest number (31) are concentrated in rivers and streams in Mpwapwa District which finally discharge into Kinyasungwe in the reach between 1GD16 and 1GD14. They amount to 1,421.3 *l*/s (Table 3.4). There are 6 licenced water abstractions upstream of 1GD16 abstracting about 1088.3 l/s of water from tributaries of Little Kinyasungwe.

Table 3.4: Summary of licenced surface water abstractions by major rivers in Kinyasungwe zone.

Zone	Major river	Amount (l/s)
Kinyasungwe	Little Kinyasungwe	1,088.30
	Great Kinyasungwe	
	Kinyasungwe	1,421.30
	Total	**2,509.60**

3.3.2 Mkondoa

Apart from changes attributed to water abstractions in the Kinyasungwe tributary, flow regime changes in River Mkondoa might also be attributed to direct withdrawal from the river as well as from its other tributaries of Lumuma and Mdukwe. Despite of unquantified illegal abstractions, there are 14 licenced abstractions amounting to 661.2 l/s in Mkondoa and its tributaries such as Ilonga draining the Ukaguru mountains and 14 in Lumuma tributary amounting to 2,645.0 l/s (Table 3.3). Currently, no water rigths have been issued for water abstractions in the catchment of River Mdukwe. Additionally, Lake Gombo provides natural abstraction of inflow from Kinyasungwe into the Mkondoa zone.

Table 3.5 Summary of licenced water abstractions by major rivers in Mkondoa zone.

Zone	Major river	Amount (l/s)
Mkondoa	Mkondoa	661.20
	Lumuma	2,645.00
	Mdukwe	0.00
	Total	**3,306.20**

Unlike the water rights for River Lumuma which have been issued mainly in 2002 and 2003, those in the Mkondoa and its tributaries draining the Ukaguru mountains have been as early as in 1950s (Kilosa Ginnery, November 1958) through the

1970s (Kilosa Urban Water Supply, July 1971) and 1980s (Katibu Mkuu Elimu, April 1981). Recent water rights have been issued in October 2003.

3.3.3 Mkata

Owing to the fact that the largest part of River Mkata lies within the Mkata plains where Tendigo swamps supply most of irrigation and domestic water, there is little abstractions from the main river. Only 6 water rights have been issued to allow direct withdrawal from Mkata and amount to a total of 54.1 l/s (Table 3.6). However, 6 water rights have been issued in River Myombo to abstract about 3,839.1 l/s. Although dates of issue of several water rights are currently missing, the available information indicates that they have been issued as early as in 1976 but mostly in the 1990s and 2000s.

Table 3.6 Summary of licenced water abstractions by major rivers in Mkata zone.

Zone	Major river	Amount (l/s)
Mkata	Mkata	54.10
	Myombo	3,839.10
	Total	**3,893.20**

Since the Myombo and Mkondoa join the Mkata within the Tendigo swamps, the effects of permitted abstractions might be small in relation to changing flow regime of the Mkata but can be significant in relation to the seasonal fluctuations of the wetlands.

3.3.4 Diwale

There are 13 licenced water abstractions within the Diwale zone withdrawing a total amount of 1902.98 l/s (Table 3.7) from the main River Diwale and its tributaries. Only 1 of the 12 issued water rights is the oldest and medium scale licence for Mtibwa Sugar Estate (MSE) allowing it to withdraw 1,500 l/s from the Diwale while others are small scale licences. Apart from this oldest water right for MSE issued in November 1981, the remaining are recent granted between 2001 and 2007.

Table 3.7 Summary of licenced water abstractions by major rivers in Diwale zone.

Zone	Major river	Amount (l/s)
Diwale	Chazi	27.80
	Dizungwi	90.70
	Divue	0.28
	Diwale	1,784.20
	Total	**1,902.98**

Such a total daily direct water withdrawal from rivers in the Diwale zone might have impacts on modifying flow regime of River Diwale. The anticipated changes can be significant in the upstream part of the river before it enters the Dakawa swamps and on the swamps. Daily flows might have decreased particularly during the dry season due to extensive use in dry season agriculture in the Turiani plains. Similarly, there might have been reduction in the extent of the swamps during the dry season due to wetlands agriculture and reduced inflows into the swamps. However, little impacts are considered to have occurred downstream of the swamps.

3.3.5 Lukingura

The available information on licenced water abstractions in the Wami River Sub-basin indicates that no any water rights have been issued to allow water withdrawal from River Lukigura and its tributaries. This does not indicate the absence of water abstractions in this zone since illegal water abstractions are not completely excluded despite difficulties in their estimation.

3.3.6 Main Wami

Among the 11 issued water rights in the main reaches of River Wami are the recent largescale water withdraws licences for MSE (2,500 l/s) and Ushirika wa Kilimo Dakawa (5,000 l/s). The two make up 80% of the total licenced withdraw of 9,339 l/s (Table 3.8). Except for one water right issued in April 1981 allowing Mkuu wa Gereza Mbigiri to withdraw water from the Wami, other licences are recent issued between August 1999 and May 2007.

Spatially, whilst there are no any licences issued for the upstream tributary of Tami, water rights amounting to about 700 l/s have been issued to withdraw water from the Kisangata tributary. The total licenced withdraws upstream of the gauging station at Dakawa (1G1) in the main Wami amounts to 5,243 l/s (Table 3.8). Permitted water abstractions between 1G1 and 1G2 (Wami at Mandera) along the main Wami total 3,280 l/s while licenced withdraws downstream of 1G2 through to Matipwili Village amount to only 116 l/s. However, there is a project proposal for a 17,000 sugarcane plantation in Gama Village, just downstream of Matipwili Village, that will require a total amount of 11,810 l/s for irrigation. The withdraw of such amount might have significant impacts on estuarine and marine morphology and ecosystems.

Table 3.8 Summary of licenced water abstractions by major rivers in Wami zone.

Zone	Major river	Amount (l/s)
Wami	Kisangata	699.90
	Wami Dakawa	5,243.10
	Wami Mandera	3,280.00
	Wami Matipwili	116.00
	Total	**9,339.00**

3.3.7 Summary of total water abstractions

Direct abstractions from the river comprises licenced and illegal abstractions. Currently, there is little quantitative information on the former while about 99 abstractions from various rivers and 14 from springs in the sub-basin have be given water rights. Despite the lack of coordinates of exact locations of almost all abstraction points, the rivers which they abstract water are known. According to available information (Fig 3.2), most of the abstractions are located in Wami Dakawa (5.25 m^3/s), River Myombo (3.84 m^3/s), Kinyasungwe (2.58 m^3/s) and River Lumuma (2.59 m^3/s) and Wami Mandera (2.50 m^3/s).

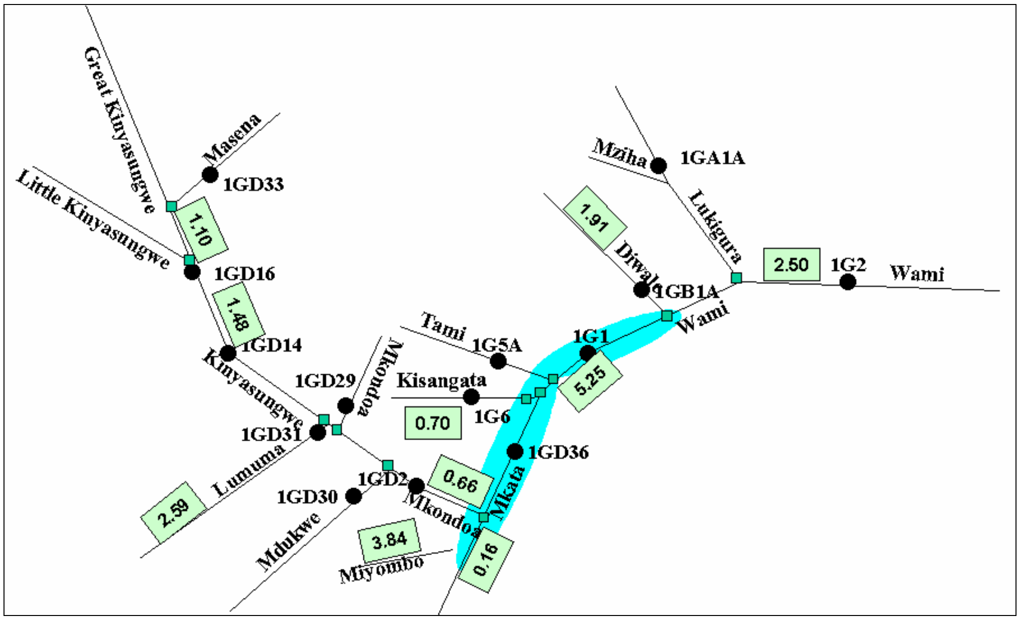


Fig 3.2: Total licenced daily water abstractions (m^3/s) in various rivers in Wami.

Although water rights or abstraction licences have been issued since the late 1950s, there has been a significant increase issuance in the recent few years of the 2000s throughout the Wami sub-basin (Table 3.9). Significant increases characterise the main Wami and Kinyasungwe zones while more water rights had been issued in the 1980s in Mkata and Diwale than in the 2000s.

Table 3.9 Summary of licenced water abstractions by decade in Wami.

Decade	Amount (l/s)					
	Kinyasungwe	Mkondoa	Mkata	Diwale	Wami	Total
to 1960s	470.10	0.50	0.00	0.00	0.00	470.60
1970s	12.70	25.90	1,130.00	0.00	0.00	1,168.60
1980s	9.50	1,310.00	2,262.00	1,500.00	37.80	5,119.30
1990s	261.50	10.00	57.10	0.00	2,500.00	2,828.60
2000s	1,567.10	1,888.90	444.10	402.98	6,801.20	11,104.28

The comparison of the total abstraction and amounts of water that is seasonally available in the rivers indicates that, for some rivers like Mkondoa and Wami at Mandera, the available is sufficiently large to cater for the total issued water rights. For others like Kinyasungwe, the licenced abstractions cannot be practical during the dry season when most reaches of the river are completely dry. Analysis of drought flows (given by that flow which has been equaled or exceeded in 70% of the time, Q70, Fig 3.3) indicated that in some perennial rivers like Lumuma (Abstractions: 2.59 m^3/s; Q70: 2.30 m^3/s), the issued abstractions have already exceeded Q70 suggesting the possibility of drying up the rivers if water rights are put in full operation. In others like Wami Dakawa (Abstractions: 5.25 m^3/s; Q70: 7.00 m^3/s), the licenced amounts are slightly less than Q70 but might have exceeding lowest flows experienced during the dry season.

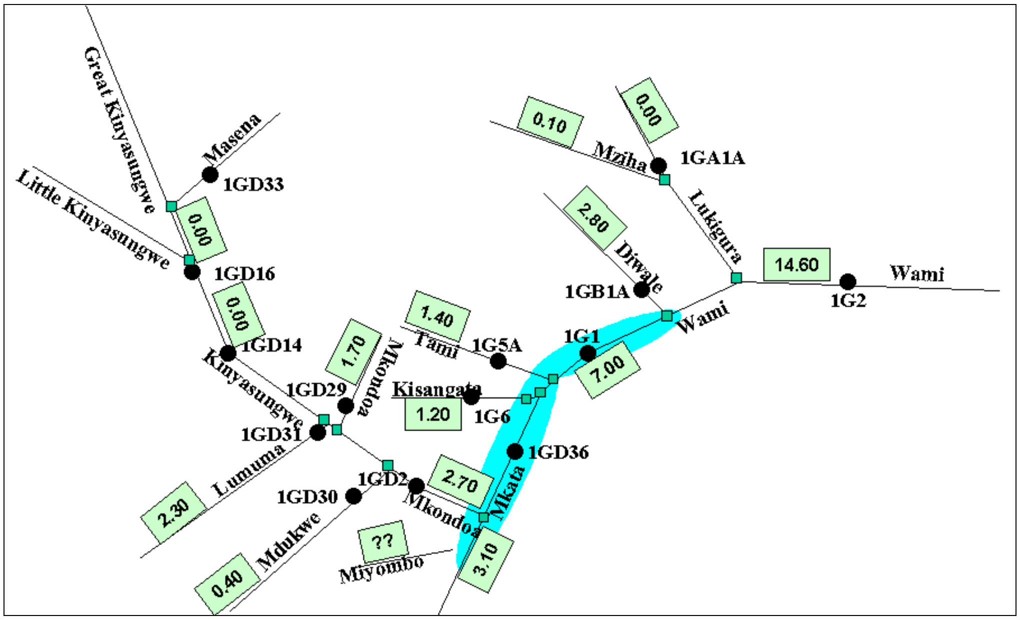


Fig 3.3: Historical drought flows (Q70, m^3/s) at various locations in Wami rivers.

Unfortunately, despite the community response towards securing water rights to leggaly abstract river water, there is currently a problem of issuing water rights in ungauged rivers where amounts of water that are available are not known. Moreover, the issued water rights do not consider flow seasonality and may create a risk of drying up some river, particularly the small perennial and therefore transforming to seasonal rivers.

3.4 CONCLUSIONS

This chapter has indicated the existence of largescale water abstractions by dams and smallscale individual abstractions through water rigths. The chapter has further indicated the spatio-temporal variations of existing icenced water abstractions in the Wami River sub-basin. Temporally, water rights have been issued since the late 1950s (in 1958) through the 1960s, 1970s, 1980s, 1990s to 2000s. Although the a few water rights were issued in the 1950s, 1960s and 1980s, a number abstracting significant amounts were issued in the 1970s and 2000s. Spatially, largescale water abstractions are practiced in dry upper catchments of Wami in Dodoma through a series of dams. Significant directly abstractions from the river characterise the Lumuma tributary of River Mkondoa and Miyombo tributary of River Mkata which are located on the upstream of Tendigo swamps as well as along the main Wami at Dakawa and Turiani. There is little licenced water abstractions in River Mkata which entirely lies within the Tendigo swamps. The existence of unregistered (or illegal) water abstractions was also highlighted.

4 SURFACE WATER RESOURCES VARIABILITY AND HYDROLOGICAL ZONATION

4.1 INTRODUCTION

This chapter describes seasonal and interannual flow variations in the Wami River Sub-basin that are important in relation to the river ecology and geomorphology and provide preliminary hydrological zonation of the sub-basin. The seasonal variation is described first using long-term average monthly flows while average daily flows and threshold flows are used to define flow seasons with regard to rainfall seasons. Thereafter, interannual flow variations are described to highlight changes that have occurred in the flow seasonality and magnitudes.

4.2 SEASONAL FLOW VARIABILITY

4.2.1 Period of high and low flows

Long-term average monthly flows indicate that the Wami River sub-basin experiences a transition pattern of intra-annual flow variation between the bimodal (double peaks) regime in the north and unimodal (single peak) regime in the south, with a defined peak during the long rains (Fig 4.1). However, a slight peak during the short rains is sometimes apparent in the large catchments. The low flows in perennial rivers in sub-basin are experienced during the dry period particularly in July-October (Fig 4.1b) with the lowest flows observed in October. Moreover, low flows in seasonal rivers starts immediately after the end of the rainy season in late April/early May. In certain dry years, some of the small and large perennial rivers completely dry up following the failure of the early season (November-January) rainfall which lead to progressive declining flows to zero flows by January or February. In exceptionally wet years with abundant early season rainfall, the peak in November-December becomes well-defined creating a bimodal flow regime.

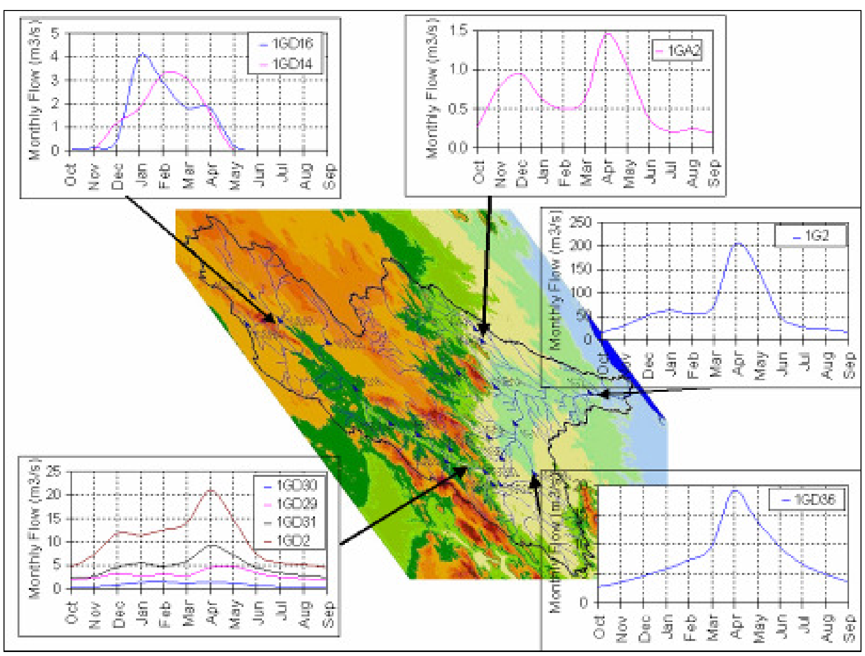


Fig 4.1 Typical seasonal flow patterns in the Wami River Sub-basin.

The average seasonal flow pattern is non-uniform across the sub-basin. The pattern varies from predominantly bimodal in rivers in the Lukigura bordering the bimodal northeast Tanzania to predominantly unimodal in rivers in the south draining the Rubeho and Ukaguru mountains (Fig 4.1). Seasonal rivers are a characteristic of upper catchments draining the arid Dodoma and include River Kinyasungwe and its tributaries. The unimodal perennial flow regime with a slight flow reduction in February characterise the remaining part of the sub-basin.

4.2.2 Flow seasons

Flow seasons usually follow that of rainfall although there is slight difference in that flows can persistently remain high during a moderately long dry spell. Therefore, of ecological importance to riverine, floodplain and estuarine ecosystem is the precise identification of different phases of the flow regime and their timing. This process separates the annual flow hydrograph into different seasons that ecologically important such as low and high flow seasons.

Hydrological analysis indicated that the Wami sub-basin lies within the meteorologically transition zone of Tanzania between the northern bimodal and southern unimodal regimes. Consequently, river flow regime varies temporally between slightly bimodal in some years like 1966/67 with abundant *Vuli* rains to typical unimodal in other years particularly dry years like 1972/73 with La Niña related failed *Vuli* rains (Fig 4.2). The flow regime also varies spatially with rivers draining northern parts of the sub-basin exhibiting predominantly quasi bimodal regime while those draining the southern part of the sub-basin showing quasi unimodal flow regime. The quasi unimodal and bimodal regimes consist of main high flow season during the *Masika* rains, the moderate flow period during the *Vuli* rains, slightly reduced flows during the trasition period between *Vuli* and *Masika* rains and the low flow period during the dry season (Figs 4.2, 4.3).

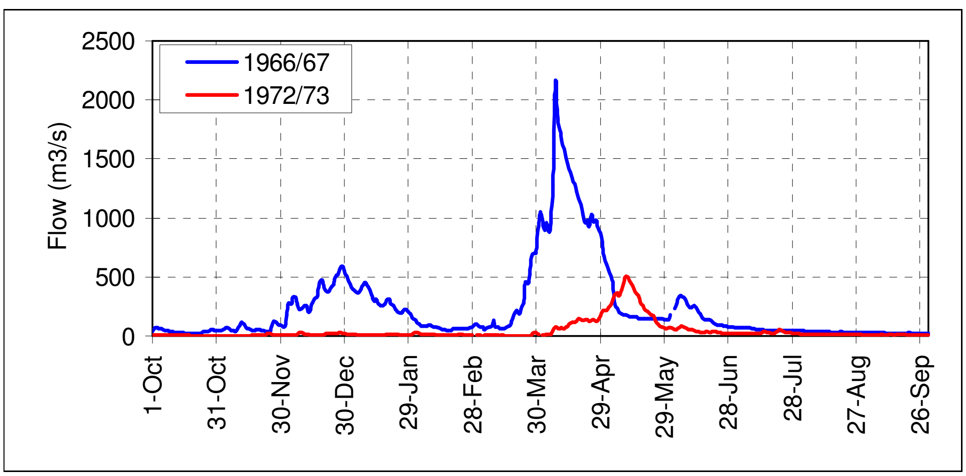
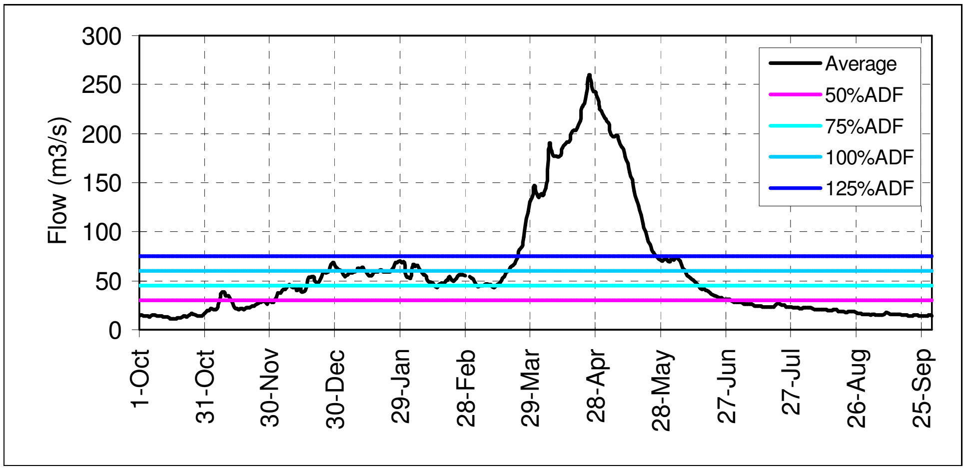


Fig 4.2: Flow seasonality at 1G2.

To appropriately establish threshold that adequately isolates the four seasons, it was important to account for the spatial variation of flow magnitudes within the sub-basin. The experience of spatial hydrological analysis in various basins in the country indicated that the use of thresholds derived from average daily flow (ADF) was appropriate to provide comparable results as ADF describes hydrophysiographic differences between the catchments. Several thresholds as percentage of ADF, ranging from 50% to 125% of ADF, were investigated to select the most appropriate threshold that applies to all catchments.



(b)

Fig 4.3: Flow seasonality and seasons identification. The coloured horizontal lines indicate different thresholds investigated.

Although the use of lower perecentages (50-80%) and higher (> 110%) of ADF was able to isolate the high and low flow periods from most records, it could not separate the *Vuli*, transition and *Masika* related flow seasons (Fig 4.3). The higher percentages (> 100%) could only isolate the *Masika* related flow season (Fig 4.3). Percentages of ADF between 80% and 110% were able to separate the high flow period into the three seasons although differently for different catchments. A close investigation indicated that the 95% of ADF was an appropriate threshold that just isolates the transition season between the *Vuli* and *Masika* rains. The use of ADF (i.e. 100% ADF) corresponded to a slightly higher value of the threshold and was not considered appropriate as it lengthens the transition season and shorten the *Vuli* season. Therefore, the 95% ADF was used as the threshold for isolation of the flow seasons in Wami River sub-basin which gave almost identical spatial pattern in the sub-basin (Fig 4.4). Similarly, the recession from high flows to low flows and a change from low flows to high flows is a length process through a transition and therefore a 45-50% ADF was an appropriate threshold to separate low flows from the transition period flows.

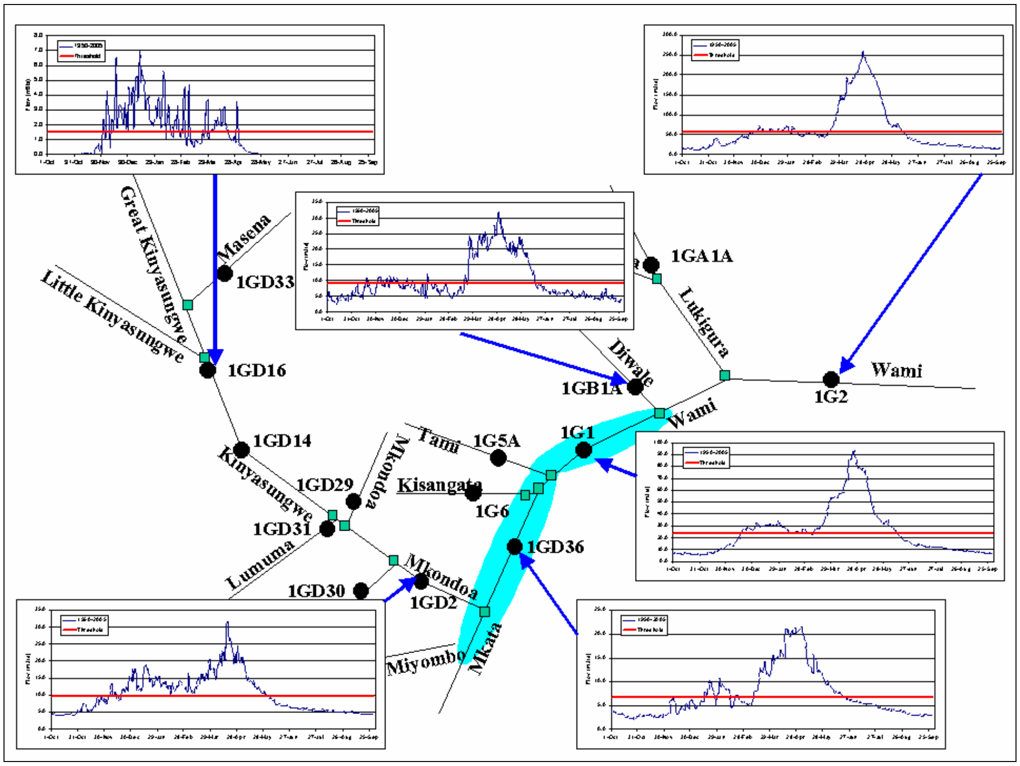


Fig 4.4: Flow seasons identification across the Wami river sub-basin: Left corner of hydrograph is 1st October and right corner is 30th September.

The results indicated that the low flow season in different parts of the Wami river sub-basin extends between late July and early December (Table 4.1) and is longer is seasonal rivers like Kinyasungwe at Kongwa (1GD16, approx 107 days) and Lukingura at Kimamba (1GA1A, 173 days) as well as in less variable flow regime of the main Wami river (1G1 and 1G2). A transition period between low flows and the *Vuli* moderately high flows (transition season 1) is experienced variably between early November and early December with a length in the range 0-48 days. For a seasonal River Kinyasungwe, for example, the transition is abrupt from the low flow season to *Vuli* season following the onset of the *Vuli* rains, which is normally in late November to early December in Dodoma. The first high flow season, the *Vuli* season, follows the onset of the *Vuli* rains and is identified to extend between early December and early-mid February with a typical length range of 55-85 days (Table 4.1). This is followed by a brief intermediate flow season of about 25-38 days before the *Masika* season between mid March and early-late June which are followed by a transition period (transition season 2) to low flow season. This second transition is much longer corresponding to the slow recession of flow hydrograph from the high flows during *Masika* to low flows period (Fig 4.2). However, the recession is much quick in small catchments like that of River Lukingura at Kimamba (1GA1A).

Table 4.1: Identified flow seasons and their length (days) in Wami River sub-basin.

Station	Season (length in days)					
	Low Flow	Transition1	Vuli	Intermediate	Masika	Transition 2
1GD16	18th Aug-2nd Dec (107)	*No (0)*	3rd Dec-16th Feb (76)	*17th Feb-26th Mar (38)*	27th Mar-6th Jun (72)	*7th Jun-17th Aug (62)*
1GD31	26th Sep-17th Nov (53)	*18th Nov-7th Dec (20)*	8th Dec-6th Feb (61)	*7th Feb-10th Mar (32)*	11th Mar-16th Jun (98)	*17th Jun-25th Sep (101)*

1GD2*	7th Sep-3rd Nov (58)	*4th Nov-5th Dec (32)*	9th Dec-9th Feb (63)	*10th Feb-14th Mar (33)*	15th Mar-1st Jun (79)	*2nd Jun-6th Sep (97)*
1GD36	10th Oct-6th Dec (58)	*7th Dec-15th Jan (40)*	16th Jan-13th Feb (29)	*14th Feb-12th Mar (27)*	13th Mar-20th Jun (100)	*21st Jun-9th Oct (111)*
1G6	1st Oct-4th Nov (35)	*5th Nov-8th Dec (35)*	9th Dec-8th Feb (62)	*9th Feb-5th Mar (25)*	6th Mar-9th Jul (96)	*10th Jul-30th Sep (83)*
1G5A	16th Sep-15th Nov (61)	*16th Nov-6th Dec (21)*	7th Dec-8th Feb (64)	*9th Feb-15th Mar (35)*	16th Mar-14th Jun (90)	*15th Jun-15th Sep (93)*
1GB1A	1st Sep-31st Oct (61)	*1st Nov-2nd Dec (32)*	3rd Dec-12th Feb (72)	*13th Feb-20th Mar (36)*	21st Mar-14th Jun (86)	*15th Jun-31st Aug (78)*
1GA1A	12th Jun-1st Dec (173)	*2nd Dec (1)*	3rd Dec-27th Feb (85)	*28th Feb-26th Mar (27)*	27th Mar-5th Jun (71)	*6th Jun-11th Jun (6)*
1G1	14th Aug-24th Nov (103)	*25th Nov-19th Dec (25)*	20th Dec-12th Feb (55)	*13th Feb-11th Mar (27)*	12th Mar-14th Jun (95)	*15th Jun-13th Aug (60)*
1G2	25th Jul-6th Nov (104)	*7th Nov-24th Dec (48)*	25th Dec-8th Feb (46)	*9th Feb-17th Mar (37)*	18th Mar-9th Jun (84)	*10th Jun-24th Jul (45)*

* High flow threshold was 120% ADF

The uneven distribution of flows within the year indicate that the high flow seasons, Vuli (December-Febraury, DJF) and Masika (April-June, AMJ), contribute respectively 17-64% and 15-55% of annual flow volumes (AFV) (Table 4.2) while 15-25% flow during the subsequent dry season (Table 4.2). Except for the Kinyasungwe where early season (DJF) flows contribute more than 55% of AFV, the contributions of DJF flows in other parts of the sub-basin ranges between 17% and 36%. The volume flowing during the two seasons, therefore, contributes about 62–82% of annual flow volumes. Therefore, such high flow contributions almost throughout the sub-basin during the long rains suggest that changes of annual flows over the years could be attributed significantly to changes during this season.

Table 4.2 Mean seasonal flow volumes expressed as percentages of mean annual flow volumes.

Zone	Code	DJF	AMJ	SON
Kinyasungwe	1GD16	64,3	17,9	1,2
	1GD14	55,9	14,9	0,0
	1GD30	36,0	32,5	10,0
	1GD29	25,7	36,0	17,0
	1GD31	26,4	37,7	13,4
Mkondoa	1GD2	29,5	35,9	13,5
Mkata	1GD36	18,7	47,5	10,3
	1G6	16,8	49,3	10,9
	1G5	24,8	46,6	11,2
Wami Dakawa	1G1	25,0	49,5	7,4
	1GB1A	21,5	47,8	12,4
Diwale	1GB2	19,6	49,7	11,8
	1GA1A	26,6	51,6	8,7
Lukigura	1GA2	28,7	39,9	16,7
Wami Mandera	1G2	21,9	54,7	7,6

4.3 INTERANNUAL FLOW VARIABILITY

4.3.1 Daily flows

The longterm averages for each of the 365 days of the year were computed and indicate flow increases since early November to distinct peak between late March through late May (Fig 4.5). A useful measure of interannual variability of daily flow is the xσ (typically x =1,2,3) deviations from the longterm averages, where σ is the standard deviation flow for that particular day. The 1σ limit above and below the longterm averages was used to establish the limits within which historical daily flows are allowed to fluctuate. The results indicate a wide variability band during the rainy seasons (Fig 4.5) suggesting high variability of daily flows and a narrow variability band during the low flow period indicating low flow variability. The results further suggest drying up of perennial river during the wet season. In reality, the historical observed minimum flows indicate that this has rarely occurred, for example, at 1G2 in April-June even in relatively dry Masika (March-May) rains of 1966 although dry Vuli rains such as that of 1973 resulted in drying up in February of 1974 in some rivers. It was therefore considered that the $\mu \pm x\sigma$ limits could give misleading interpretations unless intepreted with historical observed maxima and minima.

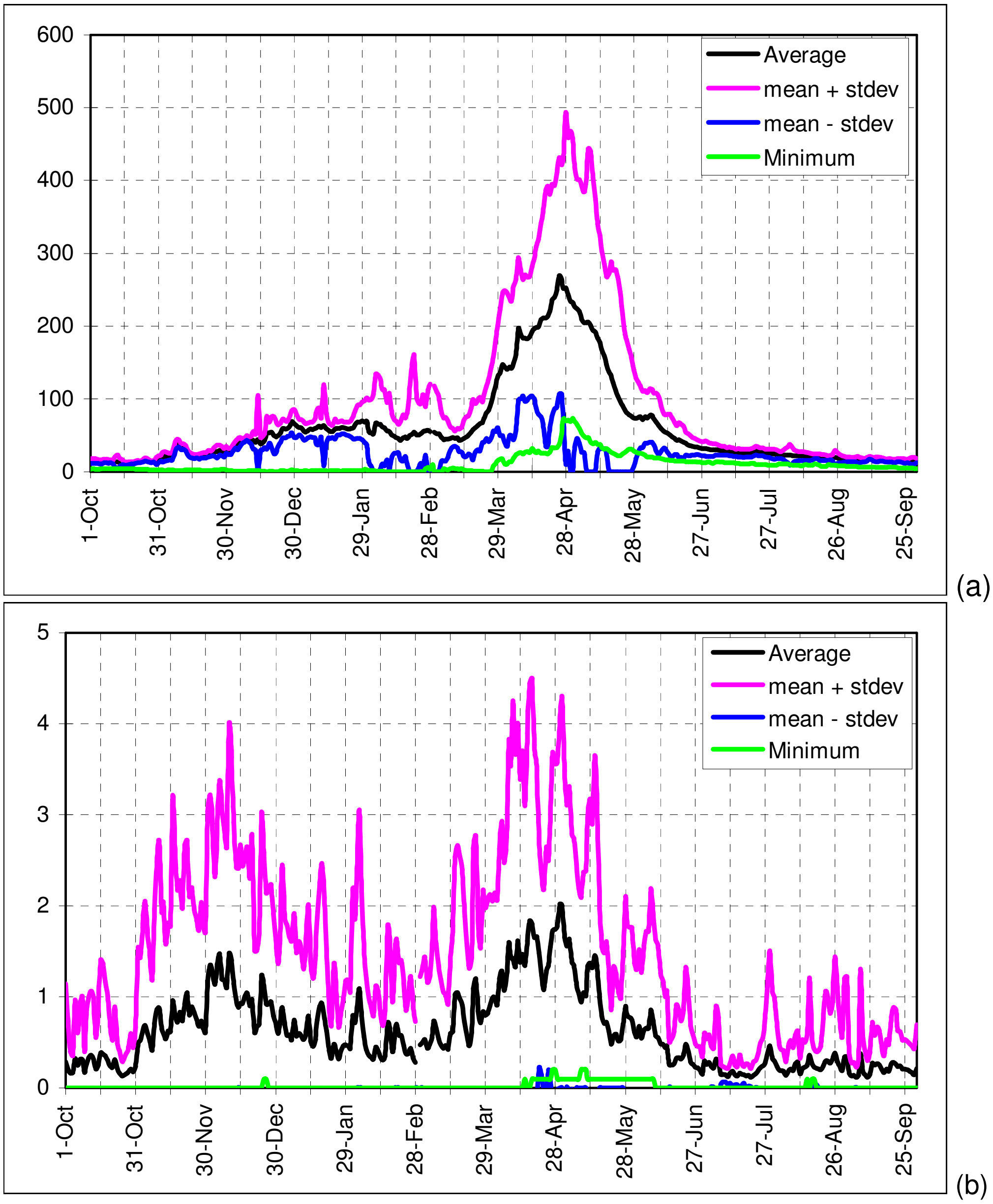


Fig 4.5: Changes of daily flow patterns in the Wami River sub-basin a) 1G2 and b) 1GA2.

Analysis of dry and wet years generally indicates that peak flows do not necessarily occur in both Vuli and Masika of the same years while lowest flows often occur simultaneously in both seasons. The occurrence of highest peaks is dependent on the abundance of rainfall during the particular season, which is induced by background climatic factors. The wettest Vuli flow at 1G2 (Fig 4.6), for example, was observed during the 1961 *Uhuru Vuli* rains and were mainly contributed by high persistent rainfall since early October through late January. The following Masika rains of 1962 were deficit which could not raise the receeding flow hydrograph contributing to relative low flows throughout the 1962 Masika season (Fig 4.6). However, in exceptionally wet years such as 1967/68, which receive abundant Vuli and Masika rains, flow hydrographs are sustained at higher flows throughout the two seasons with a reduction of flow magnitudes in February (Fig 4.7). This bimodal flow pattern reflect rainfall bimodality attributed mainly to favourable climatic conditions that contribute to the abundance of Vuli rains and a post-Vuli declining rainfall.

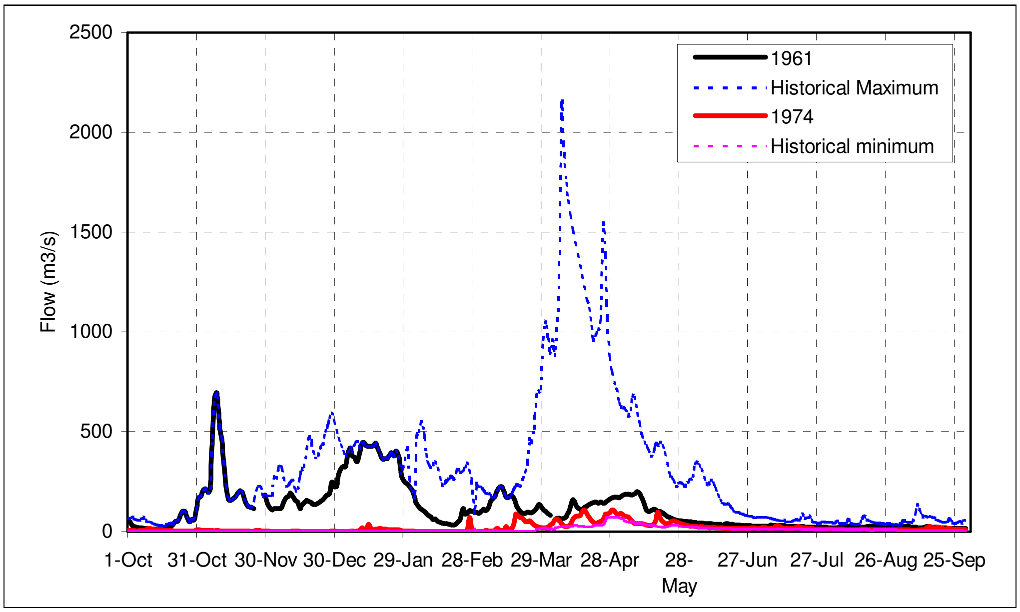


Fig 4.6: Changes of daily flow patterns in the Wami River sub-basin in wet and dry Vuli at 1G2.

Unlike the situation with highest flows during wet years, the driest years often observe lowest flows in both Vuli and Masika seasons (Figs 4.6, 4.7). In the Wami River sub-basin, the relative driest years were experienced in the mid 1970s which observed lowest flows throughout the 1973-1976 period following the longest historical La Nina event (Trenberth, 2001?). The La Nina events have been linked to reduced rainfall in equatorial Tanzania (Nyenzi *et al*., 1999; Ogallo and Nasib, 1984) and such unfavourable conditions resulted in reduced rainfall which led to a persistent reduction of flows in the sub-basin.

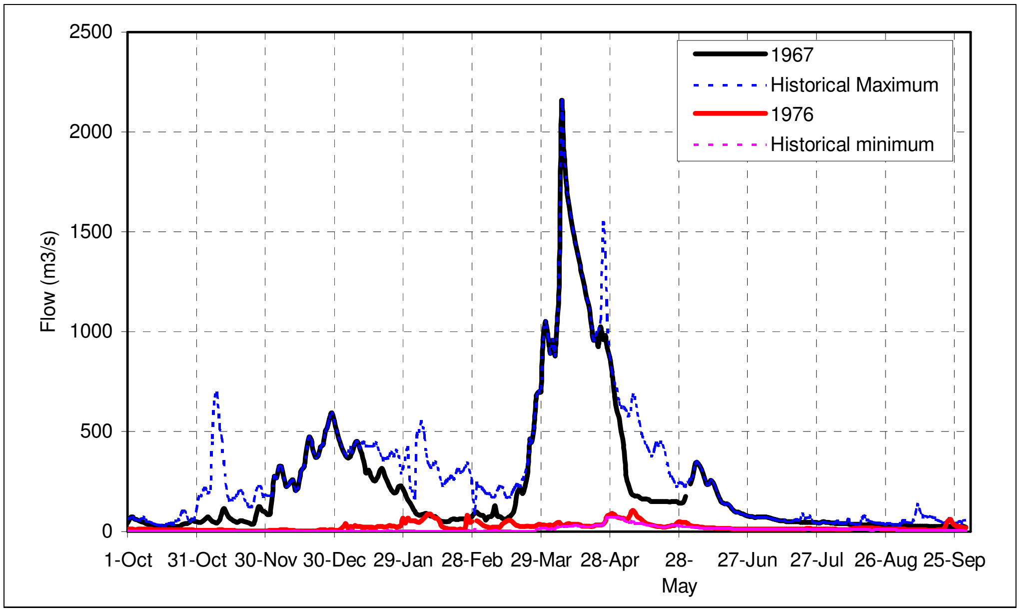
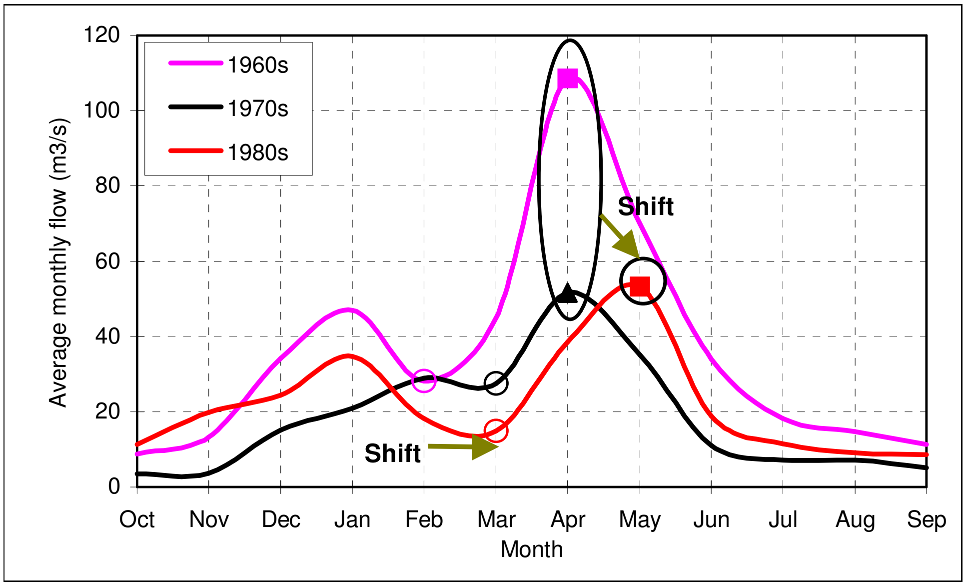


Fig 4.7 Changes of daily flow patterns in the Wami River sub-basin in wet and dry Masika at 1G2.

4.3.2 Monthly flows

One of the important observations from analysis of variability of daily flows was the changing timing of occurrence of high and low flows between the years (Figs 4.6, 4.7). Decadal average monthly flows were computed to represent the average conditions in the 1950s through 1990s. This procedure reduces the effects of one extreme wet or dry year such as 1961/62, 1967/68 and 1973/74. Results indicate consistently reducing high flows during the Masika season since the 1960s through the 1990s (Fig 4.8). Flows were extremely high in the 1960s following abundant rainfalls in the 1960s and reduce progressive to recent decades. There is an indication of shifting flow peak during the Masika from the previously peaking in April to a peak May (Fig 4.8a). This observation has also confirmed by farmers along the banks of River Wami at Mandera who used to observed high flows in April and reported a recent change towards occurrence of flood flows in late April and May. Among the major factors that could be contributing to such a condition include delayed occurrence of moderate to heavy rainfalls from early season in late March to early April to mid-late April. Although records in rivers in the Lukigura catchment did not show an evident shift, the recent high flows in April and May have similar magnitudes unlike the pre-1980s were April flows were the highest (Fig 4.8b).

Apart from reducing low flows occurring during the dry season between August and early November across the sub-basin, there is an indication of reducing flows in February and March (Fig 4.8). This is particularly evident across the whole sub-basin where unimodal flow seasonality is predominant except in the Lukigura. The changes are leading to shifting of intermediate/transition season low flows from February to March. This reduction of March flows is transforming the predominant unimodal flow regime to predominant bimodal flow regime.



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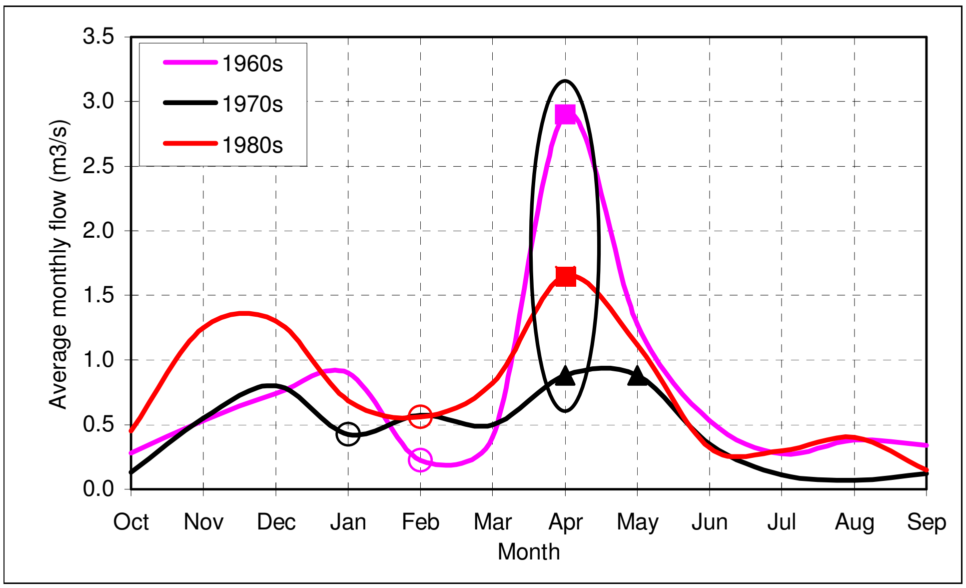


(b)

Fig 4.8 Changes of monthly flow patterns in the Wami River sub-basin a) 1G1 and b) 1GA2.

4.4 HYDROLOGICAL DELINEATION

4.4.1 Delineation criteria

The objective of this basin delineation is to divide the entire Wami sub-basin into large catchments represented by major tributaries to facilitate hydrological modelling of the sub-basin. Therefore, the criteria used in the present delineation process are

i) river should be a second order river from the main Wami and
ii) the delineation point should include rivers almost experiencing similar hydroclimatic and physiographic conditions.

From the geomorphological report of the basin, the second order tributaries of the Wami include River Lukigura, River Diwale and Rivers Mkata while the major third and fourth order tributaries are the Mkondoa and Kinyasungwe respectively. The catchment of the second order River Mkata extends between three different hydroclimatic zone, the arid upper catchments of Kinyasungwe in Dodoma, the semi-arid catchments of Mkondoa in Kilosa and the swampy areas of Mkata. To appropriately address this hydroclimatic differentiation, the delineation process had accounted for such differences. Moreover, the Mkata and Mkondoa enter the main Wami just upstream of the 1G1 gauging station while Diwale and Lukigura enter the Wami farther downstream before the last gauging station at the Mandera bridge (1G2).

4.4.2 Hydrological zones

From the criteria used in the delineation process, the Wami River sub-basin is hydrologically divided into six (6) zones, the Lukigura, Diwale, Mkondoa, Kinyasungwe, Mkata and Wami (Fig 4.9). Each zone comprises at least one gauging station with the most downstream station used in deriving the statistical characteristics of the zone.

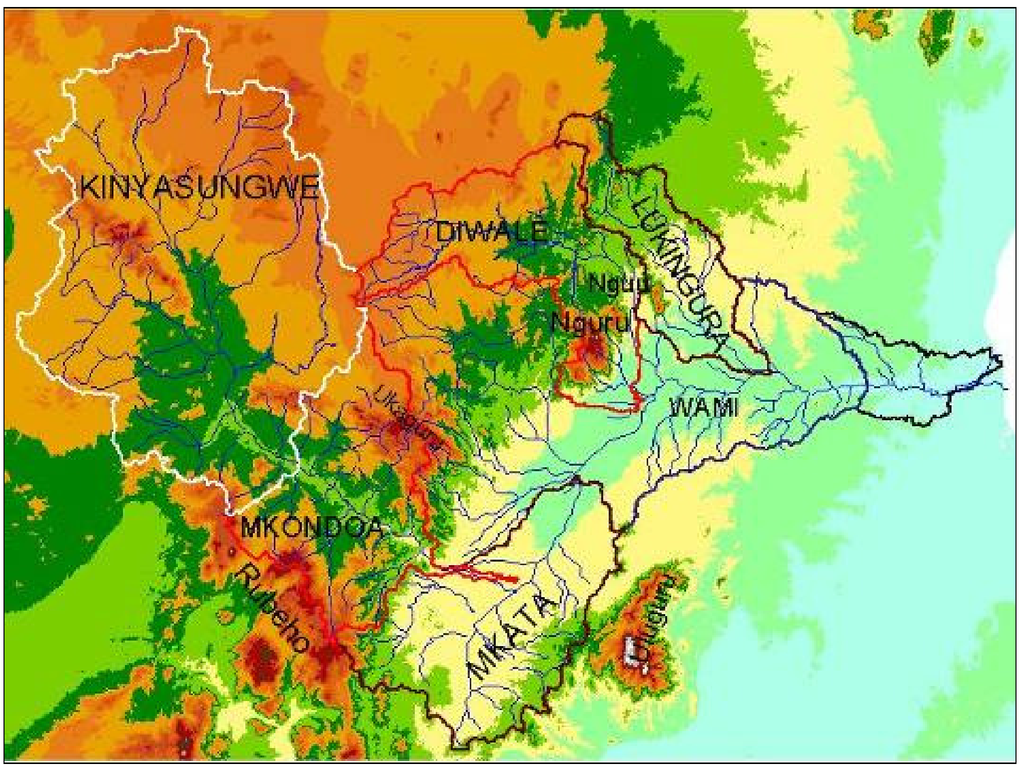


Fig 4.9: Hydrological zones of Wami.

4.4.2.1 Kinyasungwe

Regardless of the size of rivers in this hydrological zone are predominantly seasonal (intermittent and ephermeral) and usually flow during the rainy season between November and May. This is evident even in large rivers like the River Kinyasungwe (Fig 4.10) which dries out completely after the rainy season.

Flow duration curves (FDCs) constructed from daily flow records at 1GD16 and 1GD14 (Fig 4.11) illustrate this seasonal nature. The large range and steep slope of the FDC at 1GD16 indicates high intra-annual flow variability at this upstream location compared to the downstream location at 1GD14. The seasonal nature of the rivers in this Kinyasungwe zone is indicated by high percentages of time (46-53%) when rivers experience the period of no flows. This transforms to a period of flow of 6-7 months between late November and late May.

Fig 4.10: A dry River Kinyasungwe at Kongwa (1GD16) on 5th Nov 2007.

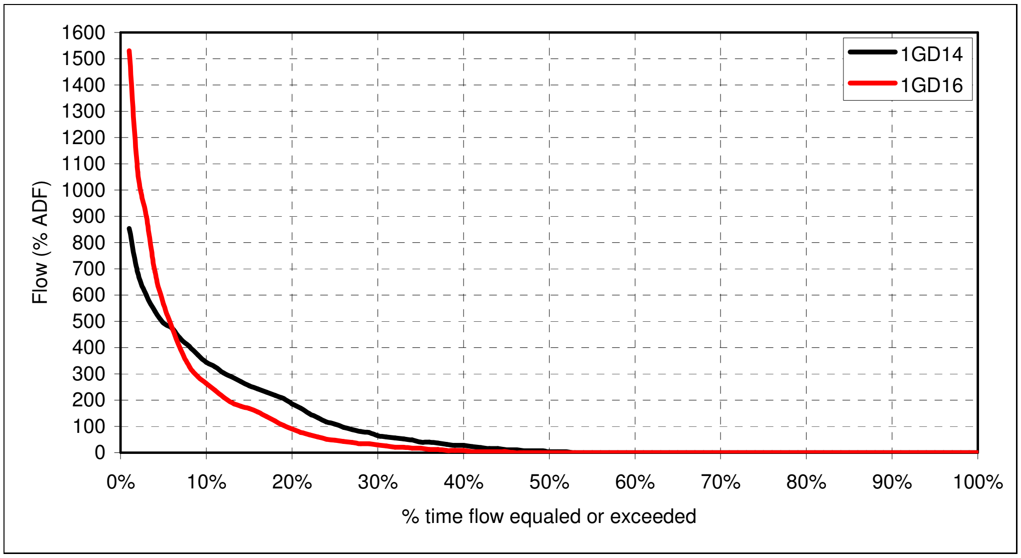


Fig 4.11: A 1-day FDC for Kinyasungwe zone.

Despite being naturally seasonal, communities living within the catchments are highly dependent on these rivers particularly for domestic and agricultural water supply. Although surface flow ceases immediately following the end of the rainy season, field survey in early November, just before the onset of the rainy season, indicated the continuation of sub-surface flow or presence of high water table beneath the main channel of the Kinyasungwe (Fig 4.12).

Fig 4.12: Evidence of subsurface flow of Kinyasungwe at Kongwa (1GD16) on 6th Nov 2007.

The predominant semi-impermeable soils, seasonal river flows and low rainfall have contributed to the construction of a number of dams in the upper catchments between 1930s and 1960s, upstream of 1GD16, to harvest the rainwater for controlling flooding, irrigation and domestic and livestock water supply. They include the Ikowa, Hombolo and Dabalo dams. With variable reservoir capacities and built across small rivers, an estimate flow of 20% of flow recorded at 1GD16 to have originated in River Majenjeule which is dammed at Ikowa, for example, is sufficient to fill the 3.107 Mm^3 Ikowa reservoir in about 2.5, 1.5 or 2 months in December, January or February respectively. This retained 30% of flow that might have reached 1GD16 from River Majenjeule might have modified flow regime at 1GD16.

4.4.2.2 Mkondoa

The largest part of flows in the Wami river sub-basin comes from headwaters of River Mkondoa and its tributaries in the Ukaguru and Rubeho mountains. Owing to moderately abundant rainfall and good soils and regardless of the size of rivers in this hydrological zone are predominantly perennial with flows throughout the year although flow variations are observed between the rainy season (November – May) with high flows and dry season (June-late November) with medium to low flows. This is evident even in River Mkondoa at Kilosa Railway station (Fig 4.13). However, flow depth is variable with cross sections of the rivers at different locations and between high and low flows.

Fig 4.13: A perennial River Mkondoa at Kilosa (1GD2) on 6th Nov 2007.

Flow duration curves (FDCs) constructed from daily flow records at various gauging stations within the zone (Fig 4.14) illustrate this perennial nature of rivers in Mkondoa. With exception of the zonal outlet at 1GD2 with a wider flow range indicating high intra-annual variability, the other rivers show moderately varying flows (50-150% ADF) occurring about 60% of the time. The steep slope at the beginning of the FDC at 1GD2 indicates high seasonal variations between the high and low flows. This FDC further indicates occasional drying up of the river during the relatively dry years such as it occurred for 17 days in October 1959.

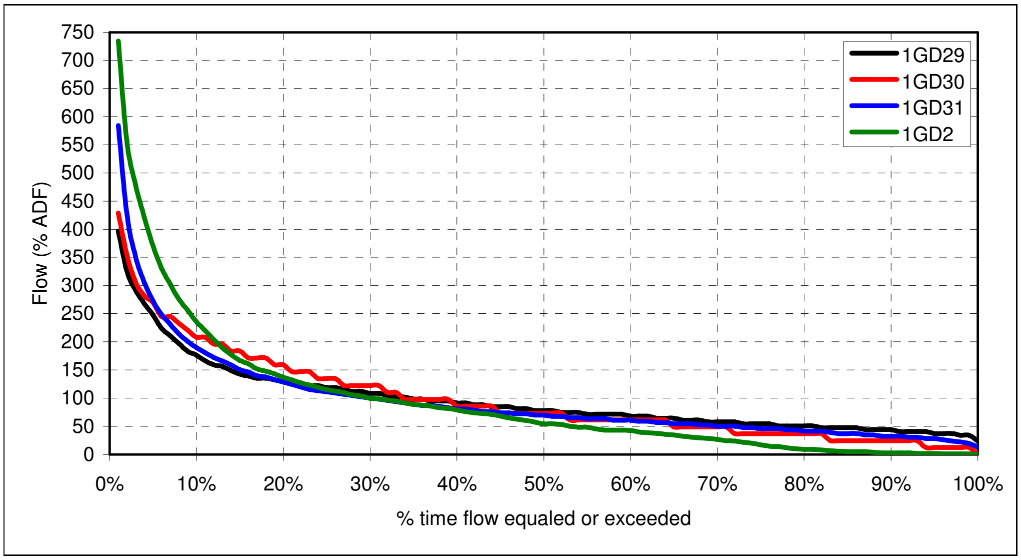


Fig 4.14: A 1-day FDC for Mkondoa zone.

4.4.2.3 Mkata

With headwaters in the small catchment of eastern Rubeho mountains, flows in River Mkata is mainly contributed by the main tributary, River Mkondoa. Unlike the Mkondoa zone, the Mkata zone is mostly an inland plain in which River Mkata (Fig 4.15) flows through the vast Tendingo swamps before joining the Wami. Occassionally each year, the river receives huge flows surpassing channel carrying capacity at its various reaches to act as the main source of water supply to the swamps. Flows from Mkondoa zone at its outlet at Kilosa contribute more than 80% of flows recorded in River Mkata. River Mkondoa enters the Tendigo swamps where it joins River Mkata. The comparison of average monthly flows into Mkata from River Mkondoa (1GD2, since flows of Myombo (1GD35) were not available) and those measured at Mkata (1GD36) (Fig 4.16) indicates significant loss of flow volume during the Vuli (October-December) and intermediate January-February seasons. The flow volume loss during this early rainy season is considered to be used in filling up the vast Tendigo swamps to their highest levels before contributing to flow increase at the downstream Mkata flow gauge since April through July. Similar to many perennial rivers in the sub-basin, rivers in this Mkata zone experience seasonal fluctuations of water levels and corresponding discharges between the high flows during the rainy season and medium to low flows during the dry season.

Fig 4.15: A perennial River Mkata at Kilosa (1GD2) on 19th September 2007.

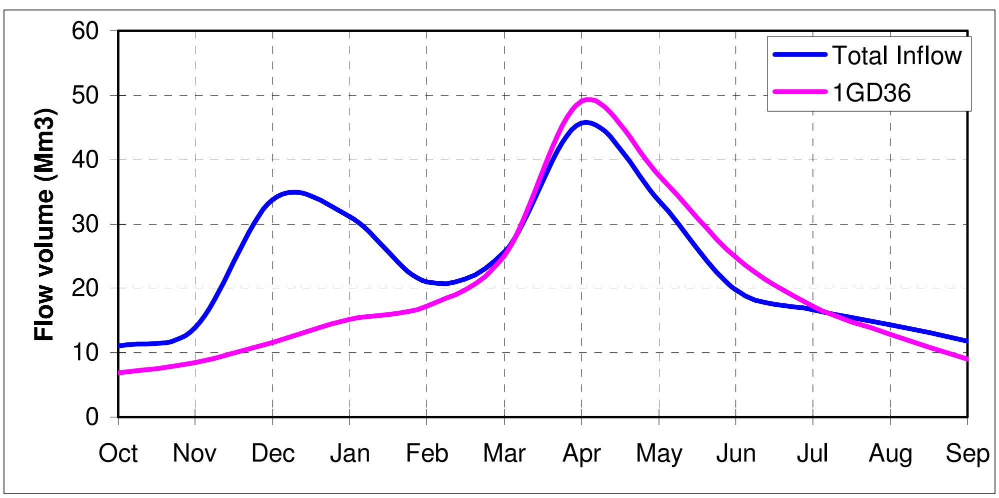


Fig 4.16: Average monthly inflows into Mkata (1GD2+1GD35) and outflow of Mkata (1GD36) for 1973-1978 period.

FDC constructed from daily flow record in the zone (Fig 4.17) resembles those for the highly contributing Mkondoa zone. The moderate flow range of flows indicating moderate intra-annual variability in which about 80% of the time flows are below 150% of ADF. The moderately steep slope at the beginning of the FDC and smoothly declining FDC at 1GD36 indicate moderate seasonal variations between the high and low flows. The zero value at the tail of the FDC indicates that, despite its perennial nature, the river can occasionally dry up as observed on 1st March 1975 following persistently low water levels following a significant La Nina induced rainfall deficit throughout the 1973-1976 period.

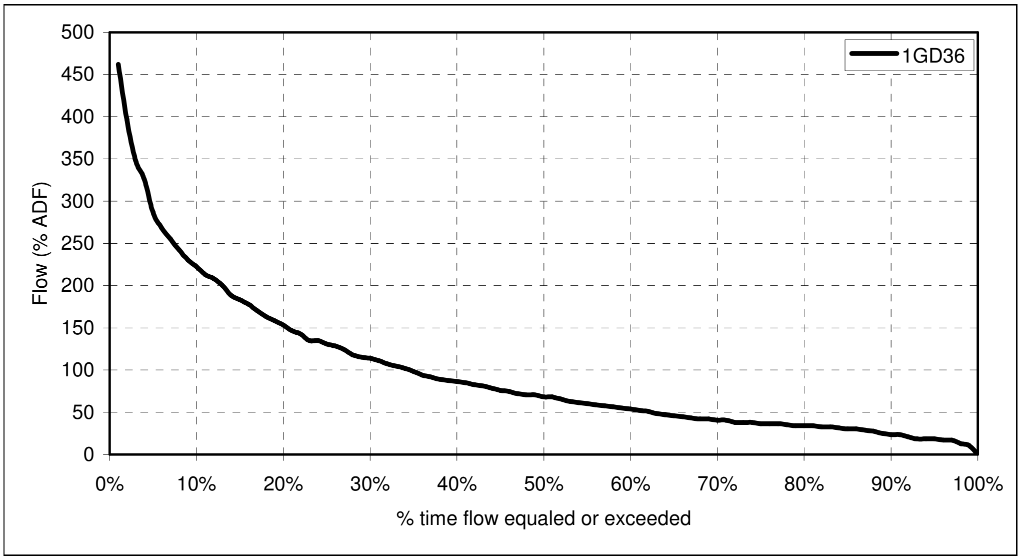


Fig 4.17: A 1-day FDC for Mkata zone.

4.4.2.4 Diwale

With headwaters in the catchment draining Nguru mountains, River Divue which drains the mountains is the major tributary of River Diwale. Owing to good soils and rainfall, rivers in the Diwale zone are mostly perennial although are experiencing seasonal variations. From its headwaters at the steep sloping rocky terrain of the Nguru mountains, River Divue immediately enters the Turiani plains at the foot of the mountains where it feeds water into the Turiani wetlands. The fertile wetlands are the major agricultural zone where small and scale farming of food and cash crops like paddy and sugarcane are practiced. River Divue joins the River Diwale (Fig 4.18) which flows into River Wami within these swampy plains. Owing to plent of water within the plains, it is assumed that there is continuous interactions between the wetlands and rivers with seasonal feeding either way. That is, the rivers feed the swamps during the rainy seasons which sustain high river flows during the dry season.

Fig 4.18: A perennial River Diwale at Mtibwa Intake on 23rd August 2007.

FDC constructed from daily flow record in the zone (Fig 4.19) resembles those for the highly contributing Mkondoa zone. The moderate flow range of flows indicating moderate intra-annual variability in which about 80% of the time flows are below 150% of ADF. The wide range and steep slope at the beginning of the FDC at 1GB1A indicate slightly high seasonal flow variations between the high and low flows. The zero value at the tail of the FDC indicates that, despite their perennial nature, rivers in this zone can occasionally dry up as observed at 1GB1A when it dried up completely for more than two months between 26th June 1981 and 29th August 1981.

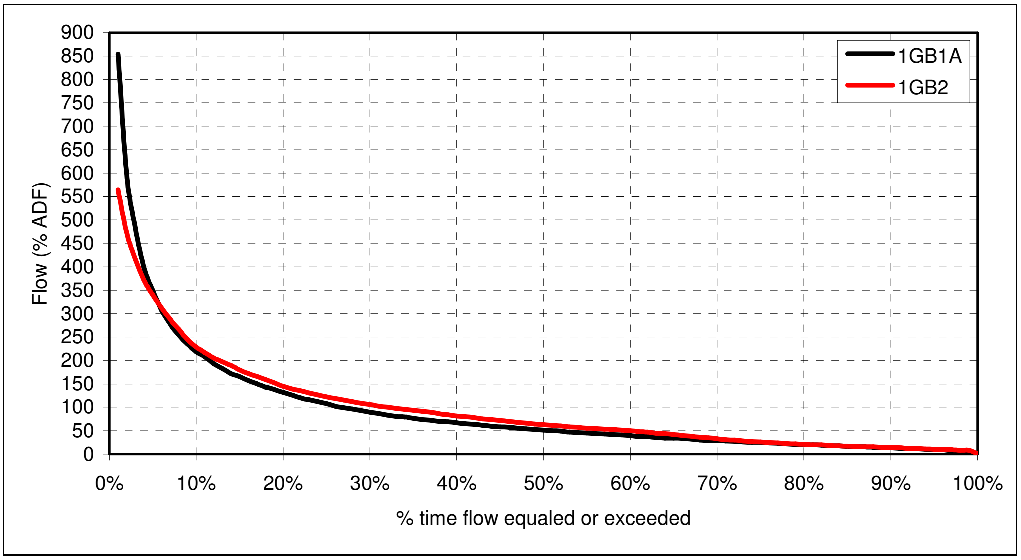


Fig 4.19: A 1-day FDC for Diwale zone.

4.4.2.5 Lukigura

Rivers in this hydrological zone drain relatively small catchments and are consequently predominantly seasonal (intermittent and ephermeral). Unlike those in the Kinyasungwe zone, most rivers like upper Lukigura (Fig 4.20), which drain the Nguu mountains and dry Maasai steppes in northern part of this zone, flow for about 10 months between late October and late August. Rivers such as Mziha, which drain the Nguru mountains, are typically perennial and experiences seasonal flow variations and less susceptible to drying up completely.

Fig 4.20: River Mziha at Mziha (1GA2) on 20th September 2007.

FDCs constructed from daily flow records (Fig 4.21) illustrate this seasonal nature. The wider range and steep slope of the FDCs indicates that rivers in this Lukigura zone experience high intra-annual flow variations. The seasonal nature of the rivers in this zone and short dry spells are existence of zero flows (30-40% of the time). Unlike the fast residing flows of Kinyasungwe, rivers continue to flow due probably to groundwater feeding of the rivers.

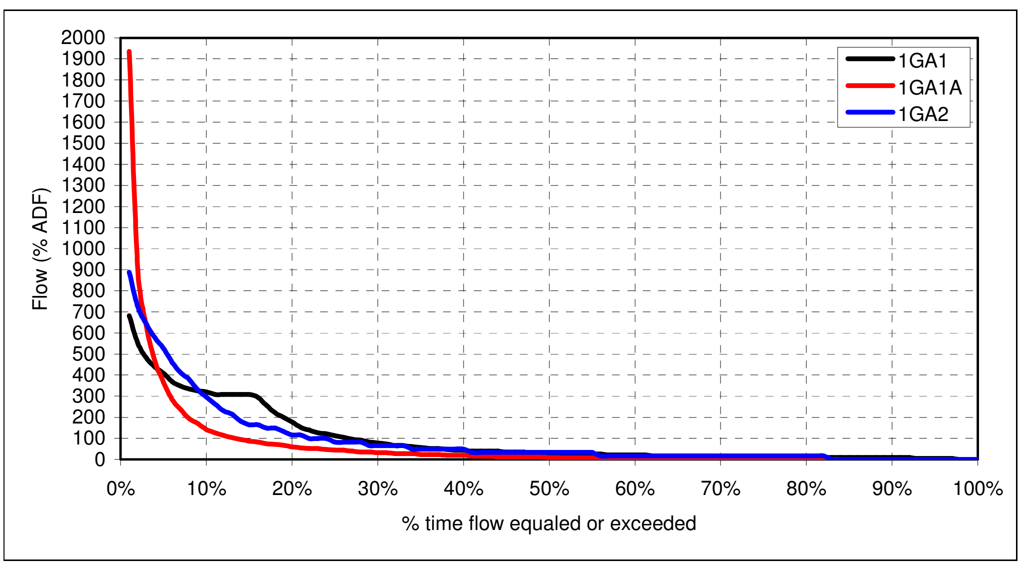


Fig 4.21: A 1-day FDC for Lukigura zone.

4.4.2.6 Main Wami at Mandera

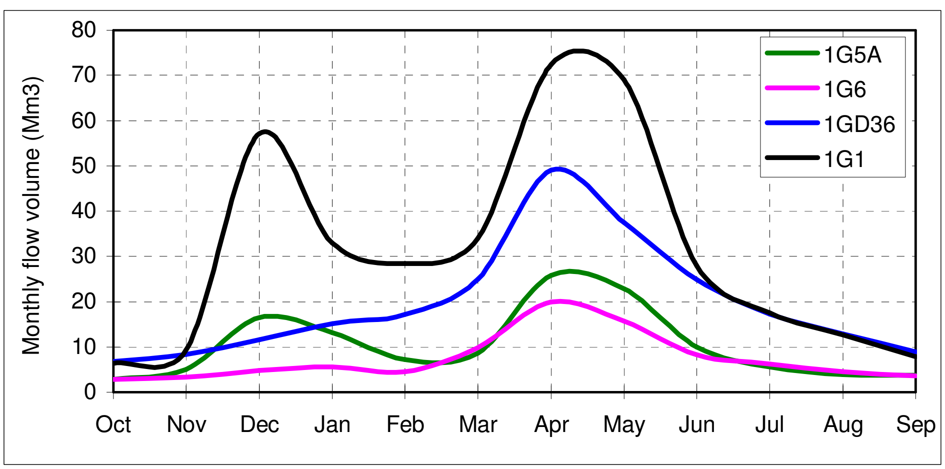
Despite infrequent low flows and some drying up, rivers in the zone of the main Wami including the upper tributaries of Tami and Kisangata are typically perennial. This perennial nature is illustrated by the upper Wami at Dakawa, middle Wami at Mandera (Fig 4.22a) and lower Wami at Matipwili village (Fig 4.22b). However, Wami river cross sections are high variable from those with wide floodplains like at Dakawa and Matipwili to those with no floodplain at Mandera. Being the resultant river of the sub-basin, the main Wami carries huge flow volumes and as often observed, it overflows at several locations to feed the vast Tendigo swamps and floodplains with water and sediments. This frequent overflows are usually experienced during the Masika rains particularly at its core in April.

Expressing flow volumes of River Mkata as precentages of flow volumes recorded in Wami at Dakawa, it indicates that the contribution of Mkata flows on Wami Dakawa flows is high and seasonally variable (Fig 4.23a). It is highest between June and November, exceeding 100% between August and October, lowest in December and moderate between January and May. The perecntages exceeding 100% suggest that some of the flows recorded at upstream Mkata flow gauge (1GD36) go to feed the swamps and do not pass the Wami Dakawa flow gauge (1G1). The high December and January flows from River Tami (1G5A) contribute significantly to flows at Wami Dakawa and recharge of the Tendigo swamps. In fact, there is flow loss between the tributaries of 1G1 (Mkata – 1GD36, Kisangata – 1G6 and Tami – 1G5A) and 1G1 from February to November (Fig 4.23b) suggesting that this water goes into recharging the swamps and is also used for dry season agriculture along Mkata and Wami river reaches in the fertile inland plains.

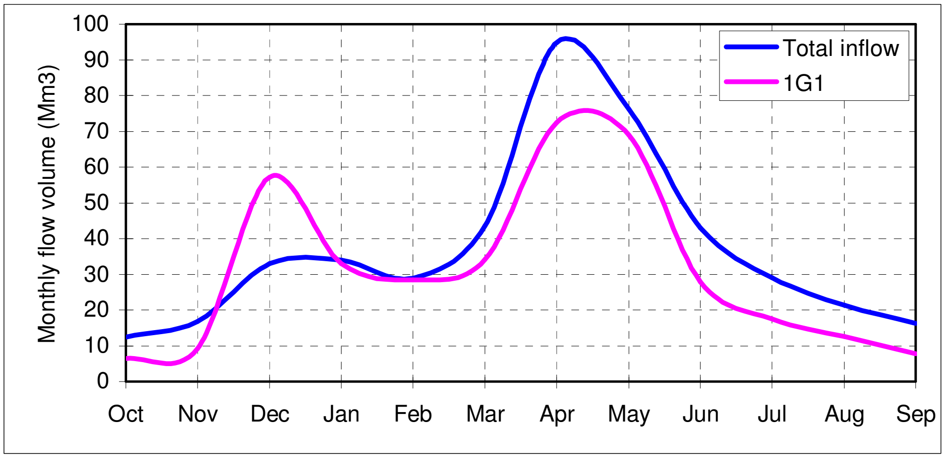
(a)

(b)

Fig 4.22: A perennial River Wami at a) Mandera bridge (1G2) on 8th November 2007 and b) Matipwili village on 9th November 2007.



(a)



(b)

Fig 4.23: Average monthly flow volumes at Wami Dakawa and its major tributaries: a) flow volumes at individual gauges and b) inflow-outflow comparison.

Water availability in Wami reaches downstream of the vast swamps, therefore, depends mainly on the process related to river-swamps water exchanges and water uses in fertile areas upstream and around the swamps. Therefore, flows from Wami Dakawa are slightly increased by flows from River Diwale, which feeds the Dakawa swamps before joining Wami some 29 km downstream of 1G1, and River Lukigura, which joins the Wami some 47 km from the Wami-Diwale Confluence and translated 47 km to Mandera (1G2).

FDCs from daily flow records at various gauging stations within the zone (Fig 4.24) indicate the perennial nature of rivers in the Wami zone with some indication of occassional drying up. With exception of wider flow ranges along the main Wami (1G1 and 1G2) indicating high intra-annual variability, the other rivers show moderately varying flows (50-150% ADF) occurring about 45% of the time. Despite the steep slope at the beginning of FDCs (0-15% of time), the curves are gently sloping thereafter indicating slightly less seasonal variations between the high and low flows. This FDC further indicates occasional drying up of the river during the relatively dry years.

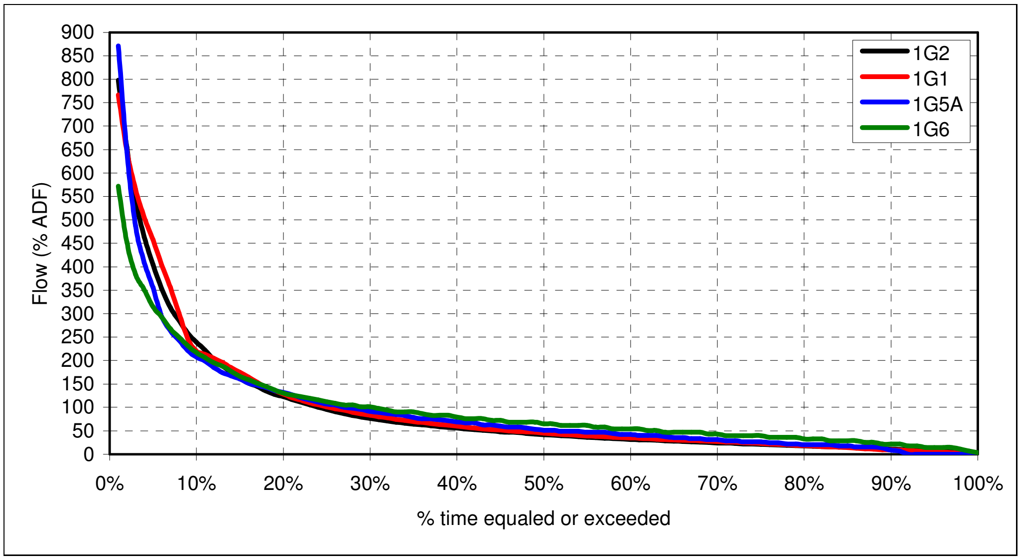


Fig 4.24: A 1-day FDCs for Wami zone.

4.5 CONCLUSIONS

Spatio-temporal variations of river flows that are relevant for ecological and geomorphological functions in Wami River sub-basin were presented followed by a prelminary delineation of the sub-basin into six hydrological zones. The analysis of average daily and monthly flows indicated the transitional flow regime between the bimodal (two distinct peaks) and unimodal (single peak) flow regimes, with the predominance of unimodal regime with a well-defined peak in April-May during the Masika (long) rains. Whilst lowest flows were experienced during the long 1973-1976 La Nina event affecting flows throughout the year, the occurrence of highest flood flows was not simultaneously in both Vuli (December-February) and Masika (April-June) flow seasons. Monthly flows further indicated decline peak flows between 1960s and 1990s and shifting peak flows from April to May and intermediate low flows from February to March transforming the flow regime towards predominantly bimodality.

The hydrological characterisation of river flows indicated that Wami river sub-basin comprises various types of rivers including ephermeral, intermittent and perennial rivers which reflect the climatic and physiographic characteristics of the zone they originate and traverse. The analysis of flow duration curves (FDCs) indicated that high intra-annual flow variations within and between the zones. In a particular zone, it has been observed that seasonal flow variations increases from upstream to downstream as indicated by increasing flow range. Comparison of zonal flow variations differentiated between perennial central and lower zones of the sub-basin (Mkondoa, Mkata, Diwale and Wami) and seasonal (Lukigura, Kinyasungwe) zones. Analysis of the inflows into and outflows from the Tendigo swamps indicated that River Mkondoa is responsible for early filling of the swamps between November and February while flows in the Mkata, Kisangata and Tami are responsible for continual filling between March and October. This swamps-river exchange relationship is important to amount of water that is available in river reaches located downstream of the swamps.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Surface water resource of Wami

The Wami River Sub-basin comprises four (4) different wetlands systems are which are palustrine, riverine, lacustrine and estuarine systems. Riverine system is the largest wetlands system in Wami River sub-basin and comprises mainly rivers and floodplains. Many large rivers in the sub-basin such as the Wami, Mkata and Mkondoa and a few small rivers are perennial while others like the Kinyasungwe as well as many small rivers are ephemeral. The Tendingo and Dakawa swamps are the major palustrine (vegetated) wetlands in the Wami sub-basin extending almost the whole length of the inland plain zone. Estuarine wetlands are found along the coastline of Bagamoyo at Saadani where River Wami discherges into the Indian Ocean. A few natural lakes such as Lakes Nzuhe and Gombo as well as several manmade lakes (reservoirs) including Lakes Hombolo, Ikowa and Dabalo constitute the lacustrine wetlands of Wami.

5.1.2 Water abstractions

There exists a number of largescale water abstractions by dams and smallscale individual abstractions through water rigths. The chapter has further indicated the spatio-temporal variations of existing icenced water abstractions in the Wami River sub-basin. Temporally, water rights have been issued since the late 1950s (in 1958) through the 1960s, 1970s, 1980s, 1990s to 2000s. Although the a few water rights were issued in the 1950s, 1960s and 1980s, a number abstracting significant amounts were issued in the 1970s and 2000s. Spatially, largescale water abstractions are practiced in dry upper catchments of Wami in Dodoma through a series of dams. Significant directly abstractions from the river characterise the Lumuma tributary of River Mkondoa and Miyombo tributary of River Mkata which are located on the upstream of Tendigo swamps as well as along the main Wami at Dakawa and Turiani. There is little licenced water abstractions in River Mkata which entirely lies within the Tendigo swamps. The existence of unregistered (or illegal) water abstractions was also highlighted.

5.1.3 Flow variability

The hydrological characterisation of river flows indicated that Wami river sub-basin comprises various types of rivers including ephermeral, intermittent and perennial rivers which reflect the climatic and physiographic characteristics of the zone they originate and traverse. Spatio-temporal variations of river flows that are relevant for ecological and geomorphological functions in Wami River sub-basin were presented followed by a prelminary delineation of the sub-basin into six hydrological zones. The analysis of average daily and monthly flows indicated the transitional flow regime between the bimodal (two distinct peaks) and unimodal (single peak) flow regimes, with the predominance of unimodal regime with a well-defined peak in April-May during the Masika (long) rains. Whilst lowest flows were experienced during the long 1973-1976 La Nina event affecting flows throughout the year, the occurrence of highest flood flows was not simultaneously in both Vuli (December-February) and Masika (April-June) flow seasons. Monthly flows further indicated decline peak flows between 1960s and 1990s and shifting peak flows from April to May and intermediate low flows from February to March transforming the flow regime towards predominantly bimodality.

5.2 RECOMMENDATIONS

Among the major key issues that have revealed in the general hydrological characterisation of the Wami River Sub-basin include

i) the spatio-temporal variations of river flows,
ii) the spatio-temporal changes of water uses in the sub-basin and
iii) the riverine-palustrine wetlands interactions.

Using available flow data that span the different periods of the 1952-2007 grand period, it was only possible to highlight the nature of flow variability in Wami in both time and space. However, the lack of reliable observed data necessitated the selection and reconstruction of suitable records that were used in the analyses. Although it was als possible to highlight the relationships between seasonal flows variations and swamps seasonality, the analyses could not establish any physical water balancing tool that accounts for the exact river-swamps relationships. Given the current limited knowledge of the riverine-palustrine wetlands relationships, the estimated flows at locations downstream of the swamp could be affected by changes of water uses and losses around swamps which are agriculturally the most productive areas of the sub-basin. As a follow up to this general hydrological characterisation, another independen study is planned to detail study the riverine-palustrine wetlands relationships through the application of hydrological models. The study will form the basis for future investigation of the water availability situation to downstream reaches due to changes (land and water use) that might occur around the swamps.

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