Ministry of Natural Resources and Tourism
Forestry and Beekeeping Division

Conservation and Management of the Eastern Arc Mountain Forests Project

Hydrological Analysis for the Eastern Arc Mountain Forests

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Executive summary

This report presents the results of a consultancy assignment named ‘Hydrological Analysis of the Eastern Arc Mountain Forests’ that was awarded to the Bureau of Industrial Cooperation (BICO) of the University of Dar es Salaam by the Ministry of Natural Resources and Tourism through the Forestry and Beekeeping Division. The study started in February 2005.

The main objectives of the study were:

a. To prepare an inventory of available data on river flow, rainfall and water quality of the rivers flowing from the Eastern Arc Mountains to the Indian Ocean, specifically for the rivers Sigi, Pangani, Wami, Ruvu, Kilombero, Ruaha and Kihansi;
b. To carry out an analysis of the changes in the quantity and quality of water flowing in the major rivers draining from the Eastern Arc Mountains over time and also to carry out an analysis of the changes in the rainfall amounts;
c. To undertake an analysis of the shape of the water flow peaks over time;
d. To identify the gaps in understanding the relationship between changes in forest cover with changes in the water quantity and quality in the rivers flowing from the Eastern Arc.

The results of the study are designed to contribute to the conservation of the river catchments draining the Eastern Arc Mountains in Tanzania.

Data inventory

A search for data and information of relevance to the study of the EAM was carried out in order to prepare an inventory of available data on river flow, rainfall and water quality for the Sigi, Pangani (Mkomazi and Luengera), Wami, Ruvu and Kilombero rivers draining the Eastern Arc Mountains.

An inventory of 49 flow gauging stations in Sigi, Pangani (Mkomazi and Luengera), Wami, Ruvu and Kilombero basins / sub-basins has been established. The distribution of stations basin-wise is 11 in Pangani (eight in Mkomazi and three in Luengera), three in Sigi, 15 in Wami, 10 in Ruvu and 10 in the Rufiji (Kilombero). Out of the 49 stations, 23 were established in the 1950s, 19 in the 1960s while only six stations were established in the 1970s. Basin-wise, the earliest stations which were established in the 1950s and 1960s are found in the central and southern basins of the Eastern Arc Mountains.

A total 335 rainfall stations have been identified to be operational within Sigi, Pangani (Mkomazi and Luengera), Wami, Ruvu and Kilombero. The stations were identified from the database with the Tanzania Meteorological Agency. The distribution of stations basin-wise is 49 in Pangani (39 in Mkomazi and 10 in Luengera), two in Sigi, 109 in Wami, 75 in Ruvu and 90 in the Kilombero. Out of the 335 stations, 86 were established before the 1950s and 205 before 1970s.

The results of the search for water quality data revealed the following:

a. There has never been a continuous monitoring program of water quality parameters in the stream draining the EAM zone. Continuous water quality data is therefore not available. However, an inventory of some of the water quality data available in the Eastern Arc Mountains has been documented. The available data are non-continuous.
b. Water quality parameters were only measured at a given location and time on specific request; such data is thus irregular in space and time and therefore has only limited use to reveal spatial or temporal trends.

c. Most of the water quality surveys documented were conducted to assess if potential sources could be used for domestic water supply, rather than for characterizing the stream flow quality at different locations.

During this consultancy, field trips were carried out in the northern portion (7^{th} – 13^{th} February 2005) central portion (18^{th} – 22^{nd} May 2005) and southern portion (19^{th} – 23^{rd} June 2005) of the EAM. The aim was to collect hydrological and physiographic data for verification of catchment characteristics / land cover and to understand the terrain, which is important in studies of water delivery and water quality processes. Moreover, the field trips provided an insight to sources of pollution in the river flows as well as allowing a field-assessment of the condition of the gauging stations and the reliability of measurements obtained from them.

The majority of the gauging stations that were visited during the field work were found not to be operational, in the sense that the recording instruments such as staff gauges and water level recorders were missing. The result is that water levels are not being recorded and consequently there are large gaps in the data sequence, especially in recent years. Some of the river gauging stations visited are also under threat of disturbance by human activities such as sand, gemstones and gold mining.

Analysis of rainfall in the EAM

Rainfall variation in the Eastern Arc Mountains has been studied to detect changes in rainfall amounts over time. The analyses were performed at both seasonal and annual timescales. The four seasonal timescales considered in the study include the two main rainy seasons, i.e the October-November-December (OND) short rains and March-April-May (MAM) long rains, the intermediate January-February (JF) season and the “dry” June-July-August-September (JJAS) season. The procedure adopted to identify gradual changes in rainfall amounts was linear trend analysis.

Seasonal rainfall analysis indicated that the rainy season is bimodal in the northern zone basins (Mkomazi, Luengera and Sigi), unimodal in the southern Kilombero basin and a transition between bimodal and unimodal in the central zone basins (Wami and Ruvu). The bimodal areas observed two main rainy seasons, the short rains (October-December) and the long rains (March-May) with a January-February transition period of reduced rains.

Long records of rainfall indicated increasing rainfall amounts during the short rains (OND) and the intermediate JF season and decreasing rainfall amounts during the long rains (MAM) and the following dry JJAS period. The rainfall increases were mainly attributed to higher rainfalls in the 1960s and 1970s than the period before. However, between the 1960s and the present, the high rainfall amounts during the two decades (1960s and 1970s) compared to those in the 1980s and 1990s resulted in decreasing trends in almost all seasons.

Analysis of stream flow in the EAM

Flow series indicated seasonal patterns that match those in rainfall with periods of high flows during the rainy seasons and low flows during the transition and dry periods. The results of linear trend analysis on annual flows indicated the following:

a. General flow declines in the Sigi, lower Luengera and Wami basins. The slopes of the linear trends were however insignificant.
b. Flow increases in the Mkomazi and upper catchment of Luengera. A mixture of flow decrease and increase in the Ruvu and Kilombero basins. The main Ruvu River indicated flow declines, but two of the tributaries joining the main river (Mgeta and Ngerengere) experienced flow increase. Flow decrease in the main Ruvu River was statistically significant. A mixture of increasing and decreasing annual flows was observed in the tributaries of the Kilombero River. The trends were however

statistically insignificant except at 1KB15 and 1KB15A which experienced significant flow increase.

Seasonal flows, on the other hand, indicated the following:

a. The predominance of declining flows during the long rains (March – May) in the northern zone basins (Sigi, Luengera and Mkomazi) and central zone basin (Ruvu and Wami) and also during the dry season (June – September), intermediate season (January – February) and the short rains (October – December), particularly in the central zone basin.
b. A mixture of increasing and decreasing flows during the short rains, intermediate season and the dry season in the northern and southern basins.
c. High flow contribution during a given season has a significant influence on the changes of annual flows.

The comparison of linear trends in stream flow and rainfall records indicated that in most cases, the nature of trends in seasonal rainfalls is comparable with that of stream flows when long records are analysed.

Water quality study
Water quality analysis indicated the following:

a. There is no continuous monitoring program of water quality parameters in the stream draining the EAM forests. It is therefore not easy to obtain continuous data for trend analysis.
b. Water quality parameters have been measured at a given site and time, on specified request, and this data is therefore irregular in space and time.
c. Most of the water quality surveys documented were conducted for qualifying water sources for domestic supply at their potential supply sources rather than for characterizing the stream flow quality at different locations. This includes borehole data, which is not directly applicable to this study.
d. During the period 1970-1980 it is reported that there was significant forest cover change in the Usambara Mountains, which may have affected the river flows. Remedial measures taken from 1986-1987 to conserve the forests may bring changes on the river flow trends beyond 1987.
e. The shift to the lowlands from the hill slopes by a large number of people in Same district between 1968 and 1970 may have an impact on the Pangani and Mkomazi river water quantity and quality.
f. There have been changes of forest cover in the Udzungwa mountains Rufiji River basin since 1950's. The change is due to poor farming techniques, fire outbreaks, forest invasion and subsequent deforestation.
g. More than 70% of the population in the study area uses pit latrines.
h. Many are ignorant of pollution they cause to the river by daily life practices like washing etc.
i. In areas with intensive agricultural activities, people cultivate up to the river bank.
j. Intensive horticulture practices with an intention to fast harvests have intensified the application of artificial fertilizers, herbicides and pesticides in the study area.

Recommendations

Data availability
One of the major constraints towards achieving conclusive results was the availability and quality of data. The data available was either for a short number of years or contains a lot of gaps. These characteristics limited to some degree the analysis of rainfall and stream flow

variations. In addition the most recent data, as observed during the field visits, is missing and many of the stations are not operational because the recording instruments are missing or not operational. Furthermore, there is a lack of flow stations, appropriate for studying the impact of forest cover on river flow regimes in some of the areas of the EAM. With regard to water quality monitoring, it has been observed that it is not regular. In this regard, it is recommended;

a. To appeal to the agencies responsible for the collection of hydrological and climatological data to take remedial measures to rehabilitate the non-operational stations.
b. To install new gauges at suitable sites close to, or within, the forest areas to investigate interactions between the forest cover and stream runoff. These include flow gauging stations, rainfall stations, climatic stations and observation wells for subsurface conditions.
c. The communities should be sensitized not to tamper with gauging stations equipment by indulging in sand or other mining activities.
d. To urge the agency (or Ministry) responsible for water quality monitoring in the country to establish a regular monitoring network for water quality.

Modelling studies

In order to quantify the impacts of forest changes (deforestation and afforestation) on river flows, it is important to carry out modeling studies preferably for small forested catchments to understand the interactions between the forest cover, surface and subsurface water. In this case distributed models are appropriate. However, such models require extensive data sets that can only be assured once additional flow gauges, rainfall and climatic stations and observation wells are installed. Whilst observation wells, within the study catchments, will provide information regarding the subsurface conditions (e.g. groundwater fluctuations), river flow gauges will provide the resulting surface flow fluctuations while rainfall and climatic stations will provide information on the background climatic fluctuations. Monitoring of vegetation cover changes can therefore be linked to these hydro-geoclimatic fluctuations once suitable distributed models have been calibrated for selected forested catchments.

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Acronyms

ADF	Average daily flow
BICO	Bureau of Industrial Cooperation
BOD	Biochemical oxygen demand
DEM	Digital elevation model
DO	Dissolved oxygen
EAM	Eastern Arc Mountains
FDC	Flow Duration Curves
GIS	Geographicl Information System
GTZ	German Development Agency
JF	January-February
JJAS	June-July-August-September
MAM	March-April-May
MORUWASA	Morogoro Urban Water Supply and Sanitation Company
OND	October-November-December
SECAP	Soil Erosion Control and Agroforestry Program
TDS	Total dissolved solids
TLRM	Total linear response model
TMA	Tanzania Meteorological Agency
ToR	Terms of Reference
TSS	Total suspended soils
UCLAS	University College of Lands and Agricultural Studies
UH	Unit hydrographs

1 Introduction

The Ministry of Natural Resources and Tourism through the Division of Forestry and Beekeeping commissioned the Bureau of Industrial Cooperation (BICO) of the University of Dar es Salaam to undertake the Hydrological Analysis of the Eastern Arc Mountains. The implementation of this assignment started in February 2005.

The main objectives of the study were:

a. To prepare an inventory of available data on river flow, rainfall and water quality of the rivers flowing from the Eastern Arc Mountains to the Indian Ocean, specifically for the rivers Sigi, Pangani, Wami, Ruvu, Kilombero, Ruaha and Kihansi.
b. To carry out the analysis of the changes in the quantity and quality of water flowing in the major rivers draining from the Eastern Arc Mountains over time and also to carry our the analysis of the changes in the rainfall amounts.
c. To identify the gaps in understanding the relationship between changes in forest cover with changes in the water quantity and quality in the rivers flowing from the Eastern Arc.

The results of the study will contribute in the conservation of the river catchments draining the Eastern Arc Mountains.

The Eastern Arc Mountains stretch for some 900 km from the Makambako Gap, southwest of the Udzungwa Mountains in southern Tanzania to the Taita Hills in south coastal Kenya (Figure 1) (Lovett & Wasser 1993). They comprise a chain of twelve main mountain blocks, from south to north: Mahenge, Udzungwa, Rubeho, Uluguru, Ukaguru, Nguru, Nguu, East Usambara, West Usambara, North Pare, South Pare and Taita Hills. All of these blocks except Taita Hills are located in Tanzania.

The Eastern Arc Mountains are covered by temperate forests and woodlands. It is estimated that the forests covering the mountains have been in existence for the last 30 million years and in the far past the forest cover of Eastern Arc Mountains was connected to the Congo River basin forest and the West African forests. (Prell et al., 1980; Lovett and Wasser, 1993). The forests are now considered to have huge biological and hydrological importance to the country.

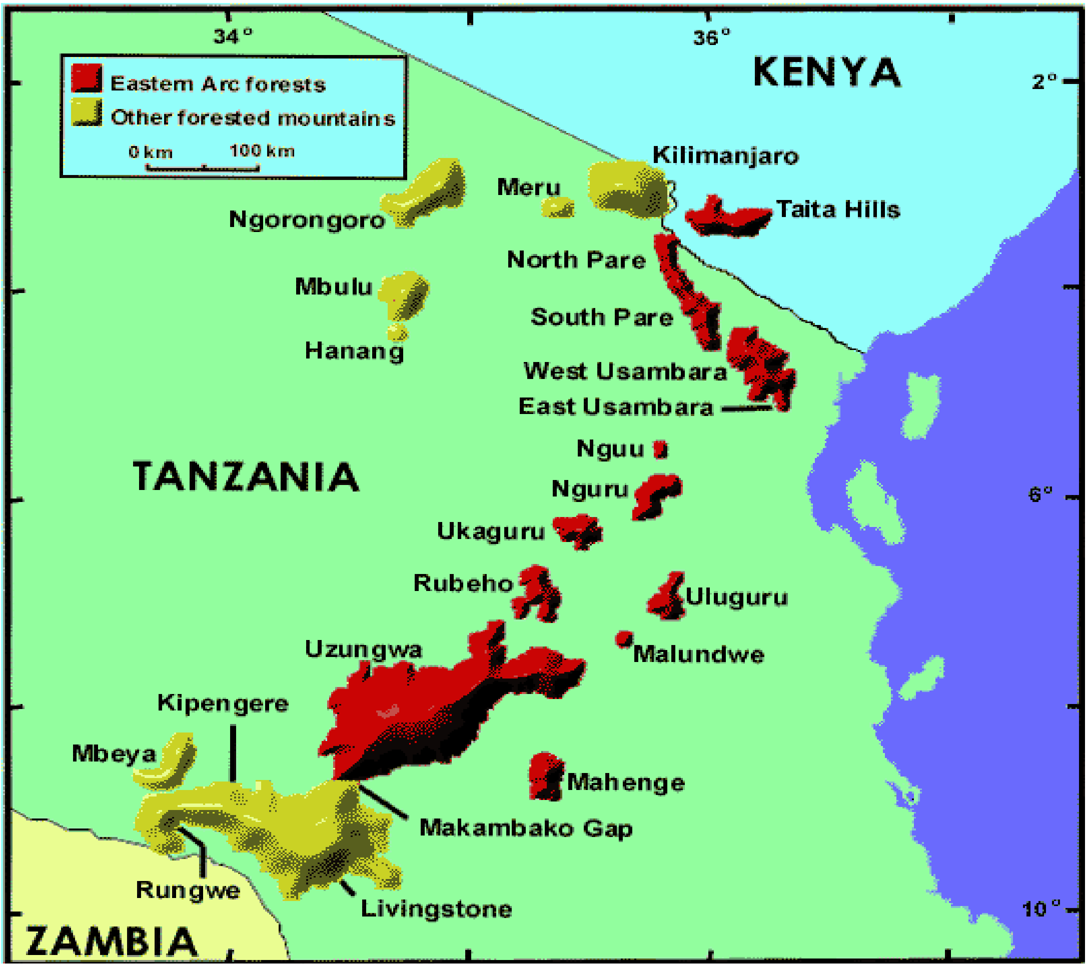


Figure 1 Location map of the Eastern Arc Mountains
Source: easternarc.org/html/map.htm

From detailed analysis of land cover maps, the total size of Eastern Arc Mountain blocks in Tanzania is 3,815,348 ha of which forests occupy 348,204 ha and woodlands 1,139,952 ha. The largest forest and woodland areas occur in Udzungwa block while North Pare block has the smallest area. It was revealed also that areas adjacent and surrounding forests are intensively cultivated. Without proper planning and management of the buffer areas, this might lead to increased illegal encroachment into protected areas (FBD, 2006).

A forest change detection analysis (FBD, 2006) found that in all Eastern Arc Mountain blocks, forest cover has been more stable than woodland because most forests are in protected areas. Higher degradation of woodlands has been observed in the 1970s-1980s compared to the periods of 1980s-1990s and 1990s-2000. The highly populated blocks of South Pare, West Usambara, North Pare and Uluguru are more affected compared to low populated ones. However, even though the rate of loss has declined towards 2000, this does not necessarily mean that the forest condition is becoming better in the Eastern Arc Mountains. Whereas deforestation for agriculture has stopped at the forest borders, illegal harvesting inside the forest is in progress and this cannot be detected by remote sensing.

1.1 Hydrological importance

The Eastern Arc Mountains are directly linked to the Indian Ocean. Incoming air masses from the ocean are forced to rise, cool and is converted to precipitation on the mountains. This phenomenon, known as the orographic effect, is responsible for availability of stable rainfall which produces sufficient runoff and groundwater recharge. Lower temperatures on the slopes of these mountains result in lower evapotranspiration rates so that the overall water balance is positive. In general the low lands immediately adjacent to these mountains have less precipitation and high evapotranspiration rates, resulting in negative water balance. The main source of water for the lowlands which are the main population centres is therefore from the Eastern Arc Mountains.

The Eastern Arc Mountains are the source of water for major rivers in Tanzania which are used for power production, irrigation and water supply. The mountains maintain the base flow in rivers making water available during dry season. More than 3,000,000 people or roughly 10% of Tanzanian population living in Dar es Salaam, Morogoro and Tanga depend on water supply derived from rivers draining from the Eastern Arc Mountains. In addition Eastern Arc Mountain rivers including Kihansi, Great Ruaha and Pangani have important hydropower plants which provide roughly 50% of the hydropower in the National grid. Of late, hydropower generation has been facing problems due to shortages of water during the dry season which have led to concerns about proper management of the head water catchments including upland forests to ensure stable river flow for hydropower generation.

Rivers draining from the Eastern Arc Mountains also support various irrigation schemes producing food and cash crops as well as providing employment to rural communities. The main irrigation schemes are located in Kilombero, Wami and Great Ruaha River basins. The commonly irrigated crops are sugar, rice and horticultural products. The Great Ruaha River basin is famous for sugar plantations in Kilombero and Mtibwa estates.

1.2 Water quality

In most forest conservation programmes one of the primary concerns is on water quality. Human beings require clean water for drinking, cooking, bathing and playing. Relevant authorities are often obliged to treat impure water so as to meet these needs. In addition to human needs, clean water is also required by aquatic living organisms. These organisms include different species of mussels and fish.

Protecting water quality demands a cooperative effort from everyone involved in land use and / or forest management. If not handled properly, these activities and conditions can adversely affect water sediment / turbidity, chemistry, and temperature.

Sediment / turbidity

The effects of sediment / turbidity are obvious in terms of reducing water quality. The scope of the potential damage to both aquatic and human habitats makes it critical that catchment managers seek to prevent erosion and sedimentation from forest and agricultural lands and through helping eroded areas to recover.

Chemistry

A number of contaminants can change the chemical makeup of surface and ground water, which in turn adversely affects all aquatic life that depends on a certain water environment. Mineral soil and organic matter derived from erosion and runoff represent major problems, though leaks and spills of petroleum products from logging equipment and vehicles can also contribute. Harvesting timber can also increase the rate at which the forest floor releases nutrients into water sources, increasing nutrient concentrations in streams and other surface water temporarily. Nitrogen, in particular, tends to increase noticeably in streams immediately after a timber harvest. Even without harvests, human made pollutions such as the use of pesticides and fertilizers can be major sources of pollution from catchment areas. Most of the commercial timber harvesting in the Eastern Arc Mountains is within commercial softwood plantations, and not in the natural forests – here commercial harvesting is allowed – although illegal pitsawing is commonplace.

Temperature
Thermal pollution represents another major danger to water quality because water temperature plays a key role in aquatic life. Water temperature helps determine how much oxygen is available for aquatic organisms, as well as their rate of metabolic activity. At the most basic level, all aquatic animals have an optimum temperature range; above or below that range, the animals experience physiological stress and, at temperature extremes, die. Temperature affects the types of species present; the timing of fish spawning and migration; animal growth and development rates; concentrations of dissolved gases; and decay rates, all of which are crucial to a healthy, balanced ecosystem.

To help preserve that balance, trees and other vegetation along stream channels serve as important temperature regulators by protecting the water from the sun's direct rays and maintaining water temperatures within appropriate ranges. Cutting these trees and clearing the vegetation exposes the water and increases the stream temperature, which in turn disrupts aquatic life cycles. The above water quality indicators are universal either for commercial and natural forests. These indicators will be used to study the impact of forest change in the Eastern Arc Mountain forests on water quality.

1.3 Ecosystem threats in the Eastern Arc Mountains

The main visible impact of the land mismanagement in the Eastern Arc Mountain is the depletion of forest cover. It is estimated that about 2000 years ago the forest cover on the Eastern Arc Mountains was 23,000 km^2, which reduced to around 15,000 km^2 by 1900 and to 5,340 km^2 in mid 1990s (Newmark, 1998; GEF, 2002). The remaining forest on the mountains is highly fragmented with mean and median forest patch sizes estimated at 10 km^2 and 58 km^2, respectively. In most cases the patches are highly degraded and do not contain a close forest cover. By 1994-96 there were an estimated 94 forest patches in the Eastern Arc Mountains of which only 27 percent had closed forest cover. The situation is likely to deteriorate further without a deliberate effort to stop the degradation trend. One result of the degradation is that an estimated 34% of the species in the West Usambara Mountains have become extinct or are in a danger of extinction (Newmark, 1998).

Analysis of some mountain blocks shows that the forest area in the Uluguru Mountains declined from around 300 sq. km in 1955 to 230 sq. km in 2001, which was <40% of the potential forest area (Burgess et al., 2002).

Using the results of the study by FBD (2006), it is shown for the Udzungwas that over a span of 12 years between 1979 and 1991, woodlands declined more compared to the forests. Between 1991 and 2000 there was no change in forest cover while woodlands decreased slightly. For the entire period between 1979 and 2000 the change of both forest and woodland is more or less similar to that of between 1979 and 1991 indicating that this period is responsible for much destruction.

In the Pare and Usambara blocks, much forest and woodland destruction occurred in the period between 1979 and 1991. However in these blocks, there is a greater percentage forest decline compared to the Udzungwa block. This could be explained by human population differences in these areas. While Pare and Usambara Mountains are highly populated, the Udzungwa block is far less populated.

In Nguu and Nguru blocks, the decline in woodland cover was more than 50% over a span of 20 years between 1970 and 1990 while thereafter lower declines were observed.

In Uluguru, Ukaguru, Rubeho and Malundwe blocks, more forest and woodland decline was observed in Uluguru block between 1970s and early 1990s when compared to Ukaguru, Rubeho and Malundwe over the same period. This is also explained by the greater population pressure in the Uluguru Mountains. As was the case with other blocks, forest decline was relatively less compared to the woodland. The period between 1990s and 2000 showed lower rates of forest and woodland destruction in the Uluguru, Ukaguru and Rubeho blocks.

In Usagara and Mahenge blocks, there was not much forest and woodland cover decline in the 1979-1999 periods as compared to other blocks. These areas are remote and less populated and have vast woodland and forest outside reserves. This could explain the observed far less forest and woodland decline.

Overall observations

a. In all Eastern Arc Mountain blocks, forest cover has been more stable than woodlands because most forests are in protected areas

b. More degradation of woodlands has been observed in the 1970s-1980s compared to the periods of 1980s-1990s and 1990s-2000. This was either due to the greater degree of open access (public lands) of woodlands than forests, perhaps also with a contribution of the villagisation programme in the 1970s.

c. There is some variation in the amount of decline of forest and woodlands among different mountain blocks. More populated blocks of South Pare, West Usambara, North Pare and Uluguru are much more affected compared to less populated ones. However, the rate of loss is declining, mainly because there is little forest remaining outside of reserved areas.

d. Overall, there was 51,560 ha of forest and 705,949 ha of woodland lost between the 1970s and 2000 in all the blocks. Between 1990s and 2000 there was far less forest and woodland destruction, which may be explained by the fact that during this period free access forest and woodland outside the reserves depleted. When the reserve borders are reached people generally stop and hence the rate of forest loss slows (FBD, 2006).

2 Data Inventory

This chapter presents an inventory of the information we obtained on river flow, rainfall water quality and land use in the catchments draining the Eastern Arc Mountains. The inventory covers the Sigi, Pangani (Mkomazi, Soni and Luengera), Wami, Ruvu, Kilombero and Great Ruaha (Lukosi) river basins (Figure 2). The method used to establish the data inventory involved searching the central databases of the Ministry of Water and Livestock Development (MoWLD), the Tanzania Meteorological Agency (TMA) and River Basin Offices for Pangani, Wami / Ruvu and Rufiji. The tasks executed under this activity involved:

a. identifying gauging stations which are used to monitor stream flows and water quality parameters from the Eastern Arc Mountains;
b. identifying rain gauges located in the watersheds draining the mountains;
c. searching for data from the identified stations;
d. documenting the length and spatial coverage of data;
e. identifying key river flow and rainfall stations whose records needs to be updated to make a long and continuous database for use in the project.

GIS maps were created to show locations of rainfall and stream flow gauging stations for which data have been inventorised.

In addition, a water quality survey at selected gauging sites was carried out during the field visits by grab sampling. This procedure aimed to assess the current water quality in the river catchments draining the Eastern Arc Mountains. Information on land use and forest cover on the EAM and the existing status of river gauges was also collected during the field visits. The field visits carried out are as listed in Table 1.

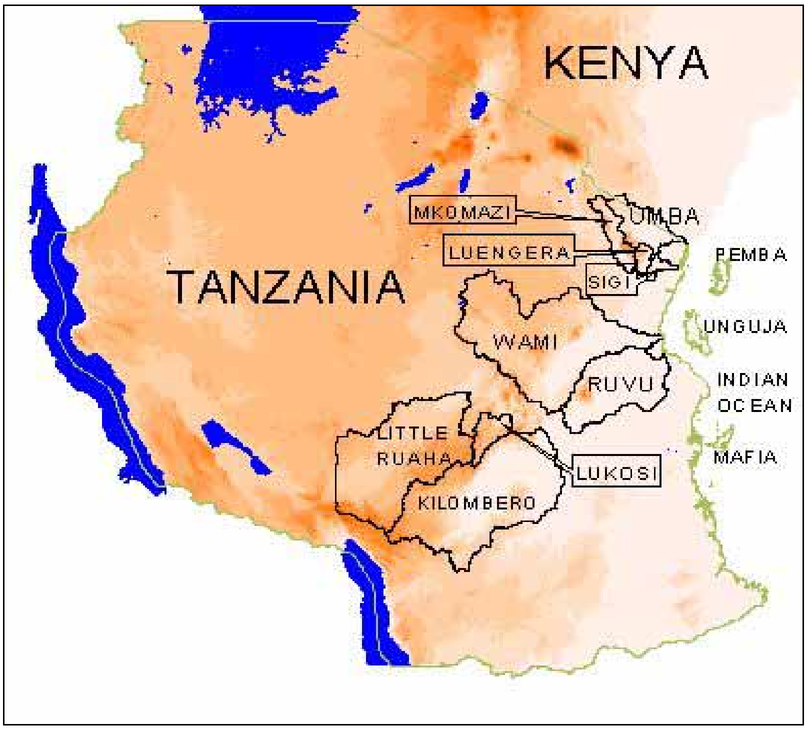


Figure 2 Location of river basins draining the Eastern arc Mountains
Topography is shown on the background on a scale from dark red (highlands) to pale pink (lowland).

Table 1 Schedule of field visits to different mountain ranges

No.	Zones of the Eastern Arc-Mountains	Period	Mountain ranges
1	North Eastern Zone	7th - 13th February 2005	East and West Usambara; North and South Pare mountains
2	Central Zone	18th - 22nd May 2005	Uluguru, Ukaguru, Nguru, Nguu
3	Southern Zone	19th - 23rd June 2005.	Udzungwa

2.1 Inventory of river flow data

2.1.1 River flow data

Table 2 presents the inventory of 49 gauging stations located within the study basins with available river flow records. The information presented includes:

a. Station code number;
b. Name of gauging station: river and location;
c. Location in terms of Latitude and Longitude;
d. Date established;
e. Catchment area;
f. Period of available records.

The spatial distribution of the river gauging stations is shown in Figure 3. The distribution of stations basin wise is 11 in Pangani (eight in Mkomazi and three in Luengera), three in Sigi, 15 in Wami, 10 in Ruvu and 10 in the Rufiji (Kilombero) River basins.

Table 2 Summary of avaiable stream flow records in the study river basins

Basin	Sno.	Code	River	Location	Lat	Long	Established	Area (sq km)	Available records
Sigi	1	1C1	Sigi	Lanconi Estate	-5.0139	38.7997	01/Sep/1957	705.0	May 1957-June 1990
	2	1C2	Sigi	Miembeni	-4.9958	38.7250	20/Jul/1976	480.0	Jan 1990-Jan 2005
	3	1C4	Sigi		-5.0956	38.6681	10/Dec/1992	251.0	Dec 1992-Jul 2004
Luengera	4	1DA1A	Luengera	Korogwe	-5.1333	38.5750	12/Mar/1953	800.0	Aug 1953-Aug 2004
	5	1DA3A	Luengera	Maji Rest Hse.	-4.8722	38.5667	11/Mar/1963	28.5	Mar 1967-Nov 2004
	6	1DA4A	Bululu	Kerenge	-5.0264	38.5333	23/Nov/1966	180.0	Mar 1952-Nov 1990
Mkomazi	7	1DB2A	Seseni	Gulutu	-4.4639	38.0611	04/Apr/1963	166.0	May 1963-Dec 1984
	8	1DB6A	Soni	Mombo	-4.7083	38.0978	17/Jun/1965	518.0	Feb 1952-Dec 1967
	9	1DB17	Mkomazi	Gomba	-5.0222	38.2792	18/Apr/1962	3,341.0	Jan 1962-Jul 2001
	10	1DB18	Hingilili	Kiruka	-4.2347	37.9736	10/May/1961	38.0	Jan 1963-Dec 1995
	11	1DB19	Soni	Soni	-4.8375	38.3708	17/Jun/1976	330.0	Jan 1976-Oct 2004
	12	1DB20	Mkomazi	Makayo	-4.6389	38.0708	18/Aug/1976		Sept 1976-Dec 1980
	13	1DB21	Mkomazi	Gereza	-5.0667	38.3167	01/Aug/1976		Jan 1977-Dec 1980
	14	1DB22	Mkusu	Kibohero	-4.7292	38.2861	17/Apr/1975	25.0	May 1975-Sep 2004
Wami	15	1G1	Wami	Dakawa	-6.4333	37.5333	14/Nov/1953	28,488.0	Nov 1953-Feb 1983
	16	1G2	Wami	Mandera	-6.2333	38.4000	09/Jun/1954	36,450.0	Jun 1954-Mar 1984
	17	1G5A	Tami	Msowero	-6.5172	37.2114	20/Oct/1964		Oct 1964-Dec 1983
	18	1G6	Kisangata	Mvumi	-6.6167	37.1833	13/Oct/1955	404.0	Oct 1955-Dec 1969
	19	1GA1A	Lukigura	Kimamba Rd. Br.	-5.8000	37.8000	01/Nov/1964	1,060.0	Oct 1964-Dec 1981
	20	1GA2	Mziha	Mziha (Kimamba)	-6.9000	37.7833	15/Oct/1964	178.0	Oct 1964-Dec 1989
	21	1GB1A	Diwale	Ngomeni	-6.1667	37.6167	10/Sep/1964		Jan 1964-Dec 1989
	22	1GD2	Mkondoa	Kilosa	-6.8333	37.0000	13/Mar/1952	17,560.0	Apr 1952-Dec 1981
	23	1GD14	Kinyasungwe	Gulwe	-6.4333	35.4167	28/Nov/1956	11,103.0	Jan 1957-Dec 1977
	24	1GD16	Kinyasungwe	Kongwa/Dodoma	-6.2000	36.2833	26/Feb/1958	9,570.0	Feb 1958-Dec 1984
	25	1GD29	Mkondoa	Mbarahwe	-6.5958	36.7833	02/Mar/1969	475.3	Apr 1969-Sep 1993
	26	1GD30	Lumuma	Kilimalulu	-6.6833	36.6667	10/Mar/1969	502.0	Mar 1969-Dec 1975
	27	1GD31	Mdukwe	Mdukwe	-6.8311	36.9333	29/Mar/1969	460.0	Mar 1969-Dec 2002

Basin	Sno.	Code	River	Location	Lat	Long	Established	Area (sq km)	Available records
	28	1GD36	Mkata	Mkata	-6.7631	37.3686	20/Mar/1973		Mar 1973-Dec 1978
Ruvu	29	1H5	Ruvu	Kibungo	-7.0167	37.8000	08/Oct/1952	455.0	Oct 1952-Jun 1987
	30	1H8	Ruvu	Morogoro Rd.Br	-6.6889	38.6986	18/Nov/1958	19,190.0	Dec 1958-May 2004
	31	1H10	Ruvu	Mikula	-7.3000	38.1667	23/Aug/1966	5,870.0	Aug 1966-Jul 1989
	32	1HA1	Ngerengere	U/S Utari Br	-7.0333	38.3667	30/Jan/1966	2,840.0	Jan 1966-Mar 1979
	33	1HA8A	Morogoro	Morogoro	-6.8653	37.6717	27/Mar/1954	23.3	Mar 1954-Oct 1979
	34	1HA9A	Ngerengere	Konga	-6.7000	37.9167	08/Nov/1962	20.5	Mar 1954-Dec 1993
	35	1HA15	Ngerengere	Mgude	-6.7917	38.1564	15/Oct/1968	2,370.0	Oct 1968-May 1972
	36	1HB2	Mgeta	Mgeta	-7.0372	37.5694	01/Jun/1954	89.6	Jun 1954-Feb 1988
	37	1HC2A	Mvuha	Tulo School	-7.2333	37.9000	28/Feb/1967	369.4	Feb 1967-Oct 1981
Kilombero	38	1KB2	Kilombero	Ifakara	-8.1500	36.6333	01/Nov/1954	30,881.0	Jan 1980-May 1984
	39	1KB4	Kilombero	Ifwema	-8.9117	35.9406	02/Jan/1955	11,995.0	Jan 1955-Dec 1983
	40	1KB8	Mpanga	Mpanga	-8.9378	35.8128	11/Dec/1956	2,546.0	Dec 1956-Oct 1991
	41	1KB9	Mnyera	U/S Taveta MissION	-9.0167	35.5167	06/Dec/1956	4,992.0	Dec 1956-May 1990
	42	1KB10	Ruhudji	Mwayamulungu	-8.9500	35.9833	14/Dec/1956	14,136.0	Jan 1960-Mar 1988
	43	1KB14	Lumemo	Kiburubutu	-8.0122	36.6572		587.6	Jan 1958-Dec 1989
	44	1KB15	Mngeta	D/s Mchombe mission	-8.3333	36.1167	01/Jan/1957	302.5	Jan 1958-Dec 1983
	45	1KB15A	Mngeta	U/s bridge	-8.3361	36.0861	08/Feb/1960	325.2	Feb 1960-Jun 1990
	46	1KB17	Kilombero	Swero	-8.2000	37.0000	29/Nov/1957	33,062.0	Nov 1957-Sep 1983
	47	1KB23	Sonjo	Sonjo	-7.8000	36.9667	20/Dec/1961	26.7	Jan 1962-Dec 1986

The inventory of stream flow gauges indicates that most of the stations were established in the 1950s and 1960s (Table 2). Out of the 49 stations, 23 were established in the 1950s, 19 in the 1960s and only six stations in the 1970s. Basin wise, the earliest stations established in the 1950s and 1960s are found in the central and southern basins of the Eastern Arc Mountains. Only three flow gauges in the northern basins were established in the 1950s. Of the remaining nine, five were established in the 60s and four in the 70s. Although the study intended to investigate changes during the past 50 years since 1950, it was not possible in the northern basins where data is only available from 1960s.

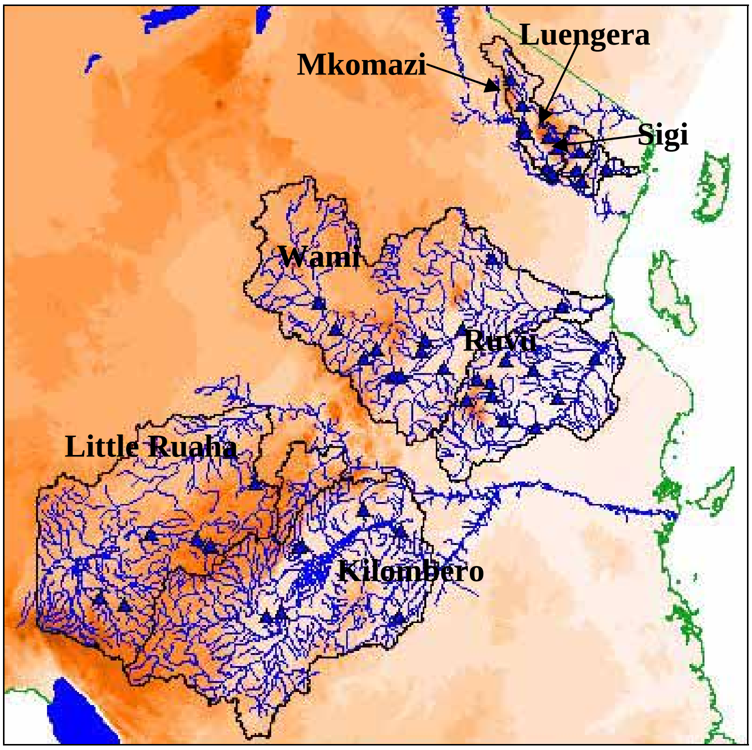


Figure 3 Spatial distribution of stream flow gauging stations with available data from different sources

2.1.2 Status of gauging stations in the rivers draining the EAM

River gauging stations provide a means to record water levels in a river which are then converted to river discharge by using a rating curve developed for a given station. The reliability of the rating is important for getting accurate discharges data at a given gauging station. The quality of the rating curve in turn depends on the physical characteristics of a gauging site. During fieldwork gauging stations were assessed in order to know the reliability of stream flow data collected from those stations. The status of river flow gauging stations in different river basins visited during the fieldwork is summarised in Tables 3, 4 and 5. The condition of the site refers to the date of visit to particular sites.

Table 3 Status of river flow gauging stations in Pangani and Sigi river basins

Station	River	Observed situation
1C1	Sigi at Lanconi	The station is located upstream of the Mabayani reservoir with the rocky River cross-section (stable) and the river is perennial. The staff gauges range is 0 – 10 m and the GPS indicated its location around 5^{o} 00’ 58” S and 38^{o} 48’ 07” E. The station is operational and gauge height reading was 0.39 m the visited. The station is equipped with an automatic data logger but it is out of use. The vegetation around the gauging site consists of dense forest and the top soil is loamy.
1C2	Soni at Miembeni	The station is located downstream of 1C4 with the rocky River cross-section (stable) and the river is perennial. The GPS indicated its elevation as 137 m. The vegetation is dense forest and the soil is loamy.
1C4		This is the most upstream station in the Sigi catchment and was established in 1994. The river cross-section at the gauge is rocky, water is slightly turbid, the stream is perennial, vegetation around is thick forest in the Amani natural forest reserve and the soil is humus. The station is operational and equipped with a data logger, which is not operational.
1DA1A	Luengera at Korogwe	The station is located in the flood plain with alluvial bed river cross-section and the river is perennial. The staff gauges range is 0 – 4 m. The GPS indicated its location as 5^{o} 08’ 06” S and 38^{o} 30’ 35” E. The station is operational and gauge height reading was 0.23 m during the time when the station was visited. The staff stage between 1 – 2 m seemed to be disturbed. The station is equipped with a data logger, which is currently not operational. The vegetation is dense forest and the top soil is loamy.
1DA3A	Luengera at Maji Rest. House	The station is located in the stable rocky river cross-section and the river is perennial. The staff gauges range is 0 – 3 m. The station is operational and gauge height reading was 0.15 m during the time of the visit. The river catchment has mountainous topography (therefore, drainage is very fast), vegetation is mainly scattered trees and the shallow soil layer is loamy.
1DB22	Mkusu at Kibohero	The station is located on a hilly terrain, with alluvial riverbed, near cultivated land with sparse and dense forest patches, and is near the Magamba and Hambarawei forests. The station is the most upstream of Soni river and seemed to be vulnerable to deposits from the cultivated land. The station is operational and gauge height reading was 0.33 m during the time when the station was visited. The topsoil is loamy.
1DB20	Mkomazi at Makayo	The station is situated before the weir near the Dar es Salaam – Moshi road bridge. It was noted that the gauge height in the range 1 – 2 m depth was disturbed due to erosion. The station is operational and gauge height reading was 0.57 m during the visit. The control section at the station is a rectangular weir, permanently constructed. The riverbed is sandy.
1DB19	Soni at Soni	The station is prone to sediment deposits following sand mining at

Station	River	Observed situation
		the station. The riverbanks are highly vegetated with shrubs, with alluvial bed and land surface looked like sandy-loam (red) soil. Nearby there was cultivated land, banana and maize grown areas, bare-land, rocky-hills and sparse forest. The station is operational and gauge height reading was 0.13 m during the time when the station was visited. Sand miners have disturbed the staff gauges range 0 – 3 m and the riverbed at the section.
1DB17	Mkomazi at Gomba	The riverbanks at the station are vegetated with grass, trees and shrubs. The bed at the cross-section is sand and with some rocks, and seemed to provide a good control section. Most upstream the station, there is irrigation schemes mainly rice paddy fields, which on dry season (Jan. – Mar.) all the water from the river is diverted to it. The gauge height reading was 0.06 m during the time when the station was visited. The staff gauges range 0 – 3 m. The catchment around is flat plain with grassland.

Table 4 Status of river flow gauging stations in Ruvu and Wami river basins

Discharge station	River	Observed situation
1HB2	Mgeta at Mgeta	Staff gauges for water level recording are slightly titled and the gauge reading was 0.48 m during the time when the station was visited. Automatic water level recorder was not working and staff gauge height in the range 3 – 4 m is damaged. There are steep side banks and downstream the gauge there is a stable rocky control. The land area around the gauging station is cultivated and vegetated riverbanks (Grassed Land). Water was slightly turbid. Plenty of water flow observed shows that there was high base flow.
1H5	Ruvu	The staff gauge in the range 1-2 m is slight covered by sediments. The water level gauge reading was 0.86 m during the time when the station was visited. The Riverbanks were covered by dense forest and the land cover around the station was dense forest. Downstream the gauging station is a bridge control. Water turbidity was very high, probably due to the rainfall showers shortly before.
1HC2	Mvuha at Mvuha	There were no staff gauges in place; all the metal bars have been removed. Land cover near the location of station is heavily grassed and with some sparse forest (the forest nearby is reserved).
1HA8A	Morogoro at Morogoro	The gauging station is located around the GPS reading 6^{o} 50’ 29.7” S and 37^{o} 40’ 15.8” E, downstream of MORUWASA water intake. There were signs of the weir walls (stones) for flow measurement but there was no staff gauge for water level recording observed. The river section is wide and shallow with rocky bed and steep bed slope. There was some vegetation on the riverbed and large stones, which may affect the water flow. Water flowed at low levels. The land area in the neighbourhood is forested. The water is relatively clean and sediment load was very low.

Discharge station	River	Observed situation
1GD2	Mkondoa at Mkondoa	The gauging station is located around the GPS reading 36^o 58' 40.6" S and 06^o 49' 54.6" E near the Mkondoa Bridge. The staff gauge water level recorders were not in place. The River originates from Kondoa Irangi in Dodoma, draining the Ukaguru mountains and forms a tributary to the Wami River.
1G6	Kisangata at Mvumi	The gauging station is located around the GPS reading 6^o 35 20" S and 37^o 10' 22.1" E. The staff gauges were damaged and some of them not in place. The most upstream is the Ukaguru mountains in the Mandege area. The Riverbanks have tall-grassed vegetation. The land area around is relatively flat with wooded trees. The water was turbid.
1G5	Tami / Msowero at Msowero	There are no staff gauges in place and therefore no recording of water levels is taking place. Riverbanks are vegetated with tall grass (aquatic grass) and the Riverbed is vegetated. The River drains the Ukaguru mountains and is very wide - more than 50 m. Water was very turbid. The River is called Tami or Msowero and drains the Ukaguru mountains range, whose peak is known locally as *Jekuru kwa Mundo* located in Jekuru area where there is a spring at Mohe village, which is also the source of Kisangata and Mkondoa Rivers in the Msowero ward (*kata*). The Msowero River is formed by merging the Kitange (from Kitange forest) and Jekuru (from Jekuru forest) strEAM. The colour of water in Kitange River is brown probably due to the forests' brown soil washout while for the Jekuru's is clear. The merging of the two Rivers with contrasting sediment loads might have contributed to turbidity of the Msowero River. The land area around the gauging station is vegetated with banana plants and the headwater mountains (the so called Mohe mountains) are forested (relatively dense).
1GB2	Mkindu at Mkindu	The River gauging station is located near the bridge at around GPS reading 6^o 14.5' 1.0" S and 37^o 33' 8.9" E. The area is near Mtibwa sugarcane estates on the RHS along the road to Turiani. The gauging station has been removed and there were no staff gauges. The River is wide and Riverbanks are highly vegetated with aquatic plants (grass and shrubs trees). The upstream (headwaters) is the South Nguru mountain range forested with patches of wooded forest. The land area near the river is covered by coconut trees and paddy fields, which

Discharge station	River	Observed situation
		are occasionally irrigated by water from the river. Water was relatively clean with very low turbidity.
1GB1A	Diwale/Ngomeni at Ngomeni	The gauging station is located around the GPS readings 6° 8’ 38.6” S and 37° 35’ 45.8” E. The gauging station was near the bridge and is non operational. The River is very wide about 80 m across with rocky river bed. The river section had a very steep riverbed and water was flowing with high velocity. The water was clear. The land area around the station was wooded. Upstream land is gently mountainous, sparsely forested and elevation increases to the mountains peaks, which are densely forested.
1G1	Wami at Dakawa bridge	The gauging station is located around the GPS readings 6° 26’ 55.6” S and 37° 32’ 01” E. The staff gauges in the range 1 – 6 m are relatively in good order except the one 0 – 1 m, which is slightly tilted. The gauge reading was 0.94 m during the time of the visit. The riverbed is deep and has a sand alluvial bed. The riverbanks are gently raising and covered by aquatic grasses. The land area around the station is a floodplain.
1HA9A	Ngerengere at Konga	The gauging station is located around the GPS readings 6° 54’ 25.1” S and 37° 35’ 59.4” E, upstream of a bridge. The staff gauge has been damaged and removed. The river drains from the Uluguru mountains and is a narrow river with less than 20 m width. The riverbanks are vegetated and the riverbed is alluvial sand. The river is perennial. The area around is a grassed land.
1HA15	Ngerengere at Mgude	The gauging station is located around GPS readings 6° 45’ 48.5” S and 38° 08’ 41.3” E, upstream the gauging station 1HA1 of Ngerengere River at Utali. The water level staff gauges were not in place. The river has a deep river bed of sand soil with aquatic grasses and river banks covered partly with aquatic grasses. There was very high bank erosion observed. The water level was low and flowed in the gentle slope of the river. The water was turbid. The land area around is a flat plain with some hilly wooded terrain.
1H8	Ruvu at Morogoro road bridge	The gauging station is located around the GPS readings 6° 41’ 30.7” S and 38° 41’ 42.3” E (UTM zone 37: 9260362 N and 0466416 E), near the Dar es Salaam water supply intake. The water level staff gauges are operational. The riverbed is deep. The banks are alluvial soils. The land area around was vegetated and on the upstream is a floodplain with elephant grass and some trees.

Table 5 Status of river gauging stations in Kilombero and Ruaha river basins

Station	River / Location	Observed situation
1KB23	Sonjo at Sonjo	The station is operational and located around GPS readings 7° 48’ 31.1” S and 36° 58’ 47.3” E (UTM zone 37: 9136327 N and 0268028 E) near the road bridge. The staff gauge height is in the range 0 – 3 m. The gauge height reading was 0.09 m during the time when the station was visited. Riverbanks were covered vegetated with forest and the riverbed is rocky. The land area in the neighbourhood is forested. Water flowed at moderate speed and the water looked clean.
1KB14A	Lumemo at Kiburubutu	The station is operational and located around GPS readings 8° 00’ 51.3” S and 36° 39’ 29.7” E. The staff gauge height is in the range 0 – 6 m. The gauge height reading was 0.5 m during the time when the station was visited. There is an automatic water level recorder but it was found to be out of order. Riverbanks and the land area around are highly vegetated with grass of about 2 m high. The riverbed is rocky. The land area in the neighborhood is forested with Miombo and Mninga trees dominating. The river is a tributary of Kilombero River. The river’s headwaters are highly forested (reserved area) in the Udzungwa mountains.
1KB2	Kilombero	This station is not operational since Dec. 2004. The location was recorded by GPS as 8° 11’ 31.4” S and 36° 41’ 33.1” E (UTM zone 37: 9094043 N and 0245771 E) near the Ferry port. The land area in the neighborhood and upstream is a vast flood plain.
1KB27	Luipa at Luipa	The station is not operational. It is located around GPS readings 8° 11’ 52” S and 36° 13’ 16.3” E (UTM zone 37: 9092854 N and 0203044 E) near the road bridge. Riverbanks are covered with some trees and grasses. The river section is wide; the riverbed is black silt probably due to granite rock weathering.
1KB15A	Mchombe at Mngeta	The station is not operational. It is located at 8° 18’ 58.4” S and 36° 7’ 11.5” E (UTM zone 37: 9079611 N and 0182712 E) near the road bridge. Riverbanks are highly vegetated with some trees and elephant grasses. The River section is wide; the riverbed is black silt probably due to granite rock weathering. The land area in the neighborhood is settlements and banana plantations. Upstream is hilly and forested.
1KB15	Mngeta at Mngeta	The station is not operational. The location measured by hand held GPS is 8° 20’ 22.1” S and 36° 5’ 12.7” E (UTM zone 37: 9076995 N and 0179135 E) near the road bridge. Riverbanks are highly vegetated with some trees, banana trees and elephant grasses. The riverbed is black silt probably due to granite rock weathering. The land area in the neighborhood and upstream is patches of wooded grassland and banana plantations.
1KB8B	Mpanga at	This station is operational and is located around GPS

Station	River / Location	Observed situation
	Mpanga	readings 8° 56' 20.7" S and 35° 49' 03.6" E (UTM zone 36: 90110690 N and 0809874 E) upstream of the road bridge. The staff gauge height is in the range 0 – 5 m. The gauge height reading was 1.02 m during the time when the station was visited and during the wet season the readings can range from 4 – 5 m. Riverbanks are highly vegetated with some trees and elephant grasses. The river section width ≈ 40 m wide; the riverbed is muddy with sediment deposits. The upstream is wooded grassland and some paddy fields.
1KB4	Kilombero at Ifweme	The station is operational but it was not accessed easily. The gauge height reading was 2.49 m according to the gauge reader on the day of the visit. The river section width ≈ 80 m wide. Upstream is a flat floodplain and a complex river network of Ruhudji, Mnyela and Mpanga Rivers, which diverge and merge before joining the Kilombero River.
1KB28	Kihansi at Lugoda	The station is operational and located around GPS readings 8° 37' 03" S and 35° 51' 19" E (UTM zone 36: 9046236 N and 0814263 E), downstream of Kihansi dam. The staff gauge height is in the range 0 – 5 m. The gauge height reading was 0.9 m during the time when the station was visited. There is an automatic data logger installed, pressure type but its operational status could not be established. Riverbanks are vegetated with some trees, grass and some elephant grasses. The riverbed is a mix of alluvial sand and rock. The land area in the neighborhood is wooded grassland and the grass is about 2 m high. Just upstream is mountainous with patches of sparse and dense forests.
1KB18	Ruhudji at Njombe	The station is not operational and located around GPS readings 8° 32' 26" S and 35° 47' 50" E (UTM zone 36: 8968668 N and 0693653 E) near the road bridge. The station was abandoned and it moved several positions (1KB18, 1KB18A and 1KB18B) due to poor control for discharge measurements. Riverbanks are vegetated with grasses. The riverbed is alluvial sand. The land area in the neighborhood is settlements and short grasses. Upstream is sparsely vegetated with wooded short grassland.
1KB19	Hagafiro at Hagafiro	The station is operational. It is located around GPS readings 9° 23' 50.3" S and 34° 49' 20.64" E (UTM zone 36: 8960703 N and 0700113 E) near the road bridge. The staff gauge height is in the range 0 – 4 m. The gauge height reading was 0.83 m during the time when the station was visited. Riverbanks are vegetated with short grasses. The riverbed is rocky. The land area in the neighborhood is wooded short grassland. Upstream is sparsely forested with dominating needle like trees ≈ 40 m high.
1KA37A	Lukosi at Mtandika	The station is operational and located around GPS readings 7° 32' 19.2" S and 36° 26' 52.1" E (UTM zone 37: 9165922 N and 0218367 E) near Kumbagula mountains. The staff gauge height is in the range 0 – 5 m. The gauge height

Station	River / Location	Observed situation
		reading was 0.73 m during the time when the station was visited. There is an automatic data logger installed, pressure type but its operational status could not be established. Riverbanks are vegetated with some trees (e.g. Mango), grasses and some elephant grasses. The riverbed is a mix of alluvial sand and rocky, with steep slope. The land area in the neighborhood is wooded grassland and the grass is about 2 m high. The most upstream is mountainous with patches of bare land and wooded grassland.

The majority of the gauging stations that were visited during the field work were found to be non operational in the sense that the recording instruments such as staff gauges and water level recorders were missing or not operational at the stations. The result of this is that no data on water levels is being recorded and consequently there are large gaps in the series of data, especially in recent years.

2.2 Inventory of rainfall data

Results of rainfall data inventory are summarised in Table 6 and Figure 4. Table 6 indicates that there are 51 operational rainfall stations in the northern zone: 39 stations are located in the Mkomazi River basin, 10 in Luengera and two in Sigi. Eighteen of these stations were established before 1950 (Figure 4b). The number of stations with records dating back to 1960s is only 25 and those with records back to the 1970s are 43 (Figure 4c). The spatial distribution of the stations within the basins indicates high densities in some areas and low in others. According to the main objective of the study, which is to identify rainfall changes over time, the high density distribution does not offer any additional information.

Table 6 Summary of inventory of operational rainfall stations in the study river basins

Zone	Basin/sub-basin	Number of operational station	Number of stations established before 1950	Number of stations established before 1970
Northern	Sigi	2	1	2
	Luengera	10	7	8
	Mkomazi	39	10	33
Central	Wami	109	28	60
	Ruvu	75	22	52
Southern	Kilombero	90	18	50
Total		**335**	**86**	**205**

Data inventory further indicates that there are a total of 184 operational rainfall stations in the central river basins, 109 stations are located in the Wami River basin and 75 in the Ruvu (Table 6). Again here, only 50 of these stations were established before 1950 (Figure 4b), 64 before 1960 and 112 before 1970 (Figure 4c). Data inventory also indicated a total of 90 operational rainfall stations in the Kilombero River sub-basin (Table 6). Out of these stations 18 were established before 1950 (Figure 4b), 28 before 1960 and 50 before 1970 (Figure 4c). The spatial distribution of the stations within the basins is also not uniform with higher densities in some areas than in others particularly for earlier periods. Similar to the case of stream flows, few stations have data of over 50 years duration.

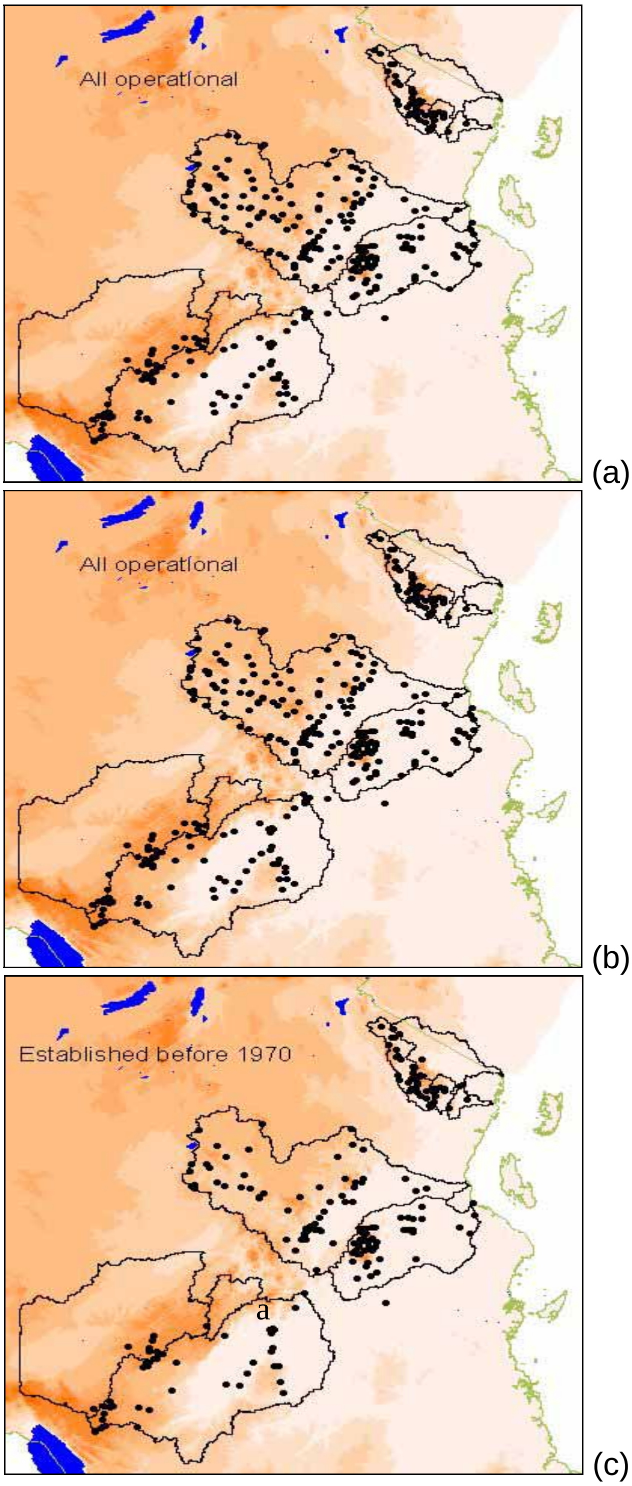


Figure 4 Spatial distribution of (a) all operational rainfall stations, operational rainfall stations established (b) 1950 and (c) 1970

2.3 Inventory of water quality data

2.3.1 Data collected from various sources

The data on water quality was collected from the Central Water Quality Laboratory at Maji Ubungo, Water Quality Laboratories located at River Basin Water Offices of different river basins and Urban Water Authorities.

Parameters of interest to study the water quality aspects include; Total Suspended Solids (TSS), Dissolved Oxygen (DO), nutrients such as Nitrogen and Phosphorous, temperature, pH and electrical conductivity. Tables 7 and 8 give an inventory of water quality data available in the Eastern Arc Mountains.

Most of the available data is neither regular nor continuous. Water quality parameters were only measured at a given location and time on a specific project request.

Table 7 Water quality data available in the Eastern Arc Mountains (nutrients)

Sampling location	basin	river nan	late	long	date of sampling	parameters
iringa municipal garden	ruaha	1e ruaha			17/6/92	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa old bridge downstr	ruaha	1d ruaha			17/6/92	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa intake at treat.plar	ruaha	1c ruaha			17/6/92	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa ndiuka	ruaha	1b ruaha			17/6/92	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa ndiuka		1a ruaha			17/6/92	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa ismani/malenga		mbunga			19/11/1990	tss,turb,colour,Ph,EC,hardness,carbonate,ca,cl,kmno4,mg
iringa ihonja village		mkitafu			15/8/86	turb.,SS,colour,Ph,EC,carbonate,hardness,ca,mg,cl,no3,kmn
iringa igwachanya/ihanja road		mbukwa			15/8/86	turb.,SS,colour,Ph,EC,carbonate,hardness,ca,mg,cl,no3,kmn
iringa mbukwa intake		mbukwa			15/8/86	turb.,SS,colour,Ph,EC,carbonate,hardness,ca,mg,cl,no3,kmn
irnga mkitafu intake		mkitafu			15/8/86	turb.,SS,colour,Ph,EC,carbonate,hardness,ca,mg,cl,no3,kmn
mpanga 1kb8		mpanga			1994 7-31 march daily	TSS.
mpanga 1kb8		mpanga			1994 1-6 april daily	TSS
lugoda 1kb28		kihansi			1994 3-22 may daily	TSS
lugoda 1kb28		kihansi			1994 2,4,5-30 june daily	TSS
lugoda 1kb28		kihansi			july 1st 1994-once	TSS
iringa-njombe,chalowe primary		mkitafu			15/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
iringa ilembula village-project c		mbukwa			15/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
iringa saja village (Near Market		mbukwa			16/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
ikingula village (near tank)		mbukwa			16/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
mlewela (igima village intake)		mkitafu			10/4/89	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
iringa mbukwa		mbukwa			21/10/89	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
		mbunga			19/11/90	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
mbukwa		mbukwa			21/10/89	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
ilamba secondary		kitalawe			21/6/89	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
tosamaganga village	ruaha	ruaha			19/6/89	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
ndiuka	ruaha	ruaha			27/11/88	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
mgololo		(tazara bridge)			13/9/88	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
mafinga (near market place)		saohill			18/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
ikingula village near reserving t		mbukwa			16/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
saja village near market place		mbukwa			16/8/86	colour,turb.,Ph,EC,SS,phenol,hardness,ca,mg,cl,kmno4,fe,nc
Water treatment Plant Ngombezi South					27/4/92	Turb.,SS,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Tanzamex					27/4/92	Turb.,SS,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Ngombezi North Treatment Plant					27/4/92	Turb.,SS,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Kulasi		Pacha			20/9/91	Turb.,SS,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mbaramo		Magoroto				Turb.,SS,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Tewe Village		Mkuu			1/1/92	Turb.,Ph,EC,Alkalinity,Hardness,Ca,Mg,No_3,Fe,Mn,Cl,F,po4,I
Korogwe	Panga	Pangani			10/1/95	Turb.,Ph,EC,Hardness,Ca,Mg,No_3,Fe,Mn,Cl,F,po4,$No_{2,SS}$,Na,
Mswaha ID	Panga	Pangani			28/4/94, 8-29/5/94	TSS
Korogwe ID14	Panga	Pangani			28/4/94, 23-31/5/94, 5/5/94	TSS
Buiko ID10	Panga	Pangani			5/5/94, 12-41/5/94	TSS
GambaIDB17	Panga	Mkomazi			7,9,15,18,16,19/5/94 & 25,28/4/…..	TSS
Mswaha ID	Pangani				24-31/3/94, 2-29 April&May	TSS
Mashewa Bridge		Bululu			03/04/98	Turbidity,settleable matter,PH colour,conductivity Alkalinity h
Mnyuzi bridge		Lwengera			10/04/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Gomba 1DB17		Mkomazi			3/5/1998,3/6/98,10/1/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Gomba Bridge		Mkomazi			10/03/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Makayo 1DB20		Mkomazi			16/3/2002,17/3/02,8/8/02,6/4/04,17	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Kwedilo 1E1		msangazi			07/04/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Buiko 1DB10		Pangani			3/3/1998,3/4/98,4/4/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Downstream Ngombezi Sisal Es		Pangani			05/04/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Hale at the Bridge		Pangani			06/04/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Head Pond		Pangani			08/04/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Inlet to the sea		Pangani			9/4/1998,3/5/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Intake Pond		Pangani			10/01/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Korogwe 1D14		Pangani			10/2/01,11/2/01,12/2/01,16/3/02,17	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mruazi-Hale Factory		Pangani			06/04/04	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Ngombezi Bridge		Pangani			25/5/2004	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Tailrace Hale		Pangani			27/5/2004	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Upstream Ngombezi Dischage I		Pangani				Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Gomba sisal estate		Recycled water			10/01/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Kifaru Bridge		Ruvu			10/03/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Amboni		Sigi			03/08/88	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Kisiwani		Sigi			03/02/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Lanconi		Sigi			3/2/98/13/2/98,16/2/98,3/3/98,13/3/	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mabayani		Sigi			08/06/02	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mjasani at the Bridge		Sigi			24/3/2003,24/3/03	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mombasa road bridge		Sigi			24/3/2004	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Kwebua stream		Soni			19/6/1985	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Rail Bridge		Soni			03/05/98	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Soni 1DB19		Soni			16/5/02,8/8/02/21/3/03/26/5/03	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Wami Bridge		Wami				Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Mjesani Sisal estate		Wastewater pond			10/02/01	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.
Ngombezi Sisal Estate		Wastewater pond			28/9/2001	Turb.,SSr,Ph colour,EC,hardness,Ca,Mg,Cl,KMn04,sulphate.

Table 8 Water quality data avaliable in the Eastern Arc Mountain rivers (sediments)

Sno	Code	River/Station Name	Period of measurements	No. of measure-ments	Period with missing data
1	1KB17	Kilomberoa at Swero	6/14/1974 7/15/1974	17	1962-1969
2	1KB6	Kigogo Ruaha at tricks bridge	2/2/1958 6/6/2960	46	
3	IH5	Ruvu at Kibungo	2/24/1962 8/10/1971	13	
4	1H10	Ruvu at Mikula	2/4/1971 5/21/1977	86	
5	1H1	Ruvu at Ruvu Sisal Estate	7/21/1958 7/22/1958	15	
6	1H3	Ruvu at Kidunda	7/5/1958 7/26/1959	53	
7	1KA27	Great Ruaha at Mkupule	9/20/1971 5/12/1973	14	
8	1KA38A	Yovi at Great Ruaha Confulence	4/24/1970 4/15/1975	28	1973
9	1KA56	Ruaha at Mlangali	6/24/1971 1/14/1972	5	
10	1KA8	Great Ruaha at Chimala	2/5/1957 7/26/1959	35	
11	1KA2A	Little Ruaha at Ndiuka	3/24/1970 10/3/1975	9	1973-1974
12	1KA4	Great Ruaha at Mbuyuni	8/1/1975 10/28/1959	126	
13	1KA8	Great Ruaha at Chimala	1/9/1956 10/24/1959	87	
14	1KA21	Lillte Ruaha at Ihimbo	2/1/1958 4/15/1981	92	1973, 1974, 1976, 1978-1980
15	1KA31	Little Ruaha at Mawande	11/17/1969 4/29/1978	13	
16	1KB4	Kilombero at Ifwema	8/29/1956 6/5/1975	137	1960-1974
17	1KA61	Gtreat Ruaha at Gorge	5/2/1971 5/14/1975	29	
18	1KA5	Great Ruaha at Mtera	5/27/1975	229	
19	1G2	Wami at Mandera	4/9/1959 5/14/1975	90	
20	1KA15	Ndemebela at Ilongo	12/10/1956 3/31/1958	33	
21	1DA3A	Lwengera at Mgoma	1/28/1970 2/25/1981	24	1976-1980
22	1G2	Wami at Mandera	8/3/1965 10/10/1969	15	1967-1968
23	1DB17	Mkomazi at Gomba	1/21/1970 10/18/1973	17	

The Morogoro Urban Water Supply and Sanitation Company (MORUWASA) monitors the quality of water at the water intakes for Morogoro town and at the Mindu reservoir. Some of the data collected from MORUWASA is presented in Table 9 below.

Table 9 Water quality data collected by MORUWASA

Year	Samples / Sampling Location	Parameters of interest analysed	EAMF Basin
2000	A total of 7 samples at the Mindu dam, treatment plant and intakes	Turbidity (FTU), pH, Color, NO^-_3	Uluguru/ Ruvu
2000/01	A total of 7 samples at the Mindu dam, treatment plant and intakes	Turbidity (FTU), pH, Color, NO^-_3	Uluguru/ Ruvu
2001/02	A total of 7 samples at the Mindu dam, treatment plant and intakes	Turbidity (FTU), pH, Color, NO^-_3	Uluguru/ Ruvu
2002/03	A total of 4 water sources:	Raw water sampled	Uluguru/

Year	Samples / Sampling Location	Parameters of interest analysed	EAMF Basin
	Mindu dam, Mambogo River, K/Nyembe River and Vituli River	and analysed for: Turbidity (NTU), pH, apparent color, electrical conductivity, NO^-_3	Ruvu
2003/04	A total of 4 water sources: Mindu dam, Mambogo River, K/Nyembe River and Vituli River	Raw water sampled and analysed for: Turbidity (NTU), pH, color, conductivity, NO^-_3, NO^-_2 and Phosphate	Uluguru/ Ruvu

Recent information from a water quality survey, carried out by the Wami/Ruvu Basin Water Office in March 2005, from the rivers draining from the Ukaguru and Nguru mountains is summarised in Table 10 below.

Table 10 Water quality data collected from the Wami / Ruvu Basin Water officer

Date	Location	Lat. (S)	Long. (E)	Parameters monitored	EAMF / Basin
12/3/2005	Msowelo River	6^o 04.965'	36^o 36.706'	pH, NO^-_3	Ukaguru / Wami
12/3/2005	Mvumi River (Kilosa)	6^o 35.339'	37^o 10.360'	pH, NO^-_3	Ukaguru / Wami
13/3/2005	Mkondoa River (Kilosa Town)	6^o 49.916'	36^o 58.650'	pH, NO^-_3	Ukaguru / Wami
13/3/2005	Ilonga River	6^o 46.139'	37^o 02.600'	pH, NO^-_3	Nguru / Wami
13/3/2005	Mkata River	6^o 45.341'	37^o 21.659'	pH, NO^-_3	Ukaguru / Wami
15/3/2005	Wami/Dakawa River	6^o 26.875'	37^o 32.005'	pH, NO^-_3	Ukaguru / Wami
15/3/2005	Divue River	6^o 10.510'	37^o 35.033'	pH, NO^-_3	Nguu / Wami
15/3/2005	Diwale River	6^o 08.647'	37^o 35.760'	pH, NO^-_3	Nguu / Wami
15/3/2005	Mvomelo River	6^o 17.573'	37^o 26.265'	pH, NO^-_3	Nguru / Wami
17/3/2005	Wami darajani (Wachina)	6^o 14.793'	38^o 23.243'	pH, NO^-_3	Ukaguru / Wami

2.3.2 Data obtained from samples collected during the field visit

As mentioned above, water quality surveys at selected points in the main rivers draining the EAM in the Northern Zone, Central Zone and the Southern Zones were carried out by grab sampling. The survey was carried out to capture the situation of water quality parameters during the study period. The survey points were the gauging stations used for monitoring stream flows from the EAM. Water samples were taken for on-site and laboratory analysis. The parameters that were analysed onsite were:

- Temperature
- pH
- Total Suspended Solids (TSS)
- Dissolved Oxygen (DO)

Laboratory analysis was carried out on the following parameters:

- Phosphate

- Nitrates
- Electrical conductivity
- Turbidity
- Suspended Solids

Table 11 summarizes the sites at which water samples were collected.

Table 11 Sites where grab samples were taken during field visits

No		Site Code No	Name of site
1	Northern Zone	1C4	
2		1C2	Sigi at Lembeni
3		1C1	Sigi at Lanconi
4		1DA1A	Luengera at Korongwe
5		1DA3A	Luengera at Maji Res. Hse
6		1DB22	Mkusu at Kibohero
7		1DB19	Soni at Soni
8		1DB6A	
9		1DB17	Mkomanzi at Gomba
10		1DB20	Mkomanzi at makayo
1	Central Zone	1HB2	Mngeta at Mngeta
2		1H5	Ruvu at Kibungo
3		1HC2	Mvuha at Mvuha
4		1HA8A	Morogoro at Mogogoro
5		1GD2	Mkongoa at Kilosa
6		1G6	Kisangata at Mvumi
7		1G5	Tami at Msowero
8		1GB2	Mkindu at Mkindu
9		1GB1A	Biwale at Ngomeni
10		1G1	Wami at Dakawa
11		1HA9A	Ngerengere at Konga
12		1HA15	Ngerengere at Mgude
13		1H8	Ruvu at Morogoro Rd Bg
1	Southern Zone	1KB14	Lumemo at Kiburugutu
2		1KB2	Kilombero at Ifakara
3		1KB27	Luipa at Luipa
4		1KB15A	Mchombe at Mngeta
5		1KB15	Mngeta at Mngeta
6		1KB8	Mpanga at Mpanga
7		1KB28	Kihansi at Lugoda
8		1KB18A	Ruhudji Njombe
9		1KB19	Hagafiro at Hagafiro
10		1KA37A	Lukosi at Mtandika

2.4 Information on forest and land cover data

The visit to the Forest Catchment Management project office of the East Usambara conservation area in Tanga enabled the study team to collect hardcopy reports on land cover information. It was noted that there are digital maps of East Usambara conservation area, archived at University College of Lands and Architectural Studies (UCLAS). The maps on the reports (e.g. East Usambara vegetation) show among other things the 1953 and 1986 forest map derived from aerial photographs.

In the Natural Resources and Forest, and SECAP offices in Lushoto there are maps 1:100,000 of forest, woodland and forest reserves with vegetation and land use in the West

Usambara Mountains. These are published by the Forest and Beekeeping Division and the Germany Development Agency (GTZ) in 1997. Several coverages in CDs are available from SECAP office in Lushoto. The CDs contain the Digital Elevation Model (DEM), land cover and soil data for the Lushoto district that was compiled by GTZ and Ministry of Natural Resources and Tourism.

There exists a forest reserve map of Tanzania in scale of 1:3,000,000, which was compiled, drawn and printed by the Department of Lands and Surveys, Dar es Salaam, Tanganyika Government (1958, 1963) in Polyconic projection. The map shows the lowland forests and the catchment forests.

There exists a map of scale 1:600,000 of forest reserves and village forest in Iringa district, created by the GIS unit of Iringa District Council, and cartographied and printed by InfoBridge Consultants Ltd, Dar es Salaam, in October 2003.

3 Rainfall variations

This section presents the details of rainfall analysis which include:

a. Data analysis to select suitable flow records for use;
b. Seasonal rainfall variations;
c. Inter-annual rainfall variations.

The analysis of data aims at assessing the quality and suitability of acquired rainfall records for intended analyses. It involves a) establishing the criteria that are used in the selection of suitable records for analyses and b) extraction of appropriate indices for studying the variability of rainfall.

The section further presents and discusses seasonal as well as inter-annual patterns of variability of rainfall indices, including mean seasonal and annual rainfall. Seasonal rainfall patterns are described based on long-term averages while inter-annual variability is based on the results of linear trend analysis. The presentation is organised according to location of the basins (northern, central or southern) and patterns of variations are presented for each basin or sub-basin separately.

3.1 Data and methods

3.1.1 Selection of rainfall and stream flow records

The intended analysis of rainfall records spanning the second half of the 20th century could not be adequately satisfied by the relatively poor spatial distribution of operational rainfall stations in the basins (Refer to section 2). In the northern zone basins, only a few poorly spatially distributed rainfall stations were established before 1950 while most of the stations were established before 1970 and provide a good spatial distribution in the Mkomazi and Luengera sub-basins. These spatial patterns are similarly observed in the central and southern zone basins. However, analysis of available records indicated that only 25, 56 and 63 stations in the northern, central and southern basins, respectively, have at least 20 years of data in the 1960-1990 period. The criterion of less than 10% of missing monthly / seasonal values retained a total of 60 stations. However, the criterion of spatial uniformity while avoiding stations which are too close geographically to offer additional information finally retained 26 for the inter-annual variability analysis (Table 12 and Figure 5). The application of the criterion of length of missing values, screened out stations with more than four consecutive values missing, provided it was not possible to obtain at least 25 years of continuous data when the period after the gap is considered (Valimba, 2004). Filling of gaps of four or more consecutive missing values might introduce an error particularly in series which are characteristically non-stationary such as those of hydrological variables in Tanzania.

Table 12 Summary of selected rainfall stations in the three sub-basins and records suitable for inter-annual variability analysis

BASIN	SNO.	Station details					Useful record	
		CODE	Name	LAT	LONG	ALT (m)	From	To
Sigi	1	09538003	AMANI MALARIA UNIT	-5.10	38.63	911	1920	2004
Luengera	2	09438023	MAZUMBAI ESTATE	-4.82	38.52	1524	1935	2004
	3	09538002	DINDIRA ESTATE (NGARAY)	-5.02	38.45	1067	1927	2004
Mkomazi	4	09438003	LUSHOTO AGRIC. OFFICE	-4.78	38.28	1396	1922	2004
	5	09438019	MAZINDE FACTORY	-4.70	38.22	439	1930	2004
	6	09438034	SHAGAYU	-4.53	38.23	1828	1955	2004
Wami	7	09535007	MAKUTUPORA MAJI	-5.97	35.72	1080	1962	1999
	8	09536000	KIBAYA	-5.28	36.57	1457	1934	1996
	9	09536004	DABALO DAM	-5.78	36.13	1524	1962	1993
	10	09635001	DODOMA AIRPORT	-6.17	35.77	1120	1922	2004
	11	09636000	MPWAPWA RESEARCH STATION	-6.33	36.50	1037	1920	2004
	12	09636013	KONGWA P.R.S	-6.03	36.33	914	1962	2004
	13	09637000	MOROGORO AGRICULTURE	-6.08	37.67	579	1922	1995
	14	09637001	KILOSA AGRICULTURE	-6.83	37.00	491	1961	2004
	15	09637047	HOBWE	-6.98	37.57	742	1954	2004
	16	09637056	WAMI PRISON FARM	-6.40	37.47	579	1963	2004
	17	09638004	MANDERA MISSION	-6.22	38.38	213	1934	1995
	18	09737030	KIKOBOGA MIKUMI	-7.35	37.15	549	1964	1994
Ruvu	19	09637015	KINGOLWIRA ESTATE	-6.75	37.77	457	1961	1993
	20	09638005	LUGOBA MISSION	-6.47	38.32	244	1934	1994
	21	09737006	MATOMBO PRIMARY SCHOOL	-7.08	37.77	388	1938	2001
Kilombero	22	09835009	KILIMA (KIBWELE) ESTATE	-8.58	35.33	1859	1939	2004
	23	09836002	KWIRO MISSION	-8.67	36.67	1006	1960	1993
	24	09836003	RUAHA MISSION	-8.90	36.73	427	1960	1993
	25	09934001	NJOMBE DISTRIC OFFICE	-9.33	34.77	1829	1927	1998
	26	09935007	TAVETA MISSION	-9.02	35.52	914	1942	1995

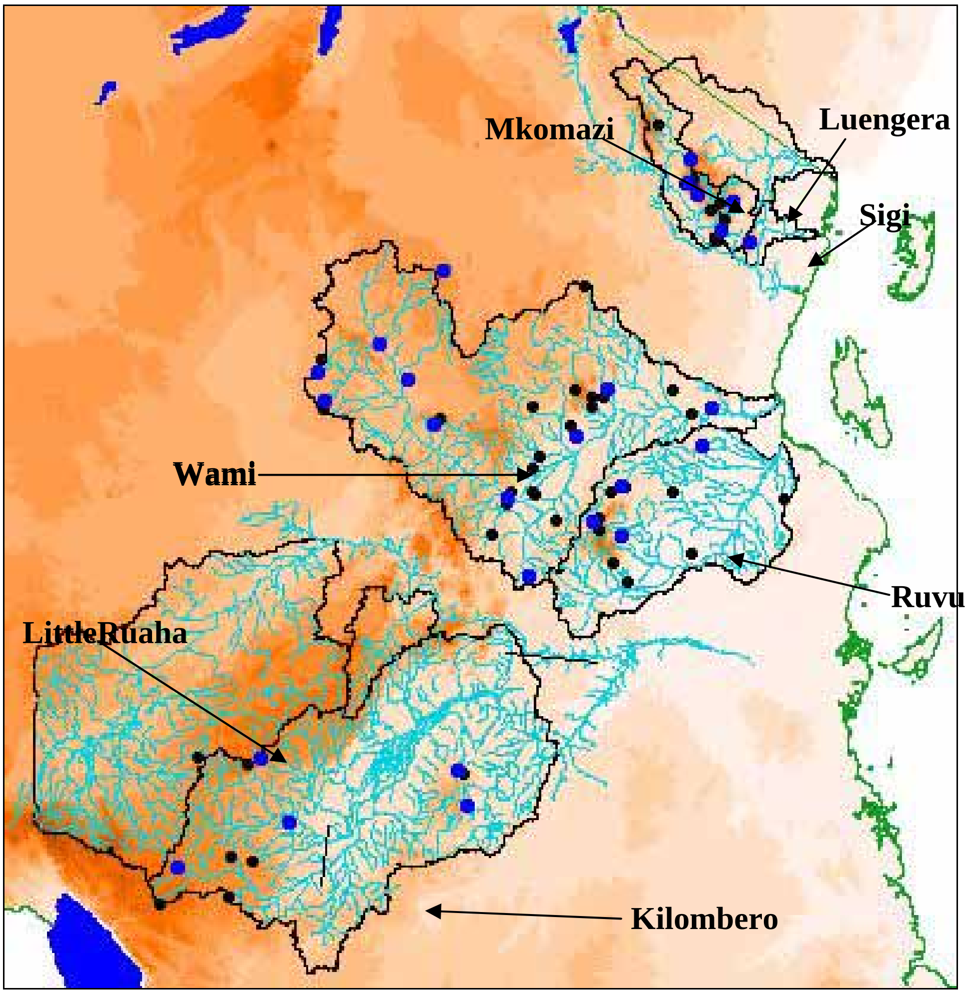


Figure 5 Spatial distribution of selected rainfall stations for inter-annual variability analysis

Black dots indicate stations which have records suitable for analysis. Blue dots are stations that are not appropriate for this analysis.

3.1.2 Study indices

In order to verify the study hypotheses of the impacts of rainfall changes on flow volumes and flow extremes (floods and droughts), rainfall amounts were extracted from available records. Annual rainfall is related to average annual discharges (or flow volumes), which can be analysed to highlight the flow increases or decreases over the years. Seasonal rainfall amounts are related to average seasonal discharges which are appropriate in relation to the effects of depleted vegetation cover. Hypothetically, in deforestation scenarios, flows are expected to increase during the rainy seasons due to a lack of vegetation cover to reduce the runoff velocity and to decrease during the dry season due to insufficient recharge of groundwater during the rainy seasons. Consequently, there is usually a relationship between rainfall amounts and stream flows in various seasons. Therefore, seasonal and annual rainfall amounts were extracted from available rainfall records and analysed to highlight the probable influences of changes of rainfall amounts, if any, on stream flow. Monthly rainfall amounts were determined only for complete months while seasonal rainfall values were computed only from complete months that form a particular season.

3.1.3 Timescale for statistical variability analysis

Some of the previous studies on rainfall variability in Eastern and Southern Africa (Hulme, 1992; Smakhtina, 1998; Valimba, 2004; Valimba et al., 2004b, 2005a,b) have concluded on the general lack of real trend in rainfall amounts in Southern Africa except in certain parts of the region like Namibia, the South African Lowveld, Southern Zambia (Sichingabula, 1998), etc. Valimba (2004) found opposing patterns of inter-annual variability between the early (October-January) and late (February-May) summers. He further concluded that such patterns were responsible for the general lack of real significant trends and abrupt changes at the annual timescale.

The analyses were performed at both seasonal and annual timescales. The four seasons were then considered and were related to rainy and dry seasons (Indeje et al., 2000; Valimba et al., 2004b). They include the two main rainy seasons, the October-November-December (OND) short and March-April-May (MAM) long rains, the intermediate January-February (JF) season and the “dry” June-July-August-September (JJAS) season. The appropriateness of these seasons for analyses in Tanzania have been described in Valimba (2004) from the patterns associated with rainfall variations and results of inter-annual variations of stream flows. Therefore, inter-annual variability analysis was performed on seasonal rainfall in these four seasons.

3.1.4 Filling of missing values

The procedure of replacing various missing monthly rainfall amounts has been described in detail in Valimba (2004). The replacement of missing monthly rainfall amounts was by long-term or segment averages at the given station. Plots of seasonal or annual rainfall amounts were used to identify the suitability of long-term averages or segment averages for filling missing values. In the case where the long-term average is likely to introduce an erroneous value, a segment average that is computed from 6-10 values on either side of the gap (with outlying values excluded) was used.

3.1.5 Methods for inter-annual variability analysis

Although it is specified in the terms of reference (ToR) that trend analysis is the only method that was considered for inter-annual variability analysis, the type of the method, whether linear or non-linear trend analysis, was not specified although the former type is widely used in hydrological analysis. It is well known that climatic changes are often abrupt and these usually induce abrupt changes in hydrological variables like stream flows. Moreover, trends are significantly affected by these abrupt changes to the extent of identifying a significant trend variable which in reality possesses no real trends in periods after the abrupt changes. It is usually recommended to identify shifts and to correct them prior to carrying out linear trend analysis to avoid erroneous conclusions.

Since change-point analysis was not performed, the procedure adopted therefore consisted of determining linear trends and discussing the results with plots of time series. The linear trend model that has been used (Zhang et al., 2000; Valimba, 2004) is given as

$$y_t = a + bt + \xi_t \qquad (3.1)$$

where y_t is an element of a time series *y* at time *t*; *a* and *b* are the linear trend parameters (intercept and slope respectively) and ξ_t is the random part with zero mean and a unity standard deviation.

Testing for a trend and estimation of a slope in this study was performed using Mann-Kendall's tau (Kendall and Stuart, 1968). Values of the test statistic are used to refer indirectly to the magnitude of a trend (slope *b* in eqn 3.1)) while its sign shows the direction of the trend (Molnár and Ramírez, 2001). Trend slope *b* was indirectly estimated by a standard normal variate, Z, defined (Yu and Zuo, 1993; Hirsch *et al*., 1993) as

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{var}(S)}} & if \quad S > 0 \\ 0 \quad if \quad S = 0 & \\ \dfrac{S+1}{\sqrt{\operatorname{var}(S)}} & if \quad S < 0 \end{cases} \qquad (3.2)$$

where S is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(y_j - y_i) \qquad (3.3)$$

in which y_i to y_n are elements of a time series and the sign function $sgn(y_j – y_i)$ is
1 when $y_j – y_i > 0$
0 when $y_j – y_i = 0$
-1 when $y_j – y_i < 0$

Mean and variance of S are given by

E(S) = 0
and

$$\operatorname{var}(S) = \frac{\left[n(n-1)(2n+5) - \sum_k k(k-1)(2k+5) \right]}{18} \qquad (3.4)$$

where *n* is the length of record used and *k* is the length of any given tie. A tie is a subset of the ordered data that comprises a sequence of the same value. Var(S) as given in eqn (3.4) includes overall correction for tied data (Hirsch et al., 1993). In this study, no correction for tied data was applied (i.e. k = 0).

The significance of the slope of a trend (Z) was assessed at 1% and 5% levels and values of Z outside the limits at a given significance level were considered statistically significant.

In order to have an up to date picture of stream flow changes within the study basins / sub-basins, whole useful records (Table 12) were used in the inter-annual variability analyses of stream flow indices, although only a few stations have long continuous records. However, since flow records have different lengths and span different periods, the spatial interpretation of the resulting patterns of inter-annual variability within a given basin requires the use of a common period. These common periods for every basin or sub-basin are indicated in Table 12. Similarly, since inter-annual variability analyses of stream flow and rainfall indices are performed separately, the comparison of results of stream flow and rainfall variations across the basins or sub-basins also uses the common periods of stream flow records within the particular basins or sub-basins. Therefore, linear trends were determined for both whole records and common periods of flow records.

3.2 Rainfall variations

3.2.1 Northern zone basins

Seasonal variations

The within-the-year variation of rainfall amounts (Figure 6) indicates the dominance of bimodal rainfall regime in the northern basins of Mkomazi, Luengera and Sigi, which is very clear along the coast. This rainfall regime corresponds to two rainfall peaks, one representing the short rains in October through December (OND) and the other the long rains between March and May (MAM). The period January-February (JF) usually receives little rainfall amounts from a few isolated rainfall events and is generally referred to as a transition period between the short and long rains. The seasonal variations further indicate the relatively dry period since June through September (JJAS) with monthly rainfall amounts predominantly below 50 mm (Figure 6), mainly resulting from 1-4 daily rainfall events, except in the coastal areas and adjacent Usambara Mountains where the monthly amounts exceed 60 mm (Valimba, 2004). Whilst August is the driest month in the basins, the highest rainfall amounts are observed in November / December in the northern part of the Mkomazi sub-basin and in March / April in the other parts (Valimba, 2004) (Figure 6).

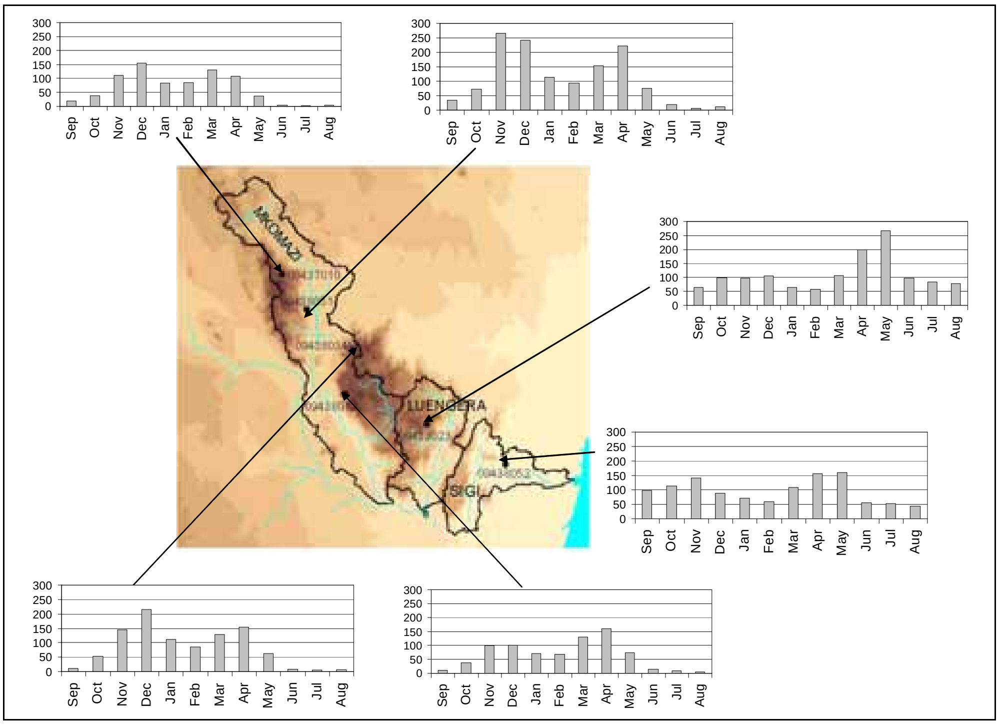


Figure 6 Typical seasonal rainfall patterns in the northern Eastern Arc Mountains
The vertical maximum is 450 mm and the interval is 50 mm while the horizontal axis is from September (left) to August (right)

Inter-annual variations

The results of linear trends on seasonal and annual rainfall amounts for the 1964-1993 periods are summarised in Table 13. They generally indicate a predominant decrease of rainfall amounts during the long rains, dry season as well as during the intermediate JF season. However, increasing trends in rainfall amounts characterises the short rains. Spatially, the decreasing and increasing trends in seasonal rainfall amounts are almost spatially uniform across the northern zone basins (Figure7).

Table 13 Trends in seasonal and annual rainfall amounts in the northern basins.

BASIN	SNO.	CODE	Useful record		Trends (1930 - 1995)					Trends (1964 - 1993)				
			From	**To**	**JF**	**MAM**	**JJAS**	**OND**	**ANN**	**JF**	**MAM**	**JJAS**	**OND**	**ANN**
Sigi	1	09538003	1920	2004	-0.11	-1.69	-0.68	0.52	-1.36	-1.20	1.32	-0.85	-0.33	-0.64
	2	09438023	1935	2004						0.19	-0.70	-0.85	0.47	
Luengera	3	09538002	1927	2004	-1.06	-2.50	-0.99			-1.18	-1.18	-1.09		
	4	09438003	1922	2004	0.34	-2.95	-1.20	1.78	-2.22	1.18	-1.07	-1.12	0.87	
Mkomazi	5	09438019	1930	2004	-0.48	-1.41	-0.26	0.28		-0.06	-0.80	-2.17	0.31	
	6	09438034	1955	2004						-0.56	-2.60	-1.01	1.63	
		Total number of stations:			**4**	**4**	**4**	**3**	**2**	**6**	**6**	**6**	**5**	**1**
		Number of increasing trends:			**1**	**0**	**0**	**3**	**0**	**2**	**1**	**0**	**4**	**0**
		Number of decreasing trends:			**3**	**4**	**4**	**0**	**2**	**4**	**5**	**6**	**1**	**1**

Empty cells indicate non-analysed series.

Since linear trends are affected by the period and length of record used in the analysis, it was therefore necessary to investigate the robustness of these trends determined from the shorter (1964-1993) span of records covering 30 years. Only four records, which span between 1920 and 2004, were analysed. The results (Table 13) were consistent with those obtained from the shorter period of records, confirming the predominance of increasing rainfall amounts during the short rains and decreasing amounts in the other seasons. The long rains in northeast Tanzania, for example, were abundant in the early 20^{th} century until the mid-1940s when they abruptly declined (Figure 8). Rainfall amounts during the short rains, on the other hand, show slight but steadily increasing trends towards wetter conditions. The higher contributions of rainfall amounts during the long rains attribute similar trends in annual amounts. This is evident in Figure 8 from the temporal pattern of inter-annual variability of MAM and annual rainfall amounts.

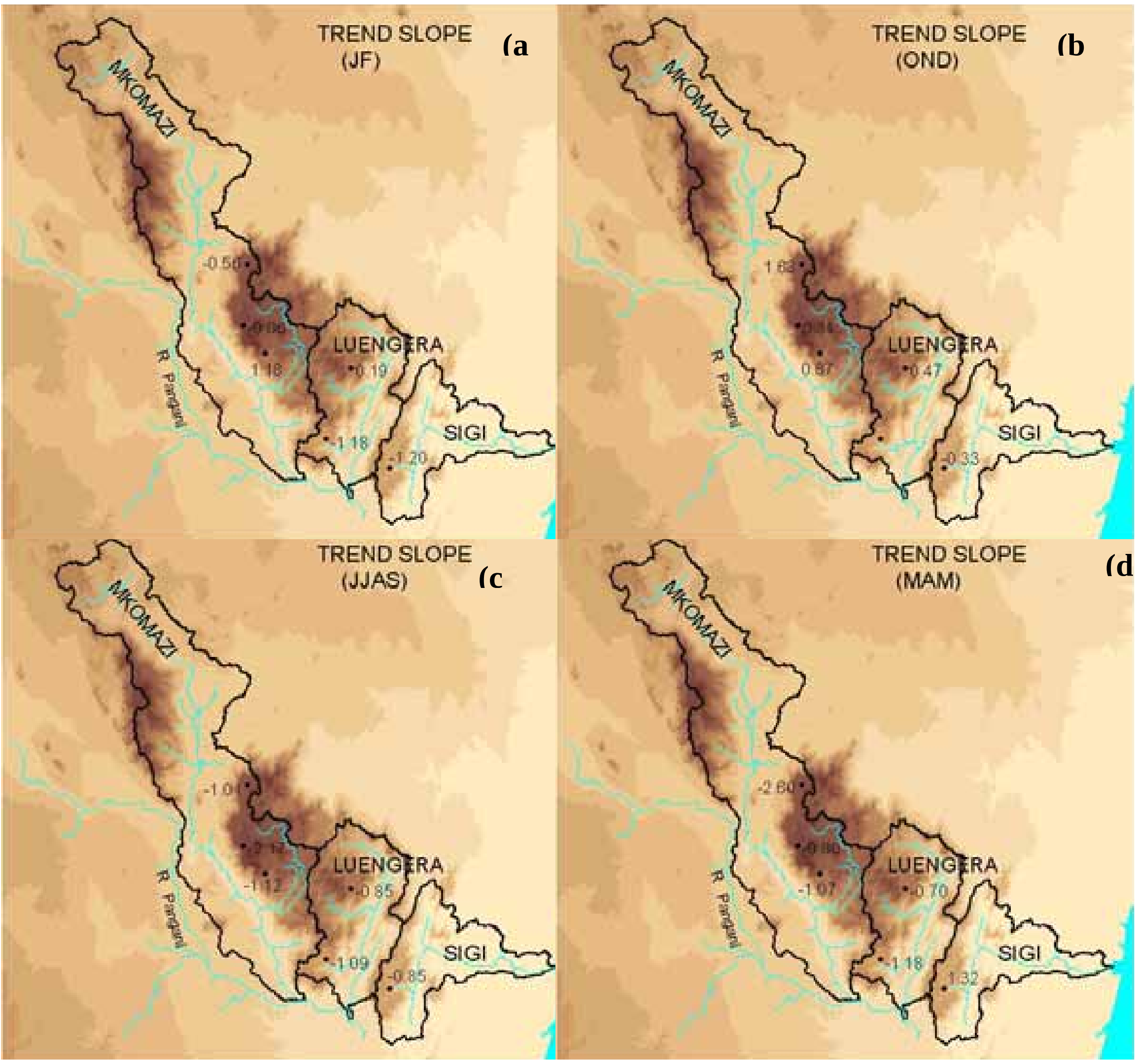


Figure 7 Spatial variation of the slope (Z) of a linear for a) JF, b) MAM, c) JJAS and d) OND seasonal amounts for the 1964-1993 period in the northern basins

It should be noted, however, that the linear trends were not strictly decreasing or increasing. Thus, despite predominantly decreasing long rains since the mid-1940s, they were abundant in several isolated years such as 1989 and 1998 (Figure 8) and dry during the droughts of 1973-1976 and 1984 (Nyenzi et al., 1999). Similarly, the short rains were very dry during the droughts of the early-1970s and 1980s (Valimba, 2004).

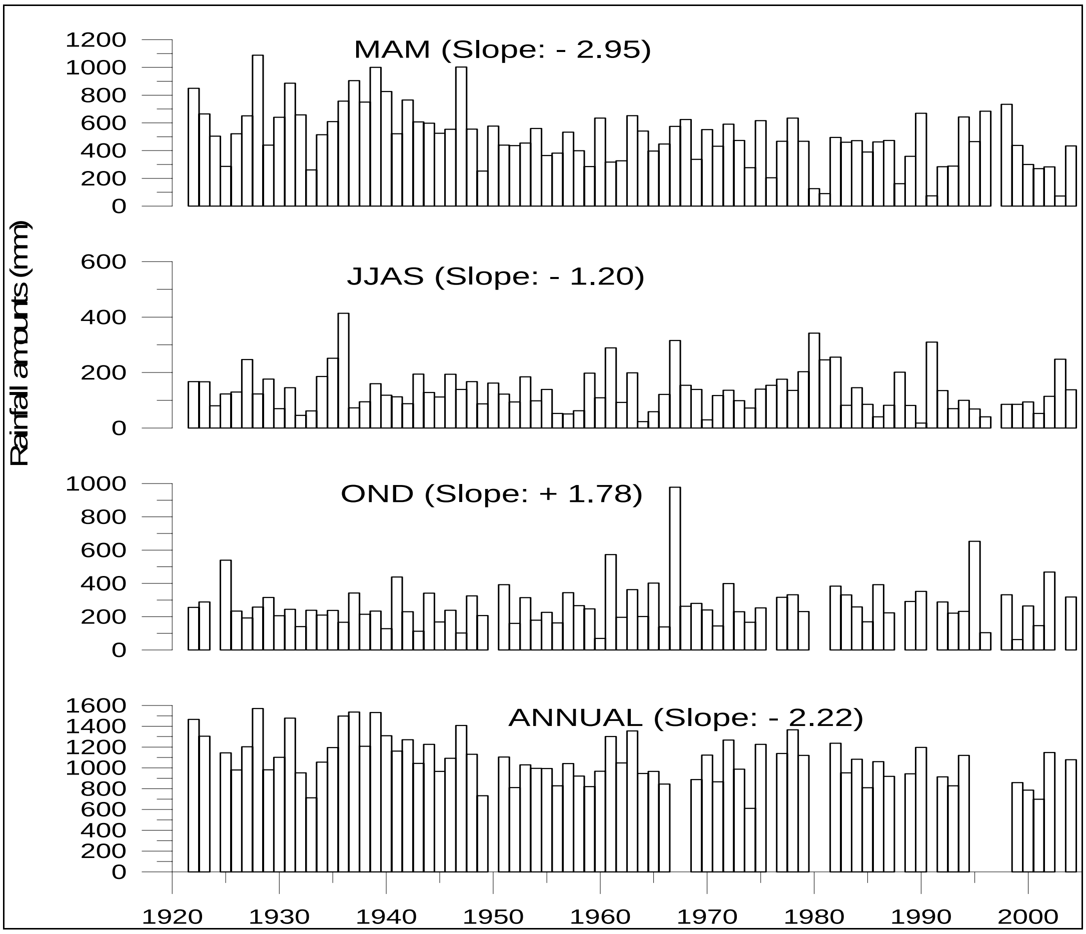


Figure 8 Time series of seasonal and annual rainfall amounts at Lushoto Agricultural Office (09438003) in the Mkomazi sub-basin

The figures indicate linear trend slopes for the 1930 – 1995 period

3.2.2 Central zone basins

Seasonal variations

The within-the-year variation of rainfall amounts (Figure 9) indicates the dominance of the transition rainfall regime in the central basins of Wami and Ruvu, with a well-defined peak during the long rains and a weak peak during the short rains, which is absent in certain dry years and becomes well-defined in exceptionally wet years usually corresponding to the El Niño rains. The seasonal variations indicate the relatively dry period between June and September with monthly rainfall amounts predominantly below 50 mm. August is the driest month in the basins while the highest rainfall amounts are mainly experienced March / April (Figure 9).

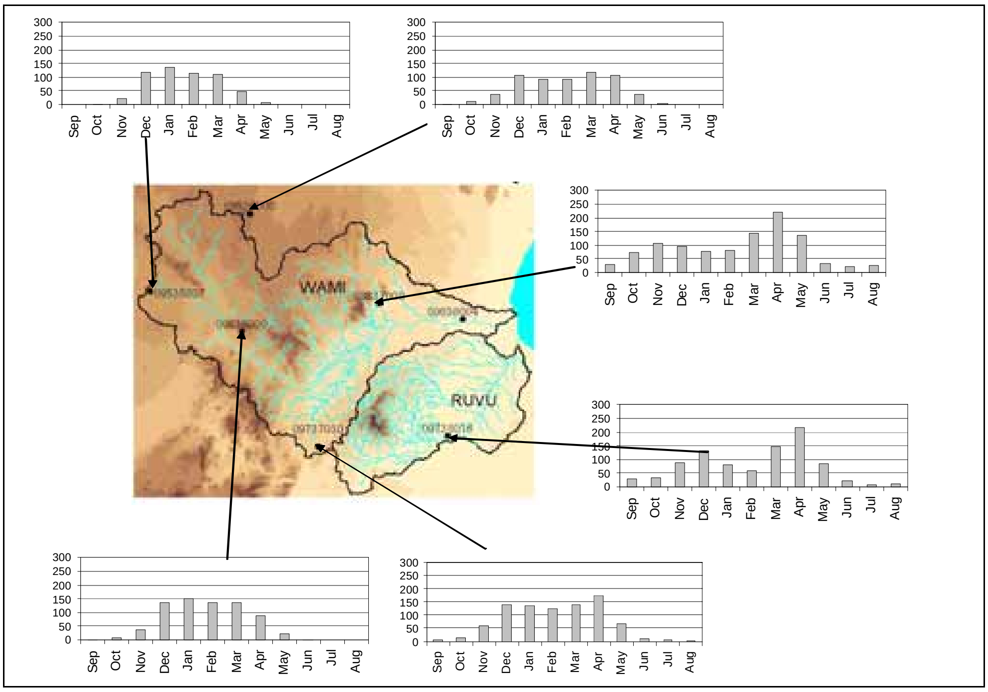


Figure 9 Typical seasonal rainfall patterns in the central Eastern Arc Mountains
The vertical maximum is 450 mm and the interval is 50 mm while the horizontal axis is from September (left) to August (right)

Inter-annual variations

The results of linear trends on seasonal and annual rainfall amounts for the 1964-1993 period are summarised in Table 14. They generally indicate declines in rainfall amounts during the long rains, dry season as well as during the intermediate JF season. However, a mixture of increasing and decreasing trends in rainfall amounts characterises the short rains.

Spatially, the decreasing and increasing trends in seasonal rainfall amounts are non uniform across the central basins (Figure 9). This spatially heterogeneity is shown by close stations experiencing different trend direction. As an example, trends in MAM seasonal rainfall amounts in the Ruvu River basin during the 1964-1993 period are decreasing around the Uluguru Mountains and increasing near the Indian Ocean coast. However, during the dry season, the stations closest to the mountains are experiencing decreasing trend while the ones far from the mountains observed a slight increasing trend (Figure 9).

Table 14 Trends in seasonal and annual rainfall amounts in the central basins

BASIN	SNO.	CODE	Useful record		Trends (1930 - 1995)					Trends (1964 - 1993)				
			From	To	JF	MAM	JJAS	OND	ANN	JF	MAM	JJAS	OND	ANN
Wami	1	09535007	1962	1999						0.99	-1.40	-0.74		
	2	09536000	1934	1996						0.02	-0.62			
	3	09536004	1962	1993						-0.27	-0.17	-1.53	0.02	-0.74
	4	09635001	1922	2004	0.87	-1.36	0.30	0.67	0.32	1.32	0.58	0.25	0.01	0.08
	5	09636000	1920	2004	-0.07	-0.97	-1.47	1.74		-0.19		-1.90	-0.66	
	6	09636013	1962	2004						1.11	-1.45	-0.68	-0.12	
	7	09637000	1922	1995	-1.07	-0.32	-1.08	1.25		-0.85	-0.68	-1.30	-0.03	
	8	09637001	1961	2004						-1.22	-0.04	-1.51	-0.54	
	9	09637047	1954	2004						-1.22	-2.64	-2.13	-0.60	-2.17
	10	09637056	1963	2004						0.78	0.56	0.37	1.05	
	11	09638004	1934	1995						-1.11	-0.33	-0.94	-0.04	-0.70
	12	09737030	1964	1994						-1.12	-0.05	-2.17	0.95	0.16
Ruvu	13	09637015	1961	1993						0.02	-1.40	0.54		
	14	09638005	1934	1994						-0.58	0.66		0.91	
	15	09737006	1938	2001						-0.89	-1.78	-0.74	-0.78	
		Total number of stations:			**3**	**3**	**3**	**3**	**1**	**15**	**14**	**13**	**12**	**5**
		Number of increasing trends:			**1**	**0**	**1**	**3**	**1**	**6**	**3**	**3**	**5**	**2**
		Number of decreasing trends:			**2**	**3**	**2**	**0**	**0**	**9**	**11**	**10**	**7**	**3**

Since linear trends are affected by the period and length of record used in the analysis, it was therefore necessary to investigate the robustness of these trends determined from the shorter period (1964-1993) of records covering 30 years. Only three records, which span between 1920 and 2004 and all found in the Wami River basin, were analysed. The results of linear trend analysis for the period 1930-1995 (Table 14) were consistent with those obtained from the shorter span of records confirming the predominance of increasing rainfall amounts during the short rains and decreasing amounts in the other seasons. All the three stations showed decreasing trends in MAM and increasing trends in OND seasonal rainfall amounts (Table 14). The long rains in the Wami River basin, for example, were abundant in the early 20th century until the mid-1940s when they abruptly declined (Figure 10). The series in the Wami River basin further indicate low MAM rainfall amounts in the 1990s. Rainfall stations in the Ruvu River basin observed the lowest MAM seasonal rainfall amounts in most of the 1980s (Figure 10). Moreover, the drought of 1973-1976 prevailed in the northern zone basins is not evident in the central zone basins.

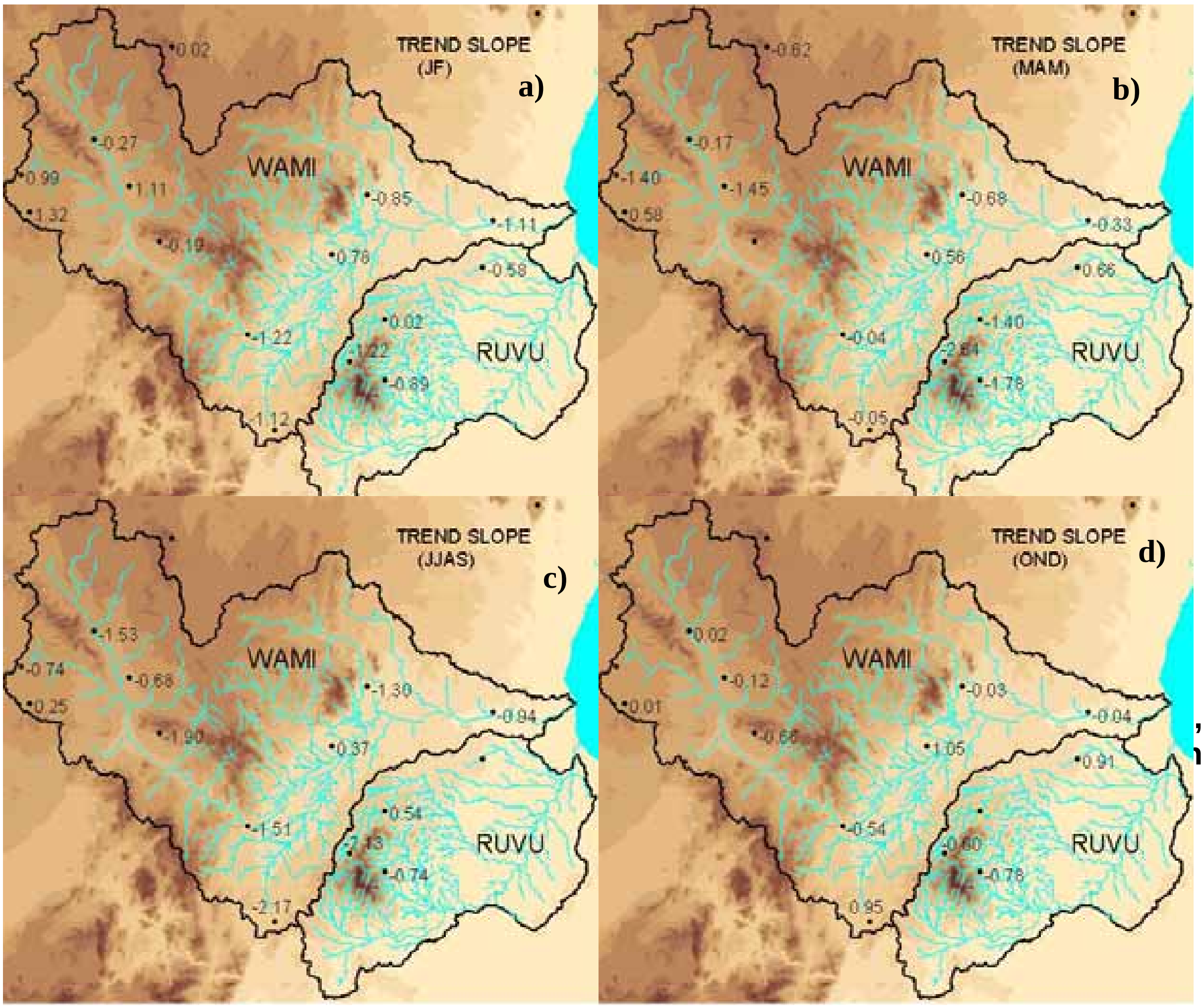


Figure 10 Spatial variation of the slope (Z) of a linear trend for a) JF, b) MAM, c) JJAS and d) OND seasonal amounts for the 1964-1993 period in the northern zone basins

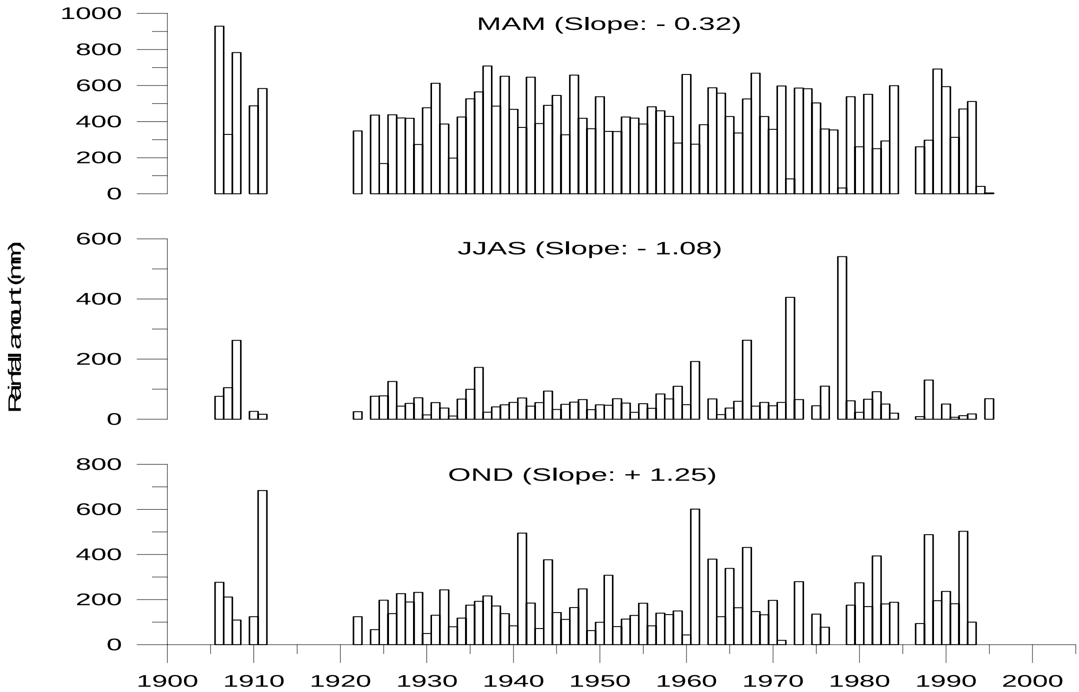


Figure 11 Times series of MAM seasonal rainfall amounts at Morogoro Agriculture (09637000) in the Wami basin
The figures indicate linear trend slopes for the 1930 – 1995 period.

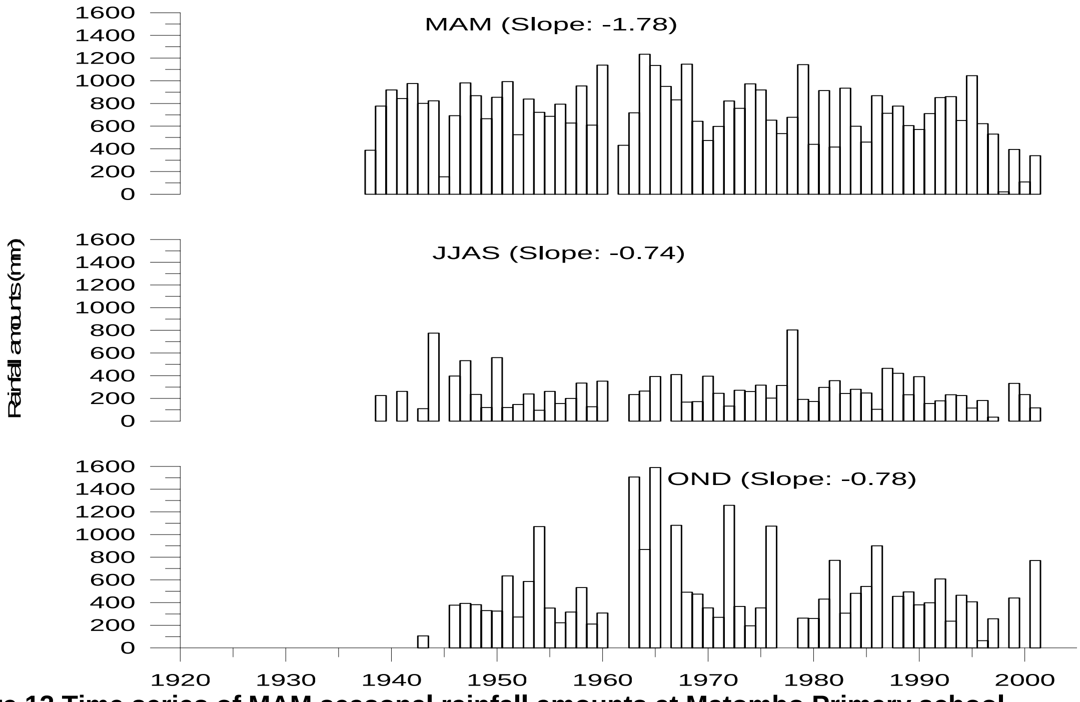


Figure 12 Time series of MAM seasonal rainfall amounts at Matombo Primary school (09737006) in the Ruvu basin
The figures indicate linear trend slopes for the 1964 – 1993 period.

Rainfall amounts during the short rains (OND), on the other hand, show increasing trends towards wetter conditions. OND seasonal rainfall amounts have increased since the late 1950s (Figure 11) to early 1960s (Figure 12), but, thereafter did not increase consistently year after year. Years 1961, 1968 and 1997 received abundant rainfall during OND and the overall trend was increasing particularly in the part of Wami River basin close to northeast

Tanzania (Figure 11). The short rains were at their lowest in 1998 following the strong 1997 El Niño event.

3.2.3 Southern zone sub-basins

Seasonal variations

The within-the-year variation of rainfall amounts (Figure 13) indicates the dominance of unimodal rainfall regime in the southern sub-basins of Kilombero and Lukosi. This rainfall regime corresponds to a single rainy season between November and May with a broad peak around January-April. The seasonal variations further indicate the relatively dry period since June through September with monthly rainfall amounts predominantly below 50 mm (Figure 13). Whilst August is the driest month in the region, the months of highest rainfall amounts vary with these highest amounts observed in March/April; this is also evident in Figure 13.

Inter-annual variations

The results of linear trends on seasonal and annual rainfall amounts for the 1964-1993 period are summarised in Table 14. They generally indicate predominant decrease of annual rainfall amounts during the long rains and the intermediate JF season. However, a mixture of increasing and decreasing trends in rainfall amounts characterises the dry season while increasing trends are predominant during the short rains.

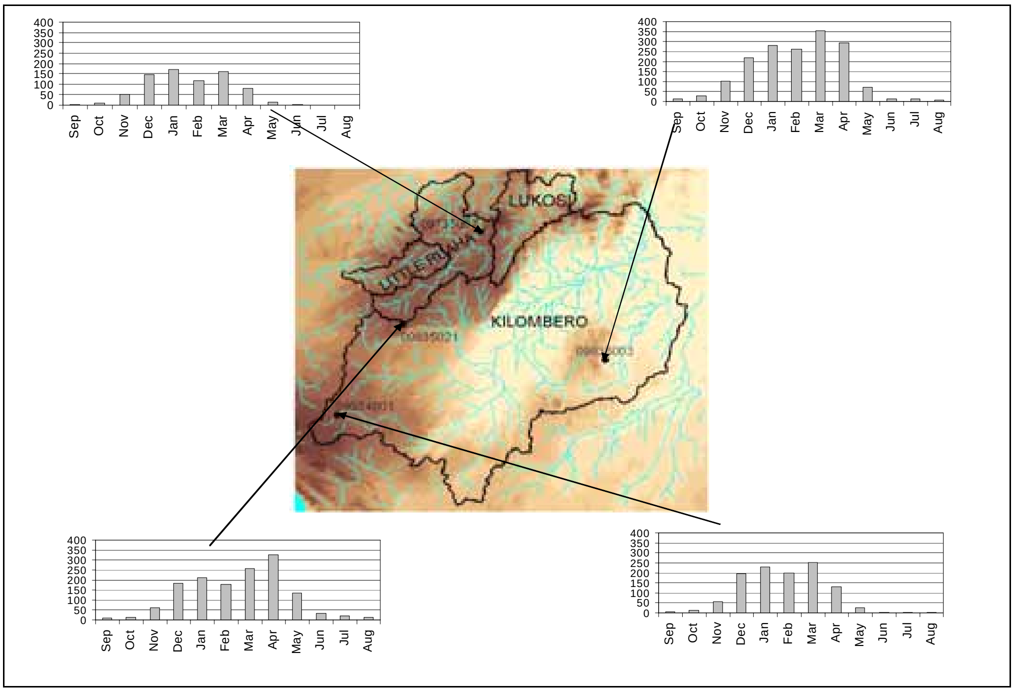


Figure 13 Typical seasonal rainfall patterns in the central Eastern Arc Mountains

The vertical maximum is 450 mm and the interval is 50 mm while the horizontal axis is from September (left) to August (right)

Table 15 Trends in seasonal and annual rainfall amounts in the southern sub-basins

BASIN	SNO.	CODE	Useful record		Trends (1930 - 1995)					Trends (1964 - 1993)				
			From	To	JF	MAM	JJAS	OND	ANN	JF	MAM	JJAS	OND	ANN
L Ruaha	1	09734000	1962	1988						-0.44	0.53	0.70	0.61	-0.63
	2	09735007	1960	1991						-0.13	-0.28	0.52	0.83	0.26
	3	09735014	1961	1988						-0.87	-1.05	-1.76	-0.23	-1.69
	4	09834006	1961	1995						-1.30	-1.35	-0.89	0.21	-1.40
	5	09834008	1957	1994						-0.43	-0.35	-0.27	0.10	-0.72
	6	09835009	1938	1994						-2.31	-1.80	0.39	-0.37	-1.90
	7	09835021	1951	1990						-0.51	-1.38			
	8	09934021	1954	1991						-0.44	0.53	0.70	0.61	-0.63
Kilombero	9	09835009	1939	2004						-0.43	-0.35	-0.27	0.10	-0.72
	10	09836002	1960	1993						-0.33	-1.05	-1.69	0.02	
	11	09836003	1960	1993						-0.29	-1.63	-1.82	0.16	
	12	09934001	1927	1998	-0.21	0.88	-0.74	1.48	0.49	0.91	0.14	0.78	-0.80	-0.06
	13	09935007	1942	1995						-0.02			-1.10	
		Total number of stations:								**13**	**12**	**11**	**12**	**9**
		Number of increasing trends:								**1**	**3**	**5**	**8**	**1**
		Number of decreasing trends:								**11**	**9**	**6**	**4**	**8**

Spatially, the decreasing and increasing trends in seasonal rainfall amounts are mostly uniform across the central basins (Figure 14). This spatial homogeneity is shown by close stations experiencing the same trend direction. As an example, trends in JF seasonal rainfall amounts (Figure14a) are negative across the two sub-basins while those in OND seasonal amounts (Figure 14d) show similar direction between any close stations.

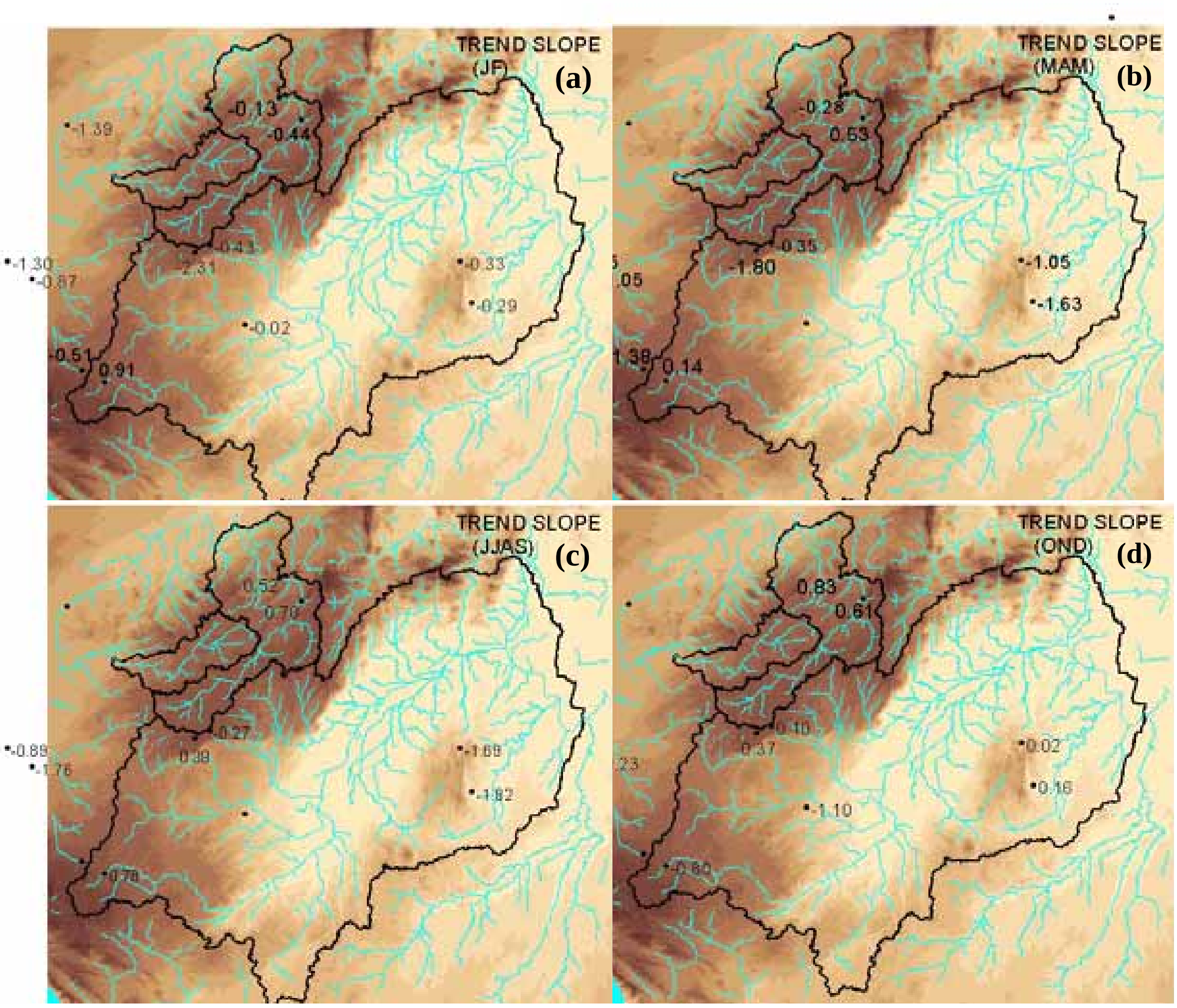


Figure 14 Spatial variation of the slope (Z) of a linear trend for a) JF, b) MAM, c) JJAS and d) OND seasonal amounts for the 1964-1993 period in the southern sub-basins

Although linear trends are affected by the period and length of record used in the analysis, it was not possible to estimate trends for longer periods (1930-1995) as for the northern and central basin since only one station has a record length which spans between 1927 and 1998. However time series of seasonal rainfall amounts in the sub-basins for the recent 50-60 years of available data indicate that the JF seasonal rainfall has decreased since the early 1990s (Figure 15). Time series further indicate that the computed linear trends were not strictly decreasing or increasing. The JF rainfall was the lowest in 1980 period and abundant during the 1960s through 1970s before declining abruptly in the mid 1980s. Similarly, despite increasing trend of OND seasonal rainfall amounts, the amounts during the short rains were low during the 1950s Period (Figure 15).

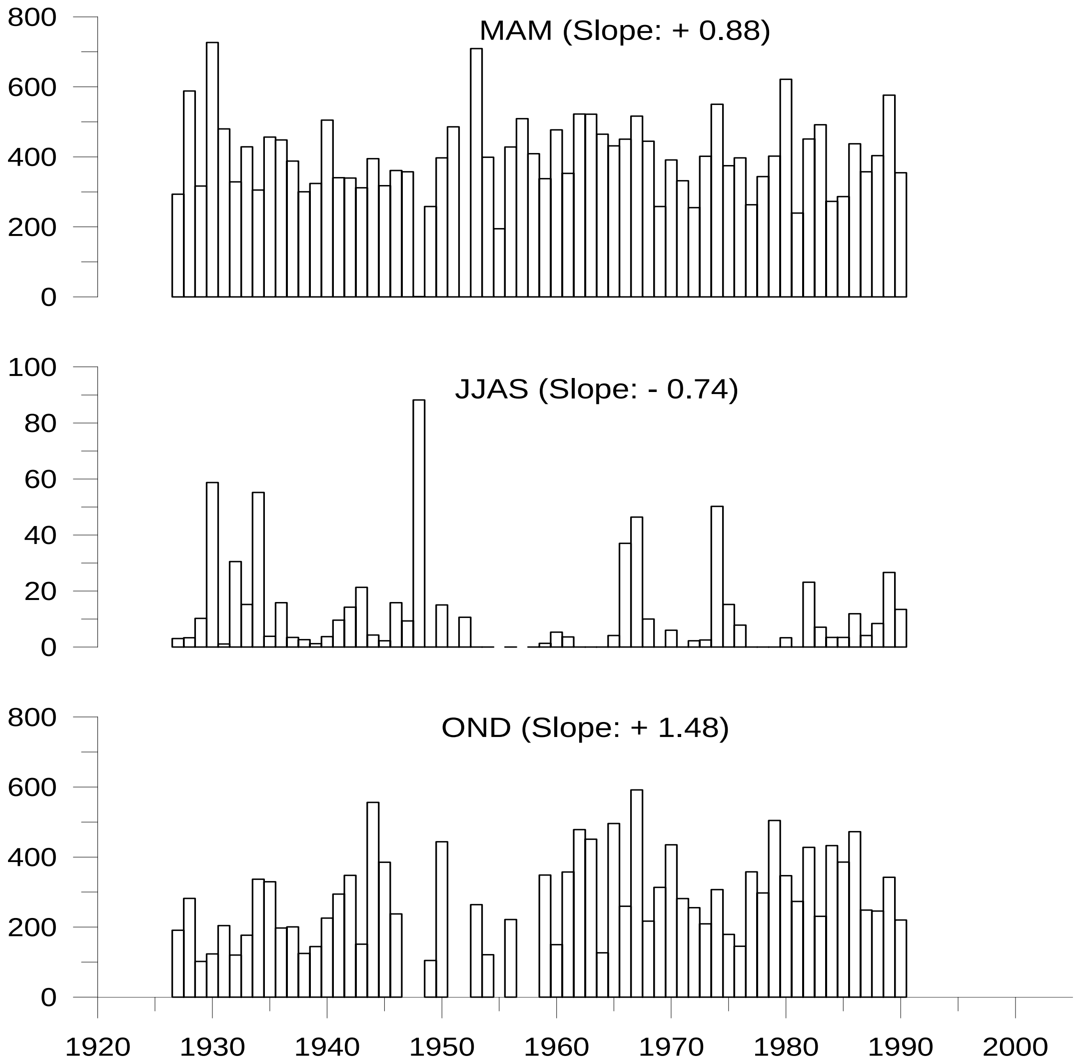


Figure 15 Time series of seasonal rainfall amounts at Njombe District Office (09934001) in the Kilombero sub-basin
The figures indicate linear trend slopes for the 1930 – 1995 period.

3.3 Conclusions

Seasonal rainfall analysis indicated the existence of the rainy season between October and May and the relatively dry season from June through September. The rainy season is bimodal in the northern zone basins (Mkomazi, Luengera and Sigi), unimodal in the southern Kilombero basin and a transition between bimodal and unimodal in the central basins (Wami and Ruvu). The bimodal areas observed two main rainy seasons, the short rains (October-December) and the long rains (March-May) with a January-February transition period of reduced rains. Long records of rainfall indicated increasing rainfall amounts during the short rains (OND) and the intermediate JF season and decreasing rainfall amounts during the long rains (MAM) and the following dry JJAS period. The rainfall increases were mainly attributed to higher rainfalls in the 1960s and 1970s than the period before. However, between the 1960s and the present, the high rainfall amounts during the two decades (1960s and 1970s) compared to those in the 1980s and 1990s resulted in decreasing trends in almost all seasons.

3.4 Recommendations

One of the major constraints towards achieving conclusive results was the non-availability and poor quality of the data. The data available was either of short record or contained a lot of gaps. These characteristics of the data to a certain extent limited the analysis of rainfall and stream flow variations. In addition the most recent data is often missing. Appropriate stations for studying the impact of forest cover on river flow regimes are lacking in some of the areas of the EAM. In this regard, it is recommende:

a. To appeal to the agencies (or Ministry) responsible for the collection of hydrological and climatological data to take remedial measures to improve data availability in the country;
b. To install new gauges at suitable sites particularly those closest to or within the forest. These include flow gauging stations, rainfall stations, climatic stations and observation wells for subsurface conditions.

4 Stream flow variations

This section presents the details of stream flow analysis which include:

a. The data analysis to select suitable flow records for use;
b. Seasonal stream flow variations; and
c. Inter-annual flow variations.

The analysis of data aims at assessing the quality and suitability of acquired stream flow records for intended analyses. It involves:

a. Establishing the criteria that are used in the selection of suitable records for analyses; and
b. Extraction of appropriate indices for studying the variability of stream flow.

The section further presents and discusses seasonal as well as inter-annual patterns of variability of stream flow indices, including mean flows and flow extremes. Seasonal flow patterns are described based on long-term averages while inter-annual variability is based on the results of linear trend analysis.

4.1 Data and methods

4.1.1 Selection of stream flow records

The criteria used in the selection of stream flow records for inter-annual variability analysis were record length, missing data and period of interest. The selection process excluded all gauging stations that were known to be located downstream of any artificial regulation point which regulates the flow measured at those particular stations. Gauging stations within the selected basins were further selected in such a way to avoid closely located gauges while retaining as many gauges as possible along the river lengths. This aimed at investigating the spatial variations of the changes of the river flows regimes, if any present, within the basins. The overall requirements of analysing long continuous records from unregulated catchments[1] within the selected basins, therefore, retained 21 stream flow records whose details are given in Table 16.

Table 16 Summary of selected stream flow records used for Inter-annual variability analysis

Basin	Sno.	Code	Name	Location	Lat	Long	Area	Selected records	Common period
Sigi	1	1C1	Sigi	Lanconi Estate	-5.0139	38.7997	705.0	1957 - 1989	
Luengera	2	1DA1A	Luengera	Korogwe	-5.1333	38.5750	800.0	1962 - 1994	1968 - 1990
	3	1DA3A	Luengera	Maji Rest Hse.	-4.8722	38.5667	28.5	1968 - 1990	
Mkomazi	4	1DB2A	Seseni	Gulutu	-4.4639	38.0611	166.0	1962 - 1984	1962 - 1984
	5	1DB17	Mkomazi	Gomba	-5.0222	38.2792	3,341.0	1962 - 1984	
Wami	6	1G1	Wami	Dakawa	-6.4333	37.5333	28,488.0	1954 - 1983	1969 – 1983
	7	1G2	Wami	Mandera	-6.2333	38.4000	36,450.0	1955 - 1981	
	8	1G5A	Tami	Msowero	-6.5172	37.2114		1965 - 1983	
	9	IGB1A	Diwale	Ngomeni	-6.1667	37.6167		1965 - 1989	
	10	1GD31	Mdukwe	Mdukwe	-6.8311	36.9333	460.0	1969 - 2002	
Ruvu	11	1H5	Ruvu	Kibungo	-7.0167	37.8000	455.0	1953 - 2004	1959 – 1987
	12	1H8	Ruvu	Morogoro Rd.Br	-6.6889	38.6986	19,190.0	1959 - 1999	
	13	1HA9A	Ngerengere	Konga	-6.7000	37.9167	20.5	1954 - 1988	
	14	1HB2	Mgeta	Mgeta	-7.0372	37.5694	89.6	1955 - 1987	

[1] *Unregulated catchment* is that catchment whose river is neither naturally regulated by lakes, swamps and wetlands nor artificially regulated by hydraulic structures like dams.

Basin	Sno.	Code	Name	Location	Lat	Long	Area	Selected records	Common period
Kilombero	15	1KB8	Mpanga	Mpanga	-8.9378	35.8128	2,546.0	1957 - 1985	1962 – 1983
	16	IKB9	Mnyera	U/s Taveta Mission	-9.1667	35.5167	4992.0	1957 - 1984	
	17	1KB10	Ruhudji	Mwayamulungu	-8.9500	35.9300	14,136.0	1960 - 1986	
	18	1KB14	Lumemo	Kiburubutu	-8.0122	36.6572	587.6	1958 - 1989	
	19	1KB15	Mngeta	D/s Mchombe Mission	-8.3333	36.1167	302.5	1958 - 1983	
	20	1KB15A	Mngeta	U/s bridge	-8.3361	36.0861	325.2	1960 - 1990	
	21	1KB23	Sonjo	Sonjo	-7.8000	36.9667	40.2	1962 - 1984	

The spatial distribution of the selected flow records indicates the availability of suitable records at the most downstream stations in all the northern basins (Figure 16). From its smaller size, the selected three stations in the Luengera River sub-basin are very appropriate for the study. This is also similar for the Sigi River basin and Mkomazi River sub-basin. The locations of retained stations in the basin / sub-basins in the central and southern Arc Mountains are close to the mountains. Such a distribution is expected to highlight the interrelationships between changes of the forest and landuse on one hand and changes of quantity and quality of river flow on the other.

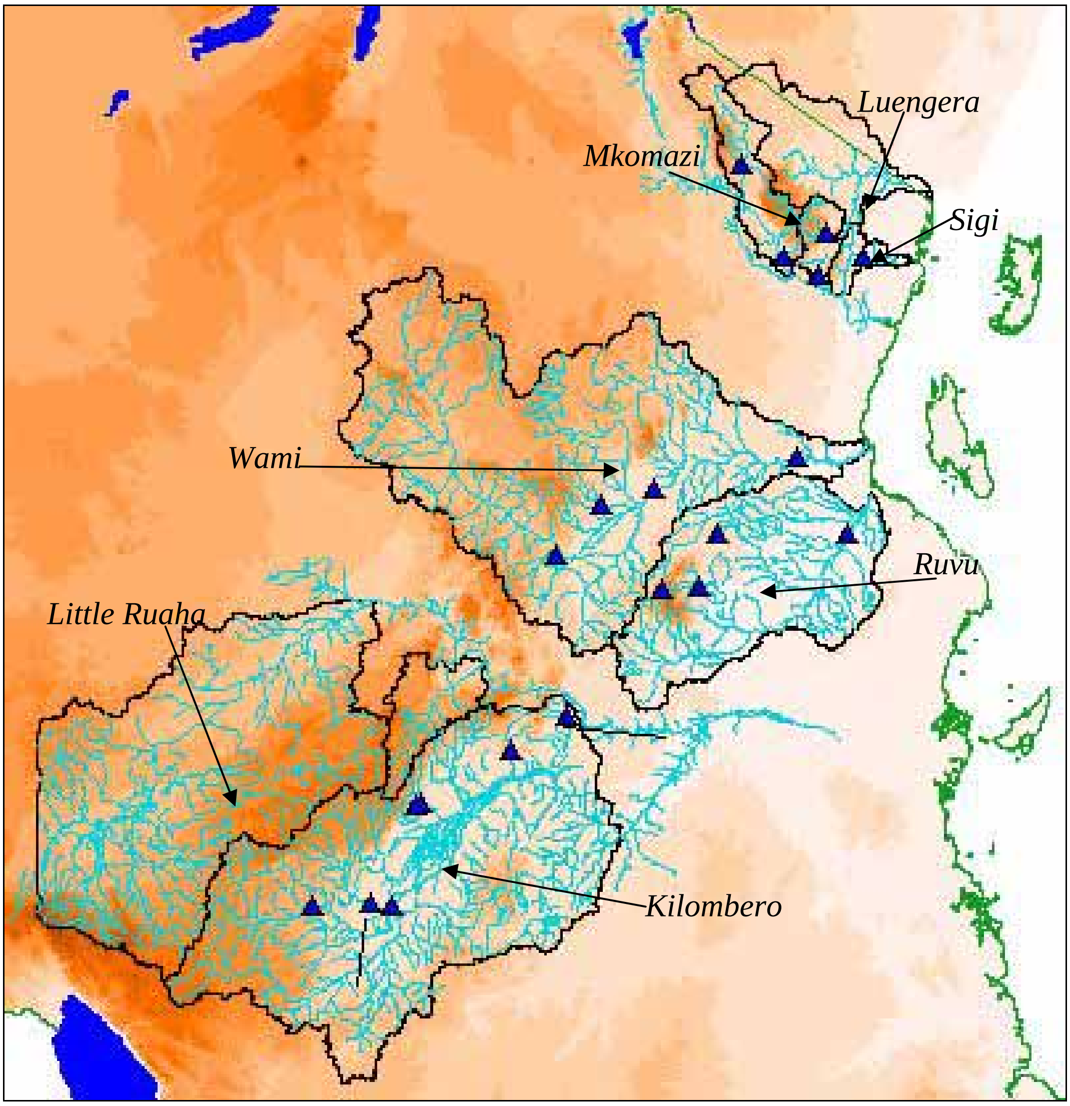


Figure 16 Spatial distribution of selected stream flow gauging stations for Inter-annual variability analysis

However, the records differ significantly in their length, record period (start and end dates) as well as the extent of missing observations. The longest continuous record of Luengera at Korogwe (1DA1A) has data since 1954 through to 1995 (42 years). Most other records are, however, relatively short with only 18-33 years of useful data and end mainly in the 1980s. Only six of the 21 selected flow records end in or after 1990, 11 of the records started in the 1950s while only nine records are continuous in the 1960-1985 period. These facts and the variable extent of missing observation within these short records will make it difficult to provide conclusive results on the impacts of landuse / landcover changes on stream flow changes that are hypothesized to have occurred since the 1980s.

4.1.2 Study indices

In order to verify the study hypotheses of reduced flows and enhanced frequency and severity of flow extremes (floods and droughts), various indices were extracted from available stream flow records. Average annual discharges (or flow volumes) were considered appropriate to highlight the flow increases or decreases over the years. Moreover, seasonal average discharges are appropriate in relation to the effects of depleted vegetation cover as flows are expected to increase during the rainy seasons due to unavailability of vegetation cover to reduce the runoff velocity, and to decrease during the dry season due to insufficient recharge of groundwater during the rainy seasons. It should be noted that monthly discharges were determined only for months with at least 90% of the daily observations available while seasonal flows were computed only from complete months that constitute that particular season.

4.1.3 Timescale for statistical variability analysis

The season, as defined in section three for rainfall, were used and they include the two main rainy seasons, the October-November-December (OND) short and March-April-May (MAM) long rains, the intermediate January-February (JF) season and the “dry” June-July-August-September (JJAS) season.

4.1.4 Filling of missing values

The procedure of replacing various missing monthly flows and rainfall indices has been described in detail in Valimba (2004). For monthly discharges, cross correlations were used between monthly values at the same gauging station and whenever this method failed to fill the gap, the long-term or segment averages (are computed from 6-10 values on either side of the gap with outlying values excluded) were used.

4.1.5 Methods for inter-annual variability analysis

Similar methods as described in section three are used.

4.2 Analysis of flow variations

4.2.1 Northern zone basins / sub-basins

Characteristics of river flow regimes

The statistics of average daily flows (ADF) (Table 17) indicate that most of the rivers are perennial although some dry up during relatively dry years. This is indicated by the relatively small percentages of days with zero flows. Flow duration curves (FDCs) (Figure 17) show that the percentage of time flows exceed the ADFs is only 20-40%. Higher FDC values and steep slopes at the beginning of the FDCs further suggest that the rivers experience high flow changes within the year responding to the wet and dry seasons.

Table 17 Summary statistics for selected stream flow stations

Basin	Flow gauge	ADF (m^3/s)	% zero flows	1-Day FDC value (% ADF)				
				Q90	Q70	Q50	Q10	Q5
Sigi	1C1	7.08	0.7	11.3	26.8	45.2	207.6	370.0
Luengera	1DA1	3.89	2.0	15.4	38.5	64.2	256.9	310.8
	1DA3A	3.48	0.0	17.2	40.2	63.2	227.1	310.4
	1DA4A	4.50	1.4	8.9	31.1	66.7	215.6	284.5
Mkomazi	1DB2A	1.95	26.1	15.4	30.8	51.3	235.8	353.8
	1DB17	1.97	3.3	5.1	20.3	40.6	147.1	370.3
	1DB18	0.68	0.2	44.0	58.6	73.3	175.9	234.5

Seasonal flow patterns

Intra-annual analysis of flow indicates periods of high and low flows in the rivers. The rivers in the Luengera and Sigi sub-basins experience high flows following the short and long rains (Figure 18). Although bimodality is evident in all rivers draining the Usambaras and Pares, the highest peak in the Luengera (Figure 18a) and Sigi (Figure 18a) is observed in May and in December (Figure 18c) in the Mkomazi sub-basin. This reflects the influence of rainfall peaks in the areas drained by these rivers, being November-December in the northern portion of the Eastern Arc Mountains and March-April elsewhere. Consequently, flow volumes during the high flow period (October-December / April-June) in these northern sub-basins contribute about 60-73% of annual flow volumes.

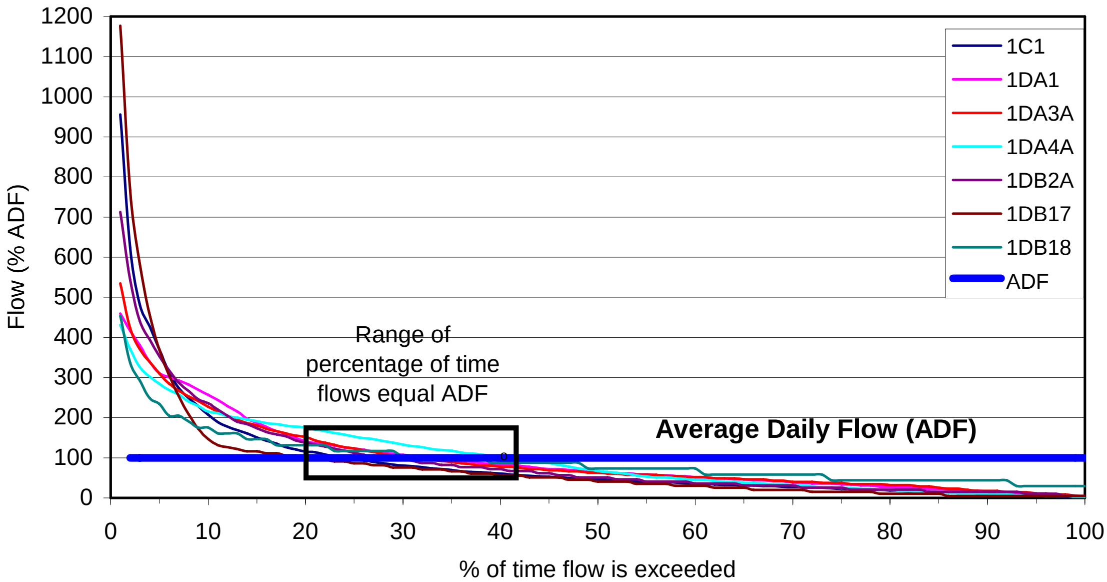


Figure 17 Flow duration curves (FDCs) constructed from non-zero flow records in the northern zone basins and sub-basins

The low flows in rivers draining the northern Eastern Arc Mountains are experienced during the dry period and correspond to rainfall regimes. In these northern zone basins / sub-basins (Mkomazi, Luengera and Sigi), they are experienced in February-March and July-October (Figures 18a-c). However, the period of the lowest flows differs between rivers in the Mkomazi sub-basin and those in the Luengera sub-basin and Sigi basin. Whilst the lowest flows in the Mkomazi sub-basin are experienced in September and October, they are observed in February and March in the Luengera sub-basin and Sigi basin. Moreover, in certain dry years, some of the rivers completely dried up. This was observed during the 1974-1976 drought (Nyenzi et al., 1999) during which period the Sigi River was completely dry for 19 days in March 1976 and Luengera river was dry for 30 days (12^{th} December 1974 – 10^{th} January 1975), 41 days (5^{th} February – 14^{th} March) in 1975 and 30 days (29^{th} January – 27^{th} February) in 1976.

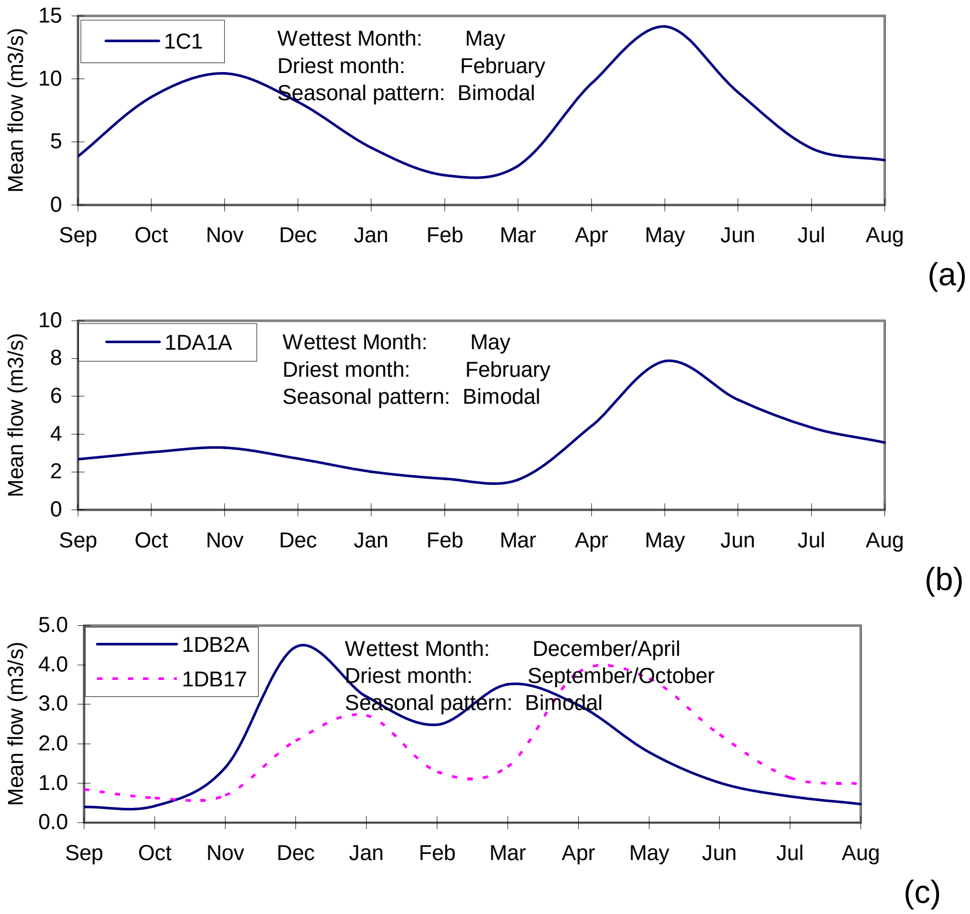


Figure 18 Typical seasonal flow pattern in the a) Sigi basin, b) Luengera sub-basin and c) Mkomazi sub-basin as computed from available records

The uneven distribution of flows within the year further indicate that about 59-71% of annual volumes in the Luengera, Sigi and lower Mkomazi flow during the long rains (March-April-May, MAM) and the subsequent dry season (Table 18). In the upper Mkomazi, the highest flow volumes (~ 60%) are experienced during the intermediate season (JF) and the long rains. Furthermore, mean flow volumes in JF exceed those during the short rains (October-November-December, OND) in the Mkomazi sub-basin reflecting the important contribution of high rainfall in November-December in the upper Mkomazi. Therefore, such high flow contributions during the long rains suggest that changes of annual flows over the years could be attributed significantly to changes during this season.

Table 18 Mean seasonal flow volumes expressed as percentages of mean annual flow volumes

Basin	Code	Seasonal contribution to annual flow volume (%)			
		Intermediate Season (JF)	**Long rains (MAM)**	**Dry season (JJAS)**	**Short rains (OND)**
Sigi	1C1	9	38	29	24
Luengera	1DA1A	9	35	41	15
	1DA3A	10	34	39	17
	1DB2A	24	43	12	21
Mkomazi	1DB17	19	44	26	11

Inter-annual flow variations

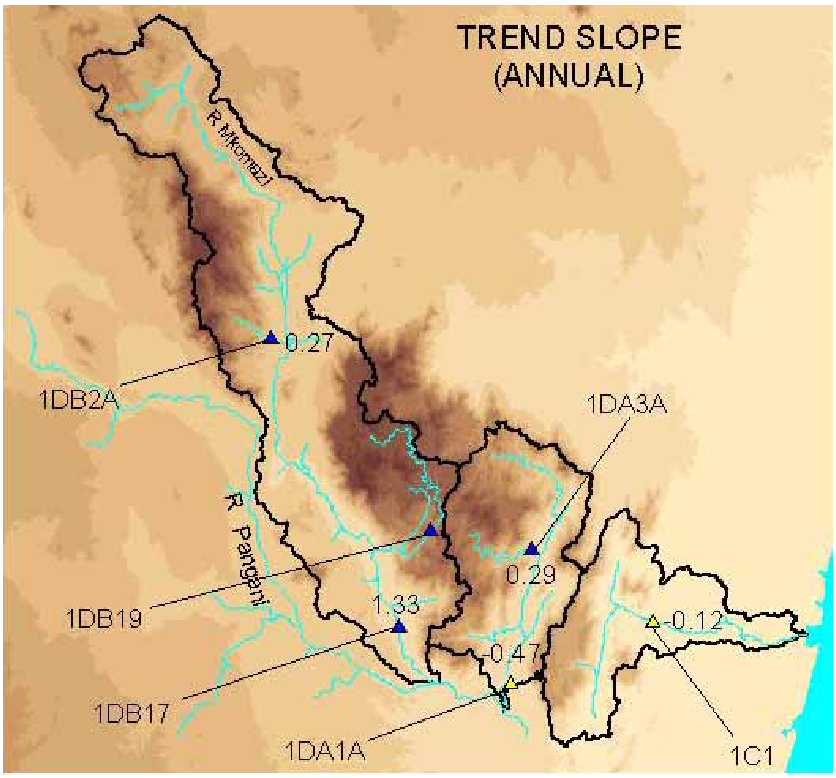
Results of linear trend analyses on annual flows for whole suitable records periods for each basin or sub-basin in the northern part are summarised in Table 19 and Figures 19 and 20. The results of linear trends on annual flows generally indicate i) flow declines in the Sigi basin and lower Luengera and ii) flow increases in the Mkomazi and upper Luengera.

Table 19 Summary of linear trend slope (Z) in seasonal mean flows for common record periods

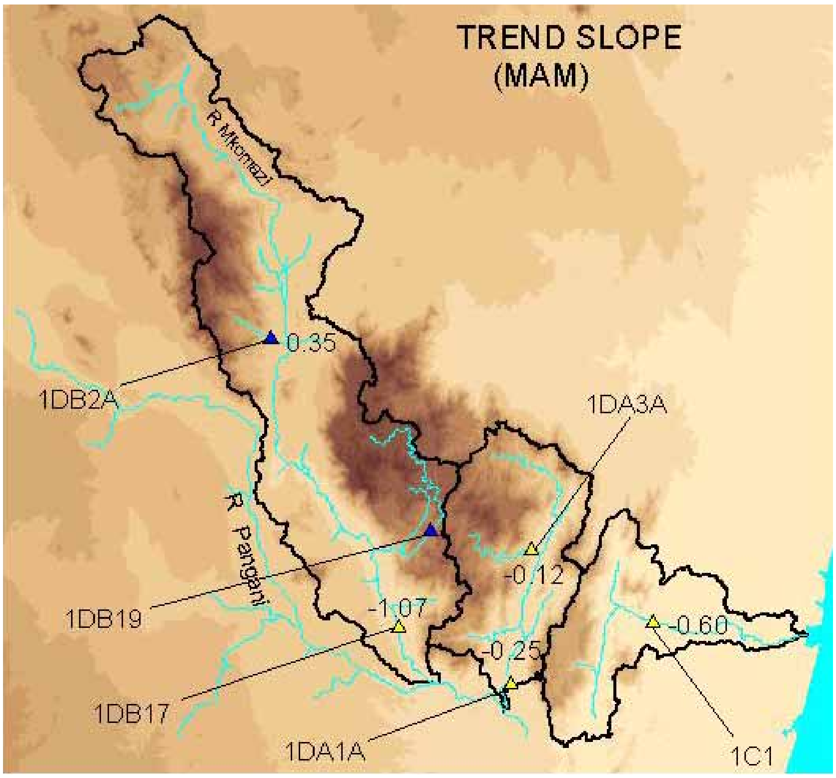
Basin/Sub-basin	Code	Whole records	Common period	Trend (whole period)				
				Intermediate season (JF)	Long rains (MAM)	Dry season (JJAS)	Short rains (OND)	Annual
Sigi	1C1	1957 - 1989		0.32	-0.60	0.85	-0.08	-0.12
Luengera	1DA1A	1962 - 1994	1968 – 1990	1.15	-0.25	-0.96	-0.05	-0.47
	1DA3A	1968 - 1990		-0.12	-0.12	-0.12	0.29	0.29
Mkomazi	1DB2A	1962 - 1984	1962 – 1984	0.02	0.35	0.41	0.47	0.27
	1DB17	1962 - 1993*		0.37	-1.07	1.09	-0.47	1.33

Significant trends are bolded.

Although decreasing trends characterise annual flows in the Sigi and upper Luengera, the trends are, however, insignificant indicating that annual flows are slightly decreasing in the basins. These slight changes are indicated by a change of mean annual flow of only 0.175 m^3/s (or 5.52 mm^3) in the Sigi at Lanconi from an average of 6.157 m^3/s in the 1957-1966 period to an average of 5.982 m^3/s in the 1980-1989 period (Figure 21a). Moreover, despite the generalised decrease of annual flow in the two basins, certain years like 1978 and 1979 experienced the highest flows while others like 1974 and 1976 observed the lowest flows. Time series (Figure 21) indicate alternating periods of abundant and deficit annual flows. The 1960s decade experienced high annual flows and was followed by drought in the early to mid 1970s before they recovered in the late 1970s through early 1980s. Annual flows have again declined since the late 1970s.



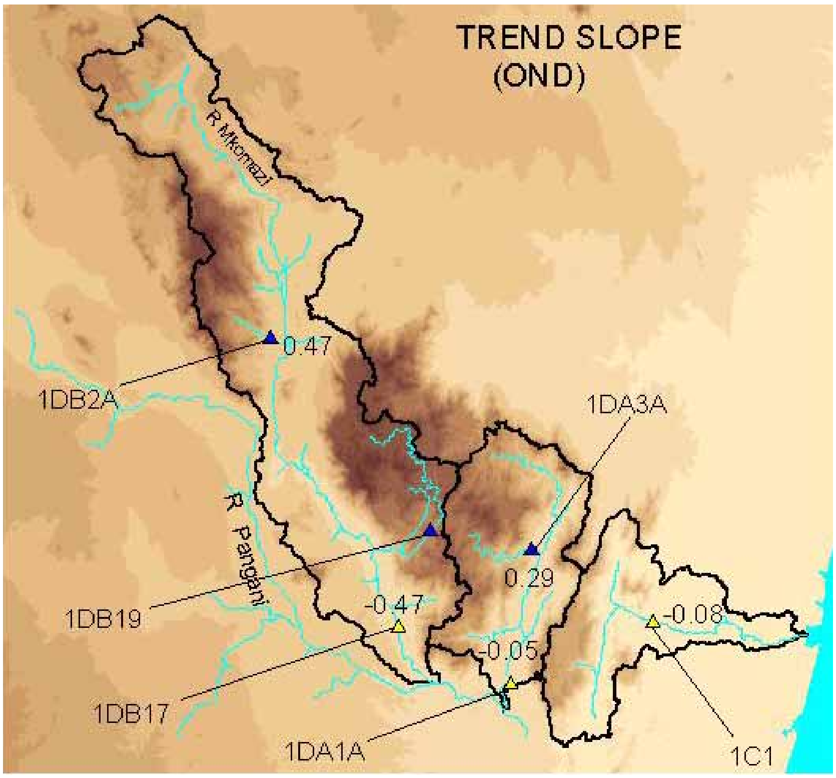
(a)



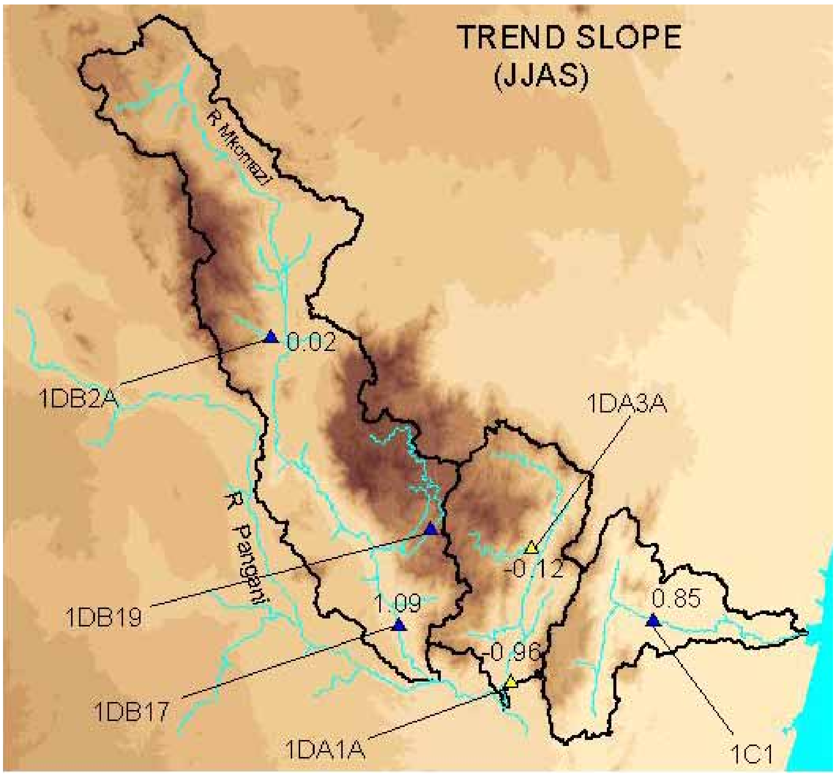
(b)

Figure 19 Spatial variation of the slope (Z) of a linear trend for a) annual flows, b) long rains (MAM) in the northern zone Eastern Ac Mountains basin / sub-basins when whole records were used

Yellow triangles indicate decreasing trends while blue ones indicate increasing trends**.**



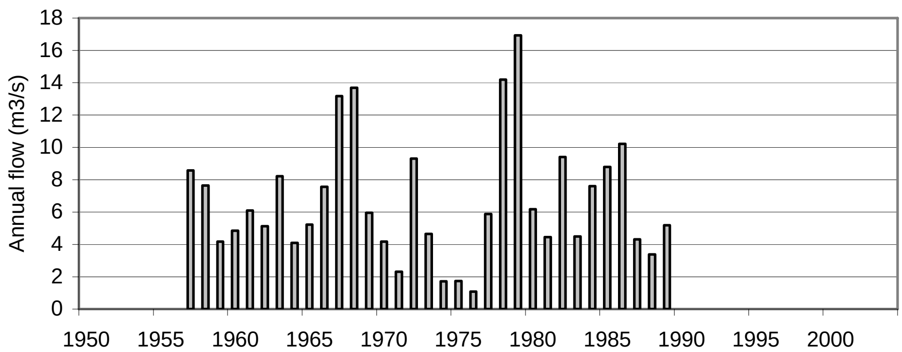
(c)



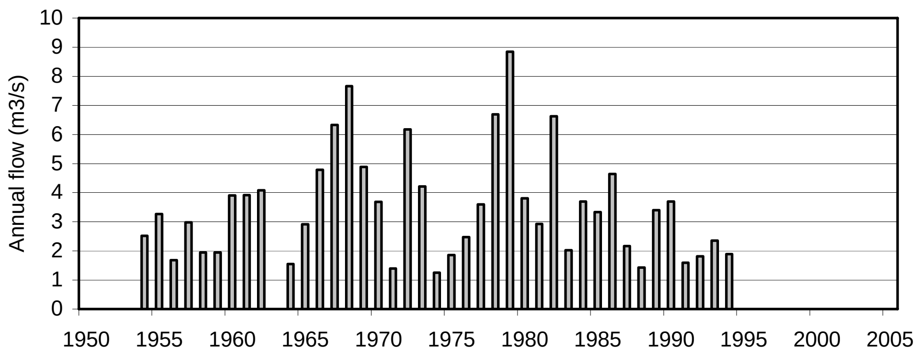
(d)

Figure 20 Spatial variation of the slope (Z) of a linear trend for c) short rains (OND) and d) dry season (JJAS) in the northern zone Eastern Arc Mountains basin / sub-basins when whole records were used

Yellow triangles indicate stations showing decreasing trends and blue ones increasing trends.



(a)



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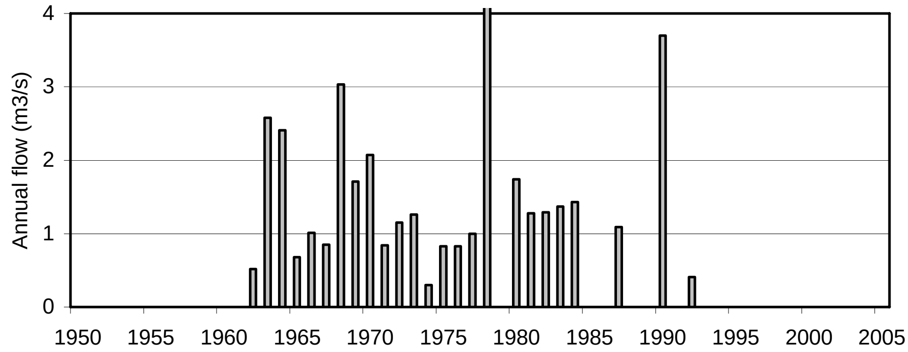
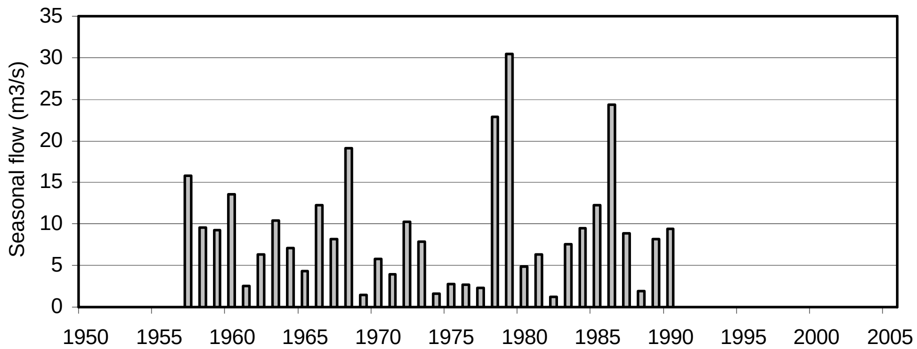


(c)

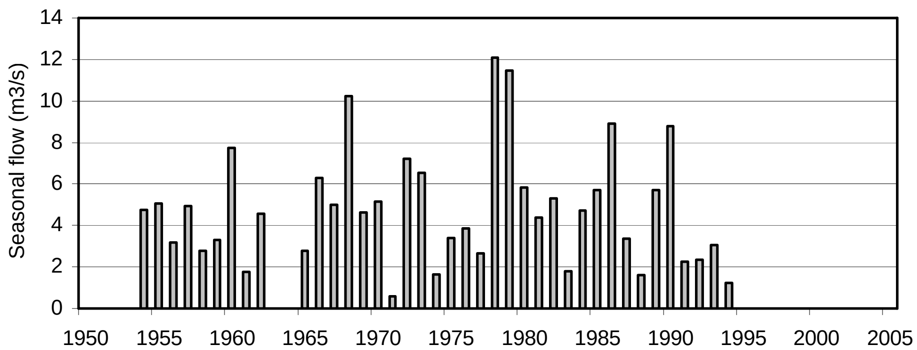
Figure 21 Time series of annual flows at a) 1C1 in Sigi, b) 1DA1 in Luengera and c) 1DB17 in Mkomazi

Theoretically, changes in vegetation cover could lead to increasing flows during the rainy seasons and decreasing flows during the dry season. In this regard, linear trends were also determined for seasonal flows. The results (Table 19, Figures 19 and 20) indicate:

a. predominance of declining flows during the long rains;
b. a mixture of increasing and decreasing flows during the short rains and intermediate season; and
c. the influence of the period of high flows on annual flows.



(a)



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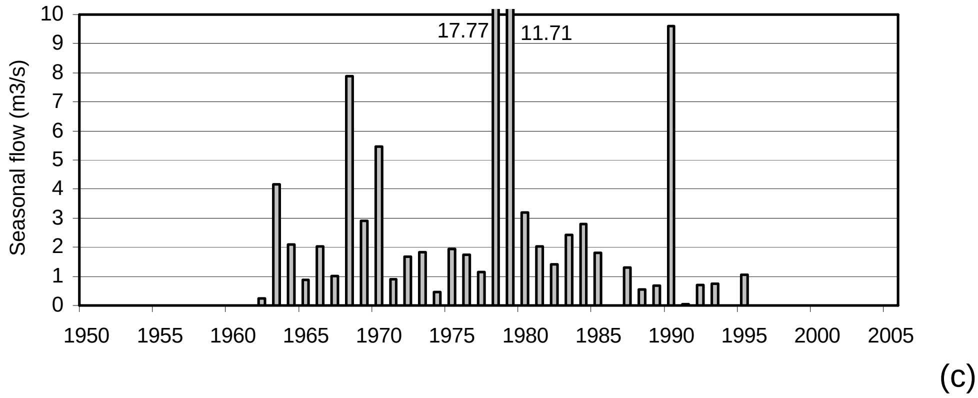
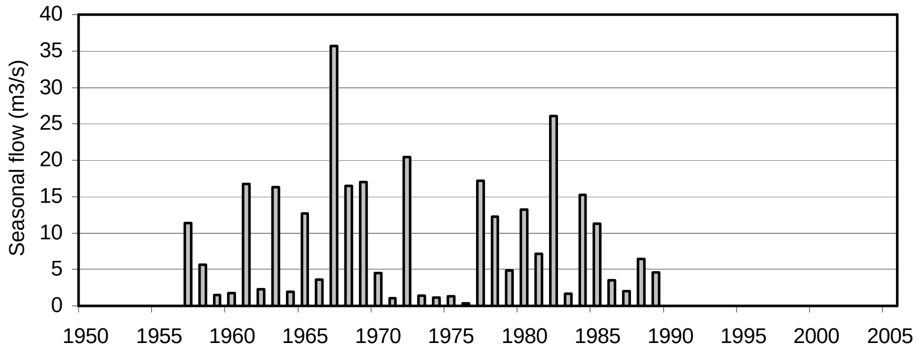


Figure 22 Time series of seasonal flows during the long rains (MAM) at a) 1C1 in Sigi, b) 1DA1 in Luengera and c) 1DB17 in Mkomazi

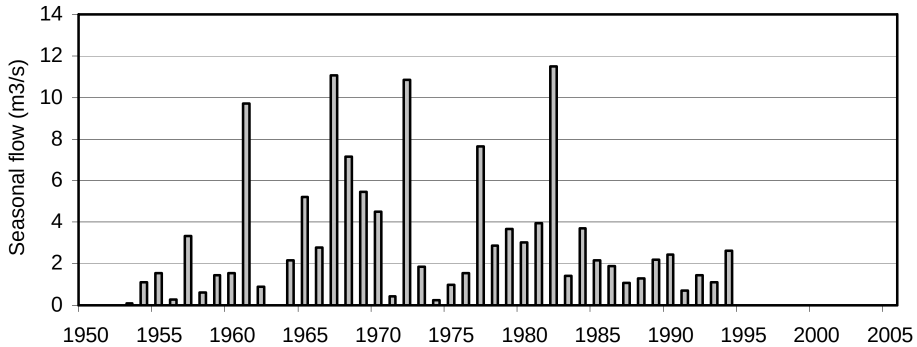
Except in a small upper catchment (of 1DB2A) in the Mkomazi basin, seasonal flows during the long rains (MAM season) in all catchments are decreasing as indicated by negative trends (Table 19). However, time series indicate that trends are not strictly decreasing since years of abundant and deficit flows are a characteristic. Low seasonal flows were experienced during the drought period 1974-1977 (Figure 22) followed by the highest MAM seasonal flows in 1978 and 1979. However, MAM flows are significantly decreasing since the late 1985. The drought period of 1974-1977 and flow decreases since the mid to late 1980s are also evident in time series of seasonal flows during the short rains (OND) (Figure 23) and dry period (JJAS) (Figure 24).

The decreasing flows during the dry seasons and increasing flows during the short rains at some gauging stations confirm theoretical expectations under depleted vegetation cover. However, predominant decreasing flows during the long rains contradict theoretical expectations and could be attributed to a combination of factors including changing rainfall, water use, vegetation, etc. Moreover, some sub-basins, like the Mkomazi, observed contrasting trends with increasing flows in the upper river reaches and decreasing in the lower river reach. Such contrasting patterns are discussed later in relation to rainfall changes.

The influence of trends in flows in the dominant seasons on trends in annual flows is evident when trends (Table 19) are compared with mean seasonal flow contributions (Table 18). Despite JF seasonal flows showing a positive trend at 1DA1A which is larger (in absolute value) than negative trends in the other seasons (Table 19), annual flows have a negative trend. The JF seasonal flows at this catchment contribute about 9% of annual flow volume while flow volumes in MAM and JJAS totally contribute about 76% of annual flows. The decreasing annual flows are therefore attributed by decreasing flows during the two seasons. This is confirmed by high inter-annual cross correlations between annual flows and MAM flows (r = 82%) and JJAS flows (r = 89%). However, it is not always that the combined influence of dominant seasons is clear. This is illustrated by flows at 1DB17 in which the decreasing flows during the long and short rains (Table 19), which contribute about 55% of annual flow volume (Table 18), contradict the increasing annual flows. The positive trend in annual flow at this gauge could be attributed to complex mixture of positive trend during the JF and JJAS seasons and negative trends during the short and long rains.



(a)



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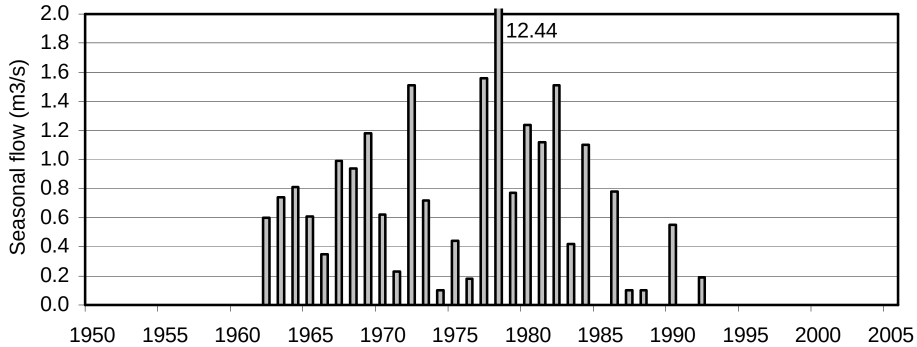

(c)

Figure 23 Time series of seasonal flows during the short rains (OND) at a) 1C1 in Sigi, b) 1DA1 in Luengera and c) 1DB17 in Mkomazi