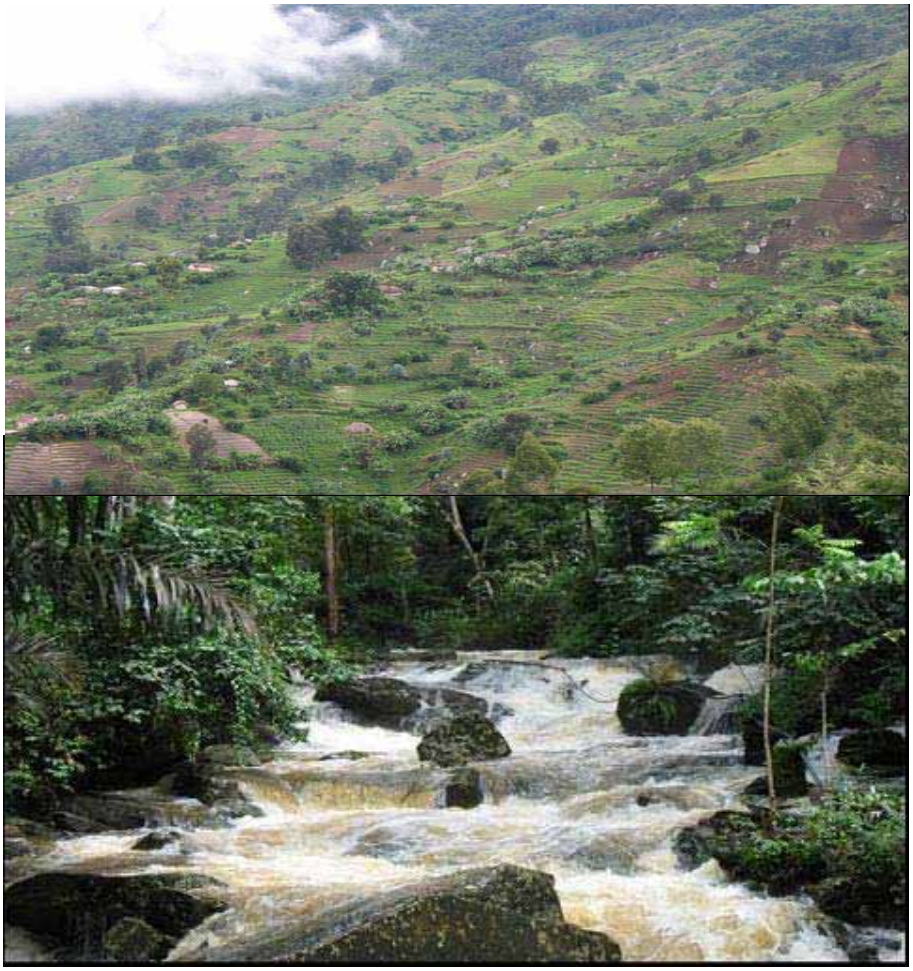
HYDROLOGIC AND LAND USE/COVER CHANGE ANALYSIS FOR THE RUVU RIVER (ULUGURU) AND SIGI RIVER (EAST USAMBARA) WATERSHEDS



By

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EXECUTIVE SUMMARY

CARE International in Tanzania in partnership with WWF Tanzania Programme Office is in a process of establishing a new project entitled "**Equitable Payment for Watershed Services (PWS)** in the Uluguru and East Usambara Mountains focusing on Ruvu and Sigi river basins. The central premise of this project is to establish an equitable payment mechanism between buyers and sellers of the watershed services. The PWS mechanism will actually promote equity in the distribution of benefits so far as this can be achieved without significantly undermining the financial viability of the initiative.

The proposed Equitable Payments for Watershed Services (PWS) initiative which is the subject of this study entails the major users of water from the Ruvu river and Sigi River ("the buyers") making a long term financial investment in modifying land use within the river basin to improve "watershed services" – specifically the reliability, and quality of their water supply. This financial investment ("the payments") would be used to provide benefits to communities that act as an incentive for them to make the changes in land use and/or natural resource management (NRM) needed to deliver the improved watershed services, and to sustain these changes over time.

The major aim of this assignment was to undertake detailed hydrological analysis of the Ruvu and Sigi River basins in relation to land use/cover change to provide guidance on what and where the PWS initiative should be focused within the upper catchments based on maximizing the buyers' return on investment in terms of their particular interests in improving watershed services. In other words where will the buyer get "the best bang for their buck". This will also within the focal areas address poverty of the poor farmers or people in general.

The specific activities undertaken included

- Review of secondary literature to gather relevant information on changes occurring in the watersheds in terms of land use and river hydrology
- Development of methodology for assessing the historical hydro-meteorological data coupled with the analysis of land use and land cover change on the Ruvu and Sigi River systems
- Collection of time series data of runoff records on the Ruvu and Sigi Rivers, and the corresponding changes in land cover over a long span of time
- Development of land cover change - runoff relationships for the Ruvu and Sigi Rivers' Catchments and assessed the influence of catchment condition and land use types on water quality and indicated the extent of linkages between declining vegetation/forest cover with stream flow, water quantity/quality in the Ruvu and Sigi Rivers.
- Identification of hydrological related problems notably stream flow, water quantity and quality
- Identification of areas that contribute significantly to the problem of deteriorating water quantity/quality in the Ruvu River and Sigi River (hotspots for interventions)
- Assessment of the major human activities that contribute to the problem of declining water quantity and/or quality in the Ruvu and Sigi Rivers and the extent to which they contribute to the problems
- Establishment of the size of the upper catchment that would need to be involved in the process of land use/NRM change to deliver the desired change in flows and/or sediment load within the Ruvu and Sigi Rivers.

- Provide technical recommendations (for land use change) on how to alleviate the problems

It was observed that water quality is of less concern to both upstream and downstream users compared to quantity. The major concern in water quality is cleanliness and therefore aspects of turbidity or sediment loading especially with large scale users in the food industry and urban water supply authorities though concerns about pathological aspects of water quality such as coliform bacteria and heavy metal contamination seem to be building up. This will likely build up more as environmental and health education and awareness in relation to water resources builds up in the society in the future.

It was learnt that there were no continuous monitoring program for water quality in the two basins thus there is no continuous water quality data available. Some data exists but 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 (FBD 2005c). However longer time turbidity data series for about 11 years could be obtained for the Ruvu River

Analysis of the 11 year series data set for mean monthly turbidity in the Ruvu River for a period of 11 years (January 1992 – November 2002) show that water turbidity in the Ruvu River increased from 130 Nephelometric Turbidity Units (NTU) in 1992 to 185 NTU in 2002. This is an increase in turbidity in the river of 5 NTU per year reflecting increases in sediment loading into the river over the same time. Such trends of increasing water turbidity are associated with vegetation degradation which result into erosion and higher sediment delivery into the streams.

The shorter time periods of available water quality data, the trends of average daily sediment load shows an increase in sediment loading in the Ruvu River up to early 1970s after which there was a decrease in sediment loading. The Sigi River shows the same trend in turbidity which is an indication of increase in sediment loading into the river up to the early 1970s. The increase in sediment loading during this period may be attributed to higher rates of reduction in vegetation cover. Land use/cover change analysis has indicated that there was a higher rate of decrease in vegetation cover during the early 1970s (FBD 2005a). This may have resulted into high erosion rates and hence higher rate of sediment delivery into the streams of the Ruvu river basin. The rate of depletion of vegetation cover after the early 1970s was lower and hence possible decreases in sediment loading into the river. It would however be necessary to obtain longer data sets to make concrete conclusive arguments.

Discussions with local informants also indicated that there has been an increase in sediment loading into streams which they attribute to unsustainable agriculture practices involving vegetation clearing. Majority of the respondents during the discussions expressed their concern that water in streams is becoming more dirty especially during the rain season and that sedimentation in rivers has become so high that most of the rivers are changing their courses. Another indication of this sedimentation process from the local people views is that the level of water from bridges that were once seen to be deep is now very close to the bridge which is an indication of increasing sediments into the rivers. Further more sedimentation into rivers causes water to spread large areas thus causing the rivers to be shallow and

widen. Majority of the respondents also observed that floods are more frequent which can be attributed to high rates of runoff but also shallow rivers and large volumes of sediments during the rain season

Analysis of land cover/use changes between 1955 and 2000 in Sigi basin has shown that there have been significant changes in land cover/use. Such process has involved substantial conversion of vegetation cover from higher forms (natural closed forest and woodland) to lower forms (mixed cropland, cultivation with bush crops and open grassland). In the Sigi basin this has been more evident in the main Sigi sub catchment. Similar trend was also observed in year 1995 to 2000. The major problems in this sub catchment include encroachment into the riparian zones for cultivation and settlement by small holder farmers and expansion of tea plantations. Further issues related to use of agrochemicals especially in vegetable farming and recently mining threatens water quality in this sub catchment. In the other sub catchments of Kihuhwi and Muzi rivers problems related to expansion of sisal plantations and subsequent expansion of human settlements as well as mining in the Muzi sub catchment are worth considering. On the other hand, there has been some conservation initiatives which have resulted into an increase in cultivation of bushy and perennial crops with integration of trees in croplands in the form of intercropping. However natural forests have become more fragmented with increasing loss of natural forest cover. Such changes likely exposed the land to degradation through erosion with subsequent increase in surface runoff and sediment loading into the rivers especially during the rain season.

In the Ruvu basin analysis of land cover/use has shown that in 1955 most of the area was covered by thickets and open woodlands. Some few areas especially in the northern part of the Uluguru Mountains were under mixed cropping. Further it was evident that in 1995 more vegetation cover has continued to be converted to farmland, in this case sisal estates and mixed crops. Between 1995 and 2000 there was an extensive expansion of agriculture at the expense of the natural vegetation cover. The land cover was characterized by mixed cropland that encroaches and extends into marginal lands such as hilly, steep slopes and river bank (riparian) ecosystems. Such situation has increased exposure of land surface to erosion agents and increased surface runoff. Three sub catchments were considered (main Ruvu (Kibungo), Mgeta River and Ngerengere River. The major problems in the main Ruvu (Kibungo) sub catchment are unsustainable farming practices characterized by flat cultivation, shifting cultivation, slash and burn with very limited use of soil conservation measures, high encroachment into riparian ecosystems and mining. The same situation exists in the other two sub catchments, Mgeta and Ngerengere with even more extensive use of land for cultivation in very fragile ecosystems. Some terracing as a conservation measure was observed in Mgeta though not adequate.

The overall analysis of land cover/use from 1955 to 2000 has shown that there has been significant change in land cover/use with reduction of high to low forms of vegetation mostly farmlands with expansion of agriculture to the riparian ecosystems and very steep slopes which are prone to erosion.

Discussions with the local people (elders) indicated that the catchments have experienced a tremendous vegetation degradation related to conversion of forested lands into agricultural lands. Worse enough most of these land transformations are

done on fragile steep slopes and are often abandoned when productivity declines leaving the areas completely bare and prone to severe erosion. Such conditions reduce the capacity of the catchment to store water with consequent declines in dry season flows as well as increasing sediment loading into the rivers with consequent decline in water quality.

Analysis of river flows in the two basins show that annual flow (discharge (m^3s^{-1}) and volumes (m^3) are predominated by decreasing trends over a period of more than 30 years. There has been slight decline in flows during the long and the short rain seasons though non significant in the Sigi basin but significant in the Ruvu basin. Of significance is the declining trend in dry season flows which are associated with degradation of natural forests/woodlands (higher forms of cover) to cultivated/bare lands (lower forms of cover).

In the Sigi River basin the mean annual and rain season discharge/flow volumes have declined very slightly in the period of 33 years. The most apparent decline is the dry season discharge and flow volumes which shows a greater decrease by about 0.8-m^3 sec^{-1} (i.e. 5.2 – 4.4 m^3 $sec\text{-}^{1}$) and 20 million m^3 (150 million – 130 million m^3) respectively. This is an annual rate of decrease of about 0.024 m^3 sec^{-1} yr^{-1} and 606,000 m^3 per year respectively. This is a significant decrease given the increasing demand for water resulting from increasing population and diversified uses downstream.

Trend analyses on annual flows for the Ruvu River generally indicate mixture of flow decreases and increases as influenced by contributions from its sub catchments. Both the annual, dry season and rain season flows in the Ruvu River basin as measured at Morogoro Road Bridge and its sub catchment at Kibungo and Mgeta show a decreasing trend in the past 46 years. The dry season flow at Morogoro road bridge declined by 5 m^3 s^{-1} (annual rate of 0.11 m^3 s^{-1} yr^{-1}) while mean annual flow and rain season flow declined by about 17 m^3 s^{-1} (0.37 m^3 yr^{-1}) and 25 m^3 s^{-1} respectively. In the Mgeta sub catchment the dry season and rain season flow declined by 0.2 m^3 s^{-1} while annual flows declined by 0.1 m^3 s^{-1} over a 35 year period. In the Kibungo sub catchment dry season flows declined by 5 m^3 s^{-1} (annual arte of 0.1 m^3 s^{-1} yr-1) in a period of 53 years while annual and rain season flows declined by 9 m^3 $s^{-1}$and 16 m^3 s^{-1} respectively over the same period. On the other hand the annual, rain season and dry season flows in the Ngerengere sub catchment show an increasing trend in a period of 54 years.

Decreasing trends in the dry season and increasing trends in the rain seasons is an indication of low water storage capacity in the catchments. The observed situation here implies different degradation conditions in the different sub catchments with the possibility that some of the sub catchments are more degraded than others impacting differently on water quantity. Generally there is a predominant decreasing trend in all the respective sub catchments especially in the dry season flow except for the Ngerengere sub catchment which shows increasing trends.

Such situations especially decreasing flow trend may as well be caused by water abstractions upstream. However water abstraction in all the sub catchments is not so significant to have high influence on flows in the rivers. Most of the abstractions in the sub catchments are for domestic consumption by piped water which is better controlled through water rights that indicate specific abstraction rates.

In the Sigi river basin, it was learnt that abstractions in the catchment upstream of the Lanzoni gauging station are minimum as most of them could be from the sisal plantations which do not operate nowadays. Further, most of these sisal farms are downstream of the gauging station and there was only one estate that could abstract water from upstream of the station – Lanzoni sisal estate which is abandoned. The tea estates are located in high rainfall and high moisture areas and water abstraction by these estates is minimal and mainly for domestic use. It was learnt that there are about 18 known abstractions which are mainly for domestic use with an average abstraction rate of about 2 Ls^{-1} per day (Pangani Basin Water Office, 2006)

In the main Ruvu sub catchment there are 7 known water abstractions with an average abstraction of 3 Ls^{-1} (261000 $Lday^{-1}$) (Ruvu Basin Water Office, 2006). Of all sub catchments in the Ruvu basin the Mgeta sub catchment seem to have higher abstraction rates mainly for irrigated agriculture through traditional furrows an effect that seem to be reflected in the declining dry season flow though not wholly as the annual and rain season flows also show declining trends. Explanations from the local people show that abstractions from this sub catchment are only from some tributaries of the Mgeta River (*i.*e. Mzinga with 5 furrows and Mbakana with 7 furrows) though the abstraction rate is not known. There are no known abstractions from the main Mgeta. Based on flow analysis it was observed that the contribution of flow into the Ruvu River by the Mgeta sub catchment is not so high as it drains a relatively small sub catchment. Land use change in this sub catchment especially degradation of cover is among the other major factors that can be attributed to decreasing flows in the sub catchment.

Although the analysis shows high degradation rates in all the sub catchments of these basins, it is not practical to undertake interventions on the whole basin thus priority sub catchments are identified based several but relevant criteria. The criteria used to select priority sub catchments include the extent and rate of change from natural forest/woodland (higher forms of cover/use) to cultivated/bare land (lower forms of cover/use), seriousness of degradation, the area of the sub catchment that reflects the proportional contribution to flow into the basin, existing conservation measures, activities with potential influence on water quantity and quality and to some extent population pressure. Here population pressure refers to the extent to which population pose pressure on land resources. In some cases such pressure may be due to high population density, and in other cases is how land resources are being managed. For example, in areas where shifting cultivation is practiced is not the factor of human population density but rather land management practice.

The sub catchment proposed for interventions in each basin in order of priority are as follows: For the Sigi River – the main Sigi sub catchment in Amani Division composed of the catchments of Dondwe, Kwamlangu, Hange, Kwekuyu and Nenguruwe streams, the Kihuhwi River sub catchment in Bombwera Division containing Semagombe, Kivemeala, Kwedidonda, Malale Mlungui and Kovukovu streams and the Muzi river sub catchment containing Semdoe and Miembeni streams

Given the rate of change in land use/cover to lower forms along the main Sigi river sub catchment, the intensity of use of the riparian zone of the streams, the high proportional contribution in flow into the basin it is proposed that interventions be

focused on the main Sigi sub catchment as a priority followed by Kihuhwi sub catchment. This will include the villages of Sakale, Chambangeda, Sangalawe, Shebomeza, Mlesa Mbomole, and the whole of Bombwera Division.

In the Ruvu River basin there is severe land degradation in each of the sub catchments assessed (main Ruvu above Kibungo Chini (with the catchments of Mbezi, Mvuha, Mmanga and Mvizigo Rivers), Mgeta (with the catchments of main Mgeta, Mzinga and Mbakana Rivers), and Ngerengere (with the catchments of main Ngerengere, Mzinga, Morogoro and Kiroka Rivers).

Other catchments that are not gauged but of interest in the eastern Ulugurus include Mvuha, Mngazi and Mngeta rivers in Mvuha Division where land degradation due to agricultural expansion was reported to have been high in the past 20 years.

Based on hydrologic assessment it seems that the main Ruvu – Kibungo sub catchment drains a bigger proportion of the basin, it is relatively more degraded and has agricultural activities that have high potential for further degradation thus more impact on flow downstream. Unsustainable agricultural practices are rampant in this sub catchment including flat cultivation on steep slopes, shifting cultivation/slash and burn agriculture as a result of declining soil fertility. This area also has a potential for production of perennial crops such as coffee as a cash crop for improved livelihood and better soil cover. Further there is extensive land fragmentation which involves ownership of more than one small pieces of land in different locations due to land scarcity. Land fragmentation partly discourages proper land management due to limited resources to invest in all the small pieces of land (economies of scale). Based on the severity of land degradation and high contribution to flow the sub catchment above Kibungo comprising the Kibungo and Kinole Wards and containing the catchments of Mbezi, Mvuha, Mmanga and Mvizigo Rivers are undergoing high rates of degradation due to agricultural expansion. Among these the Mvizigo river catchment is the most degraded and will need greater attention.

On the other hand the Mgeta sub catchment should be considered as the second priority given the fact that there is a very intensive cultivation on steep slopes where almost every piece of land is under cultivation. While there are some conservation measures like terracing they are not adequate and the need to intervene the use of fragile ecosystems such as river banks is required.

Generally we propose interventions that aim at optimizing the existing land use to better address the problem of declining water quantity and quality in these basins.

The interventions proposed for the Sigi River basin include:

- Management of riparian ecosystems will be of particular importance given the extensive use of these ecosystems resulting from population pressure and land scarcity. Establishment of riparian buffer vegetation using appropriate plant species will increase infiltration and water storage in the catchment and reduce sediment loading in the river and other pollutants such as fertilizer, pesticide and herbicide residues.

- Biological conservation measures such agroforestry using perennial crops. More focus should be paid to practices already in place. For example some community

members along the main Sigi sub catchment are already practicing agroforestry by intercropping trees with perennial crops.

- Natural forest management and conservation need to be part and parcel of the interventions to include restoration of the Derema corridor already initiated by the Amani Nature Reserve (see figures 2 – 4). Among the activities related this intervention include prevention of illegal logging, reduction of forest reserve encroachment and restoration of degraded forests through enrichment planting and/or natural regeneration using appropriate techniques

- In relation to water quality aspects of gold mining are important to consider given the current and possible future forest degradation that may result from gold mining. This activity is evident in Sakale village along the main Sigi sub catchment and Miembe/Semdoe streams along the Muzi sub catchment.

For the Ruvu River basin the interventions proposed include:

- Biological conservation measures such agroforestry using perennial crops. More focus will be paid to practices already in place. For example some community members in Mgeta sub catchment are already practicing terracing and agroforestry

- Management of riparian ecosystems – establishment of riparian buffer vegetation filters using appropriate plant species. The width of the buffer vegetation strip should be based on existing regulations e.g. land, water and forestry acts

- Awareness raising on conservation issues especially on watershed management techniques

- Alternative income generation interventions that would reduce pressure on fragile ecosystems

- Aspects of gold mining especially along the Main Ruvu (Kibungo) sub catchment are important to intervene.

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1.0 INTRODUCTION

1.2 Background

CARE International in Tanzania in partnership with WWF Tanzania Programme Office is in a process of establishing a new project entitled "**Equitable Payment for Watershed Services (PWS)** in Uluguru and East Usambara Mountains focusing on Ruvu and Sigi river basins. The central premise of this project is to establish an equitable payment mechanism between buyers and sellers of the watershed services. The PWS mechanism will actually promote equity in the distribution of benefits so far as this can be achieved without significantly undermining the financial viability of the initiative.

The proposed Equitable Payments for Watershed Services (PWS) initiative which is the subject of this study entails the major users of water from the Ruvu river and Sigi River ("the buyers") making a long term financial investment in modifying land use within the river basin to improve "watershed services" – specifically the reliability, and quality of their water supply. This financial investment ("the payments") would be used to provide benefits to communities that act as an incentive for them to make the changes in land use and/or natural resource management (NRM) needed to deliver the improved watershed services, and to sustain these changes over time.

It is understood that this PWS initiative will focus on the higher rainfall areas that lie in the "upper catchment" of the Ruvu and Sigi rivers and their tributaries within the Uluguru and East Usambara Mountains. Taking into account the coverage of the Ulugurus and East Usambaras, the average annual rainfall and evapo-transpiration rates, and comparing to the land use and population sizes of the areas, it was necessary to invest and quantify what is happening and problems in order to provide quantifiable evidences and measures to alleviate water problems through improving watersheds management.

From the perspective of the buyers it is not necessary for the proposed payments for watershed services (PWS) initiative to cover all areas of the upper catchments responsible. In some areas an investment in land use/NRM change will yield a far greater return in terms of improved watershed services than in other areas. The key issue here is the incremental benefit in terms of improved watershed services versus the incremental cost of the change in land use/NRM. Thus, this study of hydrological and land use/cover change analysis provides the basic factors for PWS initiatives including identification of focal areas of interventions ("hotspots").

Likewise the prioritization between communities in the upper catchment must be dictated primarily by considerations of the viability of the PWS initiative, but in the event that we can choose between areas with comparable potential from a PWS perspective the project will prioritize areas where the social benefits are likely to be greater.

This PWS Project aims to establish Equitable Payments for Watershed Services (PWS) in selected watersheds of the Ulugurus and East Usambaras. It is predicated that there will be effective articulation of conservation practices to ensure sustainable flow of water, while addressing issues related to poverty alleviation.

Background to Land use/cover Dynamics

The human impact on natural landscapes has been steadily increasing during the last few decades and the current decline of land cover is largely the result of human activity. Many of these activities have resulted in a wide range of environmental changes that accelerate and interact with other environmental changes at local, regional and global scales (Shemdoe, 2004). Ecosystem degradation emanating from land use/cover change in many areas of the world has resulted to the increase in watershed destruction leading to water shortage for domestic and industrial uses; and water for environmental flows.

The Uluguru and East Usambara mountains (Figure 1) are part of the Eastern arc mountain forest which are known world wide for the diversity of flora and fauna, and for the exceptionally high degree of endemic plants and animals found in these forests. These rain forests also forms good source of water supply for people in Tanga, Dar es Salaam and Morogoro. Local people in these mountains depend on the forests for their livelihood. The population is growing rapidly in these areas due to high birth-rate and immigration. People are mostly living in villages owning house or hut and a small cultivation field "shamba" in the public land. New land areas are often cleared in natural forest. In the beginning the soil is relatively fertile and can initially give reasonable crop yields, but with time its productivity declines as nutrient reserves are depleted through harvesting, loss of organic matter, leaching and soil erosion. After some years such unproductive land is abandoned and fresh land is cleared from the natural forests.

The most commonly reported threats to the sustainability of these Mountain forests are uncontrolled fire, logging for timber and wood for domestic use, clearing of forest land for agriculture, hunting, and medicinal plant collection. It has also been reported that between 1955 and 2000 there has been a forest and woodland loss of about 6% and 43% in the Eastern Arc Mountain blocks respectively and there has been more impact on the more populated blocks of North and South Pare, West Usambara, and Uluguru (FBD, 2005b; Schösler and Riddington, 2006).

The East Usambara Mountains

The East Usambara Mountains (EUMs) are located, mainly in Muheza and Korogwe Districts in Tanga Region in North-East Tanzania. The highest mountain peak reaches 1,506 metres[1]. As already mentioned, the EUMs form part of the Eastern Arc, a chain of isolated forested mountains in Tanzania (WWF & IUCN 1994). The major ethnic groups are the Shambaa who live in the higher altitude areas and the Bondei who traditionally live in the lowlands. In addition, many inhabitants of the area representing various ethnic groups are immigrants who originally came to look for employment or farming land. The majority of the population depends on small-scale agriculture and they cultivate both subsistence and cash crops (Vihemäki, 2004). The most important food crops are cassava and maize. Also, sweet potato, beans, peanut and rice are cultivated. The most significant cash crops include fruits, vegetables, cardamom and sugarcane. Also spices like cinnamon, pepper and clove are commonly cultivated.[1]

[1] http://www.easternarc.org

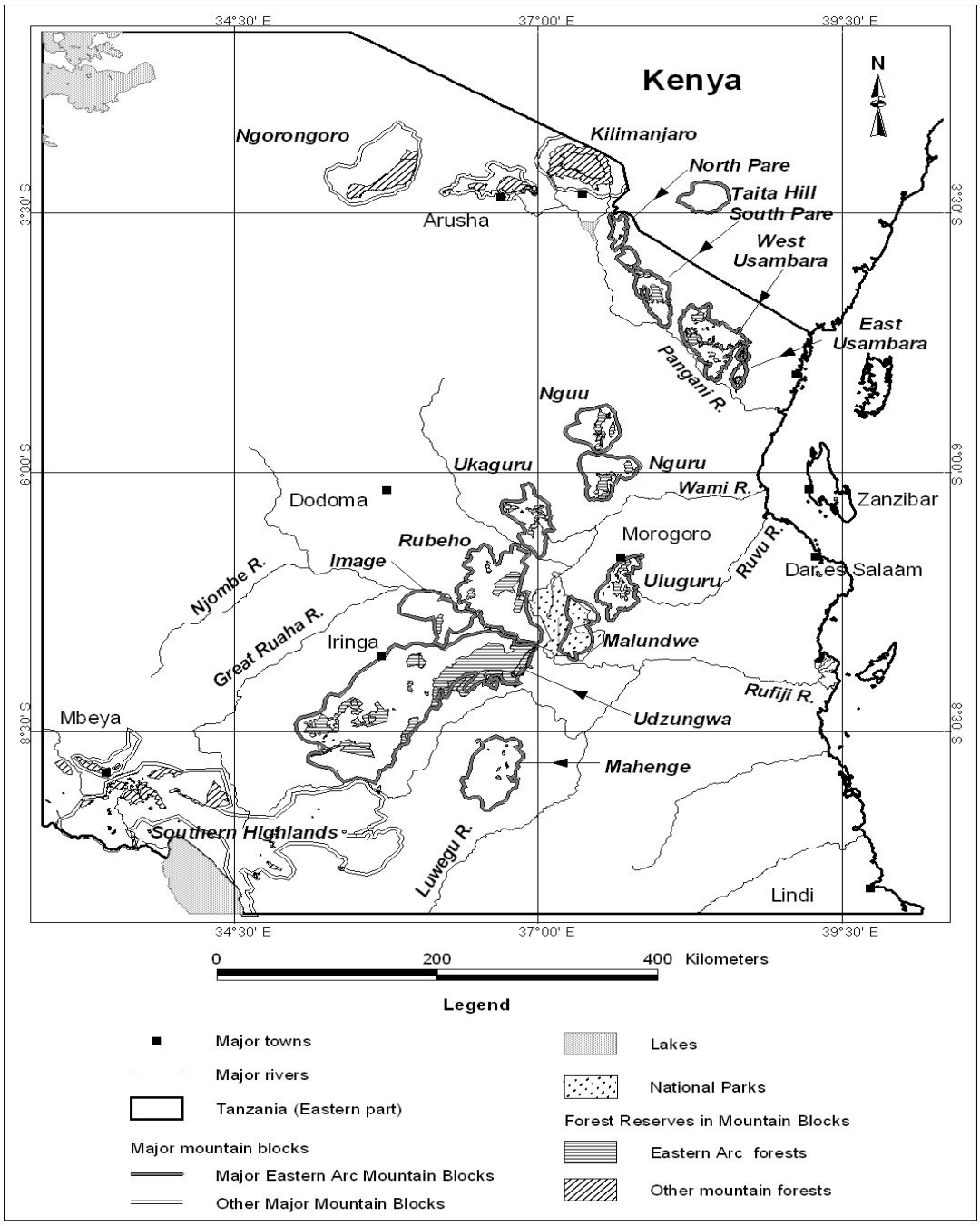


Figure 1 Location of East Usambaras and Ulugurus in Eastern Arc Mountains

Source: FBD (2005a).

Cardamom cultivation in East Usambara Mountains started to become big business in the early 1960's which created a major force for forest destruction (land cover change). Cardamom grows well on fresh forest soils in the sub-montane forest zone after smaller trees and shrubs have been removed. Yields peak about five years

after planting, but decline thereafter and less nutrient demanding crops are usually planted after eight years. Cardamom cultivation requires gradual cutting of the over-storey trees. The forest can not regenerate while cardamom is being grown and the large remnant trees are exposed to wind and tend to fall. The most common consequence of cardamom cultivation is that the forest is degraded and the topsoil is leached due to erosion. The settlements are spreading into marginal areas including steep hill slopes. The river banks are cleared for cultivation without buffer zones. So the conversion of the forests into the fields decrease the vegetative cover of the watersheds[1]

The EUMs are reported to have high population growth rate higher than the local district, regional and national averages due to the resource richness and high agricultural potential of the highlands (IIED & TRAFFIC, 2002). Most of the village land is under customary tenure conditions whereby the acquisition was originally through local chiefs followed by inheritance, but the purchasing and borrowing of land is practiced as well (Kessy 1998). In this account, land ownership conditions are generally not well defined, a situation which contributes to forest encroachment on general lands, contributing to land cover change.

The forests in EUMs have significant socio economic and ecological importance. The forests are globally known biodiversity "hotspot" and among the centres of plant diversity (WWF & IUCN 1994) as recognized by World Wide Fund for Nature (WWF) and World Conservation of Union (IUCN). The EUMs are major national, regional and local sources of hydropower, water and wide array of forest-based benefits and agricultural production (Madoffe *et al*., 2006). Furthermore, the forests also form the catchment for Sigi River and are crucial for the Tanga water supply (Johansson *et al*., 1997). Johansson and Sandy (1996) report huge shrinkage of EUMs from the original forest land area.

According to Johansson *et al* (1997), the land use/cover change situation in the EUMs is partly derived from the relatively low population density during early colonisation, which enabled Germans to take over large parts of the Amani plateau at the southern tip of the Usambaras. The forests of these German estates have over time developed into the present network of forest reserves, while the agricultural areas developed mainly into tea estates, which cover about 3,000 ha on the plateau. In a similar progression the lowland foothill areas developed into sisal and other large-scale agricultural estates forcing local small-holders to carve out their living along the slopes. Small-holder agriculture in the East Usambaras is still in a semi-shifting cultivation stage, where pressures on land and productivity have been moderated by clearing new forest areas into cultivation, and where cash crops such as cardamom have played a major role in the expansion of agriculture into the forests (Atampugre 1990).

It has been reported that in the late nineteenth century the East Usambaras contained valuable timber species and commercial logging was started late last century, while simultaneously large-scale forest clearing was done to create coffee and tea plantations, which partly continued up to independence (Iversen 1991b).. Simultaneously small-scale agriculture has expanded, often at the expense of forests cover removal (Iversen 1991a). Land clearing for agriculture has also increased forest cover fragmentation, degrading its watersheds. It has been reported by Newmark (2002) that the EUMs have experienced serious deforestation over the last

200 years; and that not only deforestation which is the threat to EUMs but also the burning of forest land as part of agricultural practices during land preparation.

Clearing of forests vegetation seems to be still going. According to MNRT, (2005a) between 1975 and 2000 the forest and woodland cover in the East Usambara Mountains decreased by 18.6% and 69.5% respectively. The decrease in woodland area which represents some of the potential areas for agriculture may be associated with anthropogenically induced factors.

Uluguru Mountains

Uluguru Mountains (UMs) block is one of the most outstanding of the Eastern Arc mountain blocks. They are situated to the south of the main chain, 180 km from the coast, and isolated from the Udzungwa and Rubeho Mountains by 70 km of low lying plains, which include the Mikumi National Park (Lovett et al., 1995). The UMs in eastern Tanzania are one of the most important mountains in Africa for the conservation of biodiversity. They are also the source of water supply through Ruvu River for Dar es Salaam, the largest city in Tanzania, with about 3 to 4 million people. In addition to these global and national values they are also home to over 100,000 people in the Luguru tribe who prefer to live on the mountains because of the favorable climate which allows them to grow crops through most of the year, including temperate fruits and vegetables which they can export to the towns and people of the lowlands[2].

The UMs form a 45.5 km long chain, rising steeply from the Mgeta and Mvuha floodplains (150 m elevation) to a peak elevation of 2,638m. Although the mountains form a continuous ridge, they are physically divided into the northern Uluguru (20.5 km long and 8 km wide) and the southern Uluguru (25 km long and up to 15.5 km wide), separated by the Mgeta or Bunduki Gap (Mbilinyi and Kashaigili 2005). The UMs landscape includes the lowland Kimboza and Ruvu Forests and several small forests patches (Lovett *et al*.' 1995). Most forest borders are very sharp, with fields extending right up to the forest edge. In some areas small clearings or areas with second-growth exist just inside the forest edge. In areas of easy access the lower part of the forest is disturbed, with strongly biased composition of tree species and often a lack of large timber trees. The general characterisations can be made about the forest cover of the lower forest edges of the Uluguru North and South Forest Reserves that large areas of forest and dense woodland, especially in the sub-montane zone, have been removed by people who now use the area for subsistence agriculture threatening the status of the watersheds(Lyamuya *et al.,* 1994),.

The inhabitants in this water shade depend directly on the resources from these mountains for their livelihoods – on forests that create and conserve soil, supply fuel wood and medicinal plants, protect water catchments and guarantee water supplies; or wetlands that yield fish and other wild food, and supply a host of materials for building, weaving, etc. Even where it is not in their long-term interest, people may have few options to increase their desperately low living standards, but to over-use these resources. Rapidly increasing human pressure on the land takes many forms: forest fragmentation, felling trees for timber, firewood and building poles, uncontrolled fires, land clearance for subsistence and cash-crop cultivation. The

[2] http://www.africanconservation.com/uluguru/

farmed sloped now, however, are an important producer of horticultural crops and are one of the two main locations supplying fruit and vegetables to Dar es Salaam. Forests such as those in the UMs are cleared because it is the simplest way to find the new land needed to grow crops – even where this might lead to soil erosion, dry up of water sources and remove supplies of valuable forest products[3].

The UMs in eastern Tanzania contain at least 16 endemic vertebrate and 135 endemic plant taxa, with hundreds of more taxa shared only with forests in eastern Tanzania. This degree of endemism is exceptional in tropical Africa, and the UMs are one of the 10 most important tropical forest sites for conservation on the continent. Surveys carried out during 1999–2001 updated information on the status of forests and biodiversity across the UMs. Forest loss has been greatest over altitudes of 600–1,600m, and concentrated in sub-montane forest. The primary cause of forest loss has been clearance for new farmland. The forest that does remain is largely confined to Catchment Forest Reserves managed for water by the Government. Without these reserves the loss of forest in the UMs would most likely have been much greater (Burgess *et al*., 2002).

Climatically induced, altitudinal zonation of forest in the UMs as reported by Pócs (1976), is that in the whole 'Low altitude dry forest and savanna woodland zone' below 600m altitude is densely cultivated, therefore only small remnants of the original vegetation can be detected; and the 'Sub-montane dry forest and miombo woodland zone' is actually mostly replaced by an open woodland of *Pterocarpus angolensis*, *Combretum* and *Terminalia* species, or by dry secondary grassland. On the eastern foothills, only on drier slopes, up to 800 m altitude. Widespread on the western, northern and southern slopes, as high up as 1500 m in the northern, and up to 1600 to 1700 m in the southern Ulugurus. These forest and woodland communities suffer the most from wild bush and grass fires. According to MNRT, (2005a) the forest and woodland cover in the Uluguru Mountains has decreased by 12.7% and 59.0% in 1995 and 2000 years respectively.

[3] http://www.easternarc.org

Background to Hydrologic Dynamics

The Eastern Arc Mountains are directly linked to the Indian Ocean. Incoming air masses from the ocean is forced to rise, cooled and 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. Colder 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 immediate 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 (Forestry and Beekeeping Division 2005a, 2005c)

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 Uluguru and East Usambara Mountains (Forestry and Beekeeping Division 2005a, b & c). Rivers draining from the Uluguru and East Usambara Mountains also support various small-scale irrigation schemes important for local livelihoods producing food and cash crops as well as providing employment to rural communities. These schemes may be observed in the Mgeta river sub catchment, the flood plains of lower Ruvu among others.

In most Forest Conservation Programs one of the primary concerns is on water quality. Human being requires clean water for drinking, cooking, bathing, and playing. We are often obliged to treat impure water so as to meet these needs. In addition to human needs, aquatic living organisms also require clean water. 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.

Obviously, any activity that disturbs the forest floor including timber harvests can lower water quality; although the forest recovers relatively easily on its own and the effects of disturbances are temporary in most cases

According to FBD, (2005c) linear trends on seasonal and annual rainfall generally indicate predominant decrease of rainfall amounts during the long rains, dry season as well as during the intermediate seasons. 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 as shown by close stations experiencing different trend direction. For example, trends in the long rain season in the Ruvu River basin during the 1964-1993 period have been observed to have decreasing trends 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.

Annual rainfall is related to average annual discharges and seasonal rainfall amounts are also 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 season due to lack of vegetation cover to reduce runoff velocity and to decrease during the dry season due to insufficient recharge of groundwater during the rainy season. Consequently, there is usually a relationship between rainfall amounts and stream flows in various seasons. Valimba (2004) found opposing patterns of inter-annual variability between the early (October-January) and late (February-May) seasons. He concluded that such patterns were responsible for the general lack of real significant trends and abrupt changes at the annual scale. 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.

Average annual discharges are 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 runoff velocity and decrease during the dry season due to insufficient recharge of groundwater during the rainy season.

According to FBD (2005c) long records of rainfall indicated increasing rainfall amounts during the short rains and decreasing rainfall amounts during the long rain season. 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.

1.2 Objectives

The major aim of this assignment was to undertake hydrological analysis of the Ruvu and Sigi River basins in relation to land use/cover change to provide guidance on what and where the PWS initiative should be focused within the upper catchments based on maximizing the buyers' return on investment in terms of their particular interests in improving watershed services. In other words where will the buyer get "the best bang for their buck". This will also within the focal areas address poverty of the poor farmers or people in general.

The specific activities undertaken included

- Review of secondary literature to gather relevant information on changes occurring in the watersheds in terms of land use and river hydrology
- Development of methodology for assessing the historical hydro-meteorological data coupled with the analysis of land use and land cover change on the Ruvu and Sigi River systems
- Collection of time series data of runoff records on the Ruvu and Sigi Rivers, and the corresponding changes in land cover over a long span of time

- Development of land cover change-runoff relationships for the Ruvu and Sigi Rivers' Catchments and assessed the influence of catchments condition and land use types on water quality and indicate the extent of linkages between declining vegetation/forest cover with stream flow, water quantity/quality in the Ruvu and Sigi Rivers.
- Identification of hydrological related problems notably stream flow, water quantity and quality
- Identification of areas that contribute significantly to the problem of deteriorating water quantity/quality in the Ruvu River and Sigi River (hotspots for interventions)
- Assessment of the major human activities that contribute to the problem of declining water quantity and/or quality in the Ruvu and Sigi Rivers and the extent to which they contribute to the problems
- Establishment of the size of the upper catchment that would need to be involved in the process of land use/NRM change to deliver the desired change in flows and/or sediment load within the Ruvu and Sigi Rivers.
- Establishment of the size of the upper catchments that would need to be involved in the process of land use/NRM change to deliver the desired change in flows and/or sediment load within the Ruvu and Sigi Rivers.
- Provide technical recommendations (for land use change) on how to alleviate the problems

2.0 METHODOLOGY

2.1 Study Sites

The study sites were the Sigi River Basin in the East Usambara Mountains and the Ruvu River Basin in the Uluguru Mountains. The study focused on the upper catchment of the basins. The Sigi Rive Basin composes of the sub catchments of main Sigi, Kihuhwi and Muzi rivers with their tributaries while the Ruvu river composes the sub catchments of main Ruvu (Kibungo), Mgeta and Ngerengere rivers (Figure 1)

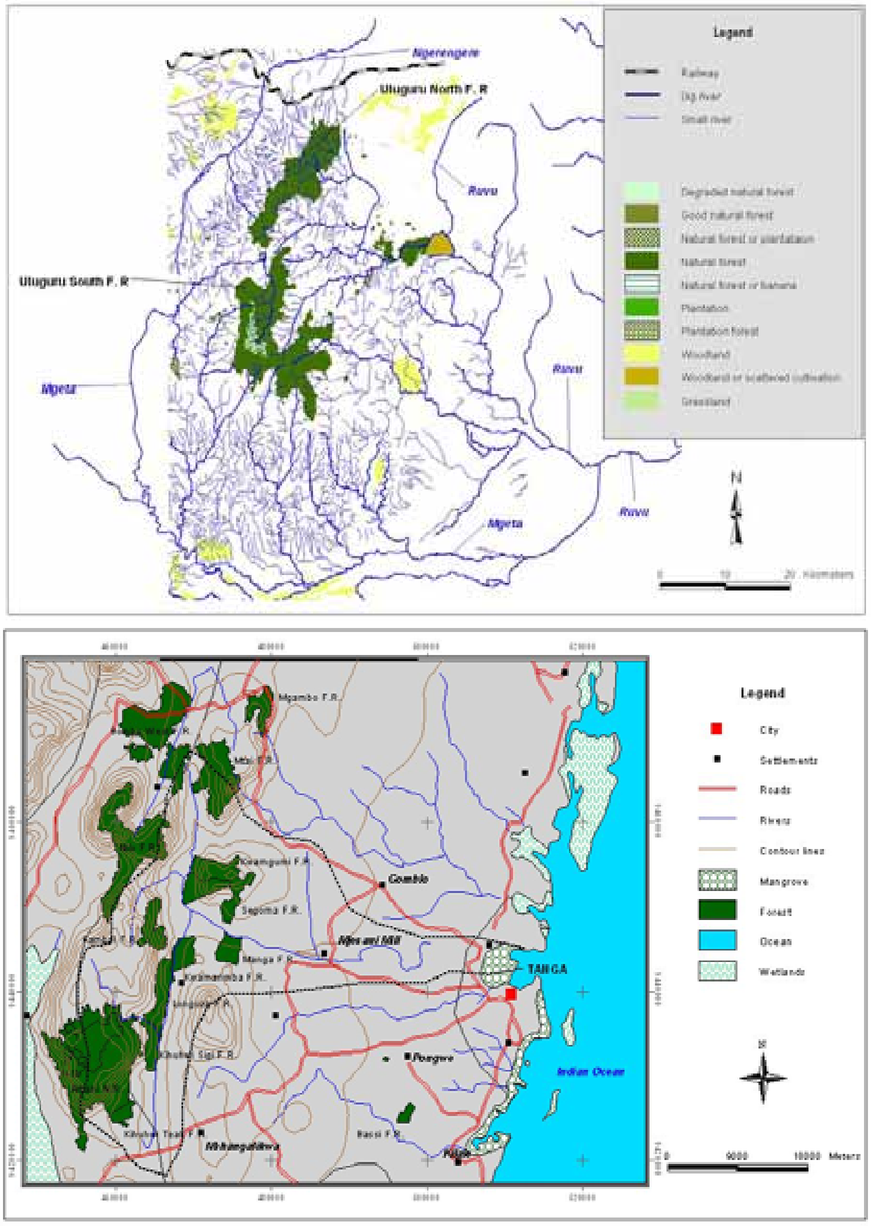


Figure 2 The Ruvu River Basin in the Uluguru Mountains (a) and the Sigi River Basin in the East Usambara Mountains (b)

2.2 Data Collection and Analysis

Different approaches or a combination of approaches were employed during this study to establish relationships between land cover/use and river hydrology. A triangulation of information sources was applied including a review of available literature on the land use and hydrologic changes in the two basins, remote sensing and GIS analysis to establish changes that have occurred in terms of land use, trend analysis of flow/rainfall data from the basins and household surveys that gave the historical perspectives of the land use/cover and hydrology in the areas.

PRA techniques (focus group discussion with key informants) complemented the analysis. Questions that captured trends in resource use were used in identifying water users/local people perceptions on important changes overtime, how and why the river flow has been changing, the extent to which vegetation cover has changed, trend in rainfall patterns and reliability. Further information was collected from water users/local people included perceptions on significance of seasonal variations in river flow against total river flow, significance of water quantity against water quality.

In the Sigi river basin three villages each in the lower, middle and upper catchment were visited to get information on local peoples knowledge and perceptions with regard to hydrologic and land use changes in the basin. These villages included Mkwajuni, Kisiwani and Kwatango, Sangalawe, Sakale, Kwavihombo/Kwamwewe, Mgambo and Mlesa. In the Ruvu river basin several areas were visited including Kinole Kibungo, Mvuha, Bwakila, Bunduki and Tchenzema Wards,

2.2.1 Land Cover/Use Change Analysis

Land cover/use change analysis involved the analysis of three sets of data representing land cover/use in 1955, 1995 and 2000 in each of the catchment i.e. Uluguru and the East Usambara mountains. Landsat TM for 1995 and 2000 were analyzed to generate the land cover/use for the year 1995 and 2000 respectively, while the land cover/use map for 1995 was generated using Topographic map of 1955. For each set, time difference was long enough to detect changes in land cover/use. The detection of the changes provided an understanding of human interference on the basins over years and its possible influence on the water flow in the river systems. Satellite image interpretation and data analysis was done in the laboratory using remote sensing software for image analysis and GIS software for data analysis. However, fieldwork was conducted for ground verification of mapped features. Particular attention was paid on hotspot areas (areas with pronounced changes) so as to document factors driving such changes. Such information was obtained through discussion with key informants in the respective catchments and participant field observations. Particular attention was paid to elderly people who have observed changes for much longer period in the areas.

Field visits were carried out in the Uluguru Mountains (Matombo, Mgeta and Morogoro Divisions and the East Usambara Mountains (Bombwela and Amani Divisions) with the purpose of making ground verification of the land use/cover change happening in these Mountains. Moreover, the purpose of this field visit was also to identify as to what are the current uses of land and the factors behind land cover changes in these mountains.

An assessment of forest degradation process through selective vegetation removal was done through literature survey on previous work in this aspect (FBD 2005; Munishi *et al.*, 2005; Frontier Tanzania, 2002).

Focused group discussion was used to supplement other data sources. This was done through discussions with the communities living in the respective villages within the basin catchments. The villages involved in the focus group discussion were namely Sangalawe, Sakale, Kwavihombo/ Kwamwewe, Mgambo and Mlesa in the East Usambara Mountains and Mgeta, Bunduki, Kinole, Mvuha, Msikitini, Mlali and Luvuma in the Uluguru mountains. A total of 60 respondents in the Sigi Sub Catchment (20 in each of the upper, middle and lower catchment) were consulted most of them being elders who are long time residents of these areas. In the Ruvu river basin we consulted 25, 30 and 15 respondents in Matombo Division, Mgeta Division and Morogoro Division respectively. In addition different government officials including Division/Ward secretaries, River basin officers, and forest officers were consulted. The discussion dwelled on changes in land use/cover, land conversion and its impacts on flow into streams.

Based on the objectives of this study the conversion of forest cover to lower forms of land cover and agricultural lands was the primary focus. The analysis of land cover/use was confined to the change analysis to transition between classes of natural or semi-natural vegetation (forest, and bush land), to cultivated fields (agricultural crops) and clearing for settlements. Further more, the study took into account the aspect of afforestation efforts that may include tree planting of any form (woodlots, agroforestry, shade planting) among others provided these features can be detected on an image.

In assessing the rate of deforestation; deforested areas were considered to be areas that changed from closed forest and/or open forest to cultivated fields, grassland and scrubland. On the other hand afforestation was considered as the change from pure cultivation to tree intercropping, woodlots and any other forms that incorporate trees or any other form of detectable biological conservation measures in the practice.

2.2.3 River Flow Assessment

Time series daily hydrological (discharge) data for the two rivers focused on discharge measurements downstream of the basins or sub catchment. These historical data were obtained from the Ministry of Water and Dar es Salaam Water Supply Company (DAWASCO) and Conservation of the Eastern Arc Mountain Forests Project (CEAMFP).

In the Ruvu basin three sub catchments were considered *i.e*. Ruvu River above Kibungo, Mgeta River, and Ngerengere all measured at sub catchment level at Kibungo Chini for the main Ruvu river, Mgeta for Mgeta river and Ngerengere for Ngerengere river. The overall flow from all sub catchment was assessed at Morogoro Road Bridge gauging station that captures all the flow from all upper catchments in the basin (Table 2.1).

Sigi River had only one point of measurement at Lanzoni sisal estate. The sub catchments of the Sigi river i.e. Kihuhwi, Main Sigi and Muzi rivers had no adequate data that could be used for analysis in this context (Table 2.1).

Based on the objectives of the study the characteristics of interest were low/dry season (base) flows and high/peak (rain season) flows. In order to investigate the dry season flow (low flow) and high flow discharge changes over the years, the average figure for the dry months and wet months were used. Hydrological data were then subjected to trend analysis over time using the rank-based non-parametric Mann-Kendall (MK) statistical test (Mann, 1945; Kendall, 1975; Mimikou and Kaemaki, 1985; Smakhtin *et al.*, 1995; Valimba 2004a, 2004b), double mass curve analysis (Munishi, 1994) and linear regression over time.

In trend analysis particular attention was paid to the relationship between flash flow and base flow on the hydrological curve. Flow duration curves (FDCs) were used to study characteristics of the average flows (Table 2.2).

Further, discussions with long time residents in the different areas provided a good evidence/approximations of historical trends in flow characteristics over time as well as changes in seasonal patterns

Table 2.1 Particulars of selected river flow stations in the sub catchments of Sigi and Ruvu river basins

Basin	St #	Station details						
		Code	Station Name	Useful Records	Record Used	Lat	Long	Area (km^2)
Sigi	1	1C1	Sigi at Lanzoni Estate	1957-1990	1957-1989	-5.01	38.80	705
Ruvu	1	1H5	Ruvu at Kibungo	1952-2005	1952-2005	-7.02	37.80	455
	2	1H8	Ruvu at Morogoro Road Bridge	1958-2004	1959-2005	-6.69	38.70	19190
	3	1HB2	Mgeta at Mgeta	1954-1988	1959-1988	-7.04	37.57	89.6
	4	1HA9A	Ngerengere at Konga	1954-1993	1959-1989	-6.70	37.92	20.5

Source: MNRT (2005c)

2.2.4 Water Quality Data

Water quality data were obtained from existing reports (FBD, 2005c, www.easternarc.or.tz) as there were no more data than those. Further discussions with the local people during field visits supplied good information that could reveal some water quality aspects of the rivers especially those related to sediment loading (turbidity).

2.2.5 Rainfall Data

Changes in river flow characteristics may be influenced by the amount of rainfall in the catchment area. Time series rainfall data corresponding to the flow data were obtained from Tanzania Meteorological Agency (TMA) and CEAMFP for a period as

long as possible for change detection and trend analysis. The rainfall data focused on measurements done in the upper catchment of the basin that is considered to contribute to discharge on the measurement point of the flow data downstream. The data were summarized into either daily or monthly averages over the years and the averages were subjected to trend analysis using Microsoft Excel program/software.

2.2.6 Assessment of Correlation between Rainfall, Land Use and Stream Flow

The land use/cover change and rainfall information generated was correlated with trends in river discharge using different and appropriate techniques/methods. Trends in annual flow volumes and dry season flow as relates to changes in rainfall amounts and land cover/use were linked to elucidate the cause – effect relationships as river discharge characteristics will either reflect catchment condition or seasonal rainfall patterns (Munishi and Temu 1993; Yanda and Shishira 1999) or temporal change in the amount of rainfall in the catchments. Furthermore trends in river discharge may also reflect spatial changes in the catchment conditions

2.2.7 Assessment of the Scale of Intervention and Identification of Priority Sub-Catchments within the Upper Catchment

The assessment of land use/cover changes assign different categories to different land cover and the potential influence of these classes to stream flow. Such categories were developed based on the extent of degradation in the upper catchment. Each area was assessed for intervention needs basing on their potential influence on discharge. Interventions were recommended based on existing land use dynamics and optimizing existing land use systems.

Priority sub catchments were those considered to deliver more positive impact to the hydrology of the rivers given a particular intervention and was identified based on the existing situation. Assessment of the existing situation was done to determine the sub-catchments within the overall upper catchment, which are most significant in terms of river flows, sediment load and percolation to recharge aquifers under the current/existing situation of land use/NRM.

Such assessments were done through the cover analysis and ground truthing, which determined the extent of degradation and other conditions that have a bearing on water quantity and quality. The criteria used to select priority sub catchments include the extent and rate of change from natural forest/woodland (higher forms of cover/use) to cultivated/bare land (lower forms of cover/use), seriousness of degradation, the area of the sub catchment that reflects the proportional contribution to flow into the basin, existing conservation measures, activities with potential influence on water quantity and quality and to some extent population pressure. Priority areas were derived from the cover analysis and classification and field verification.

3.0 LAND USE/COVER CHANGE ANALYSIS

3.1 East Usambara Mountain Block

Sigi Catchment is one of the catchments that are covered in this study. Main crops grown in the catchment are annual crops such as maize, potatoes, sunflower, beans and vegetables which do not provide adequate land cover. In the Sigi catchment, rivers like Kihuhwi, main Sigi, Nanguruwe, Kwekuyu and Semdoe are important sub-catchments that supply water for local communities and other uses upstream as well as down stream in mountains that are used for irrigation. This situation has contributed into high rates of encroachment into natural vegetation cover and marginal areas.

Drainage pattern and catchment boundaries of Sigi Catchment in the East Usambara Mountain Blocks are shown in Figure 3, and land cover/use analyses for the basin are presented in Tables 3.1 - 3.8 and Figures 4 – 6.

Table 3.1: Land use/cover types for 1955 and 1995 in Sigi Catchment

Land cover Type	1955		1995	
	Area	%	Area	%
Natural Forest	9962	85	6066	52
Cultivated Land	1090	9	5448	46
Thickets	166	1		
Woodland	510	4		
Forest Plantation			215	2
	11728	100	**11728**	100

Table 3.2: Land use/cover change between 1955 and 1995 in Sigi Catchment

1995	1955									
	Natural Forest		Cultivated Land		Thickets		Woodland		Total	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Natural Forest	5611	47.8	189	1.6	64	0.5	201	1.7	6066	51.7
Cultivated Land	4351	37.1	901	7.7	97	0.8	99	0.8	5448	46.5
Forest Plantation	0	0	0	0	5	0.0	210	1.8	215	1.8
	9962	84.9	1090	9.3	166	1.4	510	4.3	11728	100.0
Total	**9962**	84.9	**1090**	9.3	**166**	1.4	**510**	4.3	**11728**	100

Table 3.3: Land use/cover types for 1995 and 200 in Sigi Catchment

Land Cover Types	1995		2000	
	Area (ha)	%	Area (ha)	%

Bushland			91	0.78
Cultivated Land	5448	46.45	1509	12.87
Natural Forest	6064	51.71	4672	39.84
Forest Plantation	216	1.84		
Grassland			1133	9.66
Woodland			4323	36.86
Total	11728	100.00	11728	100.00

Table 3.4: Land use/cover change between 1995 and 2000 in Sigi Catchment

2000	1995							
	Natural Forest		Cultivated Land		Forest Plantation		Total	
	Ha	%	Ha	%	Ha	%	Ha	%
Bushland	5	0.0	86	0.7	0	0	91	0.8
Cultivated Land	311	34.0	1198	10.2	0	0	1509	12.9
Forest Plantation	3987	3.9	683	5.8	2	0.0	4672	39.8
Grassland	453	11.2	672	5.7	8	0.1	1133	9.7
Woodland	1308	51.7	2809	24.0	206	1.8	4323	36.9
Total	6064	51.7	5448	46.5	216	1.8	11728	100.0

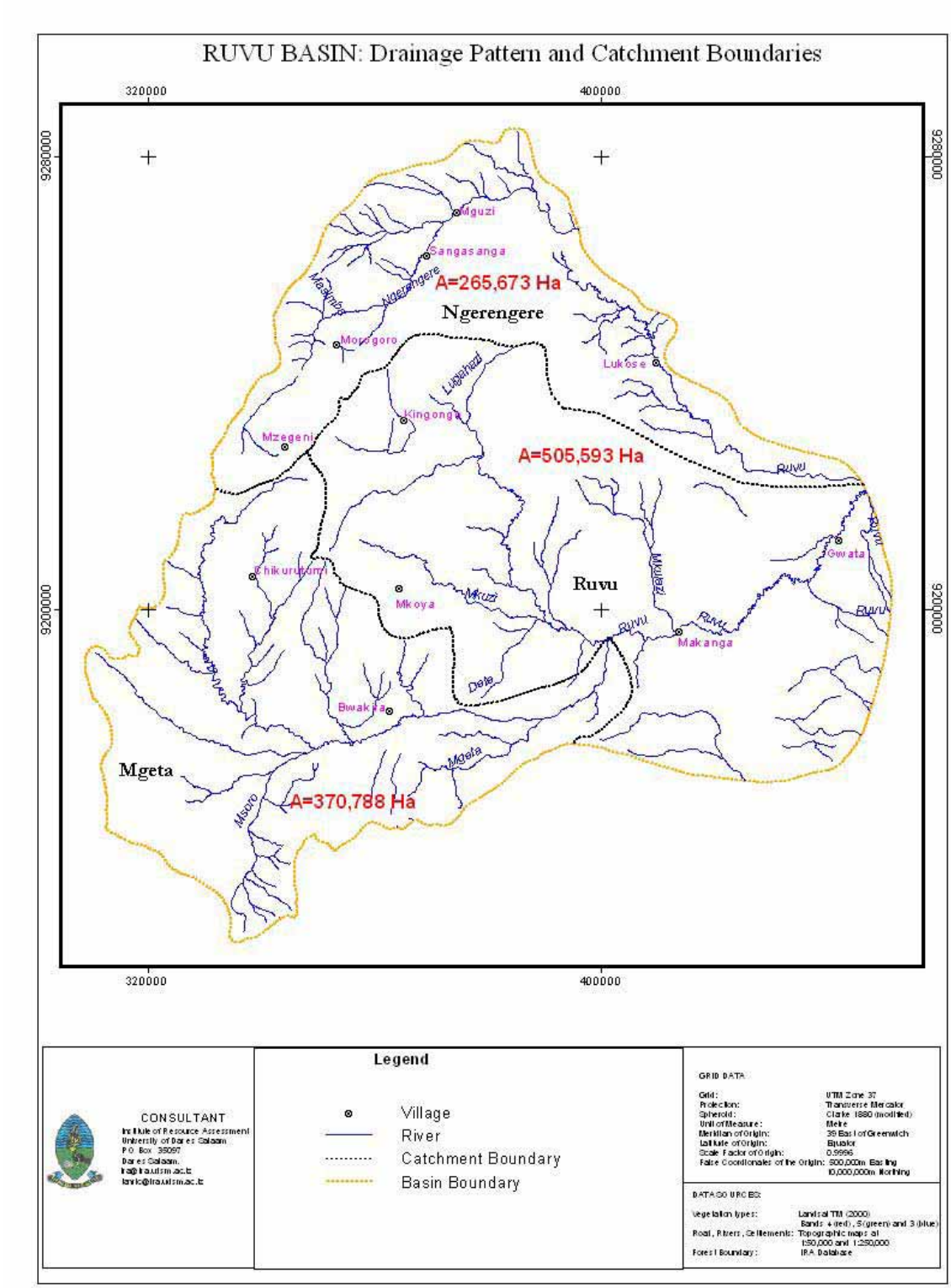


Figure 3: Sigi Catchment: Drainage Pattern and Sub-catchment Boundaries

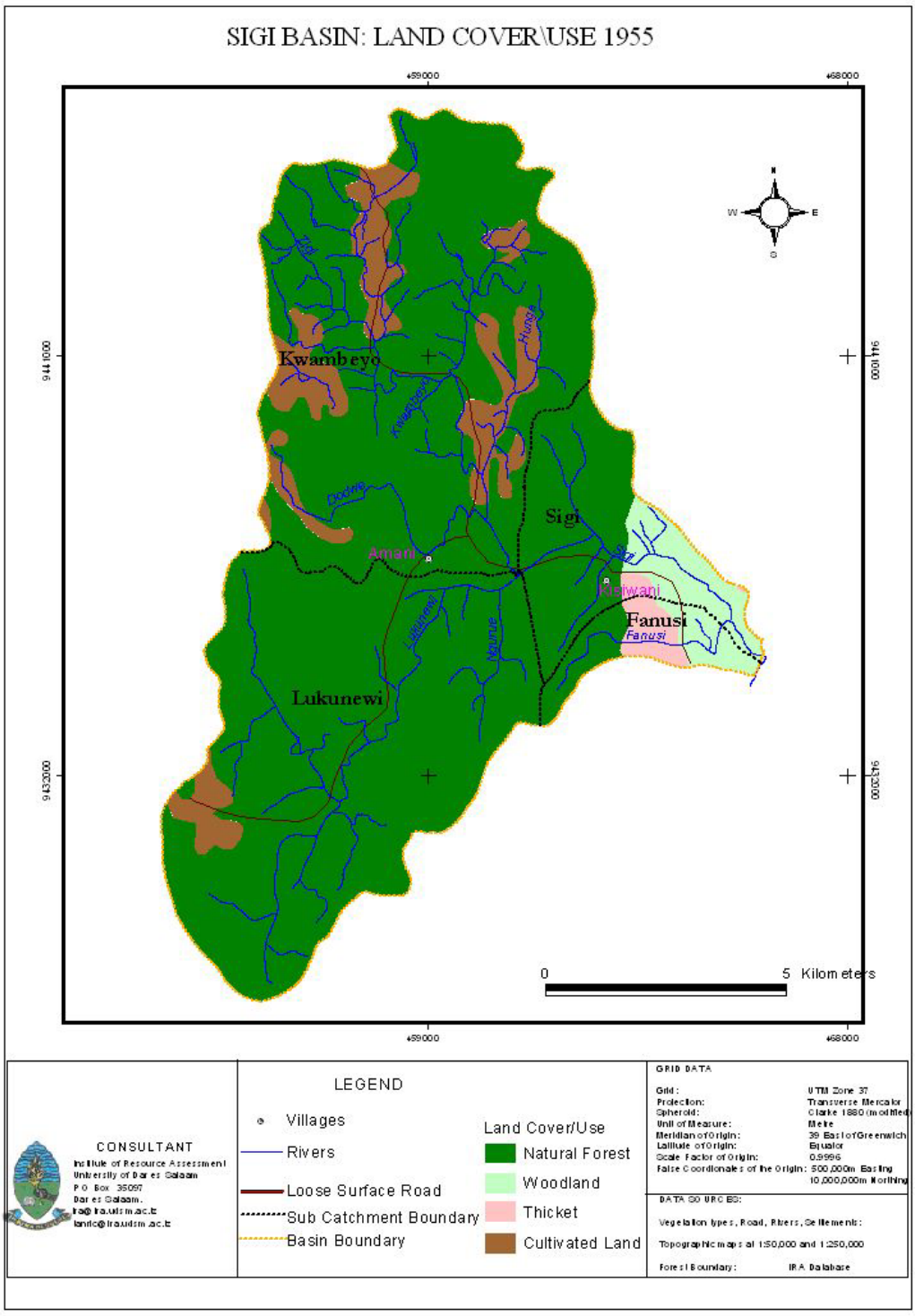


Figure 4: Sigi Catchment - Land cover/use in 1955

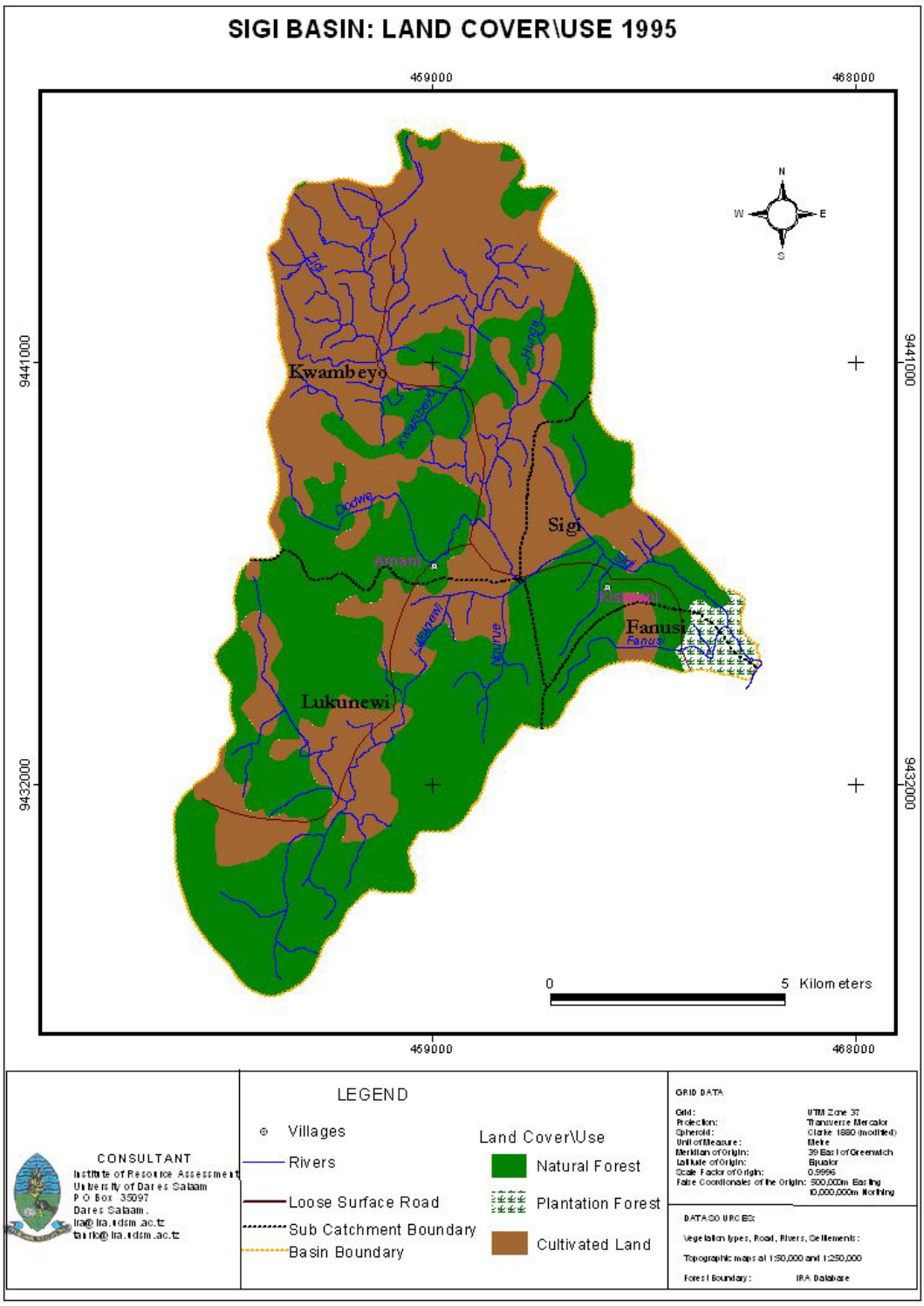


Figure 5: Sigi Catchment - Land cover/use in 1995

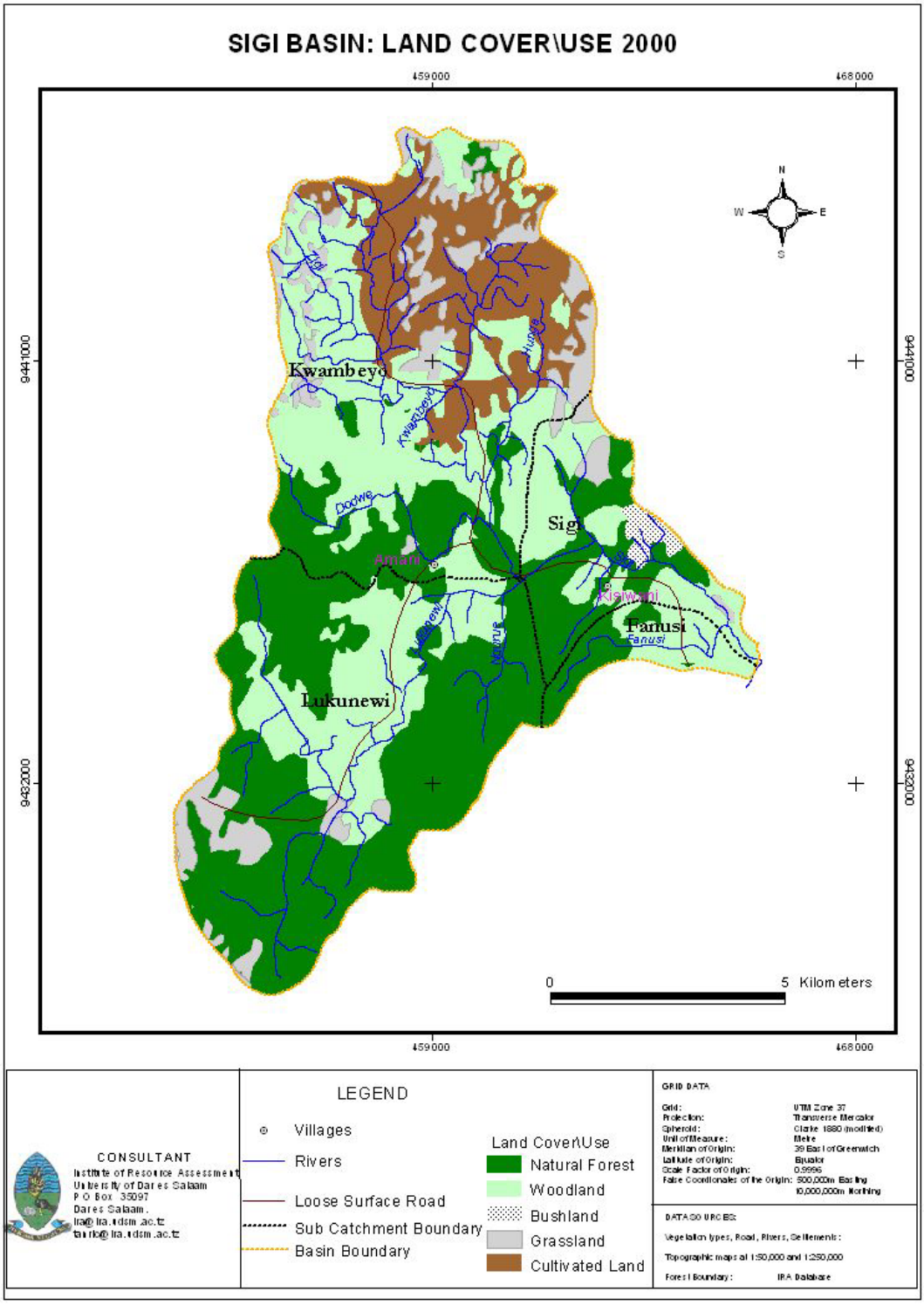


Figure 6: Sigi Catchment - Land Cover/use in 2000

Analysis of land cover/use changes between 1955 and 2000 in Sigi basin has shown that there have been significant changes in land cover/use. Such process has involved substantial conversion of vegetation cover from higher forms (closed forest and woodland) to lower forms (mixed cropland, cultivation with bush crops and open grassland). For example, it is noted that between 1955 and 1995, about 39% of the total catchment area was converted from natural vegetation to cropland (see Table 3.1). This has been more evident in the Northern part of the basin (Figures 2 & 3). This was also observed in the central part of the basin around the Amani nature reserve and the Kihuhwi sub catchment. Similar trend was also observed in year 2000 whereby about 34% of the total catchment area was converted from natural vegetation to cropland land (see Table 3.4) and (Figures 4 & 5). However, there has been an increase in cultivation of bush crops and area with integration of trees and crops. Also there has been more fragmentation of the natural forests**.** The overall analysis has indicated that the most affected area is the northern part of the catchment along the main Sigi sub catchment followed by the Kihuhwi river sub catchment and the Muzi River sub catchment that also encompasses the Derema corridor. The Kihuhwi sub catchment contains many of the abandoned sisal estates thus high settlement concentrations which make the sub catchment very prone to degradation as a result of population pressure on land resources. It should, however, be pointed out that population pressure refers to the extent to which population pose pressure on land resources. In some cases such pressure may be due to high population density, and in other cases is how land resources are being managed. For example, in areas where shifting cultivation is practiced is not the factor of human population density but rather land management practice.

Discussion with key informants in the villages of Sangalawe, Sakale, Kwavihombo/Kwamwewe, Mgambo and Mlesa confirmed that in the past most of the mountains were fully covered with natural forests. The reasons behind this land cover/use were harvesting of trees for timber by then Tanzania Wood Industries Corporation (TWICO), conversion of natural forests into tea estates (Plate 1) by Tea Authority - These estates are currently being owned and managed by East Usambara Tea Company – EUTCO, (some of these estates are Kwamkoro, Bulwa, Mgambo, Marvera, Mango, Derema etc), and the planting of Eucalyptus and Teak stands as well (Plate 2). According to the Forest and Beekeeping Division (2005a) there has been an average decrease in forest and woodland cover of over 10% and 40% at an annual rate of 0.55% and 2.5% respectively in the East Usambara Mountains between 1970s and 2000.



Plate 1 EUTCO. Tea estates established from clearing natural forests
Source: Field observation, November 2006.

Another factor contributing to land cover changes is clearing of natural forests/vegetation to establish farms for agricultural crops. This has been practiced by migrant workers in the tea estates. Plates 3 & 4 show forest land cleared mainly for agricultural expansion. Another driver behind land use/cover change included human settlement development (Plate 5) in the sub catchments of main Sigi and Kihuhwi Rivers. Sisal plantations along the Kihuhwi sub catchment seem to be the major driver of land use/cover change. On the other hand small scale farming communities like in the Derema corridor and tea plantations seem to be major drivers of land use/cover change in the main Sigi and Muzi sub catchments.



Eucalyptus Teak

Plate 2 Eucalyptus and Teak plantations that replaced natural forests



Plate 3 **Sugarcane farms in Sangalawe village – a change from high to lower forms of land cover/use.**

Source Field observation, November 2006.



Plate 4 **Forested land cleared to establish farm land along the main Sigi sub catchment Shebomeza Village East Usambaras.**

Source: Field observation, November 2006.



Plate 5 **Human Settlement development main Sigi sub catchment Shebomeza Village**
Source: Field observation, Nov 2006.

A recent land use activity in the EUMs is 'Gold Mining', which was observed at Sakale village (Plate 6). The actual activity has been stopped though potential to continues exists due to socio-economic drivers and the pits still remain open increasing the susceptibility of the area to erosion agents. Gold mining extends further into the forest reserve creating degradation pressure on the natural forest and threatening water quality.



Plate 6 **Gold Mining in Sakale village.** The foreground shows the open pits created during gold mining Main Sigi Sub catchment
Source: Field observations, November 2006.

3.2 Uluguru Mountains

The Uluguru Mountains is the main catchment of the Ruvu River. Drainage pattern and catchment boundaries of Ruvu Basin are shown in Figure 7, and land cover/use analyses for the basin from the year 1955 to 2000 are presented on Figures 8 to 10 and Table 3.5.

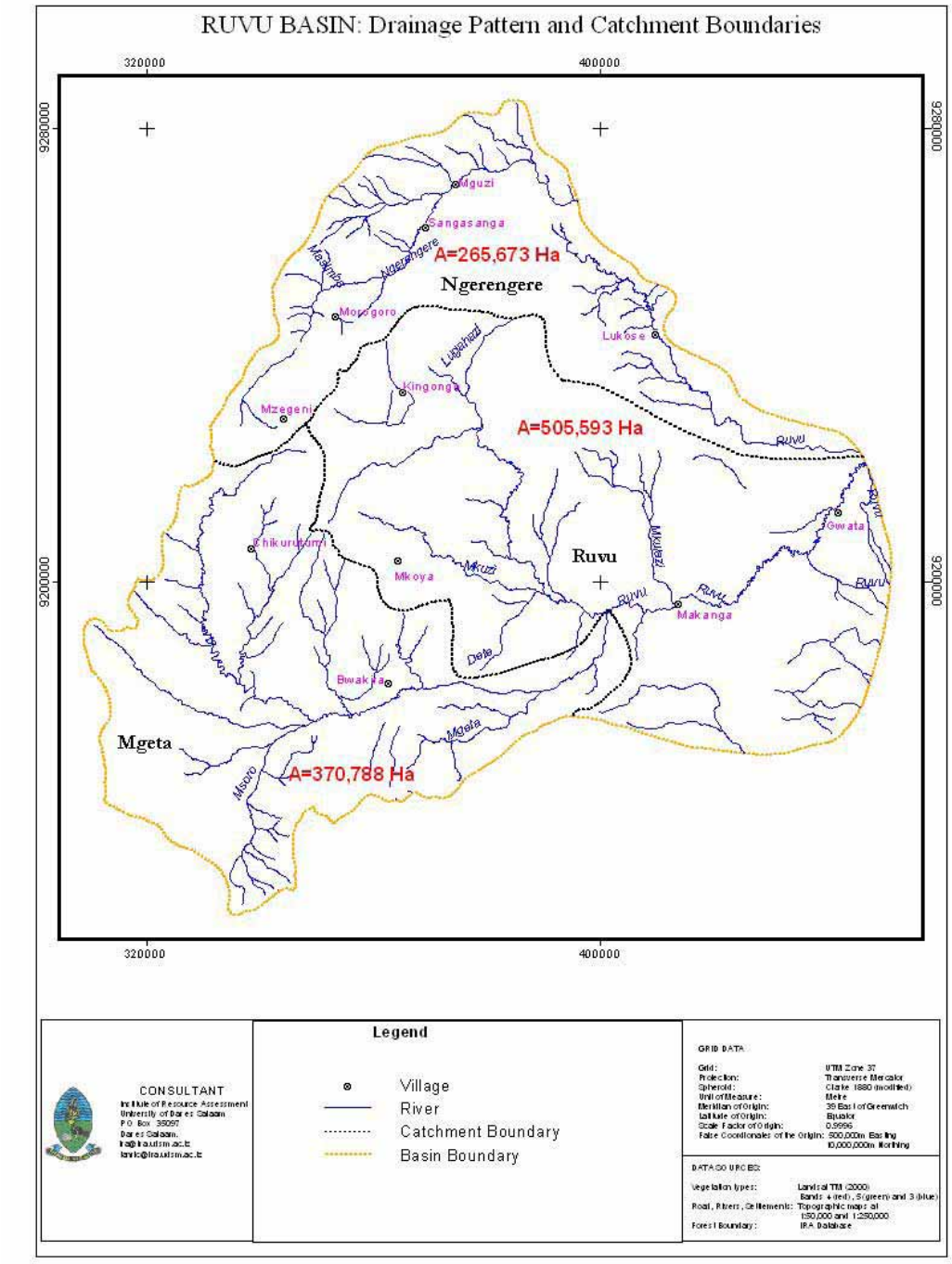


Figure 7: Ruvu Basin: Drainage Pattern and Catchment Boundaries

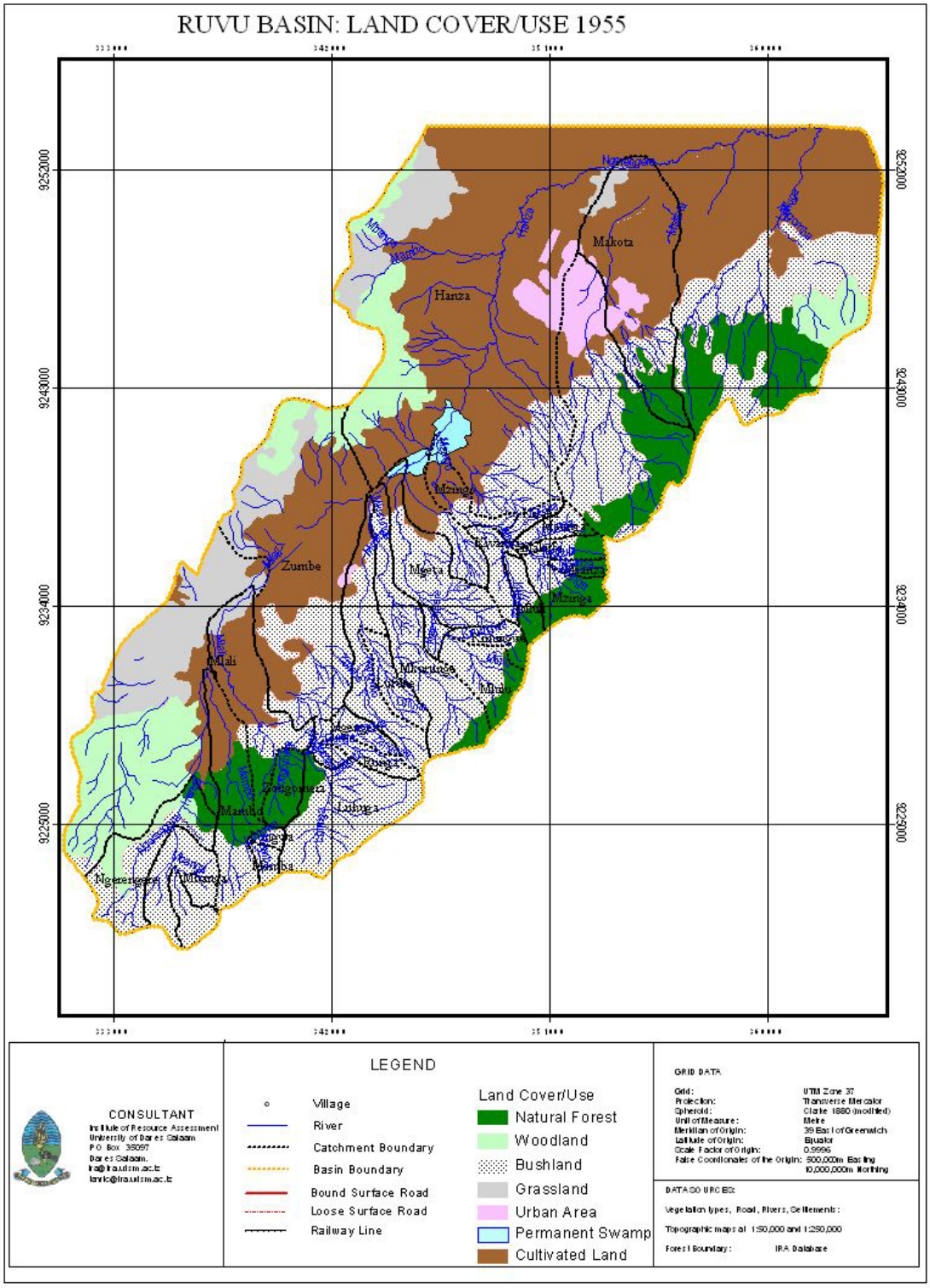


Figure 8: Ruvu Basin: Land cover/use 1955

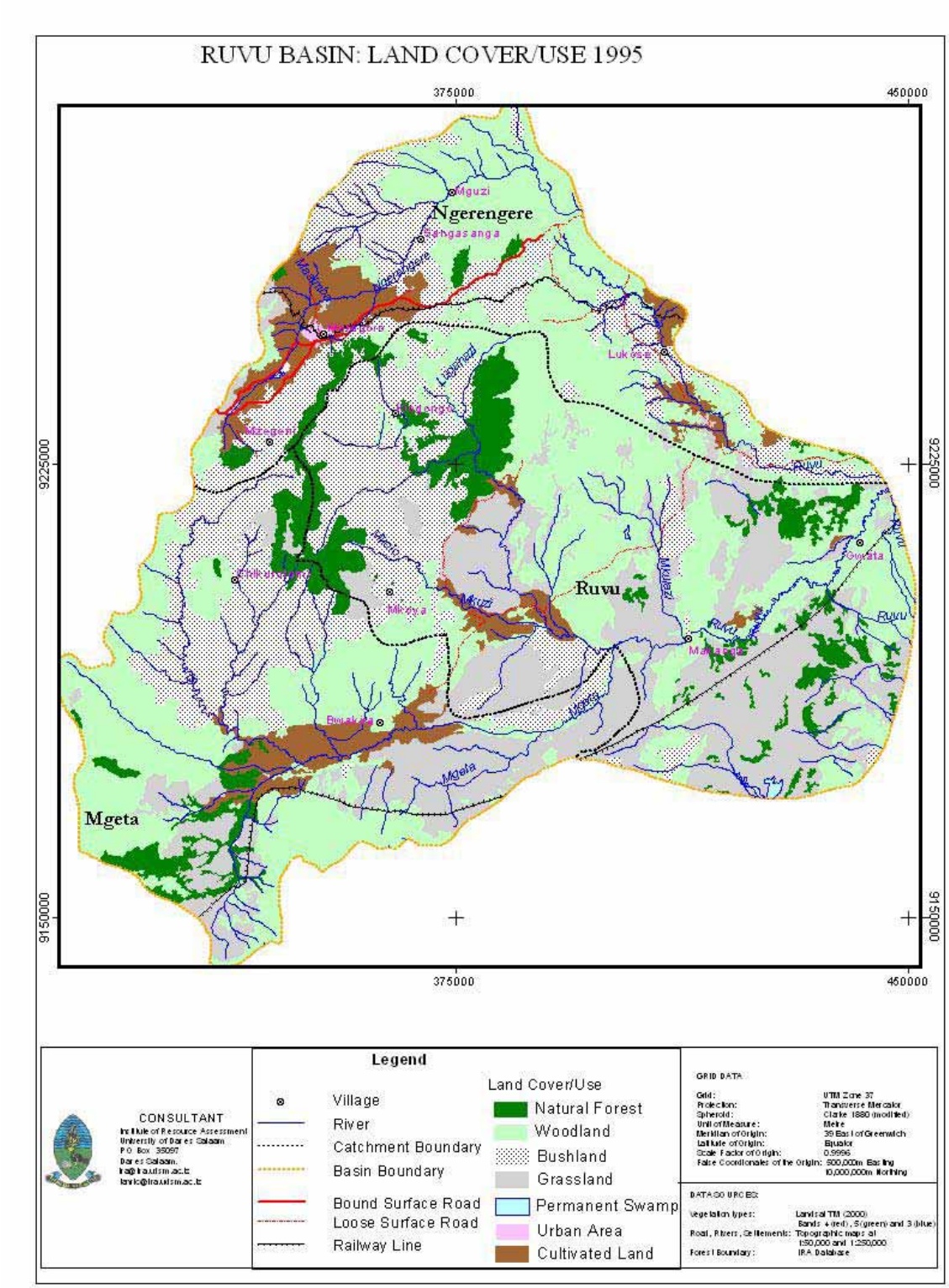


Figure 9: Ruvu Basin: Land cover/Use 1995

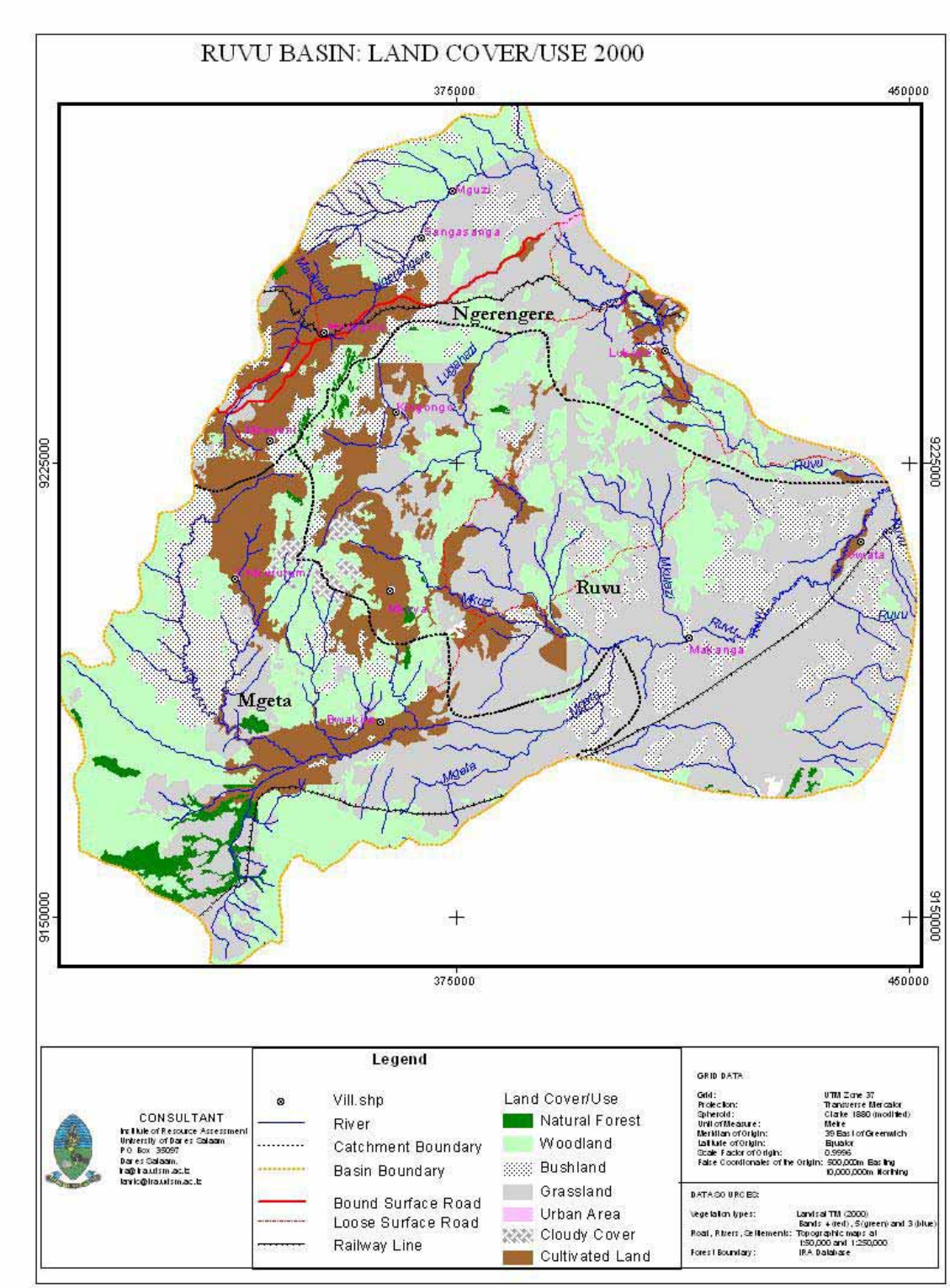


Figure 10: Ruvu basin: Land cover/use 2000

Table 3.5: Land use/cover for Ruvu Basin (1995 – 2000)

Land use/cover types	1995		2000	
	Area	%	Area	%
Bushland	293764	24	217700	18
Cloudy Cover		0	2638	0
Cultivated Land	87369	7	173468	14
Grassland	302458	25	493116	41
Natural Forest	32402	3	3833	0
Permanent Swamp	1334	0	1071	0
Urban	1401	0	961	0
Water	833	0	912	0
Woodland	495526	41	321388	26
	1215087	100	1215087	100

Analysis of land cover/use in the Ruvu basin shows that in 1955 thickets covered most of the area. Some few areas especially in the northern part of the Uluguru Mountains were under mixed cropping (Figure 8). It should, however, be noted that 1955 data do not cover the entire Ruvu Basin.

Analysis of land cover/use changes has further shown that in 1995 more vegetation cover has continued to be converted to farmland, in this case sisal estates and mixed crops (Figure 9). Such situation has increased exposure of land surface to erosion agents and increased surface runoff. Most of the farming practices in this area are characterized by shifting cultivation/slash and burn with very limited use of soil conservation measures.

Ground truthing and field observations in the Mgeta sub catchment for example show that there is a very intensive cultivation in steep slopes which extends into river banks with little or no conservation measures. Although there is some conservation initiatives such as terracing this is not sufficient given the fragility of the land in this sub catchment thus requiring conservation attention especially with regard to surface run off and sedimentation in streams. In the main Ruvu sub catchment above Kibungo there is extensive land degradation especially in the Mvizigo and Mbezi river catchments associated with agricultural practices with predominant shifting cultivation. The upper parts of the Ngerengere sub catchment are completely degraded and characterized by shifting cultivation, steep slope cultivation with no any conservation measures. In the Ruvu River basin the main Ruvu sub catchment is extensively cultivated and in some areas the buffer vegetation in the riparian ecosystems is completely lacking

In 2000 there was an extensive expansion of agriculture at the expense of the natural vegetation cover. The land cover was characterized by mixed cropland that encroaches and extends into marginal lands such as hilly, steep slopes and river bank ecosystems of the mountain (Figure 10 and Table 3.5).

The overall analysis of land cover/use from 1955 to 2000 has shown that there has been significant change in land cover/use with reduction from high to low forms of vegetation mostly farmland with expansion of agriculture to very steep slopes which are prone to erosion. For example, in 1995 cultivated covered 7% of the total basin area, and by 2000, cultivated land covered 14% of the total basin area. This was also supported by the findings from the discussion with key informants in the visited villages located in the Uluguru Mountains. It was revealed during the visit that there is a significant evidence of land use/cover change (Plates 7 & 8) resulting from wildfires; clearing trees for fuel wood for domestic consumption and for sale, farm land expansion to meet household food supply; human settlement development due to population increase; legal and illegal harvesting of forests for timber production to increase individual income. Key informants reported that people invade the forests in the mountains looking for fertile land for farming, because the land fertility in the lowland is exhausted. According to the Forest and Beekeeping Division (2005a) there has been a forest and woodland area decrease of about 12% and 39% respectively between 1970s and 2000. The rate of forest and woodland decrease was 0.5% and 1.8% per annum over the 30-year period

There is as well enough rainfall ranging from 2000 – 3000mm up in the mountains which favours good performance of crops, and again there are rivers such as the main Mgeta, Mzinga and Mbakana in the Mgeta sub catchment on the south eastern side of the Ulugurus, Mbezi, Mvuha, Mmanga and Mvizigo in the main Ruvu sub catchment on the eastern side of the Ulugurus and Mzinga, Morogoro and main Ngerengere in the Ngerengere sub catchment on the western side of the Uluguru Mountains.



Plate 7 **Land use/cover change in the UMs viewed from Mgeta village**
Source: Field observation, November 2006.



Plate 8 Land use/cover change in the UMs viewed from Nyandira village.
Source: Field observation, November/December 2006.

Key informants from Mlali and Ruvuma villages (the morning site) on the western of the UMs reported that the mountains around their villages up to and beyond the 'Morning Site' to the boundary of 'Bondwa Keria' forest reserve were covered with grass and scattered bushes with few farms in the past. However, in recent years the situation has changed dramatically whereby most of the mountains have been converted into other land uses including farming and settlement development due to population increase (Plate 9 & 10). The same results were obtained from other areas surveyed in the Uluguru Mountains (Matombo and Mgeta Divisions) on the eastern and south eastern sides of the mountain.

It has been reported as well that in the past elephant grass commonly known as 'Masinde' were planted in farmlands as a land use/management practice to conserve soil in the mountains. The seeds/transplants were distributed by the Ministry of Agriculture. Despite the fact that it is believed that planting elephant grass is one of the best measures to control soil erosion because of its fibrous rooting system, the local people abandoned it due to the reason that it widely spreads fast reducing the farmland size and also it behaves as a weed in the long run. Recently there has been some initiatives for land conservation practices using terraces though not extensively practiced (Plate 11). This can as well be an entry point to conservation initiatives in the UMs.



Plate 9 **Cultivation and human settlement development on steep slopes in Nyandira villages Mgeta Division**

Source: Field observations, November 2006.



Plate 10 **Farmland expansion into steep slopes Luvuma villages**
Source: Field observations, November 2006



Plate 11 Land use/management initiatives in Luvuma village.
Source: Field observation, November 2006.

All the informants further commented that if these trends of land use/cover change so continues, sooner or latter there will be no forests remaining. Therefore they concluded that current land use practices are not desirable because they are accelerating land cover shrinkage though there is a need to deal with all the driving factors behind these changes to reverse the situation and restore the status of these watersheds.

4.0 RIVER FLOW CHARACTERISTICS

The statistics of average daily flow (ADF) (Table 4.1) 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.

Table 4.1 Average Daily Flows (ADF) for the Sigi and Ruvu River Catchments

Catchment	S #	Station Code	Station Name	Record used	Average Daily Flow (m^3/s)	% zero flows
Sigi	1	1C1	Sigi at Lanzoni Estate	1957-1989	6.79	0.7
Ruvu	1	1H5	Ruvu at Kibungo	1959-1987	18.58	0.0
	2	1H8	Ruvu at Morogoro Rd. Br	1959-1987	61.19	0.1

	3	1HB2	Mgeta at Mgeta	1959-1987	2.60	0.0
	4	1HA9A	Ngerengere at Konga	1959-1987	0.96	0.0

Source: Adapted from Forestry and Beekeeping Division (2005c)

4.1 Seasonal Flow Patterns

4.1.1 Sigi River Basin

Figure 11 presents the flow hydrograph of the mean monthly flows for Sigi River. The hydrographs start to rise in October (responding to the onset of the short rains) and in March (corresponding to the onset of the long rain season). Although bimodality is evident in the Sigi River, the highest peak is observed in May. The recession starts with the onset of the dry season in June. The uneven distribution of flows within the year further indicates that about 66% of annual volumes in the Sigi River flow during the long rains (MAM) and the short rains (OND) while relatively small volumes flow during the dry season (Table 4.2). Such high flow contributions during the rain seasons and low volumes during the dry season and intermediate season suggest that changes of annual flows over the years are attributed significantly to changes during the two rain seasons and are associated with depletion of cover in the catchment and reduced capacity of the catchment to store moisture.

The sharp rise in the hydrograph at the onset of the rain season indicates high surface run off and less storage in the catchment which is attributed to cover degradation in some parts of the watershed.

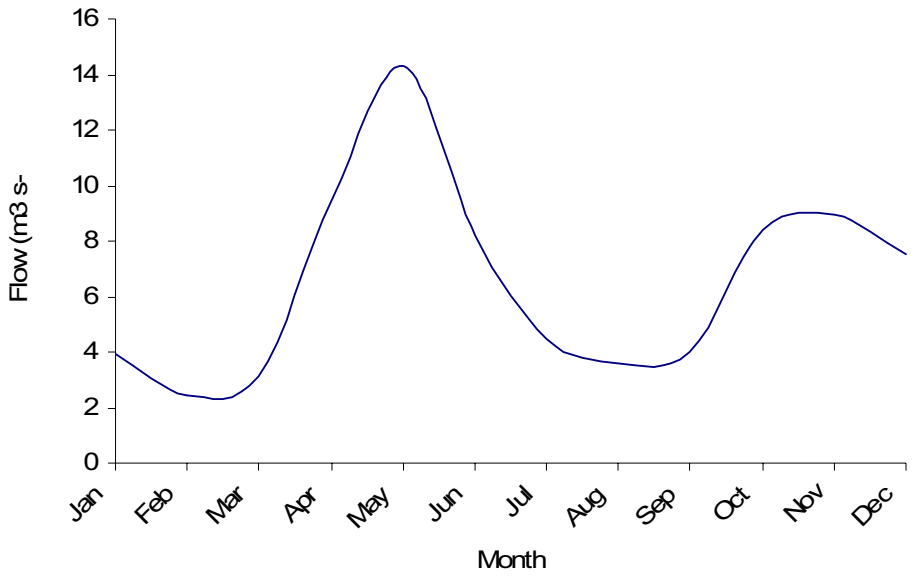


Figure 11: Mean monthly flow hydrograph for Sigi River at Lanzoni, East Usambara (1957 – 1990)

Table 4.2 Mean seasonal flow volumes expressed as percentage of mean annual flow volumes

Catchment	S #	Code	Station Name	Seasonal contribution to annual flow volume (%)			
				JF	MAM	JJAS	OND
Sigi	1	1C1	Sigi at Lanzoni	7.9	34.1	26.0	32.0
Ruvu	1	1H5	Ruvu at Kibungo	14.7	41.5	21.2	22.6
	2	1H8	Ruvu at Morogoro Road Bridge	13.6	51.7	17.1	17.8
	3	1HB2	Mgeta at Mgeta	15.6	38.5	22.8	23.2
	4	1HA9A	Ngerengere at Konga	9.4	48.4	21.2	21.2

4.1.2 Ruvu River Basin

The mean monthly flow hydrograph for the Ruvu River and its tributaries indicates periods of high and low flows corresponding to the long and short rains (Figures 12 – 14). The highest peak in Ruvu River and its tributaries is observed in April. The low flows in Ruvu River are experienced during the dry period of August-September. However, low flows are sometimes also experienced during the intermediate short rain (JF) season, especially with the smaller tributaries (e.g. Ngerengere River) (Figure 13). Again most of the flow volumes (69%) are realised during the two rain seasons (Table 4.2) indicating the significance of this in the changes that occur in flow in the Ruvu River and possible increase in surface runoff due to catchment degradation as indicated by land use change analysis.

The sharp rise in the hydrograph at the onset of the rain season may again indicate high surface run off and less storage in the catchment which can be attributed to cover degradation in some parts of the watershed. Normally wherever there is land use change that deprives the catchment with cover it reduces infiltration and the capacity of the catchment to store water for future release. Such conditions are reflected in high surface run off and short lag time displayed as a quick rise and recession in the hydrograph. Further figure 14b shows that recent periods (1985 – 1993 and 1994 – 2004) have experienced higher proportion of peak runoff during the peak flow months compared to the 1950s and 1960s.

The dry season contributes relatively low flow volumes which can also be attributed to low storage capacity in the catchment. If the amount of rainfall has remained relatively constant, such low dry season flow volumes are as well attributed to cover degradation in the catchment. Further when rainfall shows a decreasing trend the rate of decrease may be relatively small compared to the rate of decrease in flow thus still indicating impacts related to vegetation degradation.

Discussions with key informants iterate this concept whenever there is a rainfall event the streams fill up quickly but also the floods recede very quickly. Statements like "*there was flooding recently that came up very fast after the start of heavy rain*

with water passing over the bridge and cut off communication across the bridge. However the floods receded with a very short time after the rain was over". Such statements are common among the local people when discussing about floods

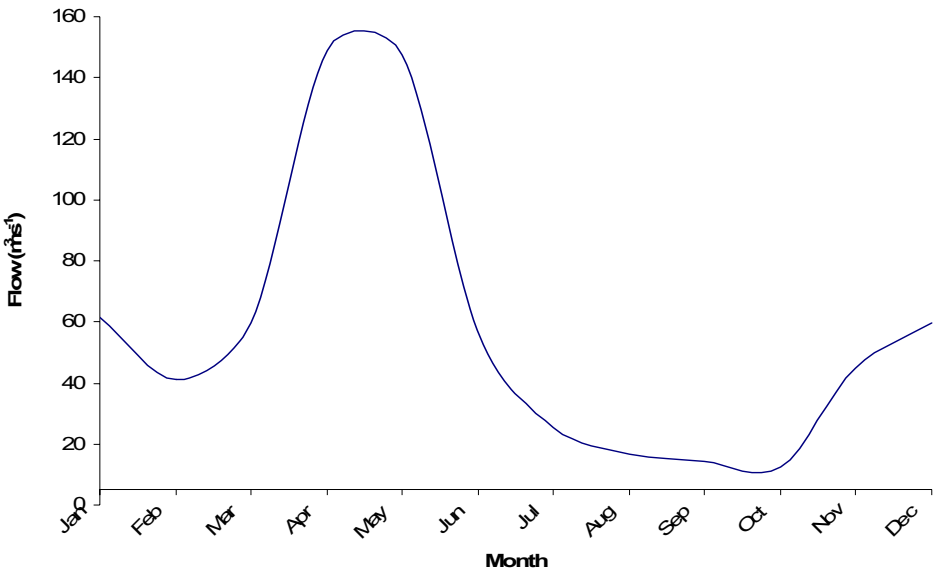


Figure 12: Mean Annual flow hydrograph for Ruvu River at Morogoro Road Bridge (1958 – 2004)

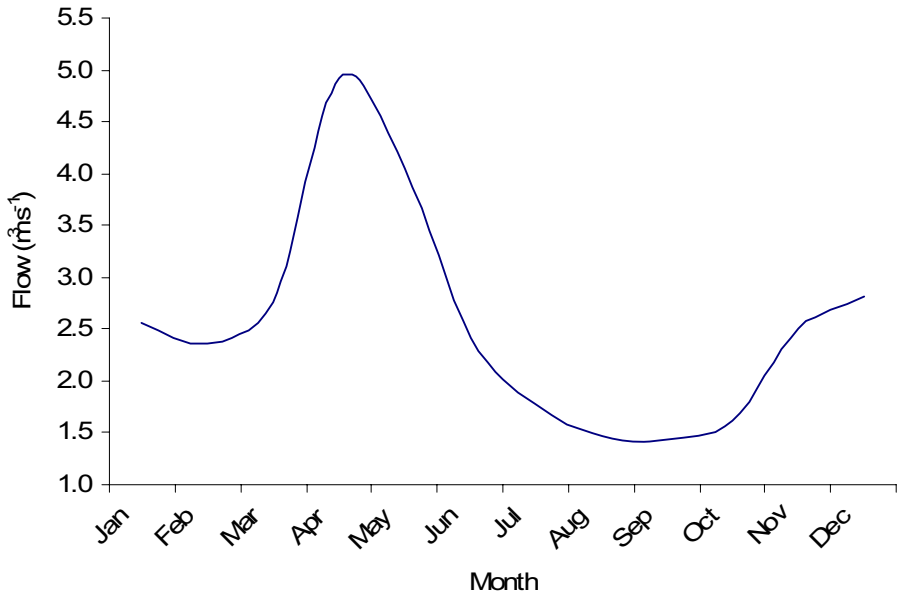


Figure 13: Mean monthly flow hydrograph for Mgeta River at Mgeta - a sub catchment of Ruvu River Basin (1954 – 1989).

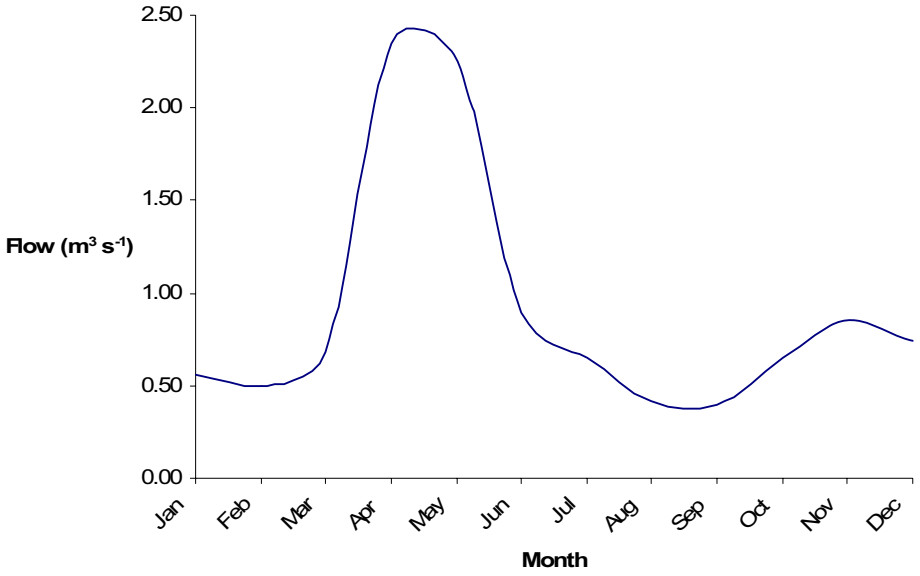


Figure 14: Mean monthly flow hydrograph for Ngerengere River at Konga - a sub catchment of Ruvu River (1954 – 1989)

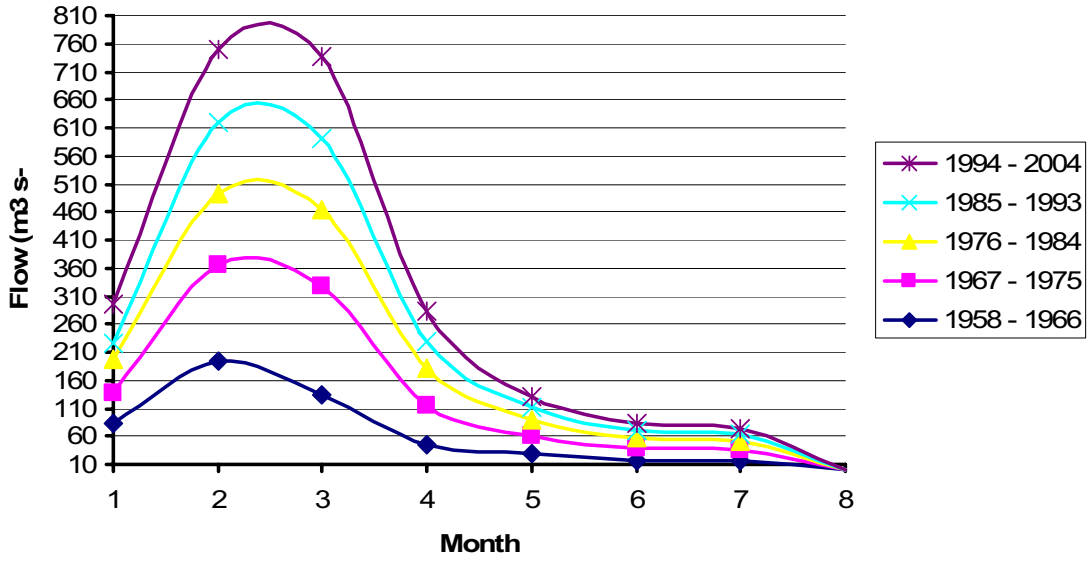


Figure 14b: Monthly mean flow hydrographs during peak flow months at different periods for the Ruvu River at Morogoro Road Bridge (1958 – 2004)

4.2 Inter-annual Flows

4.2.1 Sigi River

The mean annual discharge and flow volumes in the Sigi River for the period of 33 years seem to have been relatively constant or have shown a very slight non significant decreasing trend (Table 4.3, Figures 15a, 15c). However of significance to note is the dry season discharge (Figure 15b) which shows a greater decrease by about 0.8-m^3 sec^{-1} (i.e. 5.2 – 4.4 m^3 sec-^{1}) and dry season flow volumes decreased by approximately 20 million m^3 (150 million – 130 million m^3) (Figure 15d). This is an annual rate of decrease of about 0.024 m^3 sec^{-1} yr^{-1} in discharge and about 606,000 m^3 per year in flow volume. This is a significant decrease given the increasing demand for water resulting from increasing population and diversified uses especially during the dry season. Decreases in the dry season flows can be attributed to either decrease in the capacity of the catchment to store moisture as a result of decrease/changes in vegetation cover/land use or upstream abstractions during the dry season. Degradation of cover in a catchment results into low infiltration capacity and hence low capacity of the catchment to store moisture. Such situation results into appreciable decrease in the dry season flow volumes.

It was learnt that abstractions in the catchment upstream of the Lanzoni gauging station are minimum as most of them could be from the sisal plantations, which do not operate nowadays. Further, most of these sisal farms are downstream of the gauging station and there was only one estate that could abstract water from upstream of the station. The tea estates are located in high rainfall and moisture areas and water abstraction from these estates is minimal. It was further learnt that there are approximately 18 known abstractions, which are mainly for domestic use with an average abstraction of about 2 Ls^{-1} (Pangani Basin Water Office, 2006)

Results of trend analyses on annual flows for Sigi River Catchment are summarised in Table 4.3 and Figures 15(a-d). The results of trends in annual flows generally indicate flow declines in the Sigi River catchment. Although decreasing trends characterize annual flows in the Sigi River catchment, they are insignificant indicating that decreases in annual flows are slight. Moreover, despite the generalized decrease of annual flow in the Sigi River Catchment, certain years experienced extreme high flows while others experienced extreme low flows (Figure 15a). The time series indicate alternating periods of abundant and deficit annual flows.

Local people perceptions show that there has been an extensive decline in vegetation cover with negative consequences on water quantity and quality in all sub catchments visited in the Sigi river.

Generally the results of land use/cover and flow analysis indicate:

- Decreasing cover in the catchment as a result of conversions from high forms (natural forest/woodland cover) to lower forms of cover (agricultural land, mixed cropping)
- Slightly declining annual flows (discharge and volumes)
- Slightly declining flows during the long rains and the short rain seasons;
- Declining dry season flows and capacity of the catchment to store moisture

- High influence of long rains and short rains on flows attributed to declining cover

Table 4.3 Summary of Test Statistic (Z) in annual and seasonal mean flows in the Sigi river Basin (α = 5%)

Code	Station Name	Record Used	Parameters	Trends				
				Annual	JF	MAM	JJAS	OND
1C1	Sigi at Lanzoni Estate	1957-1989	Z	-0.015	0.108	-0.170	-0.852	-0.108
			S	DN	UP	DN	DN	DN

S = Trend Direction, Z = Test Statistic, UP = Upward Trend, DN = Downward Trend

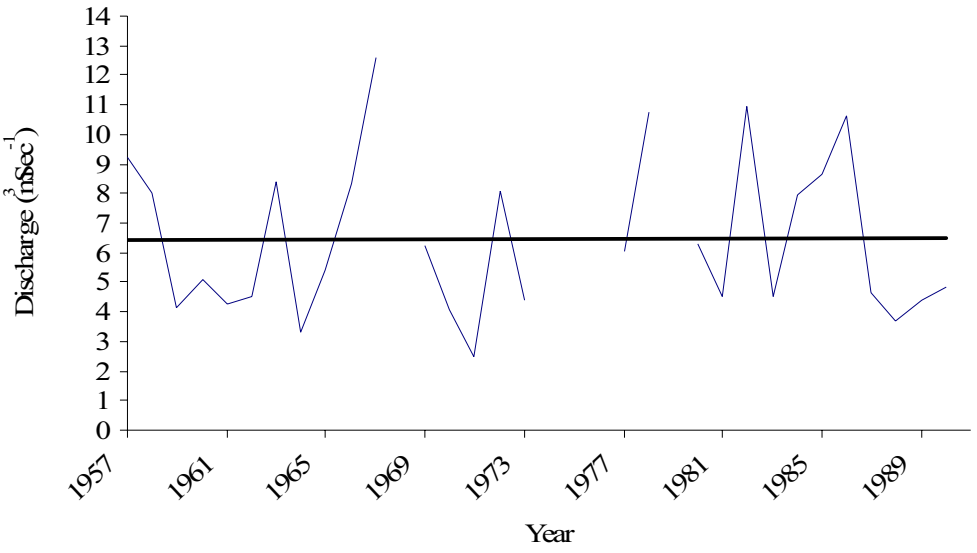


Figure 15a: Time series and trend line of annual flows (m^3s^{-1}) in the Sigi River at Lanzoni (1957 – 1990)

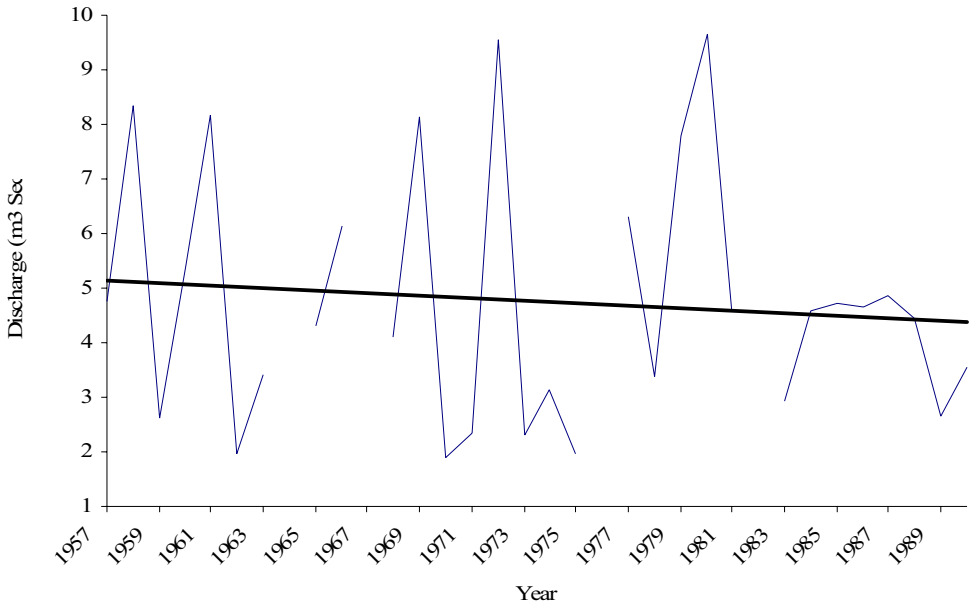


Figure 15b: Time series and trend line of Annual Dry Season flows (m^3s^{-1}) in the Sigi River at Lanzoni (1957 – 1990)

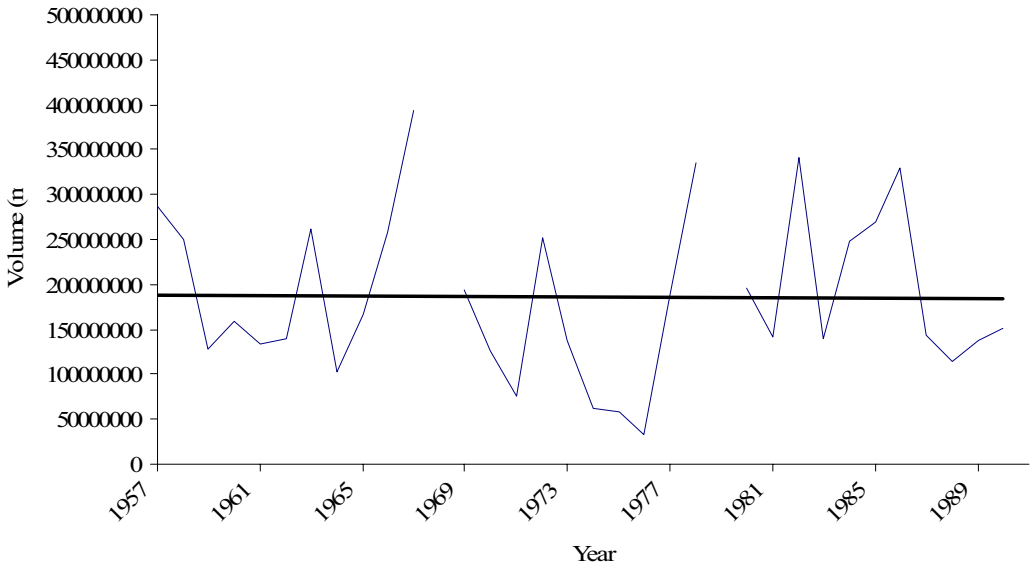


Figure 15c: Time series and trend line of annual flow volumes (m^3) in the Sigi River at Lanzoni (1957 – 1990)

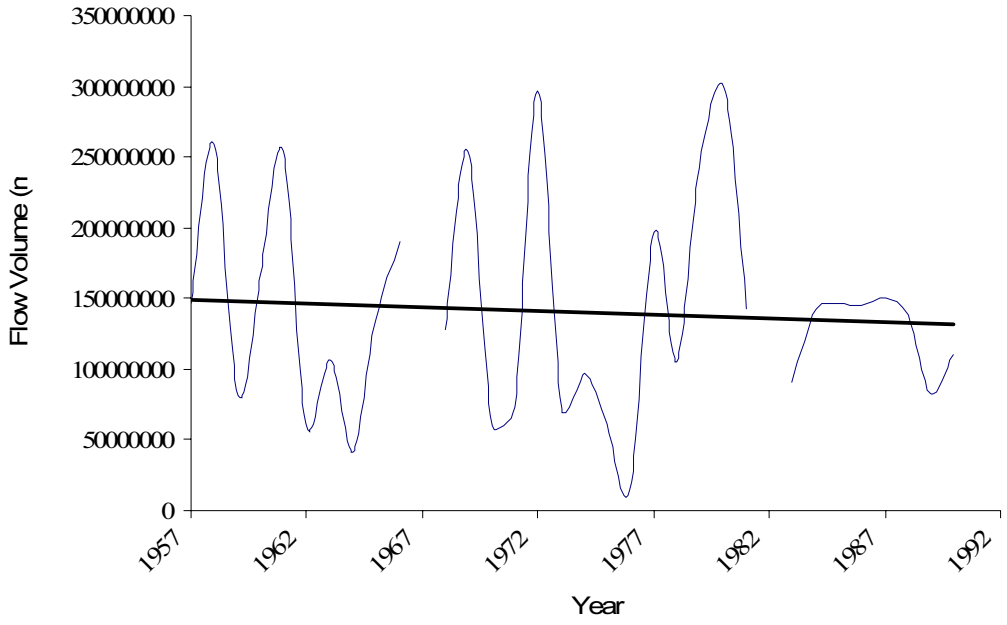


Figure 15d: Time series and trend line of Annual Dry Season flow volumes (m^3) in the Sigi River at Lanzoni (1957 – 1990)

4.2.2 Ruvu River

The results of trend analyses on annual flows for the Ruvu River generally indicate mixture of flow decreases and increases as influenced by contributions from its sub catchments (Table 4.4). Both the annual, dry season and rain season flows in the Ruvu River basin as measures at Morogoro Road Bridge and its sub catchment at Kibungo and Mgeta show a decreasing trend. On the other hand the flow in the Ngerengere sub catchment shows an increasing trend.

Decreasing trends in the dry season and increasing trends in the rain seasons is an indication of low water storage capacity in the catchments and increased surface run off resulting mainly from vegetation degradation. The observed situation here implies different degradation conditions in the different sub catchments with the possibility that some of the sub catchments are more degraded than others impacting differently on water quantity.

Generally there is a predominant decreasing trend in all the respective sub catchments especially in the dry season flow except for the Ngerengere sub catchment which shows increasing trends (Table 4.3, Figures 15e – 15j). The increasing flows in the Ngerengere sub catchment can indicate high catchment degradation resulting into high surface run-off and poor catchment storage.
The influence of trends in flows in the dominant MAM season on trends in annual flows is evident when trends are compared with mean seasonal flow contributions (Tables 4.2). The near-similarity of trend magnitude and sign between trend in annual and rain season flows at the main Ruvu River gauging stations indicate that the decreasing trends in annual flow is largely contributed by the negative trend in

rain season flow. Flow volume in MAM season contributes about 42% and 52% of annual flows in the Ruvu River at Kibungo and Morogoro Road Bridge respectively. On the other hand, the dry season flows contribute only between 17-21% of annual flow volumes in the two stations.

The influence of individual sub catchments to the total flow cannot be overlooked (Table 4.5). Despite the predominant increasing trend in the Ngerengere and slight decreases in Mgeta sub catchments the predominant decreasing trends in the Kibungo sub catchment seem to have more influence on the flow in the basin. It can therefore be said that the predominant decreasing trends for all seasons in the Kibungo sub catchment imparts a greater influence on the observed decreasing flow trends in the Ruvu River basin. The influence of the other sub catchments may however not be overlooked as their contribution to flow is significant. The contribution by the Mgeta and Ngerengere sub catchments are likely low because of their relatively smaller sub catchment area. These observations are related to the status of the basin conditions in this sub catchment reflecting possible degradation on the sub catchment that requires conservation attention.

Table 4.4 Summary of Test Statistic (Z) in annual and seasonal mean flows in the Ruvu River Basin (α = 5%)

Code	Station Name	Record Used	Parameters	TRENDS				
				Annual	JF	MAM	JJAS	OND
1H5	Ruvu at Kibungo	1959-1987	Z	-0.581	0.581	-1.219	- 0.094	0.281
			S	DN	DN	DN	DN	UP
1HB2	Mgeta at Mgeta	1959-1987	Z	-0.506	1.576	-0.469	-0.319	0.488
			S	DN	UP	DN	DN	UP
1HA9A	Ngerengere at Konga	1959-1987	Z	0.506	0.469	0.657	0.150	-0.732
			S	UP	UP	UP	UP	DN
1H8	Ruvu at Morogoro Rd. Br	1959-1987	Z	-1.482	-0.394	-1.144	-0.469	0.281
			S	DN	DN	DN	DN	UP

S = Trend Direction, Z = Test Statistic, UP = Upward Trend, DN = Downward Trend

Table 4.5 Flow Characteristics in the Sigi and Ruvu River basins

Basin	Sub Catchment	Period	# Years	Season	Change ($m^3 s^{-1}$)	Trend
Sigi	Sigi	1957 - 1990	33	Annual	Slight	DN
				Rain	Slight	DN
				Dry	0.8	DN
Ruvu	Kibungo (Main Ruvu)	1952 - 2005	53	Annual	8.5	DN
				Rain	16.0	DN
				Dry	5.0	DN

	Mgeta	1954 - 1989	35	Annual	0.1	DN
				Rain	0.2	DN
				Dry	0.2	DN
	Ngerengere	1954 - 1988	34	Annual	0.12	UP
				Rain	0.10	UP
				Dry	0.30	UP
	Whole Basin (Moro Rd)	1958 - 2004	46	Annual	17.0	DN
				Rain	25.0	DN
				Dry	5.0	DN

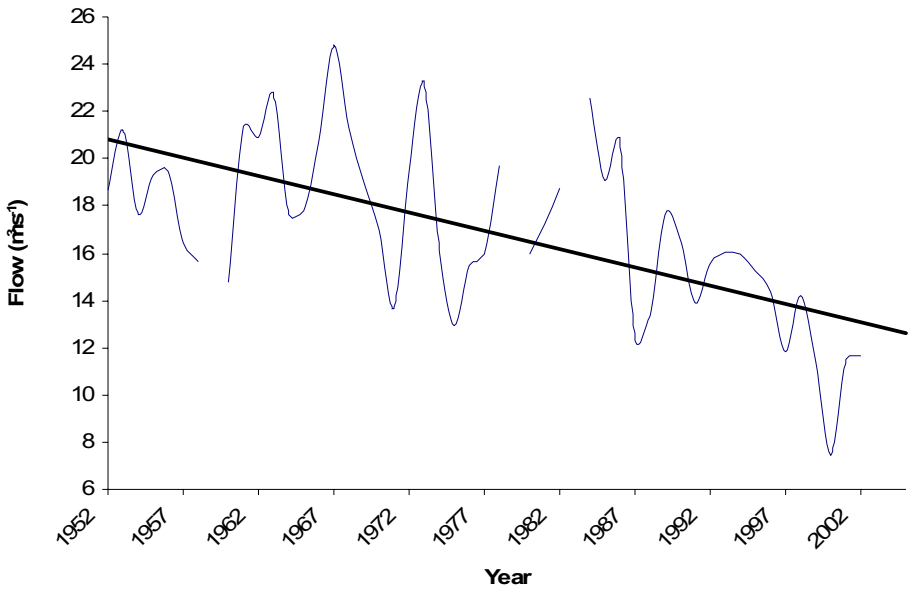


Figure 15e: Time series and trend line of Annual Flows (m^3 s^{-1}) in the Ruvu River at Kibungo (1952 – 2005)

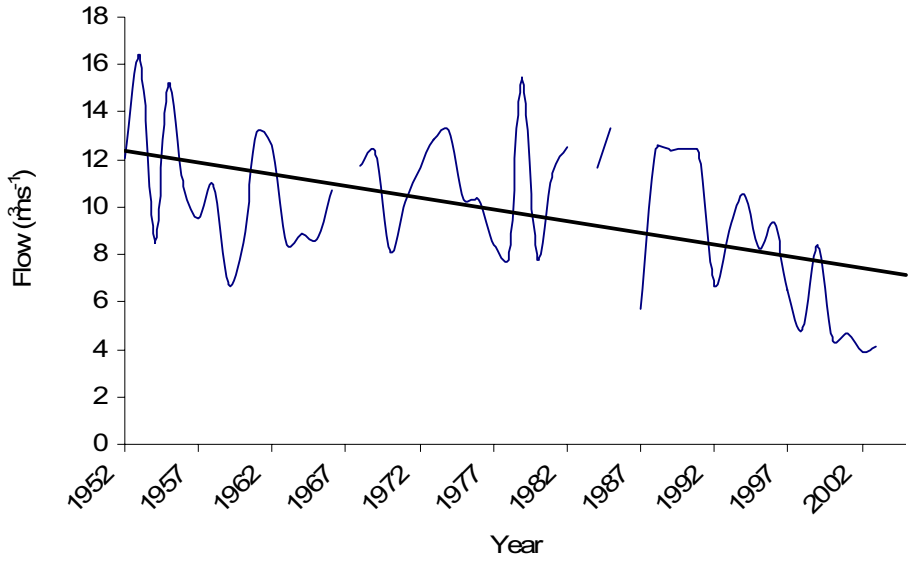


Figure 15f: Time series and trend line of Annual Dry Season flows (m^3 s^{-1}) in the Ruvu River at Kibungo (1952 – 2005)

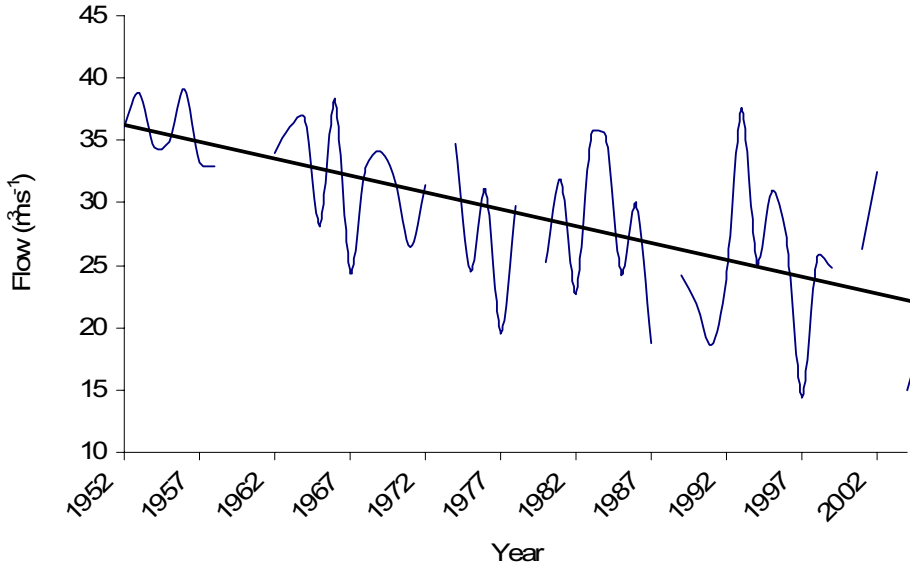


Figure 15g: Time series and trend line of Annual Rain Season flows (m^3 s^{-1}) in the Ruvu River at Kibungo (1952 – 2005)

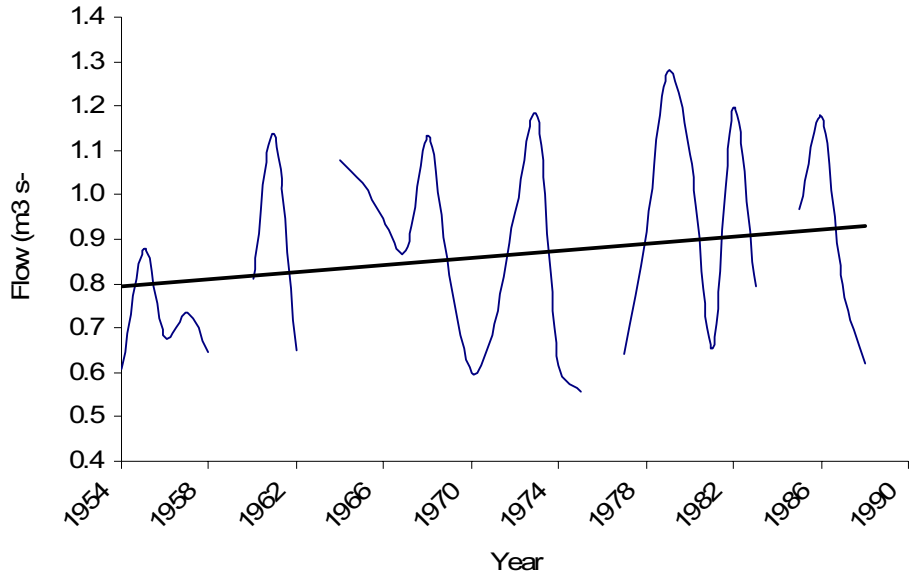


Figure 15h: Time series and trend line of Annual Flows (m^3 s^{-1}) in the Ngerengere River at Ngerengere (1954 – 1988)

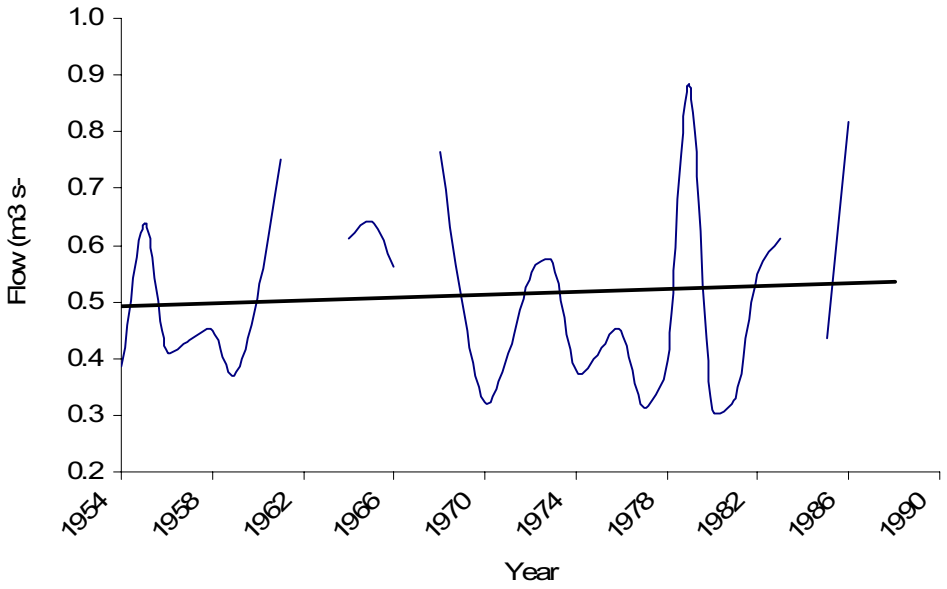


Figure 15i: Time series and trend line of Annual Dry Season Flows (m^3 s^{-1}) in the Ngerengere River at Ngerengere (1954 – 1988)

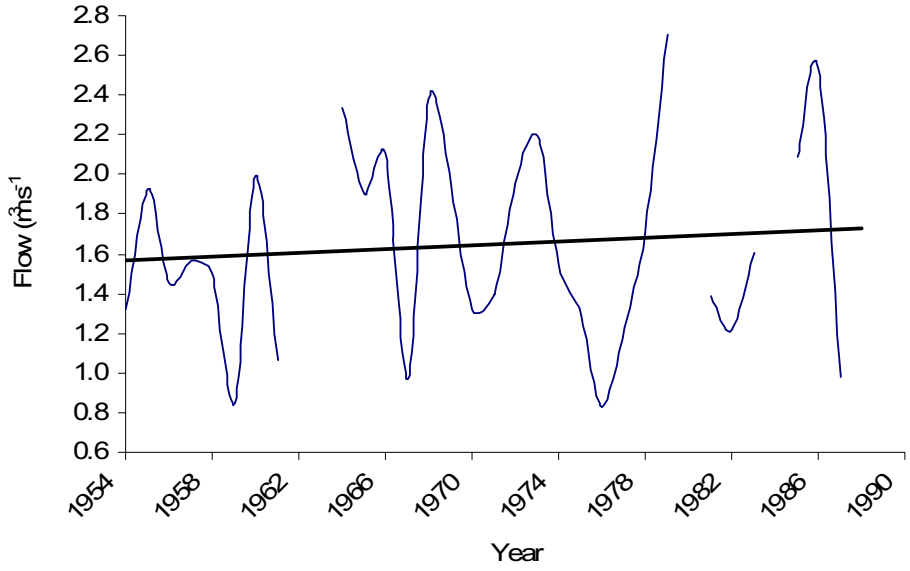


Figure 15j: Time series and trend line of Annual Rain Season Flows (m^3 s^{-1}) in the Ngerengere River at Ngerengere (1954 – 1988)

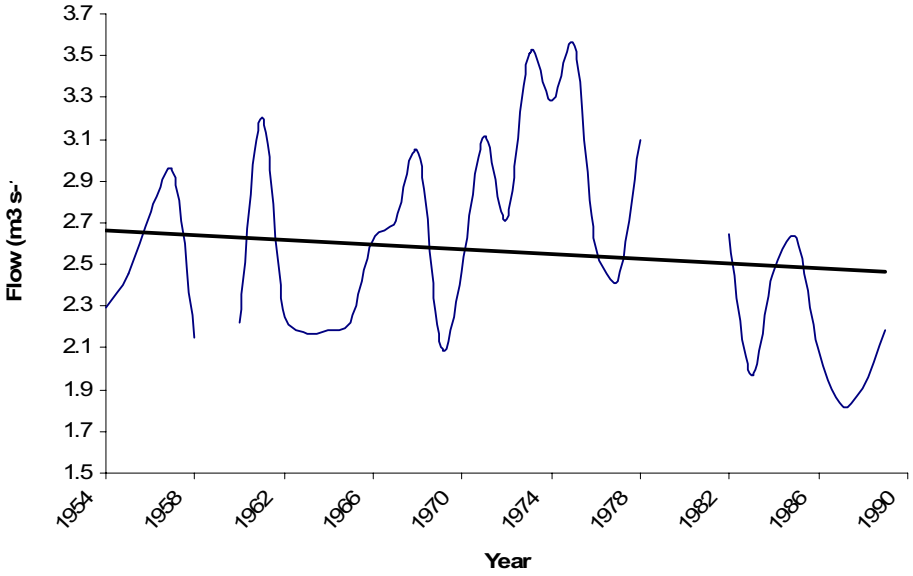


Figure 15k: Time series and trend line of Annual Flows (m^3 s^{-1}) in the Mgeta River at Mgeta (1954 – 1989)

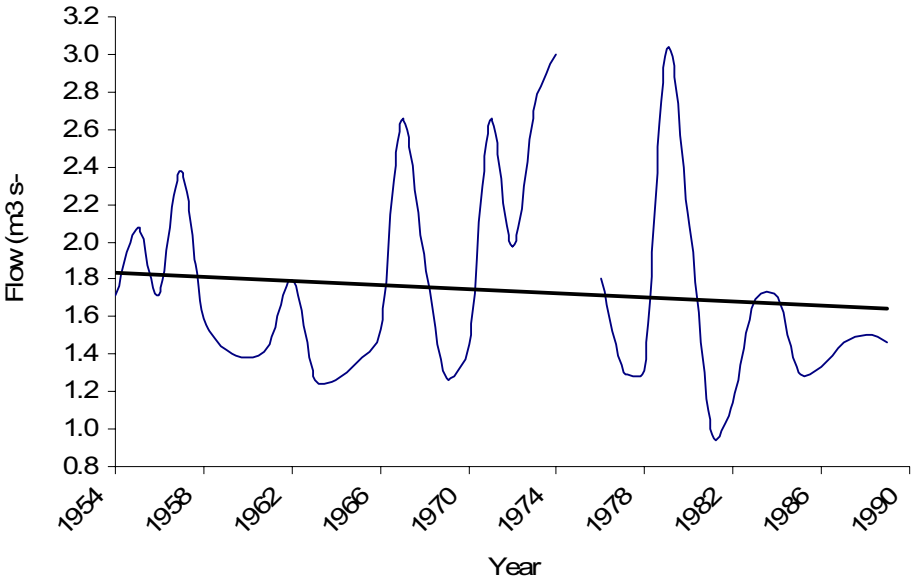


Figure 15l: Time series and trend line of Annual Dry Season Flows (m^3 s^{-1}) in the Mgeta River at Mgeta (1954 – 1989)

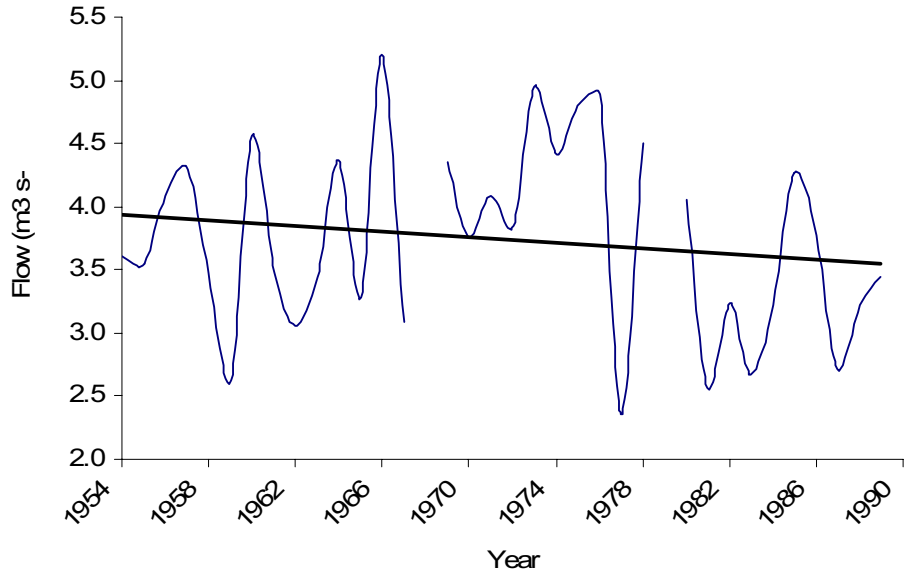


Figure 15m: Time series and trend line of Annual Rain Season Flows (m^3 s^{-1}) in the Mgeta River at Mgeta (1954 – 1989)

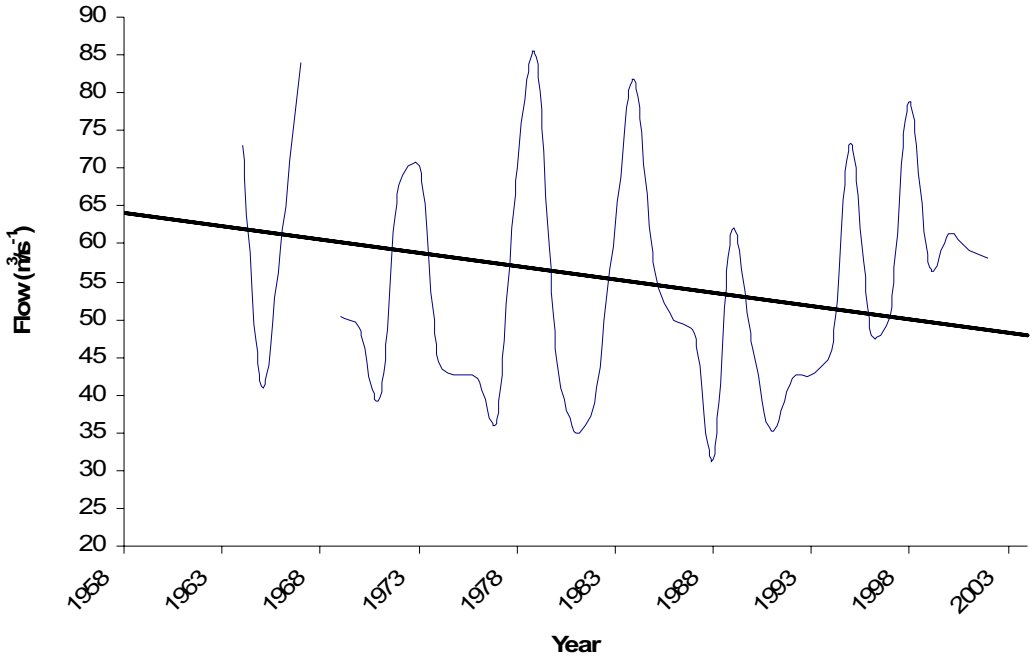


Figure 15n: Time series and trend line of Annual Flows (m^3 s^{-1}) in the Ruvu River at Morogoro Road Bridge (1958 – 2004)

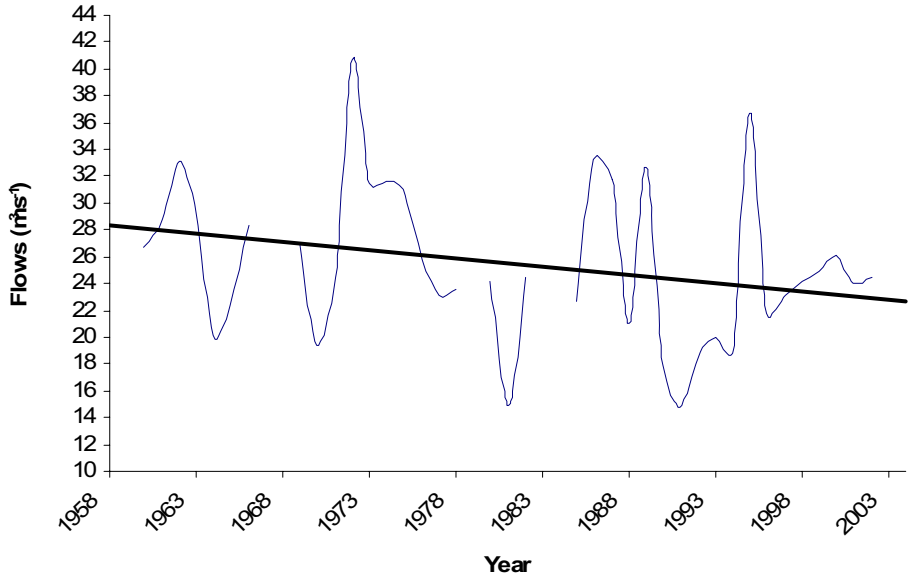


Figure 15(o): Time series and trend line of Annual Dry Season Flows (m3 s-1) in the Ruvu River at Morogoro Road Bridge (1958 – 2004)

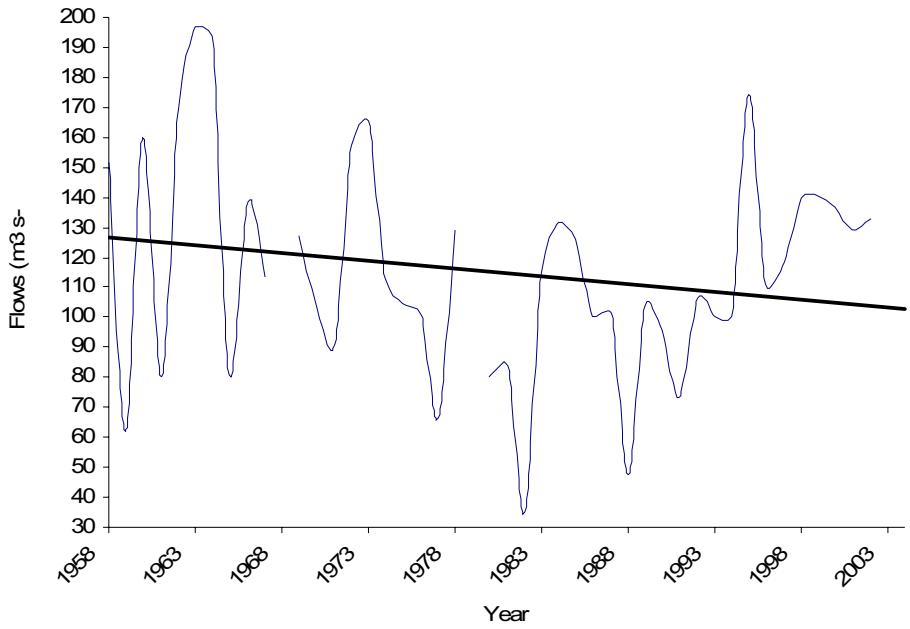


Figure 15p: Time series and trend line of Annual Rain Season Flows (m^3 s^{-1}) in the Ruvu River at Morogoro Road (1958 – 2004)

Conclusions on Flow Dynamics

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

- General insignificant annual flow and dry season flow declines in both basins
- A mixture of flow increases and decreases in the sub catchments of the Ruvu River basin.
  - A decreasing flow trend in the main Ruvu River sub catchment above Kibungo Mgeta sub catchment and at Morogoro Road Bridge downstream. Kibungo sub catchment has more influence on flows in the Ruvu River Basin
  - The Ngerengere sub catchment is predominated by increasing flow trends.

Generally there is a predominance of declining flows in the dry season and some declining flows during the long and short rain seasons in both catchments implying impacts related to catchment degradation in the upper catchments.

Discussion with key informants in all sub catchments visited had the opinion that there has been a steady decline in flow in most of the rivers especially in the dry season. Further they ascertained that rain season flows have been more variable and erratic with some seasons experiencing floods while in other seasons experience abnormally low flows associating these with declines in cover within the catchments.

5.0 RAINFALL CHARACTERISTICS AND TRENDS

Figure 16 presents the mean monthly variation in rainfall amounts at Amani Malaria Unit in Sigi River Catchment. It can be observed from the figure that the catchment experiences bimodal type of rainfall. This rainfall regime corresponds to two rainfall peaks, one representing the short rains in October to December (OND) and the other the long rains in March to May (MAM). The period January to February (JF) usually receives little rainfall 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 from June to September (JJAS) with monthly rainfall amounts predominantly below 100 mm. Maximum rainfall is recorded during the months of April-May. February seems to be the driest month in the catchment

Table 5.1 shows the trend in rainfall for selected meteorological station in the Sigi and Ruvu River Basins. The trend seems variable though a decreasing trend predominates (Figures 17 – 28). It is however not desirable to conclude on trends from a single station and an average watershed rainfall may give a better explanation of the rainfall trends in a basin. Considering the average watershed rainfall from 7 stations in the Sigi River basin and 3 rainfall stations in the Ruvu River basin there is a long term slightly increasing but non significant trend in annual rainfall (Table 5.1, Figure 18 & 28). This increasing trends in rainfall would also be reflected in flow into the Sigi river i.e. flows in the river would also be expected to show increasing trends over time

Table 5.1 Summary of Test Statistic (Z) in annual and seasonal rainfall amounts in the Sigi and Ruvu Basin (α = 5%)

Basin	St #	Code	Station Name	Record Used	Parameters	Trends					
						Annual	JF	MAM	JJAS	OND	Mean Watershed
Sigi	1	9538003	Amani Malaria Unit	1920-2000	Z	-1.415	-0.485	-1.325	-1.684	-0.249	1.432
					S	DN	DN	DN	DN	DN	UP
Ruvu	1	9637015	Kingolwira Prison	1964-1993	Z	-0.642	0.393	-1.820	0.000	0.500	1.02
					S	DN	UP	DN	DN	UP	UP
	2	9638005	Lugoba Mission	1964-1993	Z	0.963	-0.464	0.999	-0.018	0.856	UP
					S	UP	DN	UP	DN	UP	UP
	3	9737006	Matombo Pr. School	1964-1993	Z	-1.249	-0.821	-1.641	-0.393	-0.785	UP
					S	DN	DN	DN	DN	DN	UP

Note S = Trend Direction Z = Test Statistic UP = Upward Trend DN = Downward Trend

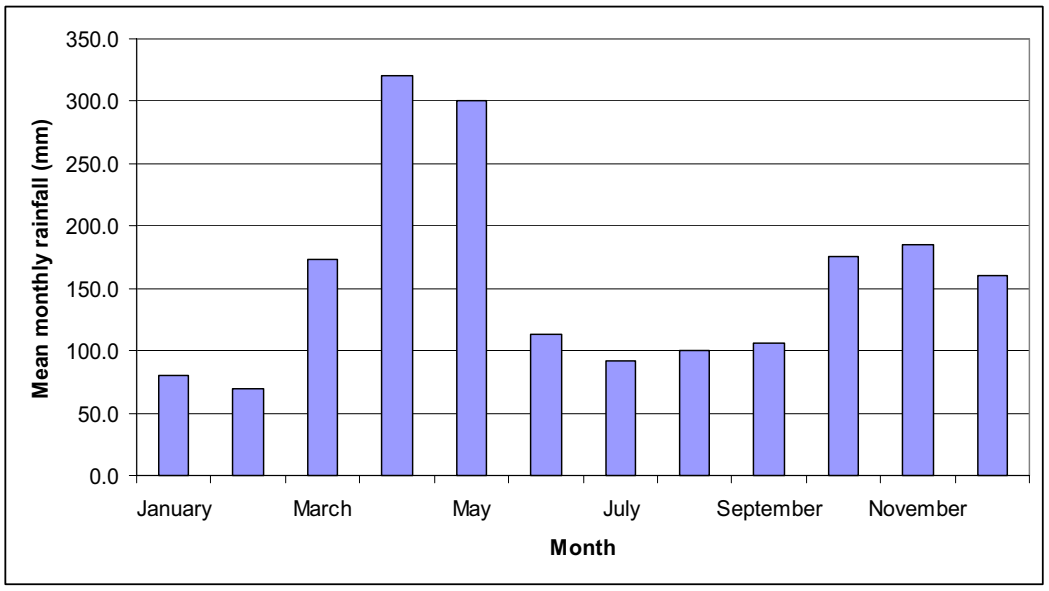


Figure 16: Mean monthly rainfall at Amani Malaria Unit - Sigi River Basin

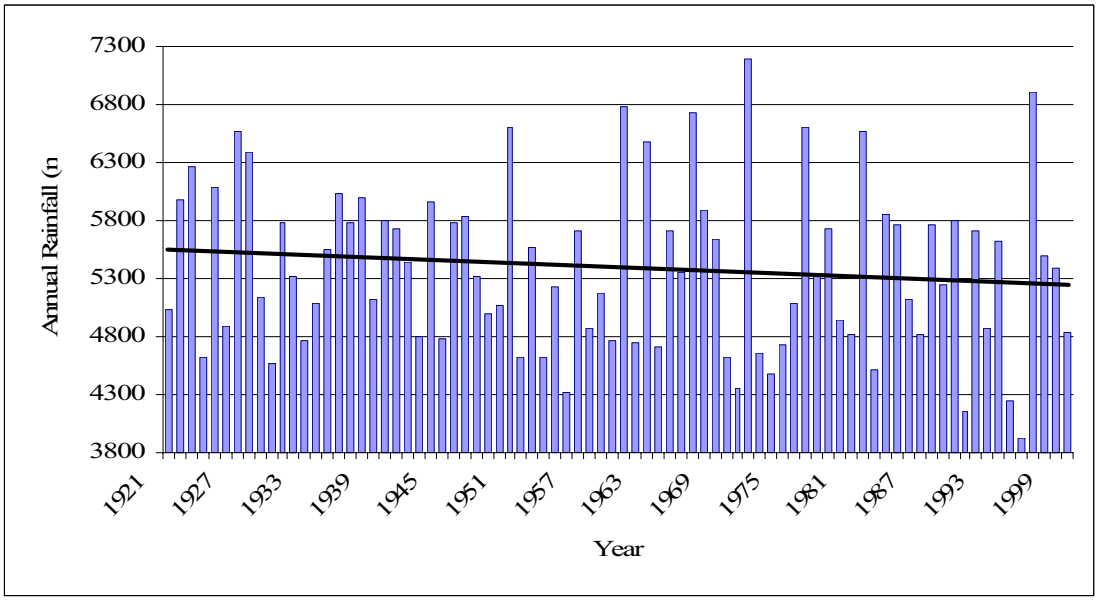


Figure 17: Trends in the mean annual rainfall at Amani – Sigi River watershed (1921 – 2000)

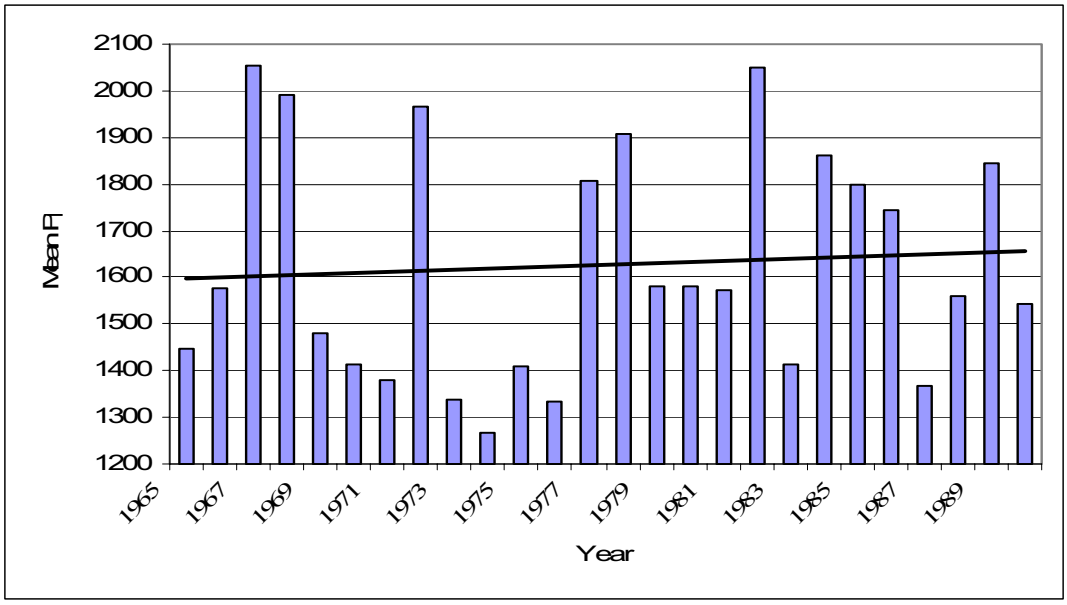


Figure 18: Trends in the annual mean watershed rainfall (7 stations) in the Sigi River watershed 1965 - 1990 (25 years period)

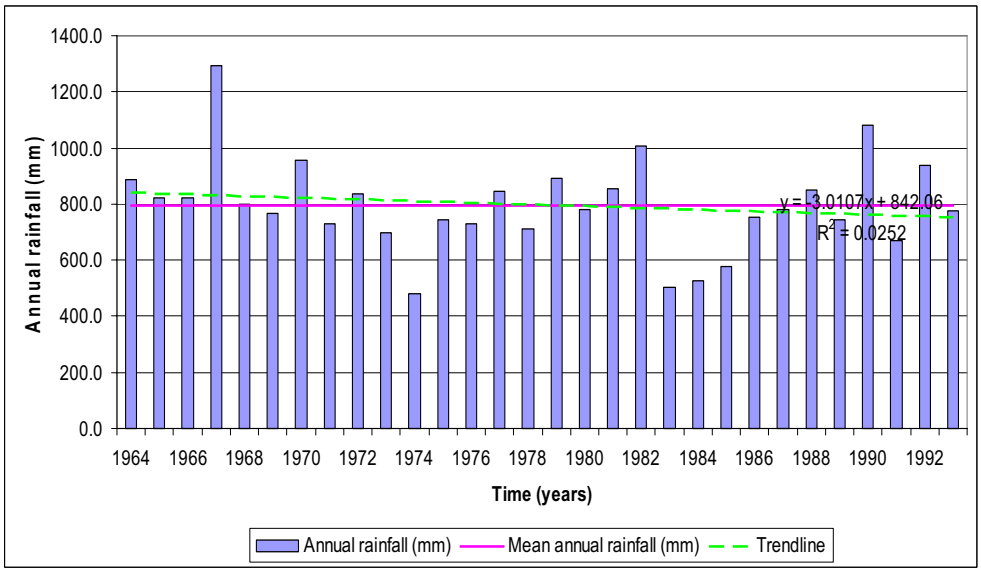


Figure 19: Time series and trend line of annual rainfall at Kingolwira Prison in the Ruvu River Basin (1964 – 1993 (29 years period)

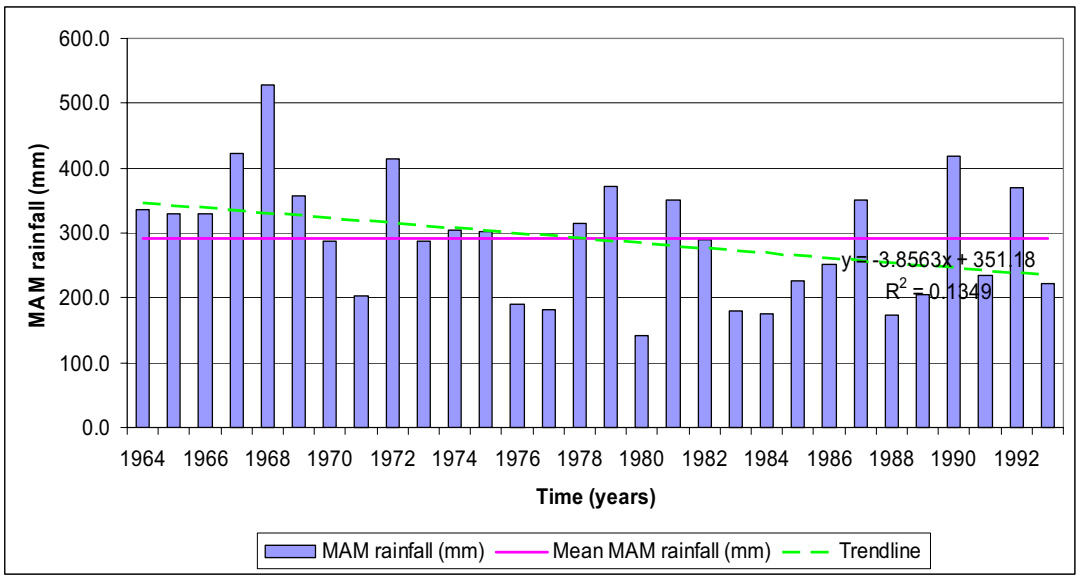


Figure 20: Time series and trend line of the mean annual rain season rainfall at Kingolwira Prison in the Ruvu River Basin (1964 – 1993 (29 years period)

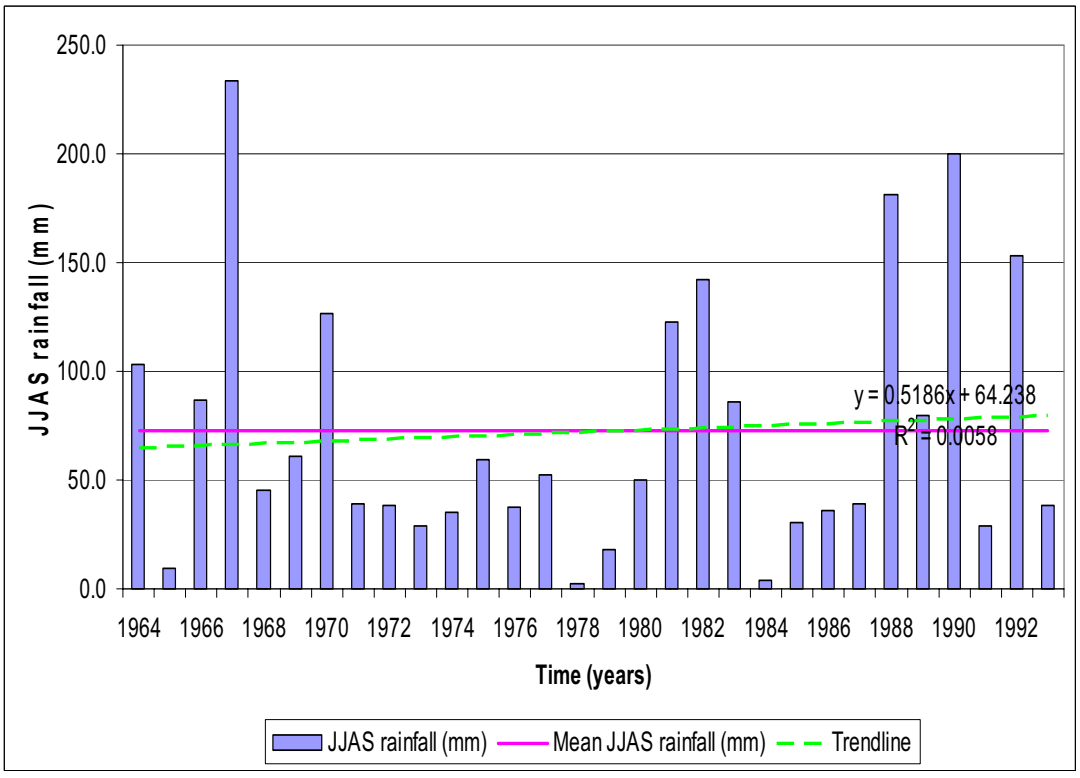


Figure 21: Time series and trend line of mean annual dry season rainfall at Kingolwira Prison in the Ruvu River basin (1964 – 1993 (29 years period)

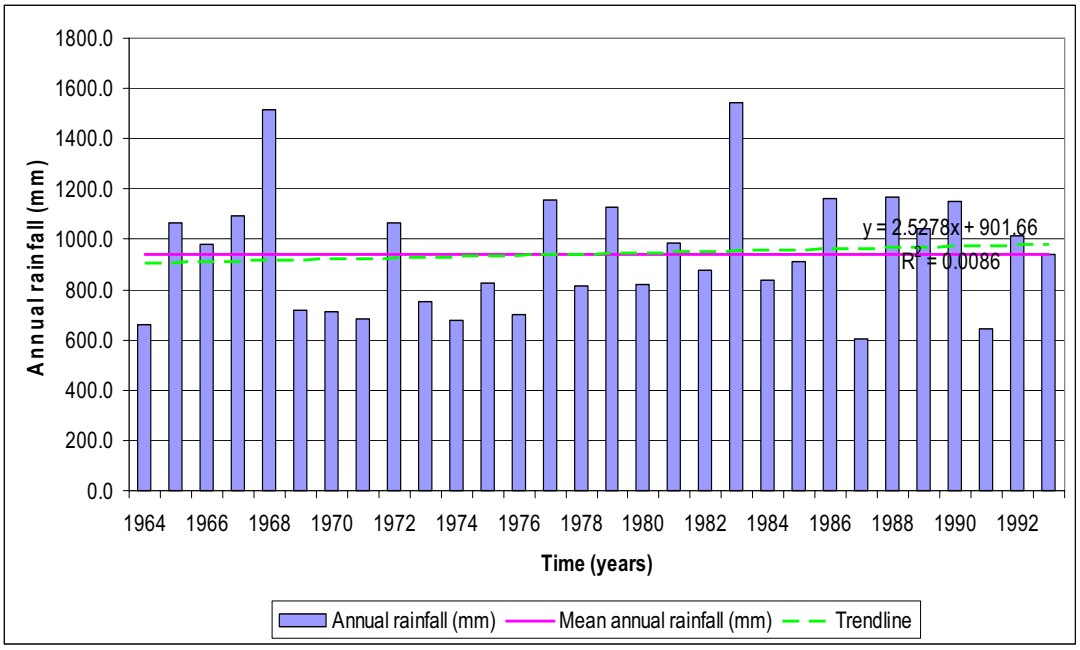


Figure 22: Time series and trend line of annual rainfall at Lugoba Mission in the Ruvu River Basin (1964 – 1993 (29 years period)

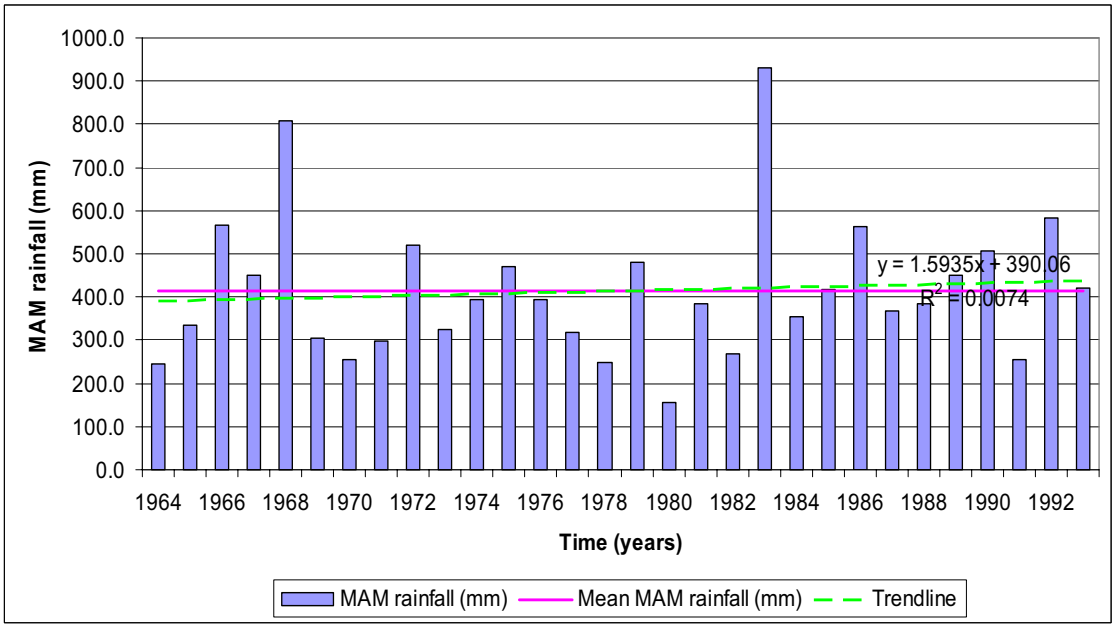


Figure 23: Time series and trend line of the mean annual rain season rainfall at Lugoba Mission in the Ruvu River basin (1964 – 1993 (29 years period)

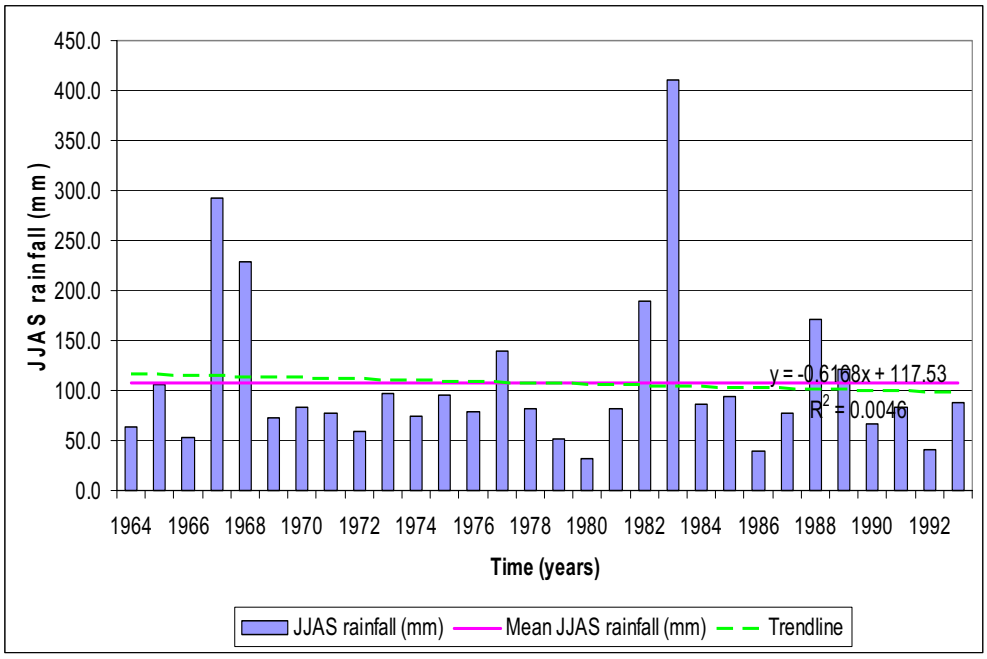


Figure 24: Time series and trend line of the mean annual dry season rainfall at Lugoba Mission in the Ruvu River basin (1964 – 1993 (29 years period)

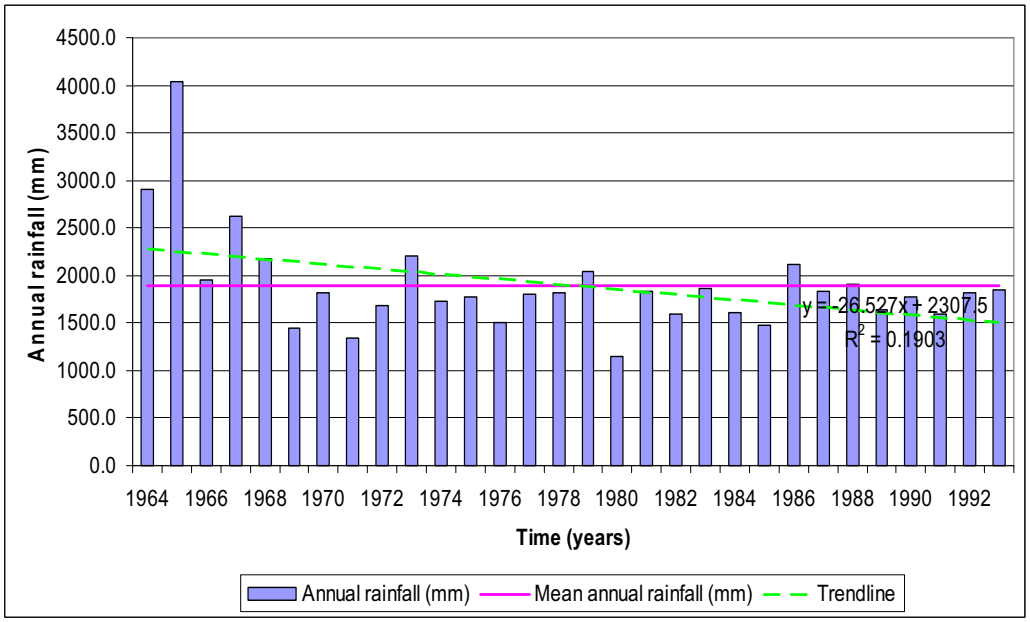


Figure 25: Time series and trend line of annual rainfall at Matombo Primary School in the Ruvu River basin

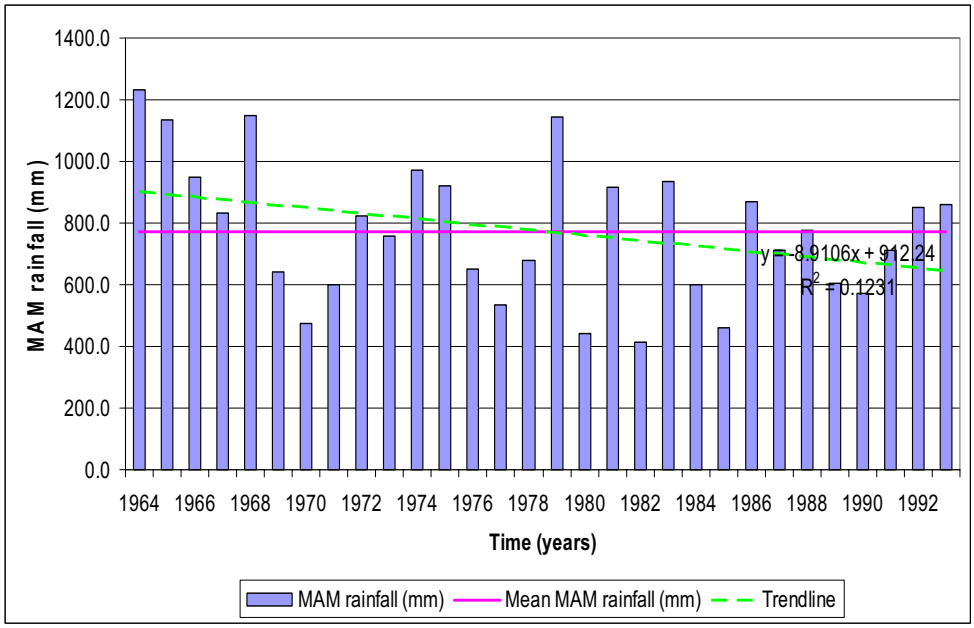


Figure 26: Time series and trend line of mean annual rain season rainfall at Matombo Primary School in the Ruvu River basin

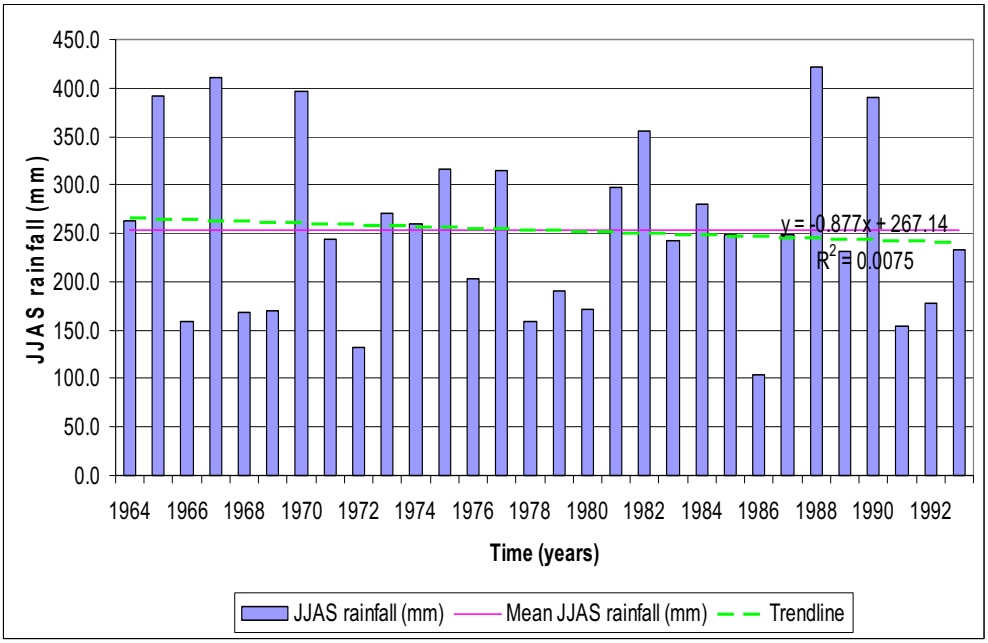


Figure 27: Time series and trend line of the mean annual dry season rainfall at Matombo Primary School in the Ruvu river basin

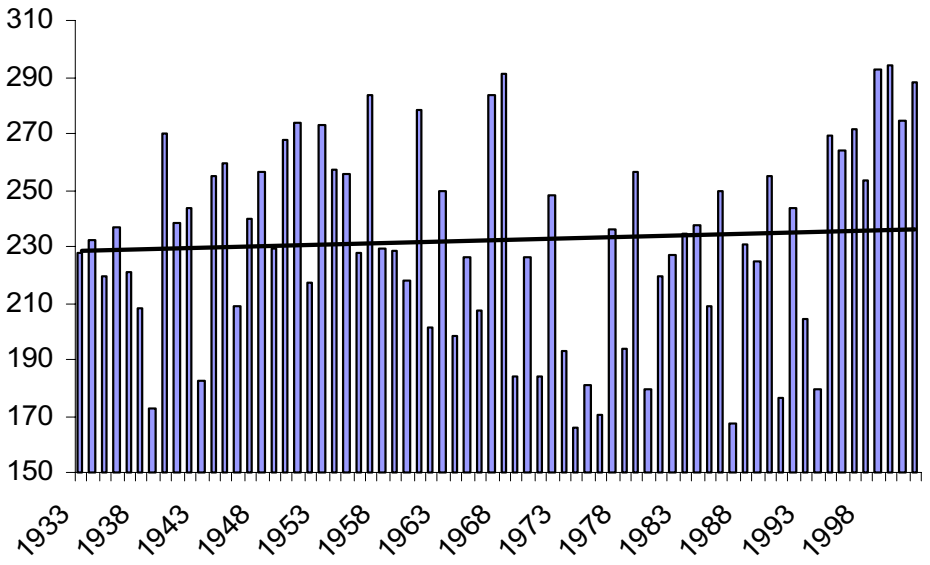


Figure 28: Trends in the annual mean watershed rainfall (3 stations) in the Ruvu River basin 1933 - 2002 (68 years period)

6.0 WATER QUALITY

It was observed that water quality is of less concern to both upstream and downstream users compared to quantity. The major concern in water quality is cleanliness and therefore aspects of turbidity or sediment loading especially with large scale users in the food industry and urban water supply authorities though concerns about pathological aspects of water quality such as coliform bacteria and heavy metal contamination seem to be building up. This will likely build up more as environmental and health education and awareness in relation to water resources builds up in the society in the future.

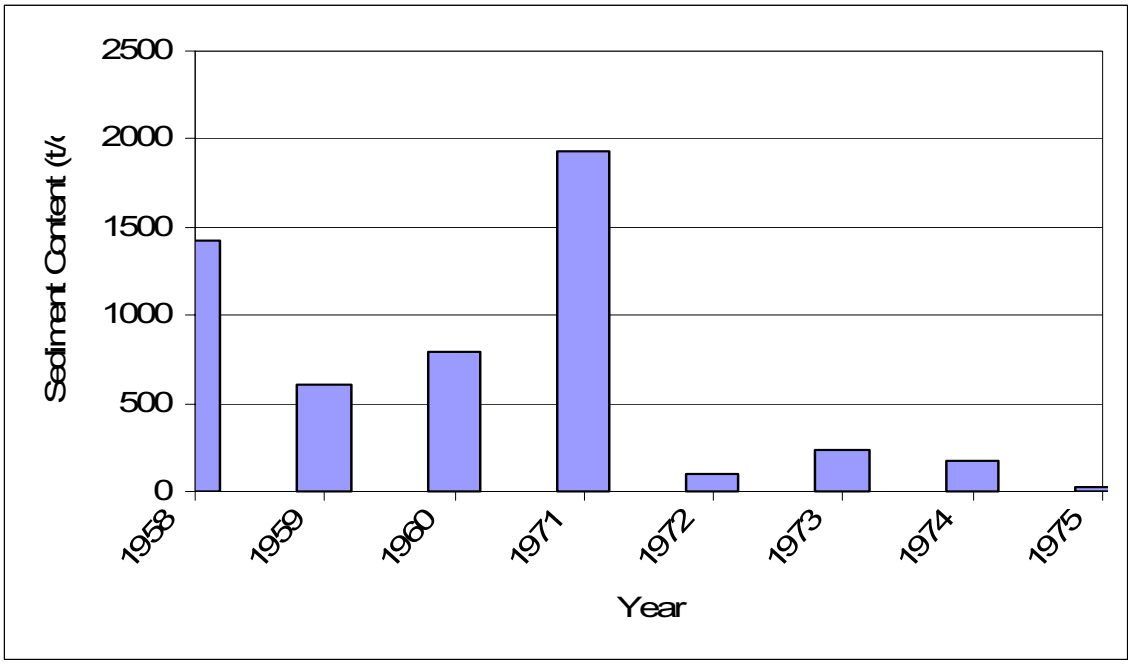
It was learnt that there were no continuous monitoring program for water quality in the two basins thus there is no continuous water quality data available. Some data exists but were only measured at a given location and time on specific request; such data is thus irregular in space and time and therefore has only limited use to reveal spatial or temporal trends (FBD 2005c). However longer time turbidity data series for about 11 years could be obtained for the Ruvu River

Analysis of the 11 year series data set for mean monthly turbidity in the Ruvu River for a period of 11 years (January 1992 – November 2002) show that water turbidity in the Ruvu River increased from 130 Nephelometric Turbidity Units (NTU) in 1992 to 185 NTU in 2002. This is an increase in turbidity in the river of 5 NTU per year reflecting increases in sediment loading into the river over the same time. Such trends of increasing water turbidity are associated with vegetation degradation which result into erosion and higher sediment delivery into the streams.

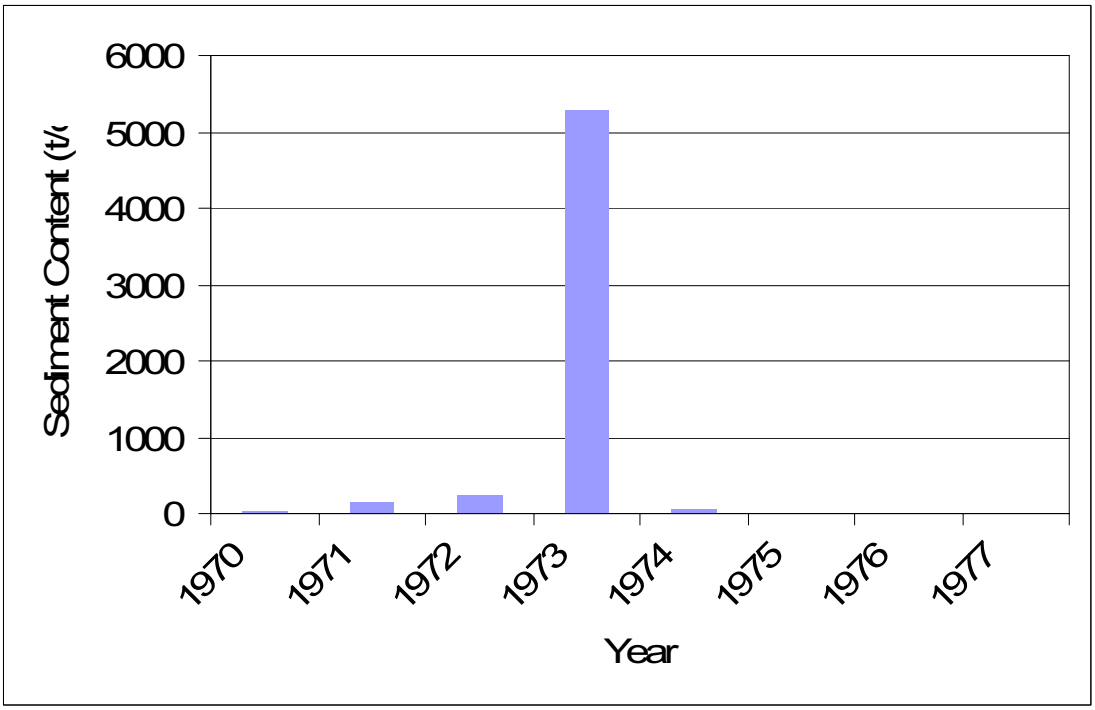
The shorter time periods of available water quality data, the trends of average daily sediment load shows an increase in sediment loading in the Ruvu River up to early 1970s after which there was a decrease in sediment loading. The Sigi River shows the same trend in turbidity which is an indication of increase in sediment loading into the river up to the early 1970s. The increase in sediment loading during this period may be attributed to higher rates of reduction in vegetation cover. Land use/cover change analysis has indicated that there was a higher rate of decrease in vegetation cover during the early 1970s (FBD 2005a). This may have resulted into high erosion rates and hence higher rate of sediment delivery into the streams of the Ruvu river basin. The rate of depletion of vegetation cover after the early 1970s was lower and hence possible decreases in sediment loading into the river. It would however be necessary to obtain longer data sets to make concrete conclusive arguments.

Discussions with local informants also indicated that there has been an increase in sediment loading into streams which they attribute to unsustainable agriculture practices involving vegetation clearing. Majority of the respondents during the discussions expressed their concern that water in streams is becoming more dirty especially during the rain season and that sedimentation in rivers has become so high that most of the rivers are changing their courses. Another indication of this sedimentation process from the local people views is that the level of water from bridges that were once seen to be deep is now very close to the bridge which is an indication of increasing sediments into the rivers. Further more sedimentation into rivers causes water to spread large areas thus causing the rivers to be shallow and widen. Majority of the respondents also observed that floods are more frequent

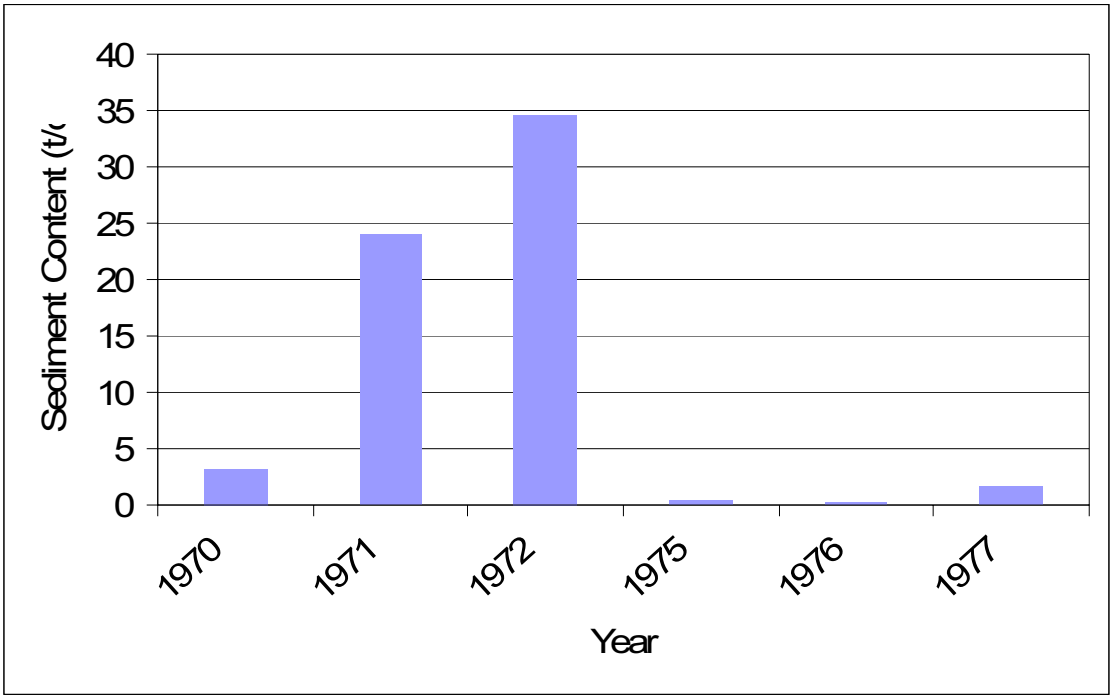
which can be attributed to high rates of runoff but also shallow rivers and large volumes of sediments during the rain season



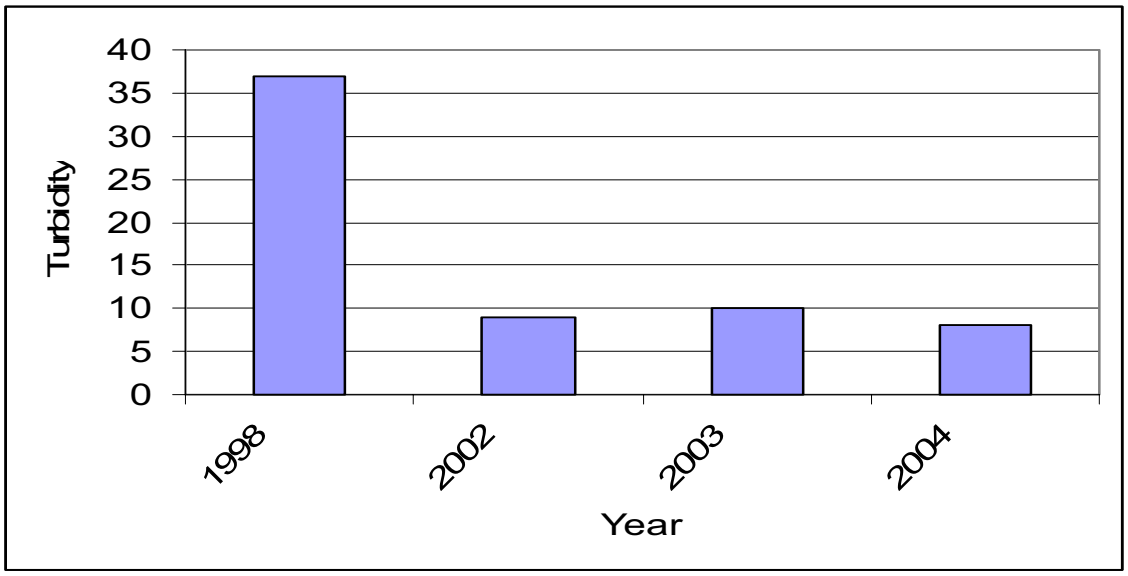
29 (a): Sediment load in the Ruvu River at Morogoro Road Bridge (Source: FBD 2005c)



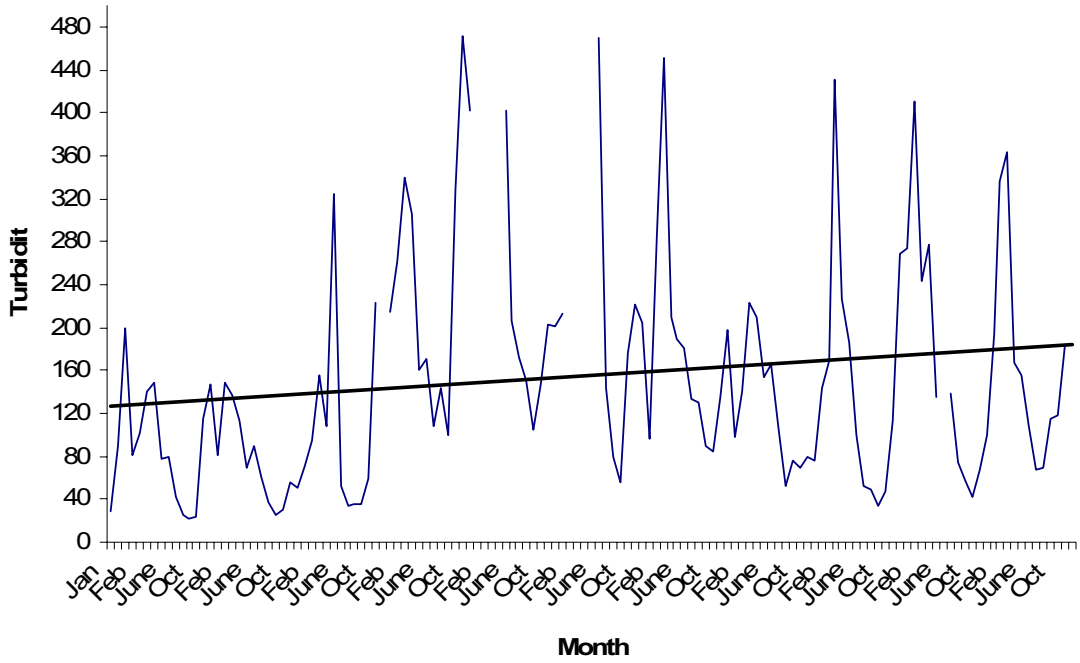
29(b): Sediment Load - Ruvu River at Mikula (Source: FBD 2005c)



29(c): Sediment load - Ruvu River at Mgude (Source: FBD 2005c)



29(d): Turbidity – Sigi River 1998 – 2004 (Source: FBD 2005c)



29(e) Mean Monthly Turbidity Trend in the Ruvu River - 1992 - 2002

7.0 RELATIONSHIP BETWEEN RIVER FLOWS, LAND USE/COVER AND RAINFALL VARIABILITY

The changes of annual flow volumes in most cases are related to changes in rainfall amounts, water use patterns and evaporation patterns from one year to the other. On the other hand changes within the year (seasonal changes) can be linked to depleted vegetation cover. River discharge characteristics reflect either catchment condition or seasonal rainfall patterns. Trends in river discharge therefore reflect either temporal change in catchment condition (Munishi and Temu 1993; Munishi 1994, Yanda and Shishira 1999), temporal change in the amount of rainfall in the catchments and may also reflect spatial changes in the catchment conditions.

The relationship between rainfall and flow volumes in the two basins is presented in Figure 30. There is a good linear relationship between rainfall and runoff in both basins. However based on the coefficient of correlation the relationship in the Ruvu basin is not so clear and is non significant. This reflects changes in flow related to land use hence impacts of land use change on flow. Non linearity between rainfall and flow normally reflects a catchment disturbance if other factors such as abstractions are insignificant. It was observed that abstractions in the basins are minimal thus insignificant in influencing flows in the basin.

Figure 31 presents the double mass curve analysis that portrays the relationship between watershed rainfall and run off volumes from a catchment. Essentially the relationship should be linear if the watershed properties related to runoff have not been changed. Any degradation in the catchment will create imbalances in the flow and the curve will deviate from a linear relationship. Greater disturbances in the catchment will induce more deviation from the linear curve. Though the curves for the two basins should be interpreted independently the curve for the Ruvu river basin (Figure 29b) displays more persistent deviations implying more disturbances in its catchments compared to the Sigi River basin.

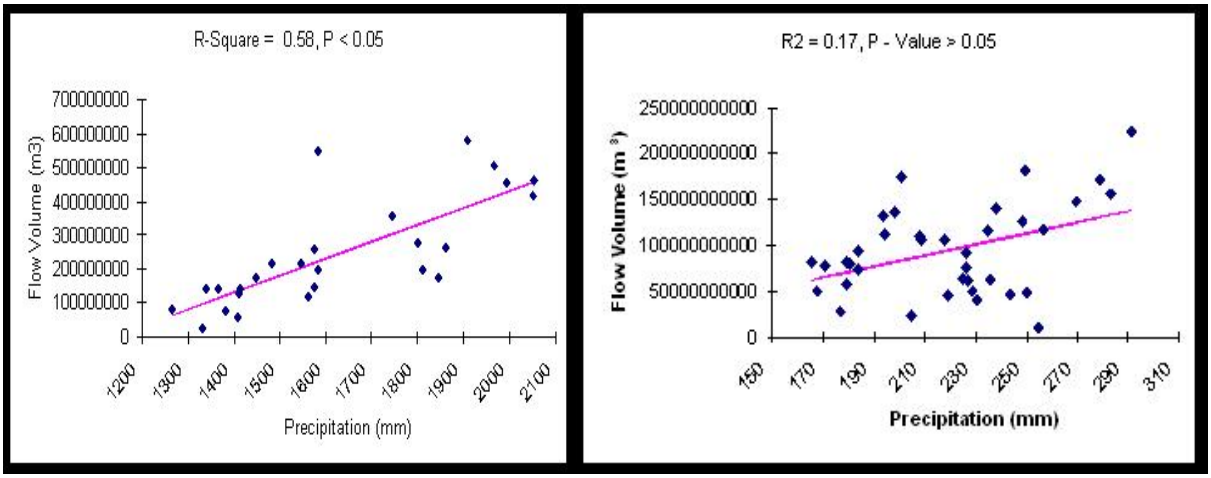
An analysis of trends in river flow in the catchments showed a generally decreasing trend especially in the dry season flows. Further analysis of trends in rainfall showed that the average watershed rainfall remained either relatively constant or had a slight increase though non significant. Principally constant or increasing rainfall trends should be reflected in flows as increasing patterns especially dry season flow if the catchment potential for moisture storage is adequate.

The relationships portrayed between rainfall and flow and the trends in flow observed indicate a low capacity to store moisture in all basins a characteristic displayed by degraded catchments especially those deprived of vegetation cover over time. This would therefore mean that the basin catchments have been deprived of vegetation over time resulting into poor moisture storage and hence distorting the relationship between rainfall and flow and decreasing dry season flows.

Analysis of land use/cover change in both watersheds showed that there has been a high rate of changes in land cover from higher forms (natural vegetation) to lower forms (farmlands, mixed cropping or bare land) land cover inferring vegetation degradation in the catchments.

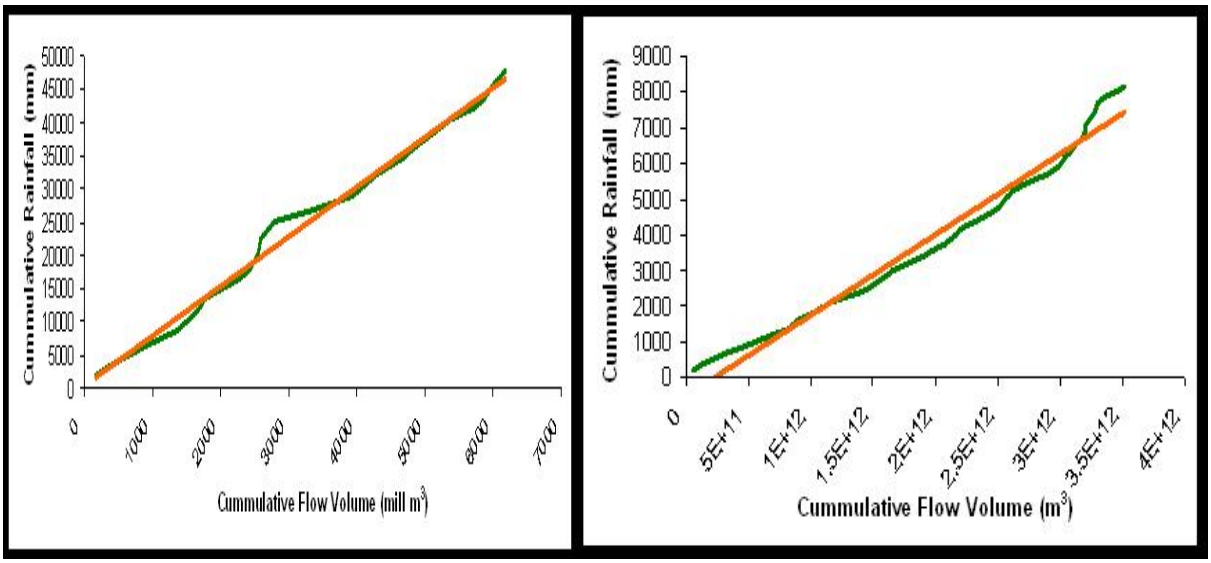
In the Sigi river sub catchment greater vegetation degradation occurred along the main Sigi sub catchment resulting from expansion of tea estates and small scale agriculture and settlements followed by the Kihuhwi river sub catchment as a result of establishment and expansion of sisal plantations with subsequent increase in human settlements. The growth of tea over time resulted into increase in cover again subsequently dampening the impacts on flow that may have been induced by the catchment disturbances. In the Ruvu river basin major declines in vegetation cover have occurred in the main Ruvu (Kibungo) sub catchment (Kinole Ward) (Mbezi, Mvuha, Mmanga, and Mvizigo streams) followed by Mgeta river sub catchment (main Mgeta, Mbakana and Mzinga streams) all resulting from expansion of small holder agriculture into marginal lands and Ngerengere sub catchment (Morogoro and Mzinga streams) resulting mainly from expansion of small holder agriculture in the upper catchments and sisal plantations in the middle catchment.

Logically the decreasing flows in the rivers can to a great part be related to disturbances in the catchments especially cover degradation given the fact that rainfall trends have been relatively constant as observed in the rainfall trend analyses. In the east Usambara (Sigi River Basin) the flow trends are not well pronounced and this may be associated with the type of cover which was observed to be more of perennial crops (that still provide some good cover) such as tea, more integration of trees in crop lands (agroforestry/mixed cropping) and more conservation initiatives compared to the Ruvu River Basin in the Ulugurus. In the Uluguru most of the crops are annual and do not provide adequate soil cover impacting more severely on flows. Among the sub catchments of the Ruvu river basin this situation is more pronounced in the main Ruvu (Kibungo) sub catchment and Mgeta River sub catchment.



(a) **(b)**

Figure 30: The Relationship Between Flow and Rainfall in the Ruvu and Sigi River Basins (a) Sigi River Basin (b) Ruvu River Basin



(a) **(b)**

Figure 31: Double mass Curve Analysis Showing the Relationship Between Rainfall and Flow Volumes in the Ruvu and Sigi River Basin (a) Sigi River Basin (b) Ruvu River Basin

8.0 THE SCALE OF INTERVENTION AND PRIORITY SUB-CATCHMENTS

Based on the land cover/use change analysis there has been a high rate of land degradation in the main Sigi sub catchment especially the northern most and central parts through land use transformations from higher forms that provide good soil cover (natural vegetation) to lower forms of land use (croplands and settlements) encroaching into stream banks and stream bottoms. The lower part of the basin has also been transformed with settlements and crop lands extending into the river valleys where there is adequate moisture. In the central parts however there is transformation into mixed cropland with trees/perennial crops which are relatively better in providing cover. A recent activity that threatens especially water quality is the gold mining in the upper catchments (Sakale village) of the basin that degrades forest cover and makes the area susceptible to soil erosion with implications on water quality. The Kihuhwi river sub catchment is also threatened by increasing land degradation that resulted from establishment of sisal plantations and consequent increase in human settlements. Small scale agriculture expansion is rampant in both the Sigi main, the Kihuhwi and Muzi sub catchments. Of particular significance within the Muzi sub catchment is the Derema corridor with streams like Miembeni/Semdoe, which feed into the Muzi river. This area also has a problem of mining.

In the Ruvu basin all the three sub catchments are highly degraded. The Ngerengere sub catchment on the western and north western side is characterized by transformation to non cover annual crops and steep slope cultivation which leave the soil bare most of the year with adverse impacts on water flow and quality. The same case is observed in the other sub catchments of Mgeta river and the main Ruvu river and Kibungo sub catchment where shifting cultivation is rampant with cultivation of annual crops and encroachment into steep slopes and river banks without any conservation measures .

Priority Sub Catchments

Priority sub catchments are considered to be those that will deliver more positive impact to the hydrology of the rivers given a particular intervention. Interventions taken in highly degraded sub catchments are likely to deliver more in terms of runoff than less degraded watersheds.
The criteria for selecting priority sub catchments are set here forth to be

- Trends in land use/cover change i.e. the extent and rate of change from natural forest/woodland (higher forms of cover/use) to cultivated/bare land (lower forms of cover/use),
- Seriousness and extent of degradation,
- The area of sub catchment and the proportional contribution to flow volumes into the basin
- Historical trends in flow in different seasons
- Existing conservation measures
- Activities with potential influence on water quantity and quality
- Extent of population pressure (historical/potential)

The different sub catchments as influenced by these criteria are shown in table 7.1

Table 7.1 Criteria for Selection of Priority Sub Catchments for interventions in the Sigi and Ruvu

Criteria	Sub Catchment			
	Ruvu Basin			
	Main Ruvu (Kibungo)	Mgeta	Ngerengere	Main Sigi
Trends in Land use/cover change	Decrease	Decrease	Decrease	Decrease
Extent of degradation	High	High	High	High
Contribution to basin flow	High	Medium	Low	High
Flow Trends	Decreasing	Slight Increase	Slight increase	Slight decrease
Conservation Measures	Limited	Some Terracing	Limited	Some agroforestry, Tree intercropping, perennial crops
Activities with negative impact on water quantity and quality	Small scale agriculture, Agrochemicals, Mining	Small scale Agriculture, Agrochemicals, Irrigation	Small scale Agriculture, agrochemicals	Small scale Agriculture, agrochemicals, mining
Population Pressure (historical/potential)	High	High	Medium	High

The Sigi River Basin

The main Sigi river sub catchment has experienced high rates of cover reduction and land degradation and contributes more flow into the basin though flow trend are observed to decrease slightly. Some conservation measures like agroforestry and more planting of perennial crops were observed (Table 7.1). It is proposed that this sub catchment be given the first priority for interventions. The sub catchment is composed of streams like Dondwe, Kwekuyu and Hange. Among the villages to be included are Sakale, Msasa, Sangalawe, Chambageda and Mlesa.

The second priority would be the Kihuhwi river sub catchment (Bombwera Division) where expansion of sisal plantations with subsequent expansion of human settlements is of concern and the rate of land degradation is high and its contribution to flow into the basin is relatively high. The Muzi river sub catchment (Amani Division) contributes less to flow in the basin and the major concern here include increasing land degradation pressure as a result of population increase and land use changes related to expansion of small scale agriculture and mining. In relation to water quality aspects of gold mining are important to consider given the current and possible future forest degradation that may result from gold mining.

Information from focus group discussions had the opinion that if the trends of land use/cover change so continues, sooner or latter there will be no forests remaining in the mountains. Therefore they concluded that current land use practices are not desirable because they are accelerating land cover shrinkage though there is a need to deal with all the driving factors behind these changes to reverse the situation and restore the status of these watersheds. This warrants the need for conservation interventions at least in the priority sub catchments

Intervention activities for the above mentioned areas include:

- Management of riparian ecosystems will be of particular importance given the extensive use of these ecosystems resulting from population pressure and land scarcity. Establishment of riparian buffer vegetation using appropriate plant species will increase infiltration and water storage in the catchment and reduce sediment loading in the river and other pollutants such as fertilizer, pesticide and herbicide residues.

- Biological conservation measures such agroforestry using perennial crops. More focus should be paid to practices already in place. For example some community members along the main Sigi sub catchment are already practicing agroforestry by intercropping trees with perennial crops.

- Natural forest management and conservation need to be part and parcel of the interventions to include restoration of the Derema corridor already initiated by the Amani Nature Reserve (see figures 4 – 6). Among the activities related this intervention include prevention of illegal logging, reduction of forest reserve encroachment and restoration of degraded forests through enrichment planting and/or natural regeneration using appropriate techniques

The Ruvu river Basin

On the part of the Ruvu River basin there is severe land degradation in each of the sub catchments assessed [main Ruvu (Kibungo), Ngerengere, and Mgeta]. However based on hydrologic assessment it seems that the main Ruvu (Kibungo) sub catchment drains a bigger part of the basin and contributes more flow into the basin (see table 2.1), is relatively more degraded with agricultural activities that have high potential for further degradation thus more impact on flow downstream. Unsustainable agricultural practices are rampant in this sub catchment including shifting cultivation/slash and burn agriculture as a result of declining soil fertility. Existing conservation measures are limited in this part of the basin. This area also has a potential for production of perennial crops such as coffee as a cash crop for improved livelihood and better soil cover. Further there is extensive land fragmentation which involves ownership of more than one small pieces of land in different locations due to land scarcity. Land fragmentation partly discourages proper land management due to limited resources to invest in all the small pieces of land (economies of scale). Use of agrochemicals and mining threatens water quality downstream. Based on the severity of land degradation in the area we propose that the Kibungo sub catchment (Kibungo Ward) that comprises the villages of Kibungo Juu, Dimilo, Lanzi, and Nyingwa to be the priority sub catchment that will likely produce the desired impact on flow downstream.

The Mgeta sub catchment shows slight decreasing trend though it contributes less flow volume into the basin. Its catchment is extensively used for agriculture which extends into fragile steep slopes and riparian ecosystems. However some terracing as conservation measure is practiced though not adequate. Agroforestry, terracing conservation awareness and alternative income generation interventions are likely to improve the conservation status of this sub catchment. The Ngerengere sub catchment has experienced high rates of decrease in cover. The flow shows a slightly increasing trend though it contributes low flow volumes into the basin. Conservation measures are limited and the catchment faces further degradation from unsustainable small scale agriculture and use of agrochemicals in some part of its catchment.

Information from focus group discussions had the opinion that if the trends of land use/cover change so continues, sooner or latter there will be no forests remaining in the mountains. Therefore they concluded that current land use practices are not desirable because they are accelerating land cover shrinkage though there is a need to deal with all the driving factors behind these changes to reverse the situation and restore the status of these watersheds. This warrants the need for conservation interventions at least in the priority sub catchments.

All these observations on the ongoing land degradation through vegetation removal for cultivation in the upper catchments and consequences on water quality and quality are enhanced by governance in natural resources management including forests. Since colonial period to present forests reserves were directly managed by the government and local communities did not see direct benefits from forests. As a result, local communities expanded their farmland into forests reserves because it was productive due to accumulation of organic matter for long time. Such processes were left uncontrolled because of the weak management of the government due to a number of reasons including inadequacy of personnel. However, recent approaches

of involving local communities in the management of forest reserves might enhance catchment conservation.

It is also noted that a catchment is sub-divided into more than one administrative unit. In some cases, upper catchment area may fall under one administrative unit and the lower catchment area may fall under another administrative unit (village or ward). In such a situation, integrated catchment management becomes difficult because each administrative unit plans independently, hence activities in the upper catchment area are likely to affect communities in the lower catchment area (Yanda and Ngana, 2006).

The intervention activities recommended include:

- Integrated approach in catchment management should be enhanced to ensure that activities in the upper catchment areas do not affect communities downstream. For example, villages in the catchments should have joint management plan that takes into account interest of all stakeholders in the basin.
- Biological conservation measures such agroforestry using perennial crops. More focus will be paid to practices already in place. For example some community members in Mgeta sub catchment are already practicing terracing and agroforestry
- Management of riparian ecosystems – establishment of riparian buffer vegetation filters using appropriate plant species. The width of the buffer vegetation strip should be based on existing regulations e.g. land, water and forestry acts
- Awareness raising on conservation issues especially on watershed management techniques
- Alternative income generation interventions that would reduce pressure on fragile ecosystems

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