UNIVERSITY OF DAR ES SALAAM
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MILESTONE 1.5

TECHNICAL REPORT ON CLIMATE CHANGE LINKAGES AND IMPACTS IN THE MEDIUM TERM

A REPORT SUBMITTED TO USAID TANZANIA
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LIST OF ABBREVIATIONS AND ACRONYMS

CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
DSSAT	Decision Support System for Agrotechnology Transfer
GCeM.	Global Circulation Model
IPCC	Intergovernmental Panel on Climate Change
IRA	Institute of Resource Assessment
NAPA	National Adaptation Program of Action
RCM	Regional Circulation Model
SWAT	Soil and Water Assessment Tool
URT	United Republic of Tanzania
USAID	United States Agency for International Development

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CHAPTER ONE

INTRODUCTION

This report analyses the inter-linkages between the historical and current water management practices, land use change and climate variability in the Rufiji Basin. It provides climate projections into the future of the target districts to determine the overall climate change impacts on water availability (currently and in the future) at catchment and basin levels, soil fertility and on crop yield. The analysis on the inter-linkages is based on existing stream flow, rainfall and temperature data, land use change data, crop area models, calibrated crop and hydrological models and downscaled Global Circulation Model (GCeM) for the Rufiji Basin.

1.1 Objectives

The general objective of this milestone is to analyze the inter-linkages between historical and current water management practices, land use change and climate variability. Specifically the milestone report is designed to:

i. Understand the historical and current water management practices in the Rufiji Basin,

ii. Analyse the historical climate trends (rainfall and temperature) in the past 30 years and provide climate projections into the future of the target districts in the Rufiji Basin,

iii. Analyse the land use/cover and the implication of land use change on water availability (currently and in the future) at the catchment and basin levels,

iv. Determine the historical climate trends and impacts on water availability (currently and in the future) at the catchment and basin levels, and,

v. Analyse the implication of historical and current water management practices on soil fertility and crop yield.

1.2 Scope of the Report

This report presents the historical and current water management practices in the Rufiji Basin; and modeling and statistical analysis results that examine the impact of climate change and variability on rice and maize productivity, and on water availability for crop irrigation. It is based on bringing together datasets from several different sources, and coupling three model types. This report incorporates other information provided in other project reports.

Generally this report is dived into seven chapters. This first chapter is followed by chapter two that provides a description on the historical and the current water management practices in the Rufiji Basin. Chapter 3 provides an analysis of the projected future temperature and precipitation maps for Basin based on recent global climate models, while chapter 4 presents preliminary findings from the hydrological modeling on the effects of climate and land use on stream flow.

Chapter 5 present hydrological modeling of Kilombero and Kilosa sub-catchments. Chapter 6 presents results of the impact of recent climate variability and projected future climate change on rice and maize productivity, and how fertilizer affects crop response. Lastly, Chapter 7 presents conclusions and next steps.

CHAPTER TWO

HISTORICAL AND CURRENT WATER MANAGEMENT PRACTICES IN THE RUFIJI RIVER BASIN

2.1 Introduction

This chapter provides highlights on the historical and current water management practices in the Rufiji River Basin (RRB) in relation to rice and maize production, particularly drawing experiences from Kilosa and Kilombero districts, in Morogoro Region. Information on historical and current water management practices will contribute to the recommendations of practical climate change adaptation strategies and interventions that will also take into account both land use and water management strategies in the RRB.

2.1 Methodology

Data for the analysis of historical and current water management practices were collected through focus group discussions, key informant interviews and complemented by desk studies on the respective themes. Focus group discussions were conducted with selected members of village water committees, environmental committees, water users' associations, farmers and agriculture extension officers in all four villages where the project is implemented. The project villages are Kisanga and Malolo B in Kilosa District, and Kisawasawa and Mang'ula A in Kilombero District (Appendix 1). On the other hand, key informants interviews were conducted with the Rufiji Water Basin officers, District Agricultural Extension Officers, Crop Officers, and Forestry Officers; as well as environmental NGOs working in the project districts (Appendix 2).

2.2 Results

2.2.1 The Rufiji River Basin in Context

The Rufiji River Basin (RRB) has been extensively described as the largest river basin in Tanzania covering an area of about 183,791 km^2 which is equivalent to 20% of the total area of Tanzania and East Africa (URT, 2006). Geographically, the basin is located between latitudes 5°35′ and 10°45′ South and longitudes 33°55′ and 39°25′ East (URT, 2006; Sokile *et al.,* 2005; and Sokile *et al.,* 2003).

The RRB receives annual rainfall of about 600mm to above 1400mm in dry lowland and mountainous areas, respectively. Two major rivers drain the basin, the Great Ruaha River (GRR) and the Kilombero River. The GRR is the principal tributary of Rufiji and drains nearly 50 % of the total Rufiji basin area. The river originates from a number of large and small streams in the northern slopes of the Poroto and Kipengere mountains in the Southern Highlands between Mbeya and Iringa regions. It flows to the Usangu plain where several other rivers flowing from the highlands join it. The rivers include Mbarali, Kimani Chimala and Madibira whereas the small ones include Umrobo, Mkoji, Lunwa, Mlomboji, Ipagatwa, Mambi and Mswiswi rivers.

In the Usangu plains, the GRR supply water to about 40,000ha of large and smallholder rice irrigated farms in the flood plains during the rainy season and more than 2,500ha of smallholder dry season irrigated crops in the upper reaches of the flood plains. From the flood plains the rivers recollects into a number of seasonal and permanent wetlands forming a perennial wetland at Ihefu. The rivers emerge through a rock outcrop into a single channel which flows into the Ruaha National Park (RNP) providing the main water source to the park.

As the GRR flows down, it is joined by Little Ruaha River before being joined by the Kisigo River and then it flows into the Mtera reservoir (3,200km2 surface area), which has installed HEP capacity of 80MW and is used to regulate water supply downstream to Kidatu hydropower station. As the river flows downstream the Mtera dam, on the way it is joined by the Lukosi and Yovi rivers before flowing westward to the Kidatu reservoir (1km^2 surface area), with installed HEP capacity of 204MW. From Kidatu dam the river flows to the Kilombero plains.

The Kilombero River originates from three main tributaries; i.e. the Ruhudji, Mpanga and Kihansi Rivers, before joining the Luwegu River to form the Rufiji River, just above the greatest HEP potential of Steigler's gorge, collecting *en route* the Kitete and Sanje rivers into the Indian Ocean (Sokile and Mwaluvanda, 2005).

2.2.2 Evolution of Water Management Policy in Tanzania

During the pre-colonial days the water resources were governed by the set of dynamic, change-sensitive and community-based traditional resource management initiatives (Sokile *et al,* 2003) based on riparian user rights. These rights provided a potential for adaptive change to the present water management efforts, given a well-designed institutional framework.

According to Sokile *et al*, (2003) the coming of the colonialists did not immediately deter the traditional water management arrangements. It was up to early 1900s when the demand for water started increasing along with the goals of the colonial economy. The 1923 Water Ordinance marked the start of the Statutory Water Law in the then Tanganyika. Water by-laws to oversee water management were for the first time mooted in 1926 basically in favour of colonialist water users.

At the local level, agriculturists were somewhat favored as compared to pastoralists. It is basically in the light of this agriculture-pastoralism hangover that many commentators have rhetorically perpetuated the view that livestock are a menace to water management in the Usangu Plains (Sokile *et al,* 2003).

The demise of colonial rule in 1961 did not, however, signify changes in the state policies. In 1967 the Arusha Declaration gave Tanzania a socialistic economy that discouraged private ownership of natural resources and insisted on the collective ownership of resources. The first steps taken were to create a policy framework incorporating natural resource management into the broader national framework of sustainable social and economic development that required a collective resource use and ownership (Sokile *et al,* 2003).

The government through the Ministry of Water started the management of water under the River Basin approach. Early in 1995 a comprehensive review of Tanzania's water resources policies and institutions was carried out by the Government of Tanzania, World Bank and DANIDA. The following year an inter-ministerial project, entitled River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP) was launched. The RBM component was hosted by the ministry responsible for water, while the SIIP component was lodged with the Ministry of Agriculture (Sokile *et al,* 2005; Lankford *et al.,* 2004).

Comprehensive water management legislation has since been developed in the country under the river basin approach. This has been facilitated by the enactment of the Water Resources Management Act of 2009 which controls protection of water sources, water development, and its quality and use. The Act differs from the previous versions in a number of ways, including regulations on water extraction, distribution, management participation and designation of water reserves. The historical development of water management in the Rufiji River Basin is illustrated in Box 1 below.

Box 1: Historical Water management in Rufiji River Basin
1967—Abolition of water user fee
1971—Launching of 20-year rural water supply program
Development of Water Utilization (Control and Regulation) Act No. 42
1972—Abolition of local governments
1974—Introduction of Water Utilization Act (control and regulation)
1975—Separation of Water Department and Irrigation Department
1981—Amendments of Water Utilization(Control and Regulation) Act No. 10
1981—Designation of Tanzania into 9 Water Basins
1991—Launching of National Water Policy
1991—Establishment of Rufiji Basin Water Board
1992 —Establishment of Rufiji River Basin Office
1994—Review of water user fee structure
1995—World Bank Appraisal
1996—Start of RBM/SIIP
1999—Draft New National Water Policy
2001—Merge Ministry of Water with Livestock
2002 Launching of the National Water Policy (Revised)
2009 Enactment of the Water Resources Management Act, 2009

Source: (Modified from Sokile *et al.,* 2003)

2.2.3 Current Water Resources Management in Tanzania and the Rufiji River Basin

Water management in Tanzania is hierarchical. It stretches from the national level, basin level, catchment level, district level and, finally, the local community or water users associations (WUAs) level.

2.2.3.1 National level

Water resources management and development is governed by the National Water Policy (NAWAPO) of 2002. The policy is the overall national level instrument for overseeing water resources management and development in collaboration with other related ministerial policies, Acts, strategies and programmes. It embodies the value of water resources under the changing climate and other macro policy targets such as the attainment of sustainable development in the context of integrated resources management and stakeholders' participation (URT, 2002; 2006).

The current structure of water resource management was first proposed and established in the new National Water Policy (2002) which have since also been translated into two separate legislations: the Water Resources Management Act of 2009 (No.11) and the Water Supply and Sanitation Act of 2009 (No.12)

In general, the Ministry of Water formulates and reviews policy as well as developing water management strategies and ensuring their execution by respective authorities under its control. The Ministry is also responsible for implementation of the Water Resources Management Act, coordination, planning and preparation of basin plans.

2.2.3.2 Basin level

The National Water Policy (2002) exemplifies that water basins are the planning and management units. This corresponds to the principles of decentralization and devolution of water supply management to the lowest appropriate level. Prior to this policy, the Water Sector had suffered from uncoordinated strategies and programmes that often resulted in unsustainable water utilization, threats to past investments in costly infrastructure, and, ultimately, unsatisfactory services (URT, 2002; 2006). The National Water Sector Development Strategy further develops the Policy aspiration and defines an implementation framework (URT, 2006).

The current approaches for water resources management at basin level has evolved overtime. After the 1981 amendment of the Water Utilization (Control and Regulation) Act No. 42, the responsibility of water management in Tanzania was devolved to the basin level, whereby the Rufiji Basin became one of the nine water basins in Tanzania. Since then, the Basin Water Boards (BWBs) became important water management and pollution control mechanisms. BWBs were, before the 1981 amendment of Water Utilization (Control and Regulation) Act 1974 known as Regional Water Advisory Boards (Maganga, 2003).[1]

BWBs are expected to advise and assist the Government, public authorities and other persons or bodies of people' measures for the more efficient control or prevention of water pollution. They are also supposed to recommend to the Minister responsible for Water Development legislative measures necessary/suitable for the effective control of water pollution and formulate effluent and receiving water standards, and programmes for ensuring compliance by domestic, commercial, industrial and other users of water.

As far as the Rufiji Basin Water Office (RBWO) which became operational in 1993 is responsible to oversee all matters concerning development, management and regulation of water resources in the Rufiji River Basin. Other functions are monitoring the available water resources in the basin using existing hydrometric network stations and installation of new ones where necessary.

The RBWO is also responsible for regulating the existing and issuing of new water right permits for water abstractions; issuing, administering and collecting the water abstraction fees associated with the issued water rights; mediating and resolving water conflicts within the basin; and conducting research in collaboration with research partners in the basin water resources.

Discussion with the Rufiji Basin Water Officers indicated that they are responsible for advising the Rufiji Basin Water Board (RBWB), which comprises of 11 members with a representation among others of farmer, private sector including NGOs. According to the interview with the Basin Water officers, the Basin Board is empowered to formulate and

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[1] A ''Water Basin'' is defined as any area of land delimited and declared by the Minister under Section 7 of the Water Utilization (Control and Regulation) Act 2009 to be a Water Basin in relation to any river or other water source. BWBs are supposed to be established in respect of each Water basin declared by the Minister—and for each BWB, the Minister responsible for water development matters appoints not less than seven nor more than 10 persons to be members of that BWB.

recommend to the Government comprehensive plans for the regulation of the discharge of effluents by industrial, trade and other categories of users of water. Also, the Board members formulate and recommend to the Minister the best ways of ensuring compliance with, uniform procedure for the sampling and examination of water sewage and industrial effluent, designating units for expressing results (URT, 2002).

The Board is likewise responsible for suggesting regulations under the power vested to the Minister for Water Development. Apart from RBWO and RBWB, it was also mentioned that, water management in the RRB involves a number of stakeholders from different sectors; including villagers, agriculturalists (large scale and small scale), livestock keepers, hydroelectric power producers, conservationists, manufacturers and fishermen.

Decentralization in water management and stakeholders' participation in managing it is one of the major policy shifts in this sector. According to the interview with Basin Officers, the formation and participation of water user associations (WUA)[2], for example, have been very instrumental in conserving water resources, development of local water resources and collection of water fees for the basin office.

The Basin Officers indicated that in order to facilitate decentralization of water resources and simplify its management, the RRB has now been partitioned into four sub-basins, i.e. the Ruaha, Kilombero, Rufiji and Luwegu river sub-basins. The delineation of sub-basins has brought different stakeholders closer than ever before in the management of water resources in the basin. As a result of this move, water is managed efficiently and effectively because environmental degradation is kept in check and natural resources use conflicts related to water use are easily solved.

Generally, it was pointed out that; water resources management in the Rufiji River Basin is, however; also legally a responsibility of two bodies: the River Basin Water Board and the Rufiji Basin Development Authority (RUBADA). The two bodies have the same responsibility in the same area of operation.

Although district, ward and village councils may deliberate on issues decisions that affect water resources management, a specific mandate for this lies within the Rufiji Basin Water

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[2] Water user associations are the last/smallest authorities in the country's water resources management hierarchy. These are legal registered local groups of water users registered by the ministry of water via their respective river basins.

Office in Iringa. The RBWO coordinates water management through Water User Associations (WUAs) and village committees in case where there are no WUAs. But, there is no specific provision for taking on board the local and customary views into the formal councils and committees (Sokile *et al.*, 2005). Occasionally, however, the basin office has used informal community leaders in implementing some of the water management activities, especially in resolving water conflicts.

2.2.3.3 Catchment level

Key informants indicated that water resources management are mainly undertaken by Catchment and sub-catchment committees including, Wards Councilors, Water User Associations (WUAs). The committees are mainly responsible for development of water management plans and water conflict resolution at the catchment level. Catchment links the basin to the lower level of water management. It is managed by the catchment committee and sub-catchment water committee with representation from private and public sectors as well as WUAs (URT, 2002).

Field survey findings indicated that Wards Councilors have major roles in the planning and management of water resources despite the fact that they are not explicitly mentioned in the tiers of governance structure for water resources. It was mentioned by respondents that the Wards Councilors frequently pass by-laws that impact on sanctions and penalties that seek to guide water allocation and quality. As reported by key informants, Ward Councilors participate in the District Councils meetings, where among other key roles, they discuss water management plans and/or approve by-laws for the management of water resources (URT, 2002). The Ward Councilors' are also very influential in the villages and in water resource management, since they represent the community members who elected them into power in the District Council.

In addition, the respondents indicated that owing to their electorate, councilors, seeking to please their voters tend to be more informal and highly interact with informal institutions, which influence water management. Similarly, Sokile *et al.* (2005) show, for example, how Councilors in the lower zones of the Mkoji sub-catchment have reportedly mobilized downstream water users for negotiating for water upstream, mobilized funds for domestic water supply, pushed by-laws for water management at the District Council, and mobilized communities towards the formation of WUAs.

On different note, during field surveys, most of the respondents had no immediate answers on the plans of communities or institutions in mitigating or adapting to the future climate conditions. Most of the respondents indicated that there is no strategies in place to coordinate adaptation activities from the national level to community and individual levels. According to the key informants, at the catchment level, the Great Ruaha Sub-Basin Adaptation Strategy (GRASS) is the most recent instituted policy instrument to address issues of climate change in the RRB.

Mwaruvanda (2014) also reports that the GRASS is constructed in line with the National Climate Change Strategy (2012) and aims at introducing some new techniques in handling water resources management in the basin. Mobilization of funds for the implementation of GRASS the RBWB plans, for example, Recently, the implementation of GRASS and RBWB plans has established agreements with WUAs for water use fee in their respective areas. According to the agreements, 20% of the revenues collected are left with the WUA as retention money.

The Basin Office is also assisting the WUAs to secure grants, loans and other forms of support for various WUA activities, including enforcement on water allocations, water source protection and other activities like tree planting. Other strategies for strengthening capacities of WUAs and mainstreaming climate change adaptation in the basin include building strong foundation of knowledge through education programmes, mainstreaming climate change aspects in planning and implementation of all development plans and continuous assessment of risks and implementation of priority adaptation actions in various sectors within the basin.

2.2.3.4 The district level

Districts were also mentioned to be represented in the basin board as well as in the catchment committees. This level of involvement is responsible for development of water resources management plans in accordance with the basin plans, conservation of natural resources in the wards and villages, by-laws development, as well as water resource conflict resolutions. The district is also responsible for assessing water demands in the district.

A caveat, however, exists in Tanzania, in that two sources of management occur for water resources; the central government and that which is provided by regional government as represented at the district level by the District Water Engineer (DWE). On the other hand there is the RBWO which caters a basin-wide approach cutting across different administrative districts. These two authorities do not always see eye to eye (Lankford *et al.,* 2004).

2.2.3.5 Local level: the village, WUAs and beyond

The lowest tier of formal institutions in Tanzania is the village (Sokile *et al,* 2005). The informal arrangements for water management are more elaborate at the grassroots level. There, formal and informal initiatives for managing water clearly co-exist. Each village has a Village Assembly of all adults, which elects 25 representatives to form the Village Council. The Village Council operates through three mandatory committees, which are vested with responsibilities for handling daily affairs of the village: the Finance, Economic & Planning Committee; the Social Services and Self-Reliance Committee and the Law and Order Committee. Water sub-committees fall under the Social Services and Self-Reliance Committee.

The strength and functioning of the village sub-committees differ from one village to another, and similarly, their specific interventions into water affairs also differ depending on the availability and the levels of demand on the water resource (Sokile *et al,* 2005). In places where irrigation is carried out only in dry season or is not carried out at all the water sub-committees are relatively redundant. There, the informal arrangements through customs, taboos, and traditional rainmakers tend to be more popular and respected (*ibid*).

Conversely, in most sub-basins including the lower GRR sub catchment where both wet and dry season irrigation is highly practiced, there is an active formal WUA, which handles both domestic and irrigation water management. Seemingly, whenever the formal village sub-committees are weak, there is a stronger informal institution that assumes the roles and fills the gap (Sokile *et al,* 2005). The 2002 Water Policy created a novelty in the form of WUAs, which are viewed as important conflict resolution tools and seek to reduce the number of water right holders for effective purpose of coordination of water use.

As summarized in Case study below, field survey findings indicated that registered water users for all purposes in the Basin stood at about 1,154. Out of these, only 661 or 57.3% had active water rights.

Case Study 1

Malolo B is among the villages where WUA has been established and registered as Chama Cha Umwagiliaji Mwega "Chaumwe". Chaumwe reflects the major river source that supply water in the village mainly for domestic uses and farming (irrigation). In the year 2001/2002, the village secured financial support via the district to support construction of a modern irrigation scheme. Upon its accomplishment in 2002, the irrigation scheme had fifteen (15) channels, 9 on the left and 6 on the right. Each irrigation channel formed a group that comprised the Chaumwe.

The association has been useful to the Malolo community in terms of ensuring water use efficiency. To the RBWO such a WUA has been effective and efficient in resolving conflicts and fees collection. However, like the majority of the WUAs, Chaumwe is challenged by poor management skills as it is registered as a cooperative and no trainings were given on governance and management issues. It also faces conflicts of interest with the village government, especially on issues of financial control. This in turn has left a majority of farmers in the village with little trust to the association as it is seen as an RBWO instrument for facilitating its interests of collecting fees (rent seeking) and conserving water, rather than those of the villagers' local development. Another challenge faced by Chaumwe is the high water use fees that ought to be paid by individual irrigator annually. Currently, each farmer within the Chaumwe river contributes 12,000/=Tsh annually where 10,000/=Tsh is paid to the RWBO and 2,000/=Tsh is paid to Chaumwe water board for maintenance of the irrigation structures. Such an amount was claimed to be bigger compared to the volume of water abstracted, especially during the dry season. Apart from that, Chaumwe is also challenged by invasion of farmers in upper stream/water source hence causing water shortages and sedimentation to the lower stream user and canals respectively.

Training WUAs on management issues (Finance, governance, conflict mitigation and resolution etc) including those under cooperatives is therefore necessary. It is also important to provide training on issues water resources management in the context of the changing climate. Likewise, the Water Basin Offices need to work in close collaboration with WUAs at all time through capacity building programs such as managing conflicts.

According to URT (2009), a WUA with a Water Right is obliged like any other Water Right holder to: (a) return water used to the stream or body of water from which it was taken; (b) ensure that water is substantially undiminished in quantity; (c) ensure that water is not polluted with any matter derived from such use by the Associations' Members; and (d) ensure that water used by their respective members is, before its direct discharge into receiving waters, be so treated as to comply with prescribed Effluent and Receiving Water Standards.

Discussion with key informants indicated that WUAs are also required to install water treatment plants to ensure that water returned by the associates after use is of the acceptable standards. Other Water Rights granted to WUAs include the obligation to install at the point of discharge all machinery and other facilities necessary for the taking of samples and the collection and treatment of effluents. WUAs are required, like the other holders of Water Rights to make periodical returns on pollution to their respective Water Officer (Maganga, 2003). WUAs are aware of water user right requirements however because of the economic and technical limitations that they barely adhere to these water user rights requirements. More investments of human, financial, technical and physical resources are required to full exercise these rights and implement their obligation.

The wider scholarly opinion seems to accentuate that WUAs are a long awaited solution to inter-sectoral water management. WUAs are generally seen as having a potential to take over all Water Rights now held by government departments, public corporations, local government authorities, et cetera (*ibid*). However, some observers argue that irrigators, with little or no acknowledgement of other users, dominate WUAs. Many WUAs, for example, do not take into consideration gender dynamics and imbalances, which normally, characterize resource use in Tanzania and in the Sub-Sahara as a whole (Sokile *et al,* 2003). WUAs are, therefore, not necessarily pro-poor, they are normally formed by the high and mid-social groups villagers that can both express themselves and win the support of the equally rigid water right acquisition procedures.

2.2.4 Historical and Current Water Management Practices in the Rufiji River Basin

Soil and water management (SWM) are the most important abiotic entities for sustainable environmental management and agriculture. Sustainability of soil and water resources depend so much on the practices employed to manage and utilize them such as in agriculture and livestock keeping. Of the major focus in this report is water management practices in the RRB.

Water management practices entail a range of issues ranging from actual uses of water drawn and/or harvested from different sources (e.g. swamps, streams, rivers, dams and lakes) and legislative procedures (laws policies and regulations) as well as plans, programmes and strategies governing such water uses.

Because of dynamics involving demographic increase, varying and changing climate, agricultural commercialization, evolving technologies and governance water management practices in the country and in particular the RRB were found to have changed dramatically and therefore comprehensive management strategies that will ensure economic, environment and social health are necessary. Based on such changes in social, climatic, institutional framework and technological aspects current and historical water management practices dating back to thirty years ago in the RRB can be explained in different sectors as follows.

2.2.4.1 Agriculture

Small scale farming dominates Tanzanian agriculture sector which is mainly rain-fed. Alongside that, throughout history traditional irrigation has also been practiced in different parts of the country. But recently farmers have been using improving irrigation schemes constructed by the government with the support of the development partners.

In Kilombero District, for instance, it was revealed that; in the past 30 years and beyond farmers have been using traditional irrigation through /rivers streams for lowland rice production. Because of unpredictable rains and drought coupled with population growth, more villages are progressively using improved irrigation schemes as in Malolo B village, Kilosa District (Plate 1)

Plate 1: Improved irrigation system/canal in Malolo B Village, Kilosa District

Flood irrigation and dug out irrigation canals in Mang'ula A and Kisawasawa villages in Kilombero District for instance were reported by farmers to lose significant amounts of water through splashing and seeping into the ground, respectively, especially during the dry season when soils are dry. Improved irrigation systems which are now used in some parts of Kilombero and Kilosa districts; featuring cemented irrigation canals and to some extent drip irrigation. These emerging water management practices in agriculture control both the quantity and quality of water from the sources to irrigation schemes.

Bands, commonly known as *majaruba* have been used in the past in both traditional and improved rice irrigation agriculture schemes but not in the magnitude they are in use right now in the basin. This practice, was said to be efficient in conserving water resources especially under the current changing climate. Additionally, *majaruba* were reported to be helpful in land management by conserving the soils and soil moisture.

Rotational agriculture was also found to be a common practice in Kilosa District as opposed to a fading traditional practice of shifting cultivation. Due to decrease of moisture and yields in the previously cultivated land, and as a result of population growth; the respondents reported that the only easy and feasible solution to such challenges was to move on and cultivate on other farms, but only if they had one. On top of that, it was also found that conservation agriculture promoted by environmental related NGOs such as Tanzania Forest Conservation Group (TFCG) had discouraged shifting cultivation which until recently had been a dominant practice deemed to be a solution to the lack of soil moisture, nutrients, and sufficient space for farming.

The respondents reported that more than 20 villages neighbouring forest reserves were involved in the conservation agriculture. This initiative has reduced pressure on forest land which are the main water sources of villages such as Kisanga and Malolo B. During Focus Group Discussion (FGD), it was revealed that promotion of conservation agriculture goes hand in hand with the sensitization on home gardening. The respondents indicated that horticulture products, especially vegetables, are grown up in sachets and buckets as a way of dealing with lack of sufficient water and space.

Moreover, in dealing with drought and manage water resources wisely, the respondents reported that seasonal movements to the highlands and river valleys for animal grazing and small scale farming is growing. Livestock grazing on the lowland open areas in the forests and bush lands is still a common traditional practice, it was reported. But, the expanding seasonal movements help conserve regular cultivated land on low lands and the general environment by putting it fallow and careful utilization of these new areas respectively.

Field survey findings in Kilombero district also provided interesting innovation related to water resources management and improvements in agricultural production. According to the respondents, of recent innovative practice for rice production in Kilombero District is the System of Rice Intensification (SRI). SRI is an agro-ecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients[3]. SRI was firstly introduced in Tanzania and in Kilombero district by Kilombero Plantation Limited (KPL) in 2006 (Katambara *et al,* 2013).

Unlike the flooding irrigation, SRI involves among others; sorting and sowing seeds and raising seedlings like nursery trees, single and widely transplanting (8-15 days old) of seedling early and regular weeding, water management and compost application (*ibid*). In Kilombero District; although it is a recent innovation, farmers have started to adopt the technology in their farms. This practice is generally reported to provide good yields with up to 50% of water saving and 90% reduction of required seeds. It is also known for minimizing the amount of fertilizers and energy required for rice production.

Discussion with the Basin Officers indicated that Basin wide, irrigation (both traditional and improved/modern) is practiced in most parts of Mbeya, Morogoro and Iringa regions especially at the Great Ruaha and Kilombero catchments mainly for paddy and sugar cane production. The Basin Officers also indicated that there has been significant increase of demand of water for irrigation activities. The key informants indicated that since 2006, registered water users for all purposes in the basin has increased from 1,154, with only 661 or 57.3% active water rights to about 1,324 registered water use rights, of which 886 (equivalent to 70%) were active irrigation water rights.

Key informants further indicated that the increase in the number of water user rights was largely associated with the population increase, which triggered high demand for land and water resources. Information from key informants correlated with other previous studies. ERB- UDSM (2006) indicated that RRB is one of the basins with high population growth.

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[3] http://sri.ciifad.cornell.edu/

The study by ERB-UDSM (2006) indicated that between 1988 and 2002, for example, the population had increased from 1.25 million to 3.05 million, respectively; the majority of which were migrating into the basin in search of farmland and livestock keeping.

Another reasons associated with the increase of water users and the expansion of irrigation activities in the RRB is the weather variability especially increase of unpredictable rainfall seasons in most parts of the basin. Key informants indicated that an increasing adoption of modern irrigation practices by private companies and smallholder farmers has been inspired by the need to ensure efficient water use and improve profits.

Also, recent increase of cultivation of new crops (e.g. sunflower and sesame) and intensification of horticulture by growing vegetables like water melons, cucumbers and onions were reported to be one of the reasons which has triggered the increase of water users and expansion of irrigation activities in Basin. The introduction of new crops such as sunflowers was mainly attributed to market forces and coping strategies for drought in the context of increasing rainfall shortages as currently experienced in some parts of the Basin. Vegetable farming was also found to be practiced by a majority of the youth because it is a fast cash earning source with markets readily available in cities such as Dar es Salaam and Dodoma. Despite the fact that vegetable farming is a water efficient type of specialized agriculture, apparently it has increased the pressure on irrigation water in the Basin.

Despite such expansion of irrigation activities, field survey findings found that there are still abundant potential irrigation area compared to the pace of its utilization. During the survey it was found that Kilombero district is one of the areas in the basin with high potential areas for irrigation. During the survey, it was found that the District had about the 74,013.33 ha potential for irrigation. However, only 9,280 ha were currently under irrigation (665 ha for smallholder farmers and 8,615 ha for ILLOVO sugar plantation). Table 1 below shows the current irrigation projects in Kilombero District.

Table 1: **Current Irrigation Projects in Kilombero District**

S/N	**Project Name**	**Potential irrigation area (Ha)**	**Current area under irrigation (Ha)**	**No. of Beneficiaries**
1	MSOLWA UJAMAA	675	50	1204
2	MKULA	254.3	100	320
3	KISAWASAWA	500	38	578
4	MAKI	300	60	320
5	SANJE	200	-	120
6	KIBEREGE	200	-	180
7	SIGNALI	200	60	170
8	KILAMA	200	20	160
9	MANG'ULA YOUTH – KISAWASAWA MPANGA.	260		354
10	KISEGESE	7,000	10	446
11	NJAGE	325	75	350
12	MKANGAWALO	200	-	234
13	IKULE	210	180	352
14	UDAGAJI	1,927	12	380
15	CHITA JKT	3,341	60	-
16	IDETE PRISON	10,000	-	
17	MGUGWE	2,200	-	492
18	MPANGA / NGALIMILA	31,000	-	864
	Sub-Total	**58,986.53**	**665**	**6,524**
19	ILLOVO Sugar Company	15,021	8,615	-
Grand Total		**74,013.33**	**9,280**	**6,524**

Source: Kilombero District Socio-Economic Profile, 2014

Generally, as discussed in previous sections, farming methods and practices were revealed to have been improved in the RRB. Terracing, zero tilling, mixed cropping and crop rotation were reported to be widely used in the basin hence encouraging efficient use of water. These methods were also reported to have been improving environmental condition and crop production especially in the highlands apart from the presence of soil which is relatively fertile.

Other strategies related to agriculture which are contributing to water resources management include harvesting rain water for domestic use and small scale irrigation around their homesteads. Harvesting of water is undertaken in order to cope with recurring drought spells. Ground water harvesting was also reported to be increasing fast in the Basin especially in the villages.

Lastly, cultivation of improved rice and maize seed varieties like SARO-5 and STAHA was also reported by farmers as indirect strategy for water management across the two project districts (Kilombero and Kilosa). According to the discussion with FGD participants, these seed varieties complete their phenology faster than traditional varieties, are less water demanding varieties, mature earlier, and thus exert less pressure on water.

2.2.4.2 Water management

Discussion with the Basin Officers indicated that there are regular mechanisms for monitoring water quantity and quality. According to the key informants, regular monitoring of water helps to ensure sustainable environmental flows and livelihoods in the basin. The strategies include water gauges which are installed to monitor water quantity especially now when climate change is affecting water resources and biodiversity, and people’s livelihoods. To control pollution, water quality is also periodically being monitored.

Key informants also added there have been various challenges affecting monitoring of water quality and quantity in the Basin. Apart from illegal water abstraction and inefficient of traditional irrigation schemes, increased sedimentation from poor agricultural practices and increased deforestation in the catchments areas deteriorate the quality and quantity of water in the Basin. According to the key informants, sedimentation is also attributed to the increased land use pressure due to the rising population in the basin, which eventually result into the conversion of forestland into farmlands, and cutting of trees for charcoal and firewood especially in the upstream.

2.2.4.3 Land use planning

Discussion with key informants are district level revealed that land use is largely dominated by zoning of land for various land uses including special pasture land. Zoning for pastureland was largely reported in Kilombero district and was being undertaken in order to regulate the current influx of migrant pastoral communities in the district. It was reported by key informants that about 68,383.29 ha outside Kilombero Ramsar wetland area in the highlands have been designated for pastoralism. By creating special areas for grazing, land and pasture related conflicts and destruction of water sources have been minimized.

2.2.4.4 Biodiversity conservation

Discussions with key informants indicated that increasing rate of declarations of protected areas is one of the reasons that has ensured and maintained availability of water in many places in the Rufiji Basin. According to the key informants, RRB has become renown because of its numerous conservation initiatives as well. Key informants indicated that RRB comprises of four national parks, about 82 forest reserves covering a total of 23200 km^2, and a number of game reserves and game controlled areas. As a result, biodiversity conservation initiatives have also contributed to instil an environmentalist mind set among the villagers who are now becoming more aware of the importance of environmental management.

Key informants mentioned that the Udzungwa National Park is one of the areas which contributes to water conservation in the Basin. It was mentioned by the respondents that since wildlife, water sources and forests are frequently located in the same localities, declarations and protection of these sites have become important especially given the climate variability. Therefore, gazetting these areas is also considered to be climate change strategy.

2.2.5 Challenges in Water Management in the Rufiji Basin

Several challenges related to water resources management in the Rufiji Basin were reported during the survey. As discussed in previous sections, apart from population increase that demands more resources, including water and land; rapid land use change attributed to arbitrary expansion of agricultural activities have resulted into high deforestation and forest degradation. Eventually, according to key informants, these activities degrade water resources through It was reported that, this accelerated sedimentation in the downstream. During the discussion with key informants, Mbarali catchment of the Kioga River was mentioned as one of the sub-basin where sedimentation has been highly visible since in 2013.

Increased in-migration of pastoralists was also reported to be one of the key challenges exerting pressure on land and water resources. Key informants indicated that the in-migration of agro-pastoralists such as Sukuma, and pastoralist such as Barbaig communities has resulted into more demand for grazing lands and water sources, hence encroachment of water sources, forests and agricultural lands. Key informants also highlighted that both Districts (Kilombero and Kilosa) face similar challenges related to the in-migration of pastoral and agro-pastoral communities. The key informants also indicated that apart from inducing conflicts among herders and farmers, and local governments; and degradation of forest resources, the in-migration also contributes to the deterioration of water resources in the Basin. Table 2 below shows the current population of livestock in Kilombero District and the area designated for livestock keeping.

Table 2: **Livestock Population and Area (Ha) allocated in Kilombero District**

S/N	Village	Number of Pastoralists	Number of Livestock				Area(Ha)
			Cattle	Goats	Sheep	Donkeys	
1	Msolwa Station	18	985	71	32		289.7
2	Kiberege	25	3400	522	663	2	4623
3	Signali	51	3342	398	429	19	1683
4	Sagamaganga	19	1186	316	140	3	1989
5	Lipangalala	10	293	63	61		729
6	Katindiuka	4	1100				2640
7	Lugongole	37	8763	632	512	9	4302
8	Kikwavila	4	130				312
9	Mahutanga	6	1223	41	13		2961
10	Ihanga	5	35				645.1
11	Namawala	11	2378	214	100	1	5263.75
12	Mofu	16	3505	331	344	27	5216.25
13	Igima	9	1353				3246
14	Mkangawalo	30	3204	876		10	5024.03
15	Lukolongo	16	6700				4650.4
16	Mngeta	17	1350				3240
17	Njagi	13	56				135
18	Ikule	27	67				162
19	Merera	44	11916	3334	6007	85	6,825
20	Kalengakelu	29	2045	34	21		4932
21	Msolwa	8	113	14	9		279
22	Mwembeni	75	1683	36	22		4056
23	Utengule	6	7000	300			1164.19
24	Mpanga	21	1805	704	1950		559.97
25	Ngalimila	20	2147				1901.9
26	Uchindile	12	507				1218
27	Kitete	5	60				144
28	Lugala	7	80				192
	Total	**545**	**66,426**	**7,886**	**10,303**	**156**	**68,383.29**

Source: Kilombero District Council, 2014

Key informants further indicated that the number of livestock in the district is thought to be higher than the figures shown in Table 2. The key informants reported that livestock keepers have tendency of hiding the true number of their animals in fear of forced destocking.

2.2.6 Land Use Change in the Rufiji Basin

Analysis of land use change in the Rufiji River Basin (RRB) was undertaken through the the analysis of land cover data over the last 17 years (between 1996 -2013) in the previous project milestone, that is Milestone Four. As illustrated in figure 1and 2, analysis revealed that Rufiji River Basin has been facing tremendous land cover changes over the past years. However, a number of land use changes in the basin are not a result of replacing or modifying the original land cover but rather by adding value into it. Over the last thirty years a number of forests, grasslands and wetland areas have been declared as protected areas (e.g. Kitulo and Udzungwa National Parks, and Ihefu and Kilombero wetlands) in the Basin.

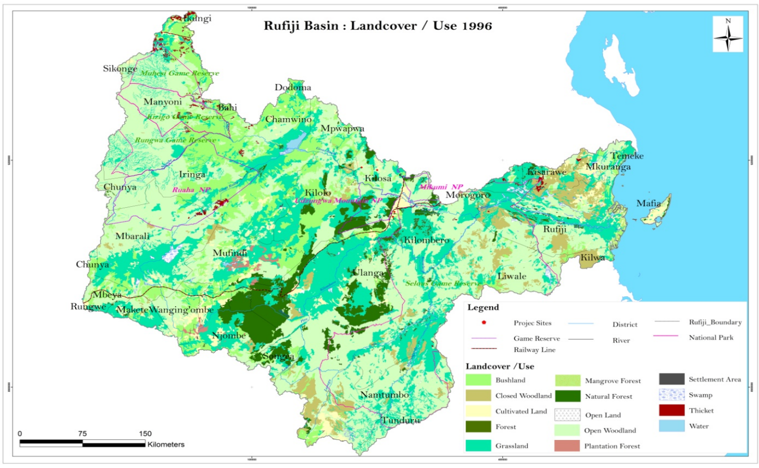


Figure 1: **Rufiji River Basin Land cover/Land use in 1996**

Source: IRA, GIS Lab (2014)

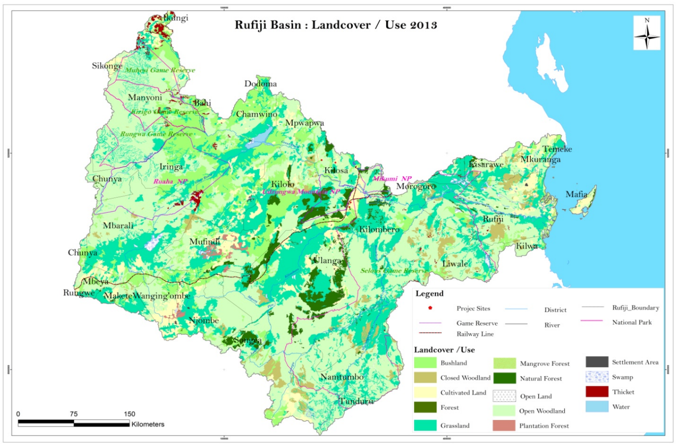
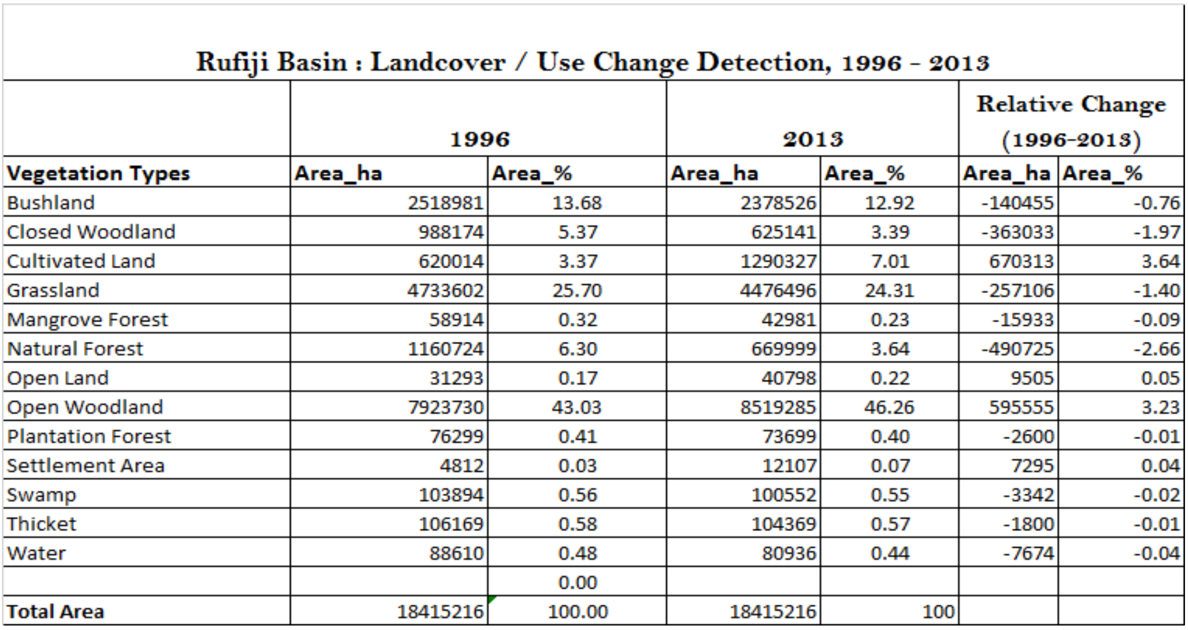


Figure 2: **Rufiji River Basin Land cover/Land use in 2013**

Source: IRA, GIS Lab (2014)

In the same period of over thirty years ago, increasingly more different types of natural vegetation, primarily forest, grasslands and woodlands outside the protected areas, have been converted into different types of land use, especially for agriculture, which has increased by about 4% (Table 3 and Figure 3).

Table 3: **Land cover / use change detection in Rufiji Basin**



Rufiji Basin : Landcover / Use Change Detection, 1996 - 2013

	1996		2013		Relative Change (1996-2013)	
Vegetation Types	**Area_ha**	**Area_%**	**Area_ha**	**Area_%**	**Area_ha**	**Area_%**
Bushland	2518981	13.68	2378526	12.92	-140455	-0.76
Closed Woodland	988174	5.37	625141	3.39	-363033	-1.97
Cultivated Land	620014	3.37	1290327	7.01	670313	3.64
Grassland	4733602	25.70	4476496	24.31	-257106	-1.40
Mangrove Forest	58914	0.32	42981	0.23	-15933	-0.09
Natural Forest	1160724	6.30	669999	3.64	-490725	-2.66
Open Land	31293	0.17	40798	0.22	9505	0.05
Open Woodland	7923730	43.03	8519285	46.26	595555	3.23
Plantation Forest	76299	0.41	73699	0.40	-2600	-0.01
Settlement Area	4812	0.03	12107	0.07	7295	0.04
Swamp	103894	0.56	100552	0.55	-3342	-0.02
Thicket	106169	0.58	104369	0.57	-1800	-0.01
Water	88610	0.48	80936	0.44	-7674	-0.04
		0.00				
Total Area	18415216	100.00	18415216	100		

Source: IRA, GIS Lab (2014)

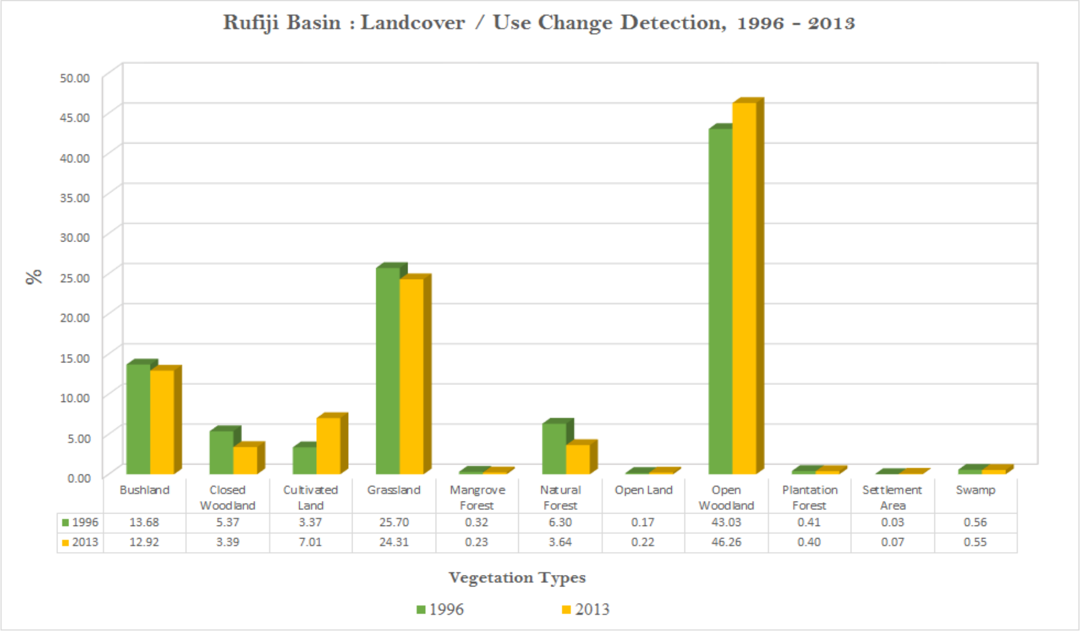


Figure 3**: Rufiji River Basin Land cover / land use Change Detection**
Source: IRA, GIS Lab (2014)

While land degradation through deforestation, bush fires and shifting cultivation, expansion of commercial agriculture and expansion of human settlements have all been reported as the sources for land cover change; population growth, policies calling for modernization of the country's state of agriculture, global growth of environmentalism and an expanding market for agricultural goods were also mentioned as the major drivers for land use change in the Basin.

2.2.7 Climate Variability and Change in the Rufiji River Basin

Monthly minimum and maximum temperatures in Tanzania, and total annual rainfall over the last 30 (between 1974 and 2004) years show upward and downward trends, respectively (URT, 2007). On top of that, projections show that Tanzania is going to warm by 2 - 4 C^{o} by 2100 which is almost close to the global estimates of 3.7°C to 4.8°C (Pavoola, 2008; Cubasch *et al.*, 2013).

On the other hand, the respondents in the field reported that in recent years RRB has been experiencing increasingly shorter growing seasons, less amount of rainfall, seasonal shift on rainfall onset and cessation, and an increase of extreme events, especially floods. All these have greatly reduced agricultural productivity in the RRB as livelihoods and property are damaged. This is in tandem with present and future estimated rainfall amount and distribution in Tanzania which shows a predicted rainfall decrease by 0 – 20 percent in the inner parts of the country and increase by 25-50 percent in the northeast, southeast and the Lake Victoria basin (URT, 2007; Pavoola, 2008).

2.2.8 Summary

In summary, an increase of water demand for irrigation, impacts of the changing climate change and variability on water resources, land degradation, conflict of interests among water users and weak support of water resources management at the lower levels could all potentially hamper a swift development and sustainable management of water resources in the basin.

Inadequate data on the water flow and total volume of water used by different users in various sub-basins within the RRB, inefficiency of irrigation schemes, increasing water demand for agricultural irrigation will also weaken adaptation efforts and sustainable management of water resources, eventually affect crop production in the Basin. Moreover, climate change impacts together with rapid population growth and unsustainable land use practices (i.e. unplanned mobile pastoralism, overgrazing and shifting cultivation) have all significant impacts on base flow in the rivers, water shortage as well as quality and quantity of water resources in the Basin. Combination of these effects will eventually increase demand and conflicts among water users.

Additionally, some parts of the country including the RRB are predicted to become drier than they are now, the future of agriculture, especially the production of the country's staple food crops maize and rice, is heavily challenged. Ultimately, the impacts of climate change coupled with natural resources degradation in the RRB will altogether have negative impacts on the availability and distribution of water resources needed for the production of these crops.

CHAPTER THREE

FUTURE CLIMATE PROJECTIONS

3.1 Introduction

Estimation of the impact of future climate change on crops and hydrology was assessed by using several Global Climate Models (GCMs) under two different Greenhouse Gas (GHG) emissions scenarios. GCMs simulated climatic processes and how they respond to enhanced greenhouse emissions affecting atmospheric and ocean temperatures, wind speed and a variety of other climatic factors. Due to inherent uncertainty of future GHG emissions and how the climate will respond, it is prudent to examine a range of possible future scenarios through different models and GHG levels. This section of the report provides results of four GCMs that have been downscaled (made to be a higher resolution) for the Rufiji River Basin. Results include projected changes in precipitation during two seasonal time periods.

3.2 Methodology

Four GCMs from the new Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) scenarios were selected for having the lowest systematic bias and interquartile range (IQR) error during their realizations of the 1981-2010 historical period for Eastern Africa (Stocker et al. 2013; Otieno and Anyah 2013). The selected models are: CCSM (USA), IPSL (France), MPI (Germany) and MRI (Japan).

Results from both low and conservative (RCP4.5, left side) and high or runaway (RCP8.5, right side) Representative Concentration Pathways (RCPs) or levels of greenhouse emissions are provided. Illustrated are projected results of changes in precipitation from current to mid-century periods during the March-April-May and the October-November-December periods.

All data were downscaled following Hutchison (1998) using the ANUSPLIN software. These are 20-year means centered on 2050 chosen mainly because the warming trends are not sufficiency linear around 2050 for 30-year means to be as representative. Change was calculated simply by "GCM projected mean" minus "GCM current mean". WorldClim historical data will be added to this perturbation in the next phase of work using the Delta Method to give actual values for use in the crop and hydrological models. This coupled modeling approach has been followed in earlier analyses (Moore *et al.,* 2012).

3.3 Results

The first set of figures (4 and 5) shows projected precipitation changes of four GCMs from current to mid-century during the March-April-May (MAM) months. Figures 6 and 7 show projected precipitation changes of four GCMs between current and mid-century during the October-November-December months. Again, RCP4.5 (left maps) represents changes assuming lower and RCP8.5 (right maps) higher GHG emissions.

Most of these models project a warmer, wetter east Africa partially as a result of stronger low-level moisture transport across the Indian Ocean during boreal Spring. Actual historical trends suggest that this wetting trend is unrealistic, however, due to stronger deep convection over the Indonesian Warm Pool. This enhanced deep convection acts to counteract the easterly winds off the Indian Ocean, thereby diminishing flow and thus the amount of moisture arriving in east Africa (Williams and Funk 2011). Though the GCMs used here have the lowest bias and IQR error, there is still little consistency among the models for the MAM period.

Synoptic flow for east Africa is heavily influenced by the start of the monsoon in India (the Walker circulation), and as a consequence a Walker-type circulation has been observed to develop over east Africa driving rainfall during MAM.

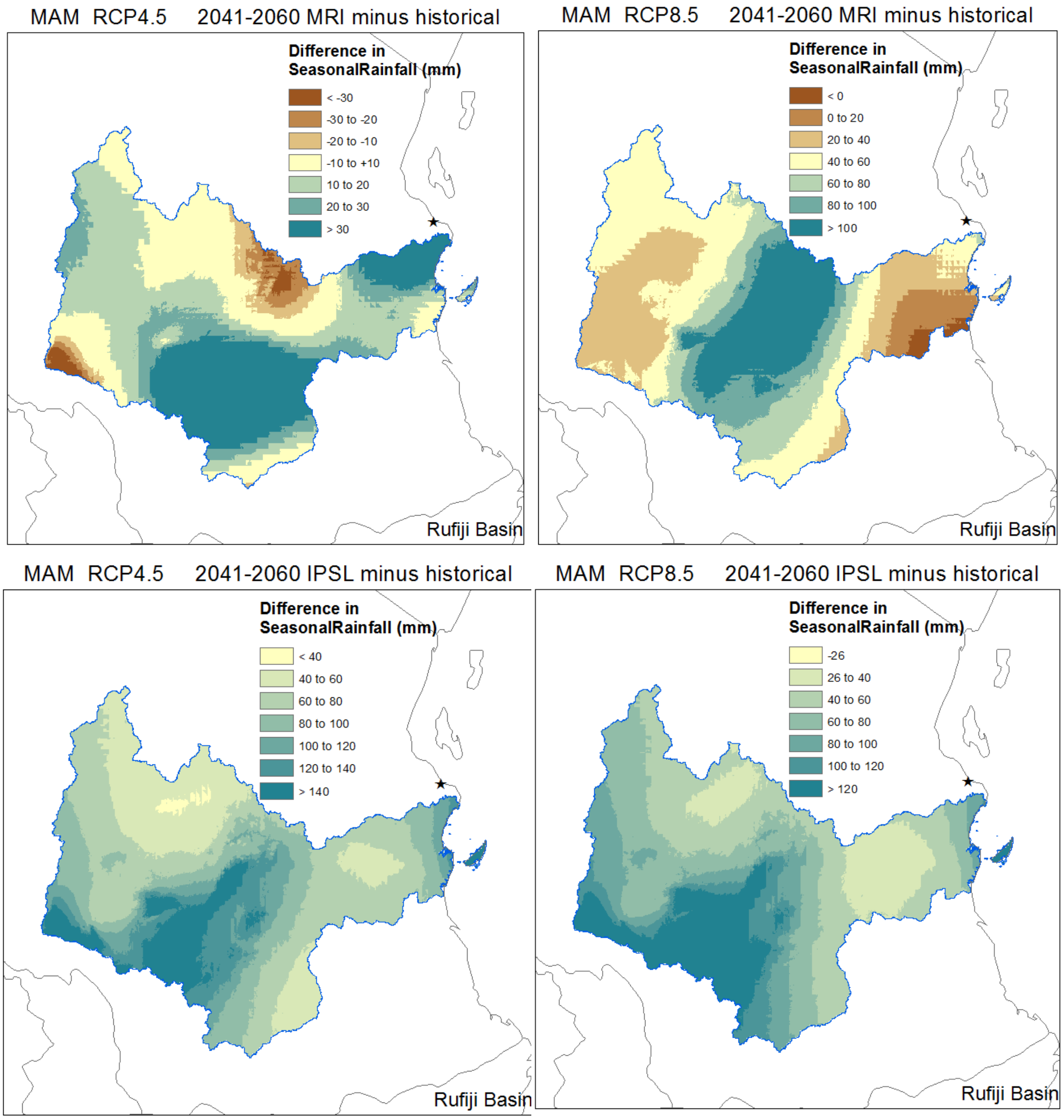


Figure 4: **Projected changes in precipitation between current and mid-century periods during March-April-May by MRI and IPSL under low and high GHG scenarios.**

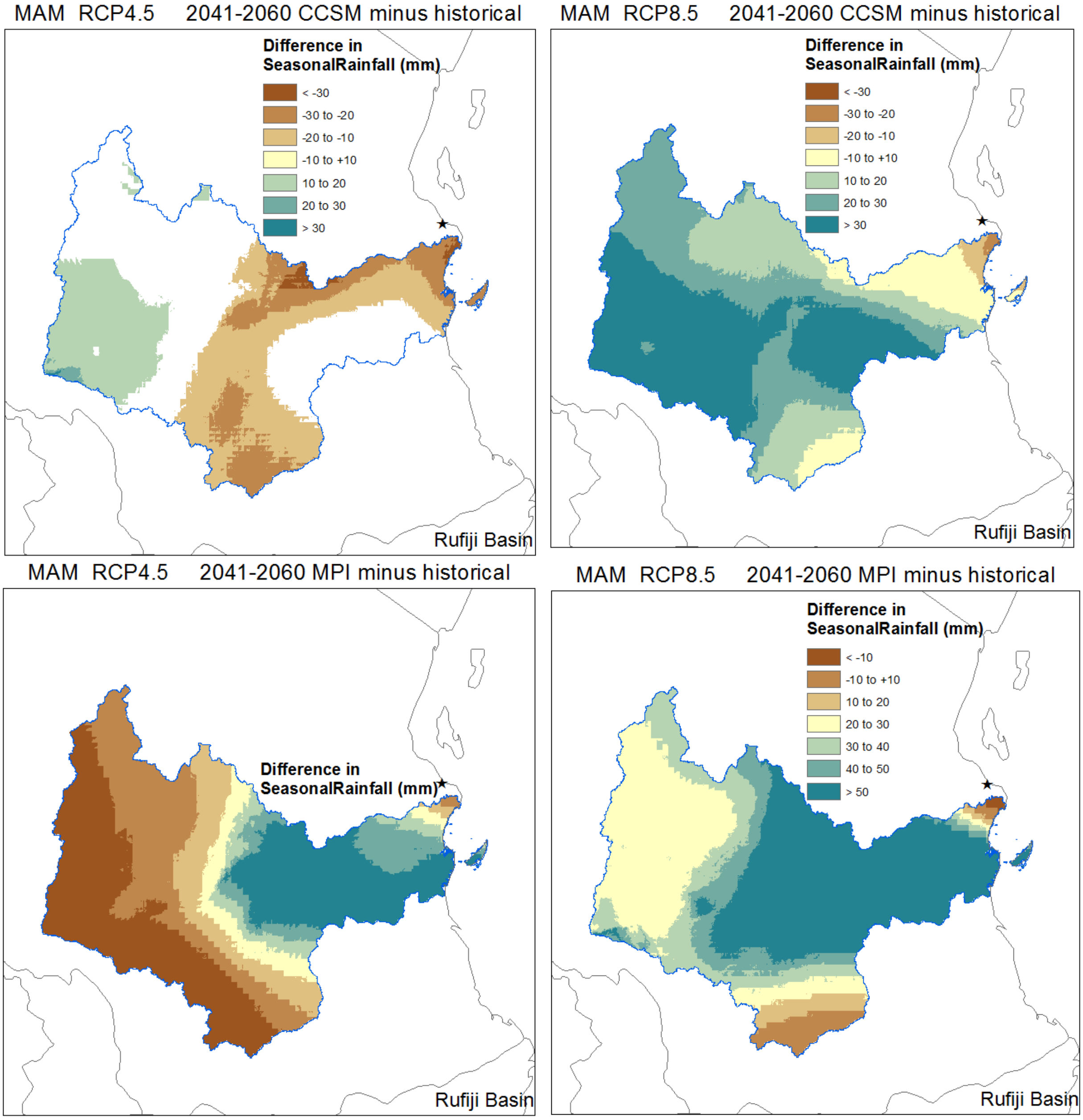


Figure 5: **Projected changes in precipitation between current and mid-century periods during March-April-May by CCSM and MPI under low and high GHG scenarios**

Rainfall during the October-November-December (OND) period is much more consistent between GCMs. The synoptic forcing is much weaker because the Indian monsoon will have ended by October. With the exception of the IPSL model, the projections consistently indicate a vastly reduced OND “short rains” period. Declines of up to 50mm are projected, primarily in the headwaters of the Rufiji Basin. Minor increases are evident near the coast, but this is attributed to an enhanced sea breeze effect due to warmer land surface temperatures. The sea breeze effect is not realistically capable of enhancing rainfall more than ~50 km inland, and so will not provide a significant source of rainfall for the region.

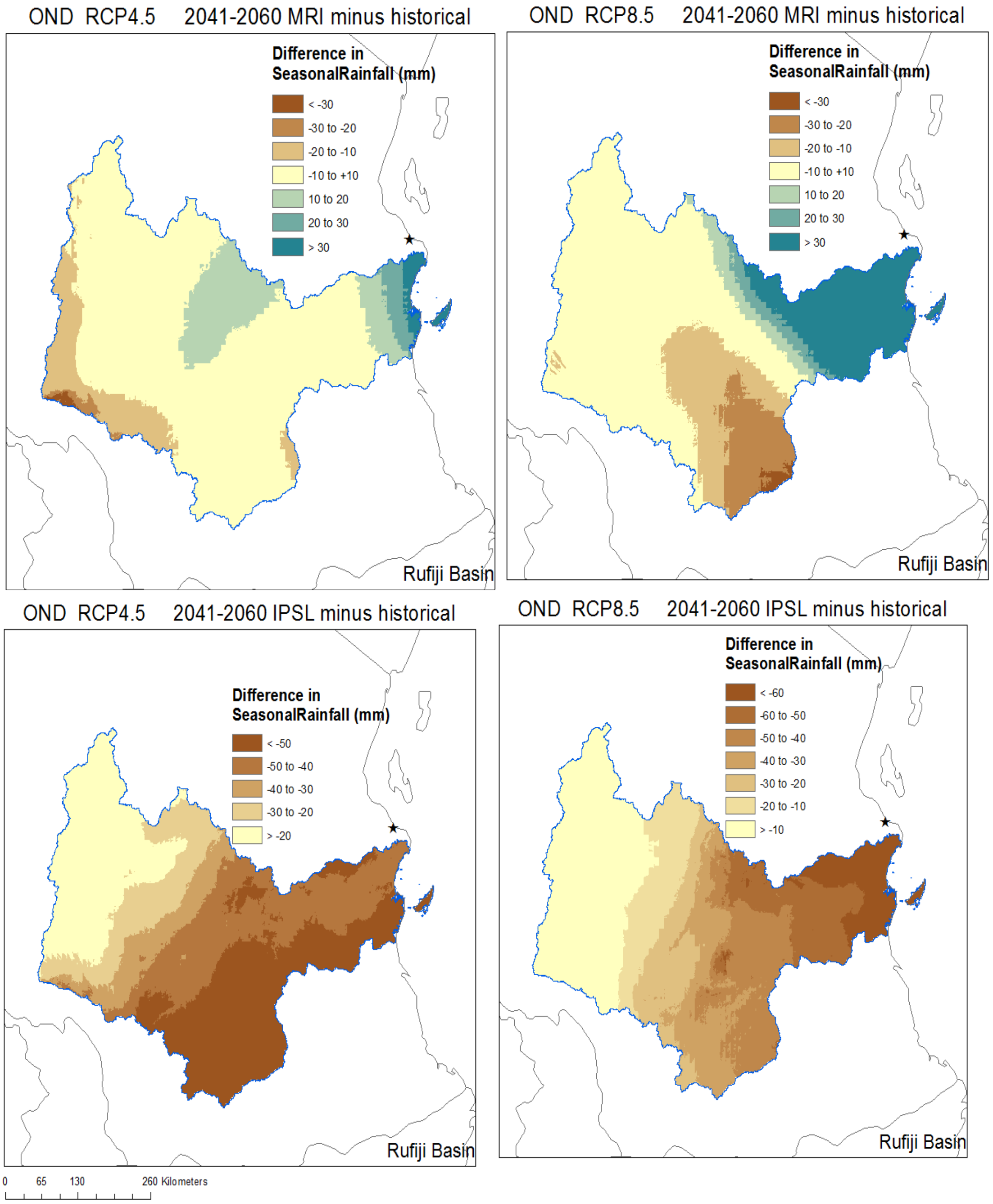
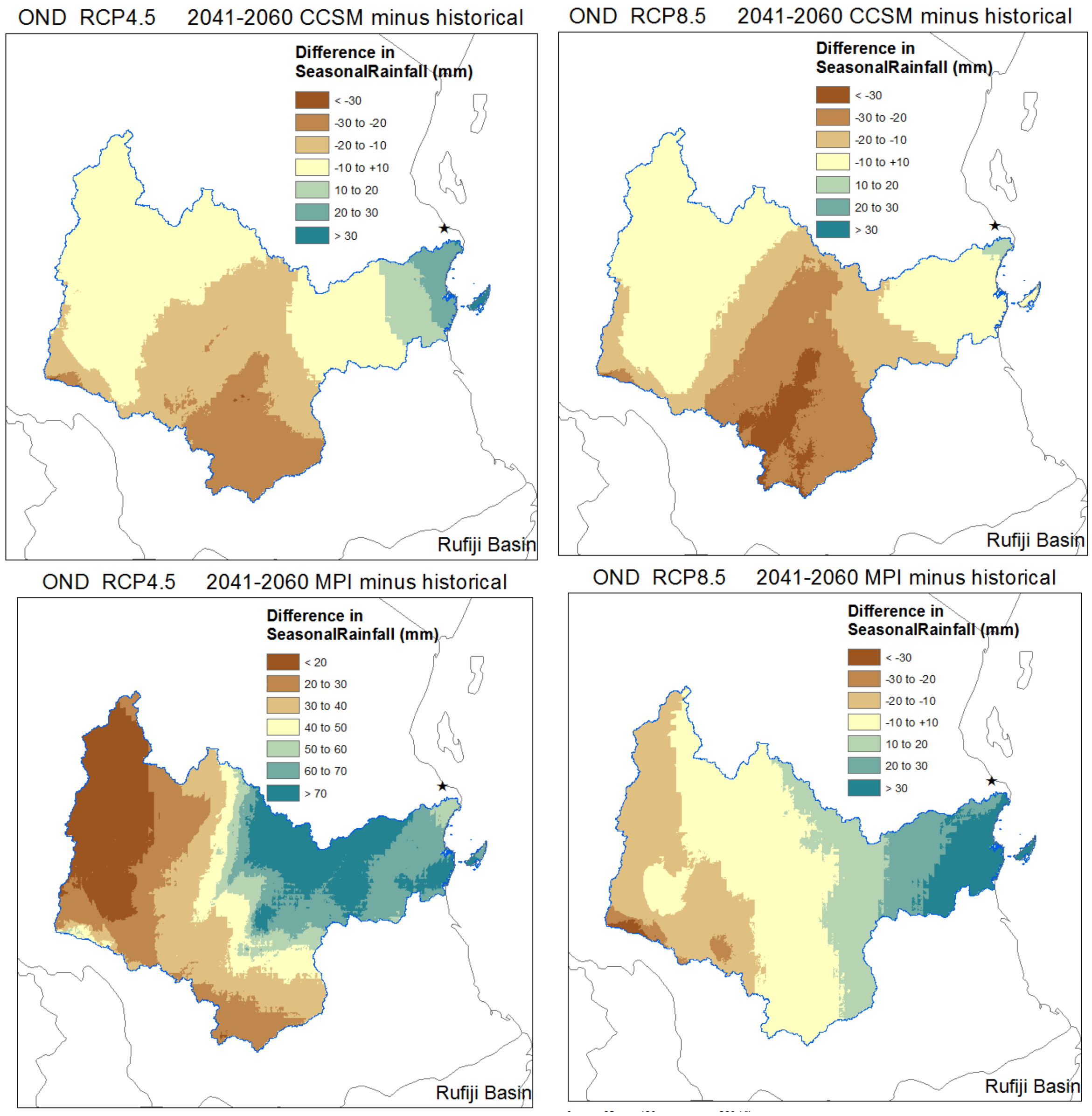


Figure 6: **Change in precipitation between current and mid-century during October-November-December by MRI and IPSL under low and high GHG scenarios.**



OND RCP4.5 2041-2060 CCSM minus historical

OND RCP8.5 2041-2060 CCSM minus historical

OND RCP4.5 2041-2060 MPI minus historical

OND RCP8.5 2041-2060 MPI minus historical

Figure 7: **Change in precipitation between current and mid-century during October-November-December by CCSM and MPI under low and high GHG scenarios.**

In summary, the results for change in rainfall during the MAM period are difficult to discern; the models show little consistency. IPSL is the only model that did well against the historical trends for MAM. Results for the OND period are much more consistent. They basically show that these rains are expected to largely decline. Projections for the OND period would be expected to be easier since there is basically no large synoptic forcing.

CHAPTER FOUR

HYDROLOGICAL MODELING

4.1 Introduction

The purpose of hydrological modeling for agriculture is to provide information on stream water availability for irrigation or other uses. Hydrological models can simulate the impact of different water management practices and land use on steam flow. They can also reflect the impact of climate change and variability on water availability. In this project, therefore, results of the hydrological modeling will inform key improvements in water and land use management to reduce the impact of climate change and variability on irrigation water. It will also provide information on expected availability of water for expanded (or current) irrigated rice production.

In this first year of the study, the Rufiji River Basin was parameterized with the ArcView-SWAT model interface. The model was initially ran with available weather data but was not calibrated due to a lack of downstream flow data. The model was then run on a highly agricultural sub basin of the Great Ruaha River watershed using local weather and flow data. The model was calibrated and initial irrigation scenarios were run using the local cropping practices.

4.2 Methodology

The SWAT (Soil and Water Assessment Tool) model is a continuous-time, semi-distributed, process-based river basin model. It was developed to evaluate the effects of alternative management decisions on water resources and nonpoint-source pollution in large river basins. The model was used in the Rufiji basin to evaluate the hydrologic impact on water resources due to climatic changes and the shift from grassland land cover to irrigated agriculture within the basin.

The SWAT model is a data intensive model that requires base input data for soils, elevation, land cover and weather. The model also requires input data concerning land management practices, groundwater, stream routing, water use and optional parameters such as water quality parameters. In this study, the SWAT2005 version of the model was used in conjunction with the Arcview GIS interface. In this initial setup of the model, the Rufiji river basin as a whole was simulated using weather data from 1982 – 2012.

There are three fundamental GIS layers used in the SWAT model: a digital elevation model (DEM), land use / land cover, and soils data. Each of these data layers were collected for Tanzania and were projected from geographic coordinates into African Albers Equal Area Conic projection. SWAT requires GIS data to be projected so that area calculations of land use and soil type can be performed on the GIS data.

The Digital Elevation Model (DEM) used in the modeling of the Rufiji basin was obtained from the Consortium for Spatial Information (CSI) of CGIAR (Jarvis et al., 2008). This dataset is derived from the NASA Shuttle Radar Topography Mission (SRTM). The SRTM is a joint project between the National Geospatial Intelligence Agency and NASA. The objective of this project is to produce digital topographic data for 80% of the Earth's land surface which includes all land areas between 60 degrees north and 56 degrees south latitude. The X-Y resolution of the data in this project is 90 meters. The CGIAR-CSI product is an enhancement of the base SRTM dataset where dataset voids have been filled providing complete coverage.

The Rufiji basin was delineated from the Tanzanian DEM coverage. By using the Tanzanian river coverage in conjunction with the DEM, the drainage basin of the Rufiji River was delineated by a semi-automated process within the Arc view- SWAT interface. Twenty three major tributary sub basins were delineated within the main basin. Sub-basin physical properties such as: area, slope and flow length were calculated. Figure 8 shows the digital elevation model of the Rufiji River and its sub basins used in the modeling work. Table 4 shows a summary of each sub-basin and its physical characteristics.

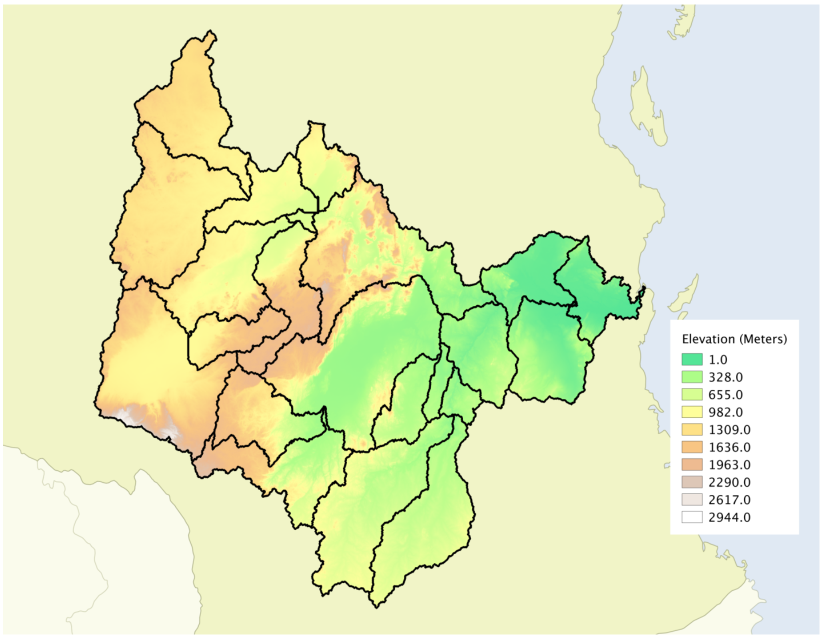


Figure 8:**Digital Elevation Model of the Rufiji Basin delineate**

Table 4: **Physical characteristics of Rufiji sub basins within the SWAT model**

Sub basin	Area (ha)	Flow Length (m)	Slope (%)
1	925,071	305	2.6
2	1,410,024	267	4.5
3	507,729	184	2.5
4	42,024	48	2.6
5	1,299	18	0.6
6	366,283	144	6.8
7	941,596	261	6.0
8	697,767	305	7.4
9	495,645	196	2.6
10	552,591	162	2.2
11	804,071	187	2.8
12	1,602,523	408	16.1
13	630,117	185	3.8
14	1,672,323	212	6.5
15	405,321	194	6.3
16	1,950,298	400	11.0
17	396,813	225	10.1
18	134,986	92	4.2
19	157,308	99	5.1
20	686,823	271	14.0
21	861,692	276	14.6
22	1,338,763	355	8.9
23	1,031,013	345	5.4

The land use coverage in this study was obtained from the 30-meter Global Land Cover Dataset developed in 2014 by the National Geomatics Center of China (NASG, 2014). The dataset covers land area from 80 degrees north to 80 degrees south and consisted of 10 land cover types, which include cultivated land, forest, grassland, shrubland, wetland, water bodies, tundra, artificial surfaces, bareland and permanent snow and ice. The classification data images of the datset are mainly 30 meter multispectral images included Landsat TM and ETM+ multispectral images and multispectral images of the Chinese Environmental Disaster Alleviation Satellite (HJ-1). Cloudless images acquired over vegetation growing season within +/1 one year from 2010 were selected for this dataset.

Within the SWAT model, the land cover dataset was clipped by the sub-basins and the individual areas of each land type was calculated by the model. Each land use class was assigned a hydrologic classification from the SWAT land use database to determine the hydrologic response characteristics. Figure 9 shows the land use coverage used for the Rufiji basin.

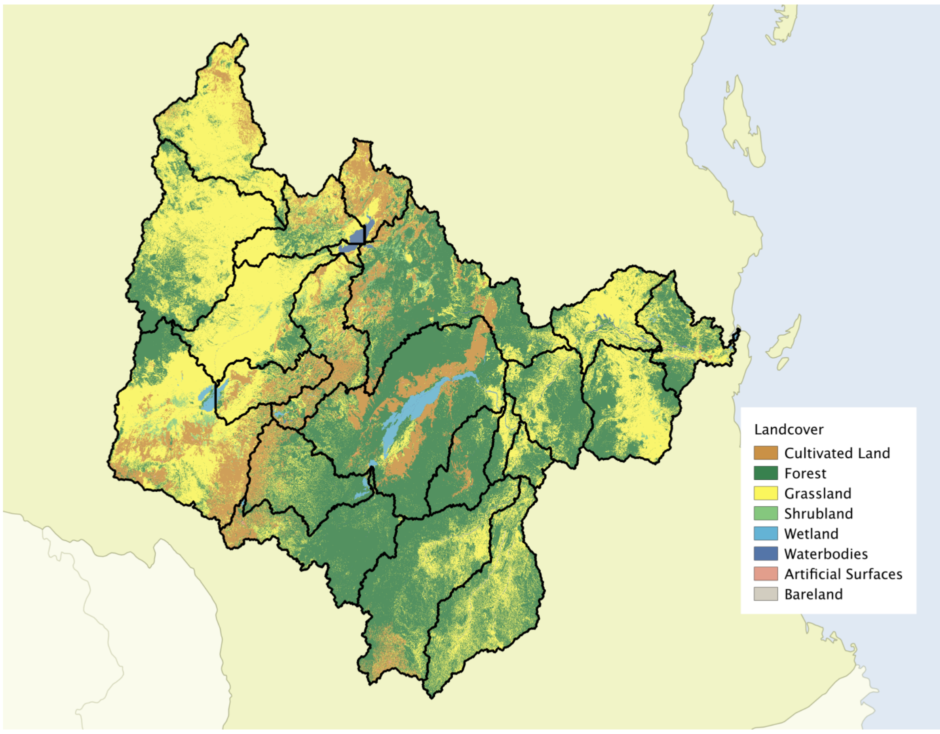


Figure 9: **Land Cover for Rufiji River Basin**

The soils data for the Rufiji basin were developed using the FAO Harmonized World Soils Database (HWSD) (FAO, 2012). The HWSD is a 1 kilometer resolution soils coverage developed from a variety of soils sources. Eastern Africa is derived from Soil and Terrain Database (SOTER). The database contains soil physical and chemical properties for use in the SWAT model.

In the SWAT model a custom soil properties database was constructed based off of the data from HWSD for Tanzania. Individual soil types were determined for each sub basin within the Rufiji watershed. Individual soil properties were extracted from the database and inserted into the soils input files for each of the sub basins. The soils coverage used in this study is shown in Figure 10.

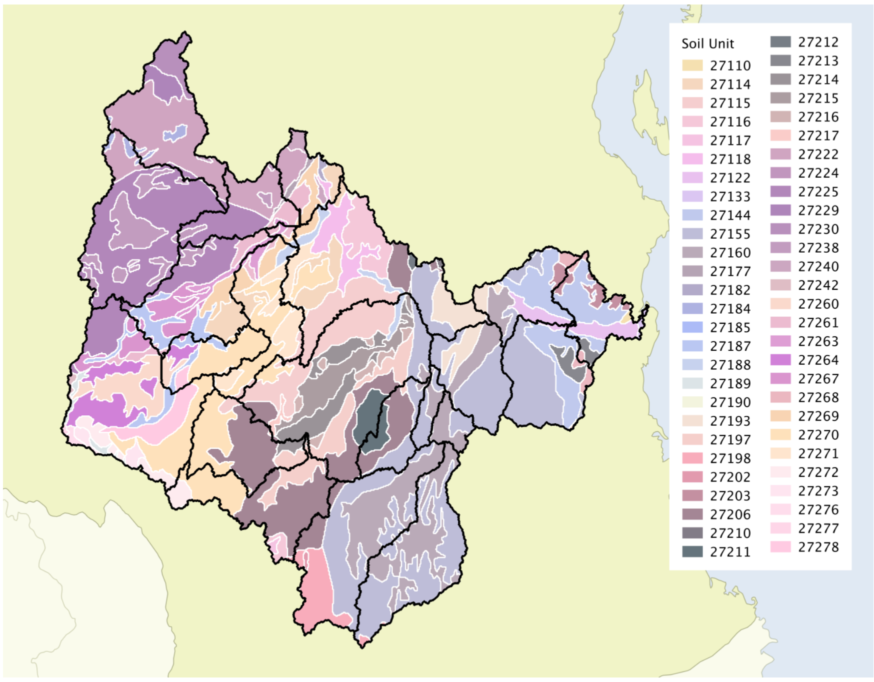


Figure 10: **Soils coverage of Rufiji River Basin**

Several sources of weather data have been collected for this project. Weather data required by SWAT include daily precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. Data sources being used in this project include local rainfall data provided by the Tanzania Meteorological Agency (TMA) as well as satellite based data at a 1/8 degree resolution from the NASA Global Land Assimilation Data System and station based data collected from the National Centers for Environmental Prediction's Climate Forecast System Reanalysis.

For further refined model calibration and validation, additional local station precipitation will need to be collected. Observed daily stream flow data was obtained from the Rufiji River Basin Office. This data was used in the calibration of the Little Ruaha River watershed. Additional stream flow data needs have been identified for simulating the flow of the entire Rufiji basin.

4.3 Results

Modeling of the entire Rufiji River Basin was conducted with available data as an initial step. Please note that since we do not yet have stream flow data to calibrate and validate the model, we were not able to make adjustments to the model to reflect the hydrology of the watershed. Thus, un-calibrated result of daily hydrology from 2000 – 2012 is shown in Figure 11.

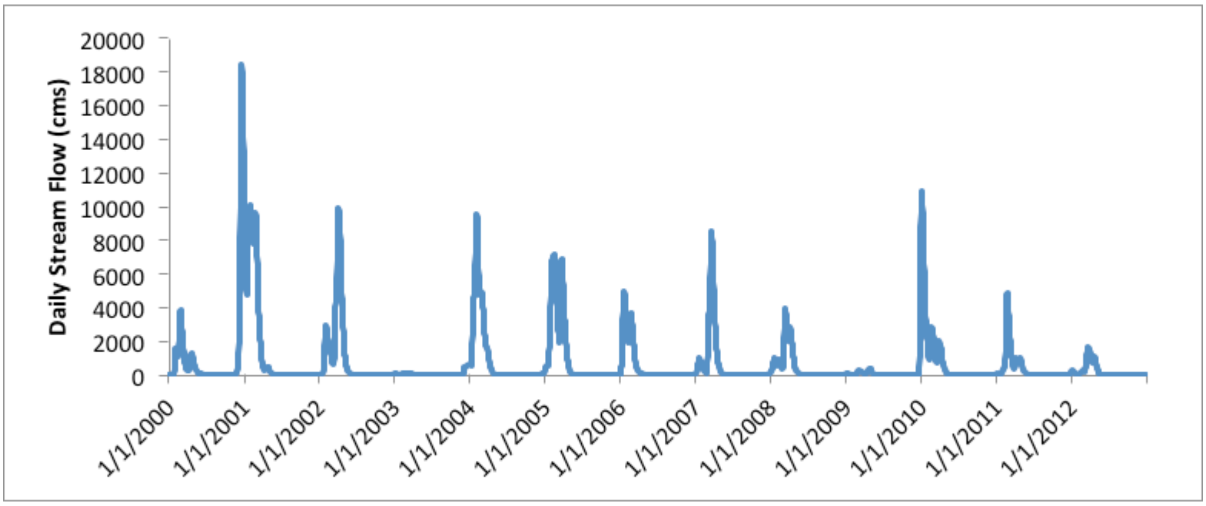


Figure 11: **Un-calibrated stream flow results for Rufiji basin (2000 – 2012)**

The un-calibrated results however are in line with the magnitude of flow for the basin described by the Rufiji River Basin Office. These results also accurately reflect the extreme flow regimes of the watershed—very high flow rates during the wet season and exceedingly low flow rates of the basin during the dry season. The results also show a slight temporal trend of decreased flow as more recent years have had less overall rainfall. This observation will need to be confirmed once we receive more observed weather and flow data for the basin in the next phase of the of the project. The modeling of the entire basin with calibration will begin during this next phase once we receive additional observed data to fully calibrate and validate the basin model.

The Little Ruaha River (LRR) is a tributary to the Ruaha River which drains into the Mtera Reservoir. The LRR was chosen to for an initial detailed modeling study because of its intense agriculture (37%) and the availability of observed weather and stream flow data. At the far downstream gauging station at station, 1KA31 at Mawande, the LRR drains approximately 521,000 hectare. Streamflow was simulated for the period of 2000 – 2012, which corresponded to having complete records for observed precipitation and streamflow. Precipitation records from the Iringa Maji station while the other weather parameters were obtained from the National Weather Service NCEP database. Figures 12 to 14 show maps and data for the Little Ruaha River as it was modeled within SWAT.

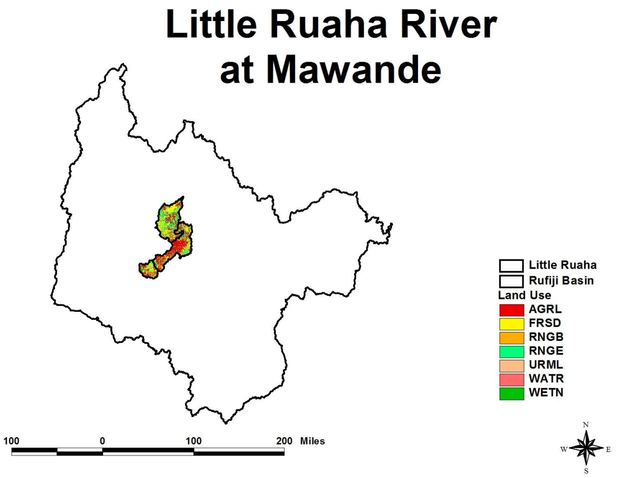


Figure 12: **Location of Little Ruaha River Basin**

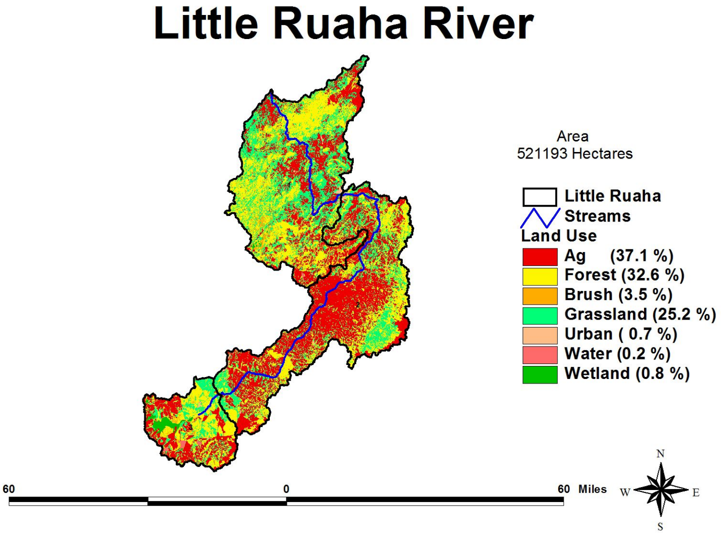


Figure 13: **Land cover for Little Ruaha River watershed**

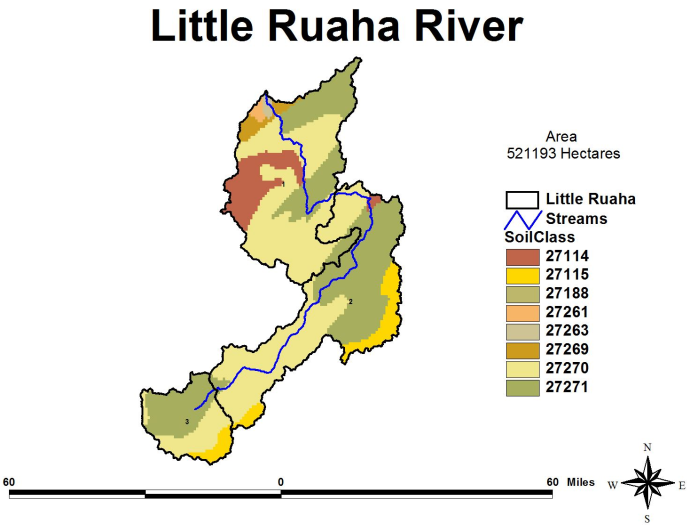


Figure 14: **Soils map for Little Ruaha River watershed**

A cropping scenario was developed that had a double crop of rice planted in November and maize planted in May. For both of the crops, irrigation water was supplied from a surface water source taken directly from the Little Ruaha River. The SWAT model was calibrated for both surface runoff and stream base flow. A base flow filter program was used to separate the observed stream flow into its surface run-off and base flow components and the model was calibrated for both components.

Figure 15 shows the daily flow calibration results for the LRR for the period 2000 – 2012. Based on the observed results and the parameterization of the model it appears that soil cracking in soils with high clay content during the dry season is a major pathway for early wet season rainfall to be converted into stream base flow in this sub basin. Surface run-off occurs only during large rainfall events. Overall, the base flow accounts for approximately 71% of the total flow of the stream. Over the time period the average annual basin wide irrigation was approximately 4,600 ha-m of water. This corresponded to roughly 6.5% of the stream base flow for the year. In the next phase of the study we will analyze this on a monthly basis to determine the overall water resources impact.

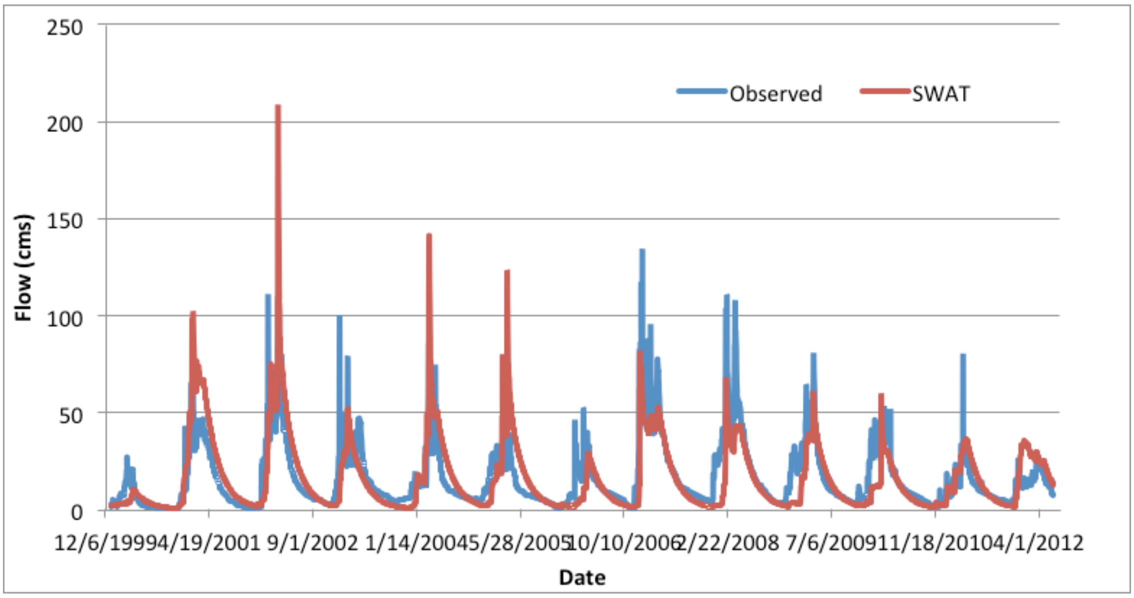


Figure 15: **Calibrated stream for Little Ruaha River watershed at gaging station 1K31A**

4.4 Summary

The purpose of the hydrological modeling phase of the Rufiji River basin is to understand the impact of climate variability and future climate change on the stream flow. Additionally, we seek to understand the effects of changing land cover from grass land to cultivated agriculture with its associated irrigation needs on the river flow and water resources within the basin.

During this first phase of the modeling work we have successfully calibrated the SWAT model to simulate the stream flow response in the intensely cropped Little Ruaha River watershed. We were able to quantify the different components of streamflow and to estimate the average annual irrigation requirements for a double cropping rotation of rice and maize. The next phase of the modeling work will be to:

1) Calibrate and validate the overall flow of the Rufiji River
2) Estimate irrigation requirements of the current land use within the watershed on a monthly basis.
3) Estimate the current overall impact of irrigation on water availability spatially across the watershed in all of the sub basins that currently have agriculture
4) Extend the results of the current irrigation scenarios to simulating a matrix of future climate scenarios along with future agricultural expansion within the basis and determine the stresses on water resources.

CHAPTER FIVE

HYDROLOGICAL MODELLING OF KILOMBERO AND KILOSA SUB-CATCHMENTS

5.1 Introduction

The adverse impacts of the changing climate on agriculture sector and environment are already vivid and have the potential to undermine and even undo progress so far attained in the development of the socio-economic well-being of Tanzanians. The threat to livelihood is even more serious considering agriculture is rain-fed and is the backbone of the Tanzanian economy. The impacts of climate variability and change can be significantly reduced by having sound adaptation strategies, which will contribute to resilience of staple food production particularly for rice and maize. These will enable farmers to make informed decisions on their farming practices including land and water management. Apparently, not much has been done to document and validate the impacts of climate variability and change in the various agricultural systems.

Distributed hydrological watershed models are increasingly being used to support decisions about alternative management strategies in the areas of land use change, climate change, water allocation, and pollution control. The main objective of this section was to set up hydrological model by using soil and water assessment tool (SWAT) model for prediction of stream flow changes.

Precipitation and temperature data are the key inputs in SWAT model. However, in developing countries, records collected in long periods of time contain gaps. The common practice has been to use SWAT's built in stochastic weather generator, WXGEN for filling missing data. This may not give realistic sequences of weather data and possibly affects the accuracy of predictions made by SWAT. During model set-up, a reduction of the number of model parameters was obtained using an LH-OAT sensitivity analysis.

The selected parameters were optimized by a manual and an auto-calibration. The auto-calibration and uncertainty analysis is based on Sequential uncertainty fitting (SUFI-2), generalized likelihood uncertainty estimation (GLUE). In general, a reasonably fair match was observed in the shape of simulated and observed hydrographs for the 1977 – 1985 calibration and 1986 – 1989 validation periods. The model evaluation statistics were verified by R^2 and NS values greater than greater than 0.5 and 0.4 during calibration and validation respectively, which is a satisfactory accuracy among the applications of SWAT model.

5.1.1 Specific Activities

The hydrological modeling entails using SWAT Model calibration in order to providing climate change projections 30 years into the future targeting some key catchments in the Rufiji Basin with keen interest in Kilosa and Kilombero districts in order to determine the overall climate change impacts on water availability (currently and in the future).

i. Carry out primary and secondary data (spatial and temporal) collection and documentation of the various data sets needed for the study
ii. Undertake detailed modeling of the hydrological system of the selected sub-basin of the Rufiji Basin
iii. Develop plausible scenarios for current, and future irrigation demand while taking into account different irrigation technologies, population growth and changing climate (i.e., Simulating the impact of climate change on water resources availability).

5.2 Study Area

5.2.1 Description of the Kilombero Sub-basin

The Kilombero Valley (Figure 16) of central Tanzania forms one of the four principal sub-basins of the Rufiji River Basin and covers an area of approximately 35,000 km². The Kilombero Valley is situated between 34°33′ E and 37°20′ E and between 7°39′ S and 10°01′S. In the northwestern part of the catchment, the Udzungwa Mountains rise up to 2576 m and are comprised of steep slopes and dense forest. Along the southeastern side the land rises more gradually, eventually changing to a steep escarpment and the Mahenge Mountains that reach a maximum height of 1516 m (Hughes and Hughes, 1992).

Tributaries originating in these mountains form the headwaters of the valley’s river system. In the valley’s central floodplain the main river becomes a braided network. The whole valley is thus a complex system with perennial and seasonal river channels, oxbows, swamps, ponds, lakes, grass and woodland. Kilombero Valley is generally hot and humid in the valley bottom with a mean daily temperature of 24°C and annual precipitation between 1200 and 1400 mm while the mountainous regions around the basin are considerably cooler and wetter with a mean daily temperature of 17°C and average annual precipitation ranging from 1500 to 2100 mm (ERB, 2006).

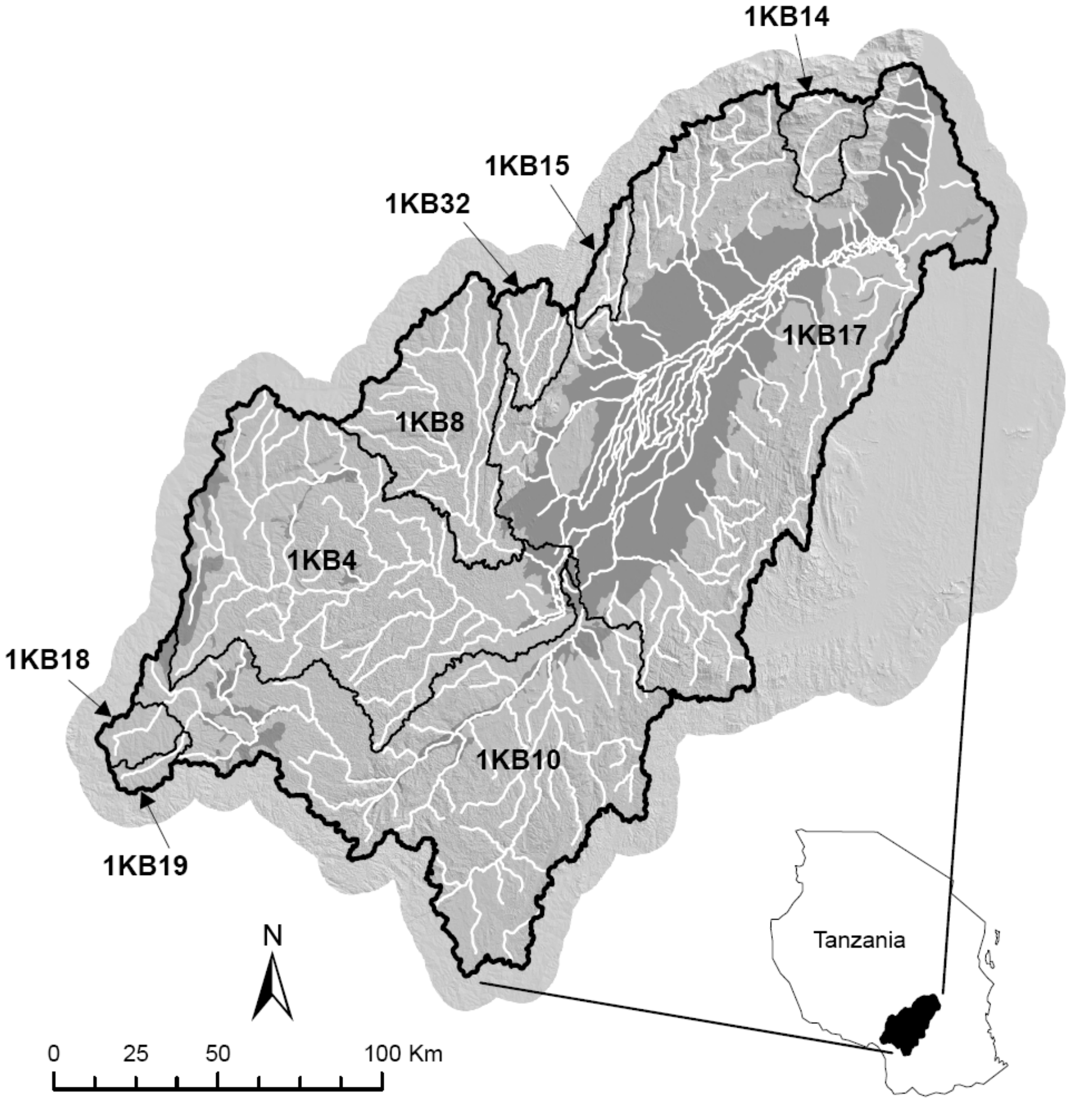


Figure 16: **Kilombero basin (Source: Lyon *et al.,* 2014)**

5.2.2 Description of Yovi Sub-basin

Yovi is a tributary of the Great Ruaha Basin. The basin is located between Latitude: -7°34'42.46" and Longitude: 36°47'28.4". Yovi River joins the Great Ruaha River downstream of the Mtera Dam.

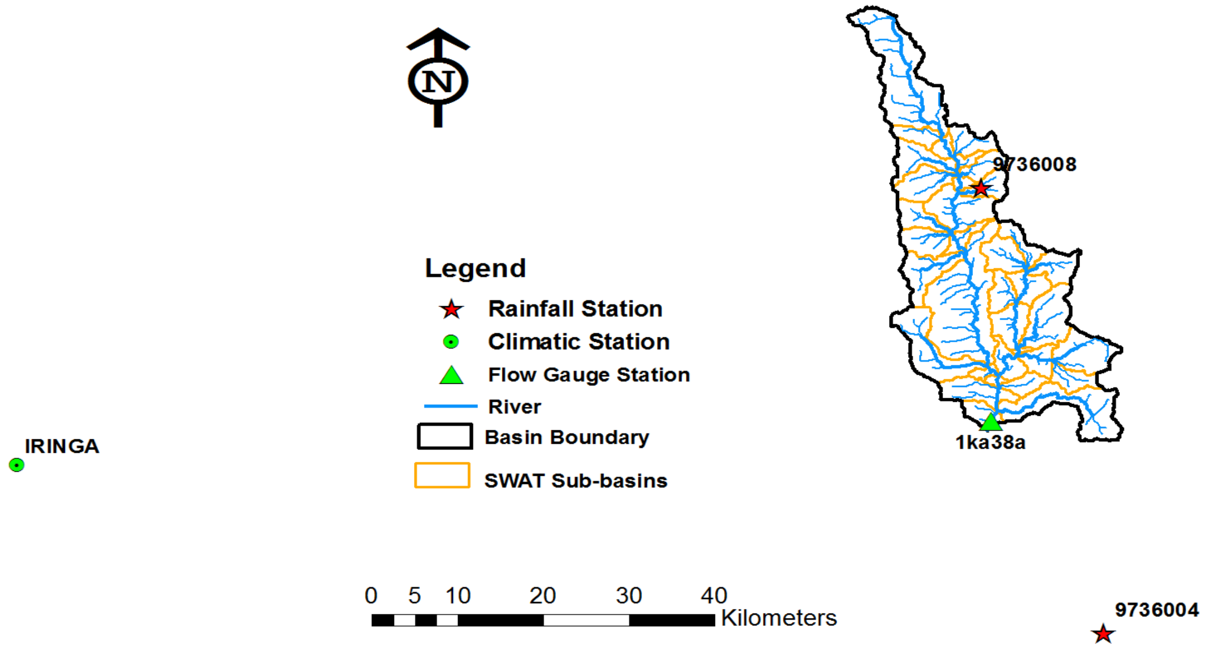


Figure 17: **Yovi River Sub-Basin**

5.3 Data and methods

5.3.1 SWAT model description

The Soil and Water Assessment Tool (SWAT) is physically based hydrological model developed by the USDA to predict the impact of land management practices on water, sediment and amount of chemicals originating from agriculture, in large complex river basins with varying soils, land use and management conditions over a long period of time. It uses hydrologic response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The hydrologic routines within SWAT account for snow fall and melt, vadose zone processes (i.e., infiltration, evaporation, plant uptake, lateral flows, and percolation), and ground water flows. The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw} \right)_i \qquad \text{(Eqn. 1)}$$

in which $SW_t$is the final soil water content (mm), SW_0 is the initial soil water content at the start of the simulation i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

Surface run-off is calculated using the modified Soil Conservation Service (SCS) curve number CN2 (USDA-SCS, 1972) technique when a daily time step is used or the Green and Ampt (1911) infiltration equation when an hourly or subdaily time step is used. In this study, the SCS curve number method was used. For evapotranspiration (PET) estimation, three options are available in SWAT: the Penman–Monteith method (Monteith, 1965), the Priestley–Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves *et al.*, 1985).

Penman–Monteith is considered the best but has high data requirements. Hargreaves or Priestley–Taylor have the advantage of needing less information and can be used when some of the weather data are missing. For this study, we have used the Hargreaves method. Interflow is computed as a function of topographical and soil hydraulic features. Water percolating from the bottom of the soil profile can join the shallow or the deep aquifer.

Seepage to the deep aquifer is considered as a loss from the model so only water from the shallow aquifer can produce slow flow in the river or re-enter the soil profile through capillary forces. The volume of slow, interflow and quick flow generated by HRUs are aggregated per sub-basin and routed through the stream network to the outlet off catchment. In SWAT, water is routed through the channel network using either the variable storage routing or the Muskingum River routing method. More detailed descriptions of the different model components are listed in Arnold *et al.* (1998) and Neitsch *et al.* (2005).

5.3.2 SWAT model input

5.3.2.1 Weather Data

SWAT requires daily meteorological data that can either be read from a measured data set or is generated by the WXGEN weather generator (Sharpley and Williams, 1990). These data are daily rainfall, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity. In this study, daily precipitation, minimum and maximum air temperature for the period 1977 – 1989 were used for driving the hydrological balance. The data is obtained from the Rufiji Water Basin Office, Tanzania Meteorological Agency (TMA) and the Water Resource Engineering Department (WRED) of the University of Dar es Salaam for stations located within and around Kilombero and Yovi basin.

Precipitation data

The precipitation data were available as daily totals from 34 gauges within the Kilombero Valley basin. These gauges all experienced periods of missing data and have varying periods of record covering 1957 through 1990. These data have been averaged spatially and temporally to estimate long-term monthly precipitation totals in this current study. All available daily precipitation records were also analyzed for inclusion in this analysis (Table 5).

The records are, however, characterized by long periods of missing data and are irregularly distributed within the basin. Most of the rainfall stations (83%) are located in the more populated areas, usually in the lower part of the basin while 17% are situated at elevations higher than 1000 m.a.s.l. The next step was to fill data gaps in the time period covered by each series. We focused on conceptually simple and computationally inexpensive methods based on the information from neighboring observatories.

Temperature data

The daily minimum and maximum temperature records were sparse and irregularly distributed in around the basin. We used linear regression to fill the missing data. Linear regression is very suited to obtaining reliable dependence models among a candidate observatory and auxiliary observatories used in the reconstruction (Vicente-Serrano et al, 2010). This approach has been used to reconstruct daily temperature series (e.g. Allen and DeGaetano, 2001), as this variable is not affected by abrupt spatial changes, and varies gradually in space.

WXGEN weather generator

WXGEN is used in SWAT to fill in and generating missing climatic data using monthly statistics. But these monthly statistics must first be calculated based on the available daily data, hence, WXGEN cannot be used for areas with no daily data. The WXGEN model defines the wet days based on a first-order Markov chain model, which means that it takes the wet or dry status of the previous day into account. The amount of precipitation is then generated using either a skewed distribution with three parameters (Nicks, 1974) or a one-parameter exponential distribution. Air temperature and solar radiation generation is done using a continuous multivariate stochastic process (Hayhoe, 1998).

Serially correlated and cross-correlated normally distributed residuals for maximum temperature, minimum temperature and solar radiation are required for the calculation of daily values (Richardson, 1981, Richardson and Wright, 1984). These correlation coefficients were originally determined for 31 stations in the US (Richardson, 1982) and then kept constant for application to all locations. While the minimum temperature does not depend on the wet or dry status of the day, the influence of wet/dry days is incorporated into the generation of the maximum temperature and the solar radiation. In this study, monthly weather statistics for close to the catchment were calculated from available daily weather records to parameterize the WXGEN weather generator.

Table 5: **Inventory of rainfall stations used in the study**

STNID	LAT	LONG	ELEVATION	DATA_LENGTH
9635010	-6.900	35.467	-	1959 – 1995
9736003	-7.667	36.000	1372	1957 – 1991
9736008	-7.300	36.783	-	1959 – 1993
9835009	-8.580	35.330	1859	1944 – 1994
9835019	-8.500	35.430	1890	1951 – 1991
9835022	-8.620	35.280	1951	1951 – 1991
9835024	-8.630	35.230	1981	1951 – 1990
9835025	-8.700	35.200	1890	1951 – 1991
9835026	-8.53	35.38	1920	1951 – 1991
9835034	-8.580	35.350	-	1951 – 1991
9934013	-9.570	34.670	2134	1968 – 1993
9934015	-9.420	34.750	1890	1950 – 1991
9934018	-9.230	34.870	1829	1954 – 1995
9934019	-9.250	34.830	1829	1954 – 1991
9934020	-9.230	34.770	1829	1954 – 1991

5.3.2.2 River Discharge Data

A total of 13 time series of daily streamflow from two different sources were considered. Some came from the Rufiji Basin Water Office, and the department of water resources engineering at the University of Dar es Salaam and constitute raw (i.e. unaltered) data available from stream monitoring stations. The data from the department of water resources engineering are based on Yawson *et al.* (2005) and have been processed to remove potential inaccuracies and to fill data gaps. Between these two sources, there were four redundant streamflow records such that we have streamflow data for 9 unique catchments (Table 6).

Missing discharge records were filled with a seasonal mean. Comparison of the results obtained using these gap-filled data indicates that this influence is likely small as the filled periods typically do not correspond to extensive drought periods and are mainly influencing the highest flows. However, the quality of the data considered here for climate change impact assessment unavoidably impacts the results. Regardless, there is still potential value in using the best available data since these data increase spatial coverage of this study. Precipitation data from the valley and surrounding area were available from the department of water resources engineering at the University of Dar es Salaam and the Rufiji Basin Water Office.

Table 6: **Stream flow datasets considered in this study from the Kilombero Valley, Tanzania**.

Catchment ID	Period of Record	Missing data (%)	Type
1KB4	1955-1982	0	processed data
1KB8	1956-2007	27	raw data
1KB10	1960-1987	0	processed data
1KB14	1958-2002	23	raw data
1KB15	1960-1989	4	raw data
1KB17	1957-1981	15	raw data
1KB18	1976-2010	20	raw data
1KB19	1961-1978	3	raw data
1KB32	1984-2011	36	raw data

5.3.2.3 Spatial Data

Digital elevation model (DEM) data

In addition to hydrologic data, several spatial datasets were considered to characterize the catchments. Catchment drainage areas and corresponding topographic information were derived from a Shuttle Radar Topography Mission (SRTM) digital elevation model with a 90 m raster resolution. Vegetation coverage, soil information, and landform data were obtained from the FAO's Africover and Geo-Network datasets (both available through www.fao.org/geonetwork) and had spatial resolutions ranging from 1:100,000 to 1:350,000.

Land use and soil data

The 1km resolution landuse data from the Global Land Cover Facility (Hansen et al., 2000) was used to determine the types of land use and cover for the two basins. The land use map was generated from AVHRR satellites imagery acquired between 1981 and 1994. The main land cover types are Forests (21%) in the upper slopes, Dryland cropland and pasture (77%), Cropland/woodland mosaic (0.9%), Shrubland (0.9%) and Savanna (0.2%).

Land use is one of the most important factors that affect surface erosion, runoff, and evapotranspiration in a watershed. The soil data used in this study was from FAO/UNESCO 1:5 million scale soil maps (FAO/UNESCO, 2003). Major soil types in the basin are clay loam and sandy loam with soil hydrological group C ratings (USDA–SCS, 1972). SWAT requires different soil textural and physicochemical properties such as available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These values were obtained from literatures.

5.3.3 SWAT model setup

The model set-up involved input data preparation, watershed delineation and HRU analysis. The watershed delineation process include five major steps, DEM set-up, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. A drainage area of 18 km^2 was used as the threshold for the delineation and it produced 21 sub catchments in the study basin. The hydrological response units (HRUs) were defined based on land cover, soil, and slope information.

The topographic slope was derived from the DEM by using the SWAT's HRU definition tool. Three categories of slope (0-8%, 8-30%, and greater than 30%) were used in the HRU definition. These slope categories represent level to undulating lands (0-8% slope), steep lands (8-30% slope), and mountains area (>30% slope) (FAO, 1995). A threshold value of 20 % land use, 10 % soil and 20% slope was used in the multiple HRU definition option.

The ArcSWAT user's manual suggests that those thresholds are adequate for most applications. Subdividing the sub watershed into hydrological response units (HRU's), which are areas having unique land use, soil and slope combinations makes it possible to study the differences in evapotranspiration and other hydrological conditions for different land covers, soils and slopes (Setegn *et al.,* 2010).

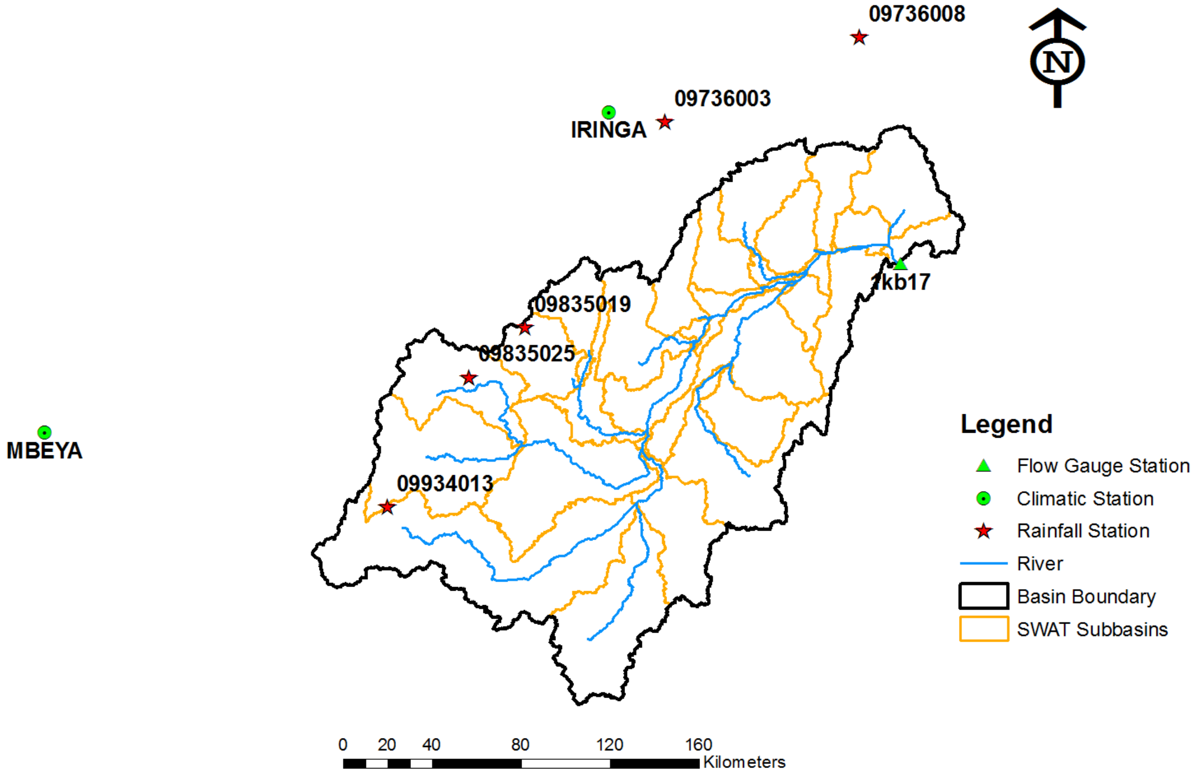


Figure 18: **Delineated Kilombero River Basin**

5.3.4 Identification of most sensitive model parameters

Sensitivity analysis is important to indicate the most influential parameters and for assessing if the model is over-parameterised. The sensitivity analysis method implemented in SWAT is Latin Hypercube one-factor-At-a-Time (LH-OAT) (van Griensven et al., 2004). The LH-OAT method combines the OAT-design (Morris, 1991) and Latin Hypercube sampling (McKay et al., 1979) by taking the Latin Hypercube samples as initial points for an OAT-design.

As a result, the LH-OAT sensitivity analysis method is a robust and efficient method: for *m* intervals in the LH-method, a total of m×(n+1) runs is required. Here, the sensitivity analysis was performed for all 27 parameters that may have a potential to influence Kilombero and Yovi River flow. The details of all hydrological parameters were derived from Winchell et al., (2007) and Holvoet *et al.* (2005).

5.3.4.1 Model calibration, uncertainty analysis and validation

After setting up the model, the default simulation of stream flow, using the default and initially determined parameter values, was run at a daily time. The data for period 1960–1966 were used for calibration and from 1967 to 1969 were used for validation of the model at Kilombero (1KB17) gauging station. The data for period 1960–1963 were used for calibration and from 1968 to 1974 were used for validation of the model at Yovi (1KA38) gauging station. The calibration and uncertainty analysis were done using the ***Sequential uncertainty fitting (SUFI-2) algorithm***: In SUFI-2, parameter uncertainty is assumed to account for all sources of uncertainties such as uncertainty in driving variables (e.g. rainfall), parameters, conceptual model and measured data (e.g. observed flow).

The degree to which all uncertainties are accounted for is quantified by a measure referred to as the *p*-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. Another measure quantifying the strength of a calibration/uncertainty analysis is the *r*-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data (large *p*-factor, maximum 100%) with the smallest possible uncertainty band (small *r*-factor, minimum 0). When acceptable values of *r*-factor and *p*-factor are reached, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the R^2 and/or Nash-Sutcliffe (NS) coefficient between the observations and the final “best” simulation. Coefficient of determination (R^2) calculated as:

$$R^2 = \frac{\left[\sum_i (Q_{m,i}-\bar{Q}_m)(Q_{s,i}-\bar{Q}_s)\right]^2}{\sum_i (Q_{m,i}-\bar{Q}_m)^2 \sum_i (Q_{s,i}-\bar{Q}_s)^2} \qquad \text{(Eqn. 1)}$$

Nash-Sutcliffe (1970) coefficient (NS) calculated as:

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^{\,2}}{\sum_i (Q_{m,i}-\bar{Q}_m)^2} \qquad \text{(Eqn. 2)}$$

5.4 Results and Discussion

5.4.1 Parameter sensitivity analysis

Sensitivity analysis was conducted to determine the influence a set of parameters had on predicting total flow in the study area. The analysis was carried out based on the SSQ objective function for the 27 model parameters and 10 intervals of LH sampling. Results of the sensitivity analysis are shown in Table 7. The greater the mean sensitivity, the more sensitive a model output variable is to that particular parameter. Those with mean sensitivity ≥1 were considered as high sensitive parameters, whereas those with 0.1 ≤ mean sensitivity < 1 are considered as normally sensitive ones and values less than 0.1 indicate low sensitivity (Ndomba *et al.,* 2008, Li *et al.,* 2010).

The most sensitive parameters for flow are sequentially Cn2, Alpha_Bf, Ch_K2, Esco, Sol_K, Surlag, Canmx, Slope, Sol_Awc, Ch_N2 and Sol_Z. Generally, those parameters govern the surface and subsurface hydrological processes and stream routing. This result illustrates how parameter sensitivity is site specific and depends on land use, topography and soil types, as compared to other studies elsewhere.

Table 7: **Parameters ranges, sensitivity ranking, and category of the most sensitive parameters. Min and Max refer to the lower and upper bounds of parameter**

Parameter	Description	Min.	Max.	Rank	Mean	Level	Process
Cn2	SCS runoff curve number for moisture condition II[b]	-50	50	1	7.600	High	Runoff
Alpha_Bf	Base flow alpha factor for recession constant[a] (days)	0	1	2	0.806	Normal	Groundwater
Ch_K2	Channel effective hydraulic conductivity[a] (mm/hr)	0	150	3	0.773		Channel
Esco	Soil evaporation compensation factor[a]	0	1	4	0.459		Evapotranspiration
Sol_K	Saturated hydraulic conductivity[b] (mm/hr)	-50	50	5	0.340		Soil
Surlag	Surface runoff lag time[a] (days)	0	10	6	0.318		Runoff
Canmx	Maximum canopy storage[a](mm)	0	10	7	0.269		Runoff
Slope	Average slope steepness[b] (m/m)	-50	50	8	0.253		Geomorphology
Sol_Awc	Available soil water capacity[b] (mm H_20/mm soil)	-50	50	9	0.220		Soil
Ch_N2	Manning's ''n'' value for the main channel[b]	-50	50	10	0.216		Channel
Sol_Z	Soil depth[b] (mm)	-50	50	11	0.147		Soil
Rchrg_Dp	Deep aquifer percolation fraction[a]	0	1	12	0.069	Low	Groundwater
Gwqmn	Threshold water depth in the shallow aquifer for flow[c] (mm)	0	5000	13	0.047		Groundwater
Biomix	Biological mixing efficiency[a]	0	1	14	0.028		Soil
Gw_Revap	Groundwater ''revap*'' coefficient[a]	0.02	0.2	15	0.016		Groundwater
Slsubbsn	Average slope length[b] (m/m)	-50	50	16	0.015		Geomorphology
Epco	Plant evaporation compensation factor[b]	-50	50	17	0.009		Evaporation
Revapmn	Threshold water depth in the shallow aquifer for revap[*][a](mm)	0	500	18	0.005		Groundwater
Gw_Delay	Groundwater delay time[c] (days)	0	100	19	0.001		Groundwater
Sol_Alb	Moist soil albedo[a]	0	1	20	0.000		Soil
Blai	Leaf area index for crop[b]	-50	50	21	0.000		Crop

[a] replace by value [b] multiplication of value, [c] addition of value, [*]Revap is defined as the movement of water into overlying unsaturated zone

5.4.2 Model calibration and validation

In this application, the SWAT model was formulated with two scenarios. The default simulation of stream flow, using the default parameter values and daily weather data (precipitation, maximum and minimum temperatures) filled with the WXGEN weather generator was the first scenario (Case I). For the second scenario (Case II), daily weather data were filled in using filled in from nearby stations using algorithms tested in this study. A comparison was made between the model performance achieved by Case I and Case II. The results indicate that Case II improved the simulation of streamflow using the Coefficient of Determination (R^2) and the Nash-Sutcliffe efficiency (NS) respectively. We therefore, adopted Case II parameterization for further simulations.

SWAT model has a large number of model parameters that are used to incorporate the spatial heterogeneity of watershed characteristics and processes into a simulation. Based on the sensitivity analysis results (Table 8), a total of 18 model parameters that govern the hydrologic processes in SWAT were selected for calibration. Some of parameters have a very low sensitivity to the model, but were included because they are related to water components of the hydrological cycle that needed to be optimized.

Before applying auto-calibration, a rigorous manual calibration ranging exercise was performed. This helped in defining suitable initial values/ranges of the parameters, which were based on the information from various sources of information that included measured data, global data sources, SWAT soil and land cover database, literature, discussion with the local experts, and field visits. The resulting parameter values/ranges were in line with the literature (e.g., Neitsch et al., 2005; van Griensven et al., 2006; Van Liew et al., 2007). The auto-calibration and uncertainty analysis were done using SUFI-2. Once calibration of the model was completed, validation was performed to check the ability of the fitted model to predict values from an observational data set different from the calibration data.

The comparison between the observed and simulated streamflow indicated that there is a fairly good agreement between the observed and simulated discharge which was verified by coefficient of determination (R^2) and NS-coefficient values greater than 0.5 and 0.4 during calibration and validation respectively. Calibrated and validated model predictive performances for the Kilombero and Yovi Rivers on daily flows are summarized in Table 4 for all calibration and uncertainty analysis methods.

Table 8: **Stream flow calibration and validation results for Kilombero river basin using SUFI-2**

	Calibration (1960-1966)				**Validation (1967-1969)**			
Objective function	**R^2**	**NS**	**p-factor**	**r-factor**	**R^2**	**NS**	**p-factor**	**r-factor**
Kilombero (1KB17)	0.75	0.72	81%	0.58	0.56	0.48	76%	0.52

Table 9**: Stream flow calibration and validation results for Yovi river basin using SUFI-2**

	Calibration (1960-1963)				**Validation (1968-1974)**			
Objective function	**R^2**	**NS**	**p-factor**	**r-factor**	**R^2**	**NS**	**p-factor**	**r-factor**
Yovi(1KA38)	0.71	0.68	78%	0.52	0.62	0.59	78%	0.51

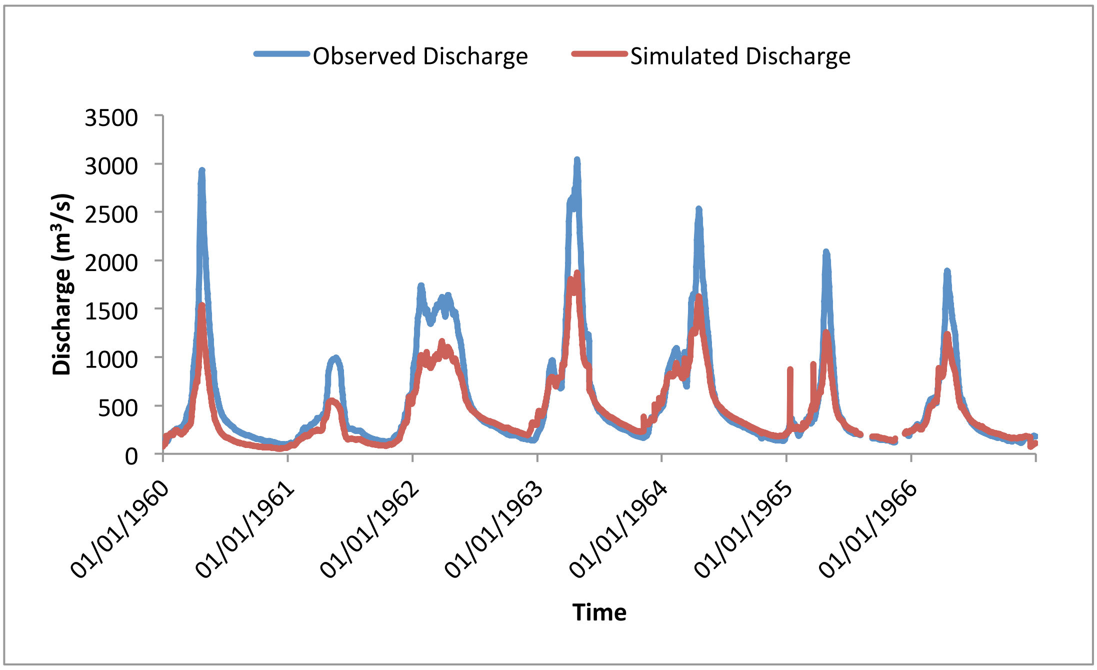


Figure 19: **SWAT calibration results for the Kilombero basin gauging station (1KB17) for the period 1960-1966**

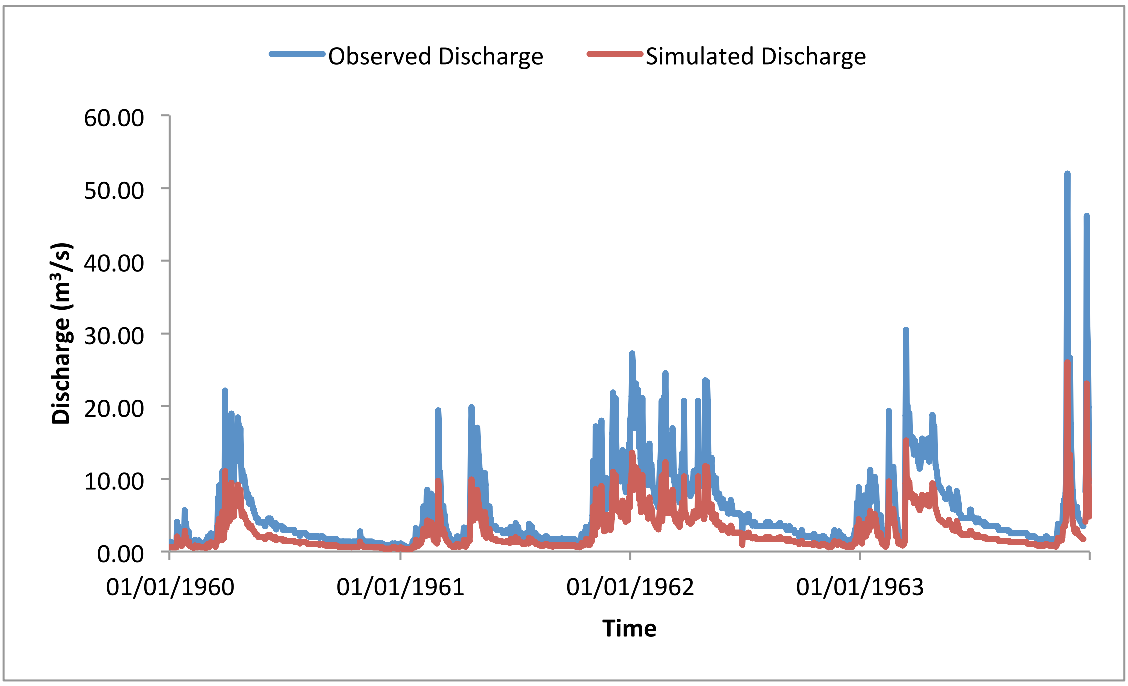


Figure 20**: SWAT calibration results for Yovi basin gauging station (1KA38) for the period 1960-1963**

5.5 Climate change impact assessment

5.5.1 Data and methods

The CORDEX GCM ensembles projections for 2051-2100 were obtained from the Swedish and Danish Meteorological and Hydrological Institute. Eight (8) GCM's were downscaled using the Rossby Centre Regional Climate Model (RCA4) for the whole African domain at 0.44^o resolution for both RCP 4.5 and 8.5 climate change scenarios for the period 1951-2100 (historical 1951-2005 and future 2006-2100).

The table below gives GCM's with corresponding RCM and scenario used. The table also shows originating institute where; Danish Meteorological Institute(**DMI**),; Swedish Meteorological and Hydrological Institute (**SMHI**), the Royal Netherlands Meteorological Institute (**KNMI**),, Université du Québec à Montréal (**UQAM**) National Centre for Meteorological Research (CNRM), Canadian Centre for Climate Modeling and Analysis (**CCCma**);Max Plank Institute (**MPI**); **NCC** National Climate Centre ;Geophysical Fluid Dynamics Laboratory (***GFDL***) , Aire Limitée Adaptation dynamique Développement (**ALADIN**)

Table 10: **GCM with corresponding RCM, and Scenario used**

GCM	**RCM**	**Institute**	**Near Future**	**Scenario**
NCC-NorESM1_SMHI-RCA4	RCA4	NCC	2031-2060	RCP 4.5
MPI-ESM_SMHI-RCA4	RCA4	MPI	2031-2060	RCP 4.5
MIROC-MIROC5_SMHI_RCA4	RCA4	SMHI	2031-2060	RCP 4.5
GFDL-ESM2M_SMHI-RCA4	RCA4	GDFL	2031-2060	RCP 4.5
CNRM-CM5_SMHI-RCA4	RCA4	CNRM	2031-2060	RCP 4.5
CCCma-CanESM2_SMHI_RCA4	RCA4	CCCma	2031-2060	RCP 4.5
MOHC-HadGEM2_SMHI-RCA4	RCA4	MOHC	2031-2060	RCP 4.5
EC-EARTH_SMHI-RCA4	RCA4	ICHEC	2031-2060	RCP 4.5

5.5.1.1 Downscaling methods

The delta change approach is a method that makes the output of GCMs useful for catchment scale analysis and hydrological modeling (which means that the GCM outputs are used indirectly). The method is based on the use of a change factor, the ratio between a mean value in the future and historical run. This factor is then applied to the observed time series to transform this series set into time series that is representative of the future climate. Various approaches are used for generating climate change projections for the future. Three of the most widely used approaches includes; i) Use of raw GCM data ii) Delta change (perturbation) method ii) GCM bias correction climate change projection.

In the use of raw GCM time series approach the impact of climate change is estimated by comparing the modeled future climate condition relative to the modeled historical climate condition. The main assumption here is that GCM's are capable of reproducing the present climate in addition to modeling how the regional climate will evolve in response to changes in greenhouse gases and aerosols. The delta change method the difference between the baseline and future GCM simulations are applied to historical observations (Hay *et al.,* 2000; Reynard *et al.,* 2001; Fowler *et al.,* 2007; Prudhomme *et al.,* 2002). Under delta change approach there are two methods: (i) the constant scaling method and (ii) the quantile-quantile scaling method (also known as the daily scaling method).

The bias correction approaches uses the GCM simulated time series taking account of the bias in the GCMs' outputs against the historical climate. The major aim of bias correction is to adjust GCM output so that it statistically 'matches' the observations during a historical overlap period. This method uses three datasets: i) observed historical climate time series ii) GCM simulated historical time series iii) GCM simulated future climate time series. Then the bias correction is done by comparing datasets (i) and (ii) and bias correction factor is then applied to dataset (iii).

In this research the delta change approach was used to generate time series of future precipitation and temperature for hydrological modeling. The assumption used in delta change method is that there are no change in variability and spatial patterns but it eliminates the biases associated with using GCM data. The RCM projections of change in monthly precipitation and potential evapotranspiration were estimated using the delta change approach where future climate conditions are compared to a reference period 1976-2005. In the present study, two 30-year windows were used, 1976–2005 as historical and 2031–2060 as future period, according to the 30-year definition of the climate normal. Throughout the analysis the spatial resolution of the RCM data (0.44 deg.) is maintained in order to describe spatial differences in the change signal.

5.5.1.2 Hydrological modelling methods

Hydrological modelling setup for both baseline and near future scenarios of climate change was evaluated within SWAT for the selected GCMs. The SWAT model were used to simulate the future scenarios of climate change and to evaluate their impact on Kilombero basin.

5.5.2 Results

5.5.2.1 Future scenarios of change in temperature

Results show a 1.5 to 2.3 degree temperature increase throughout the year across all RCM models suggesting that the Kilombero and Yovi basin will become warmer by 2060. Temperature increase has implications on evaporation and soil moisture storage. Evaporation component plays an important part in the water balance of the basin such that a slight increase in temperature might lead into high evaporative losses and eventually leading to less runoff. Figure 21 below shows the changes predicted by thirteen RCM's, all in agreement of temperature increase.

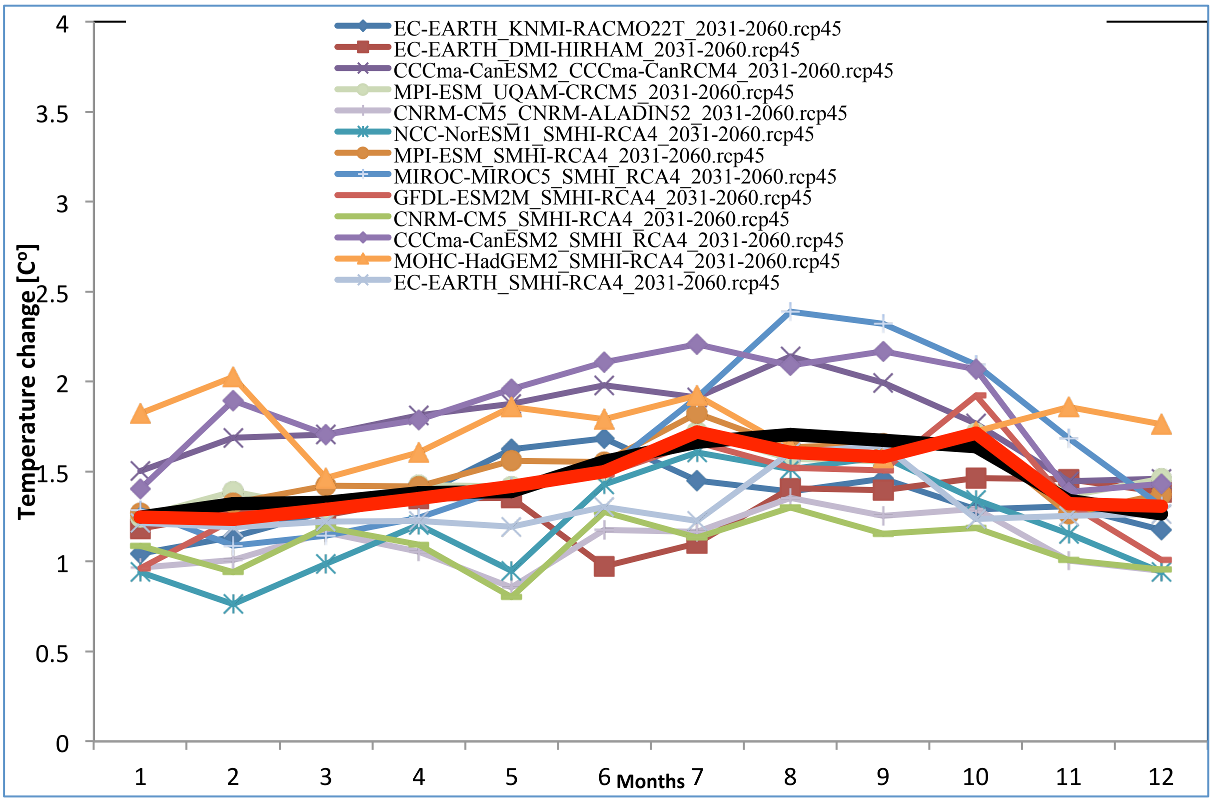


Figure 21: **Temperature trends in the Rufiji basin: a consistent 2-3 degree temperature increase across all RCM models**

5.5.2.2 Future scenarios of change in rainfall

The section presents an assessment of rainfall changes in the Rufiji basin sub-basin by 2060. The changes are examined based on delta change signals applied to the observed rainfall (1976-2005). Results indicate a clear tendency across the RCM to increased precipitation in the wet season and decreased precipitation in the dry season with an overall annual increase in precipitation. Rainfall seasonality (unimodal) has been well captured.

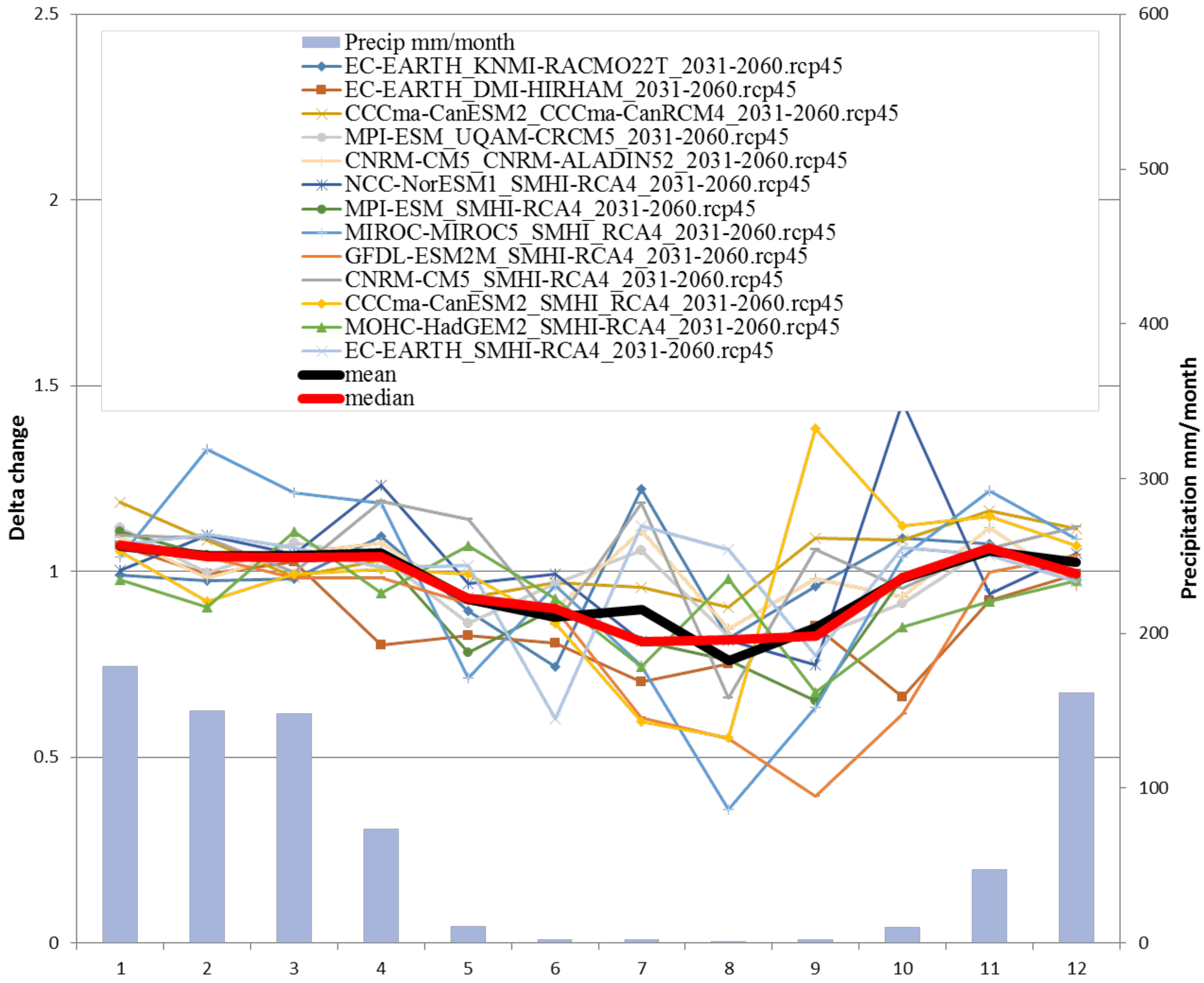


Figure 22: **Results indicate a clear tendency across the RCM to increased precipitation in the wet season and decreased precipitation in the dry season with an overall annual increase in precipitation.**

5.5.3 Climate change impacts on the hydrology of the Kilombero and Yovi Sub-Basins

The established hydrological model (SWAT) with behavioural has been utilized to simulate the effects of climate change projections on stream flow as given by three (3) GCM/RCM combinations using the RCP 4.5 emission scenario for the near future period 2031-2060. The RCM projections of change in monthly precipitation and temperature were estimated using the delta change approach where future climate conditions are compared to a reference period 1976-2005. Preliminary results based on three GCM_RCM combinations (NCC_RCA4, MPI-ESM_CRCM5 and MIROC5_RCA4) clearly indicate a shift in mean discharge (Figure 23). There are notable changes in both high and low flows. In all three GCM-RCM combinations, low flows are lower than the historical flow conditions, while high flows are higher than historical flow conditions. The high flows correspond to the projected increase in precipitation where initial results indicate a clear tendency across the RCM to increased precipitation in the wet season and decreased precipitation in the dry season with an overall annual increase in precipitation. Temperature tends to increase due to a consistent 2-3 degree temperature increase across all RCM's. The decrease in low flows is largely a result of the increased evapotranspiration and, therefore, decreased soil moisture storage.

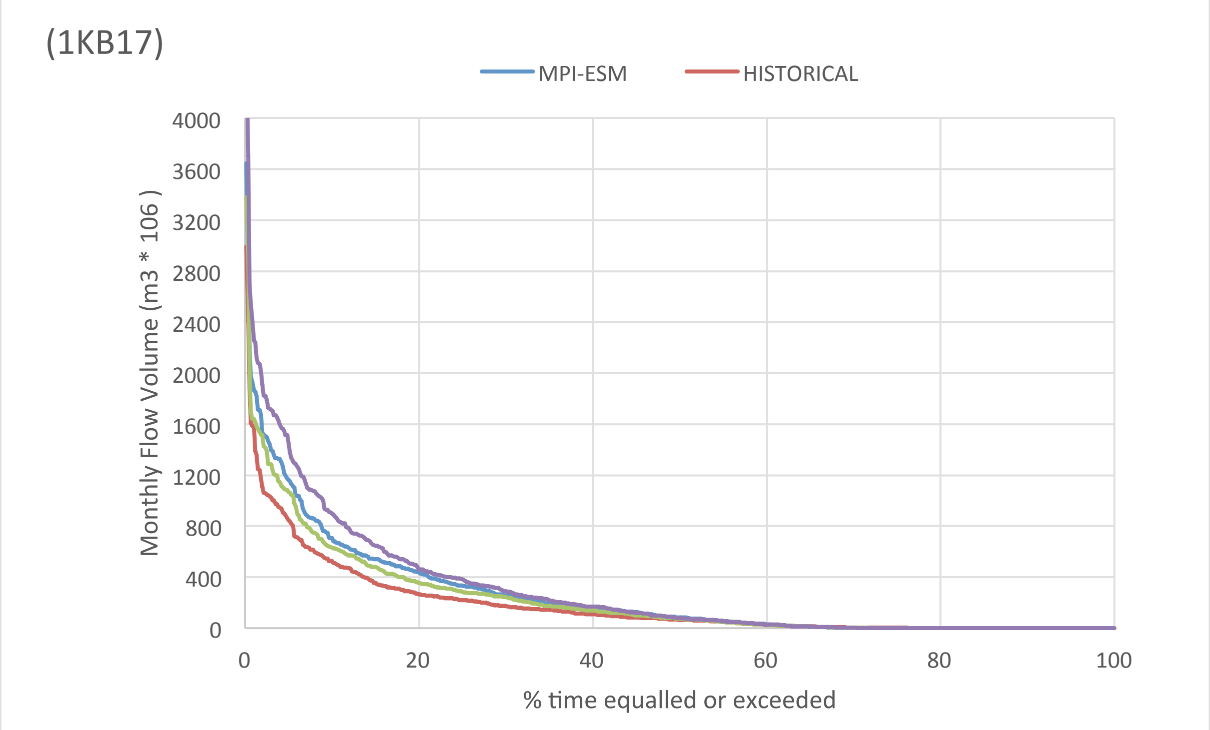


Figure 23: **Flow duration curve plotted with normal scale indicating the historical and near future stream flows for sub-basin 1KB17. The red continuous line is the historical stream flow for the period (1976-2005)**

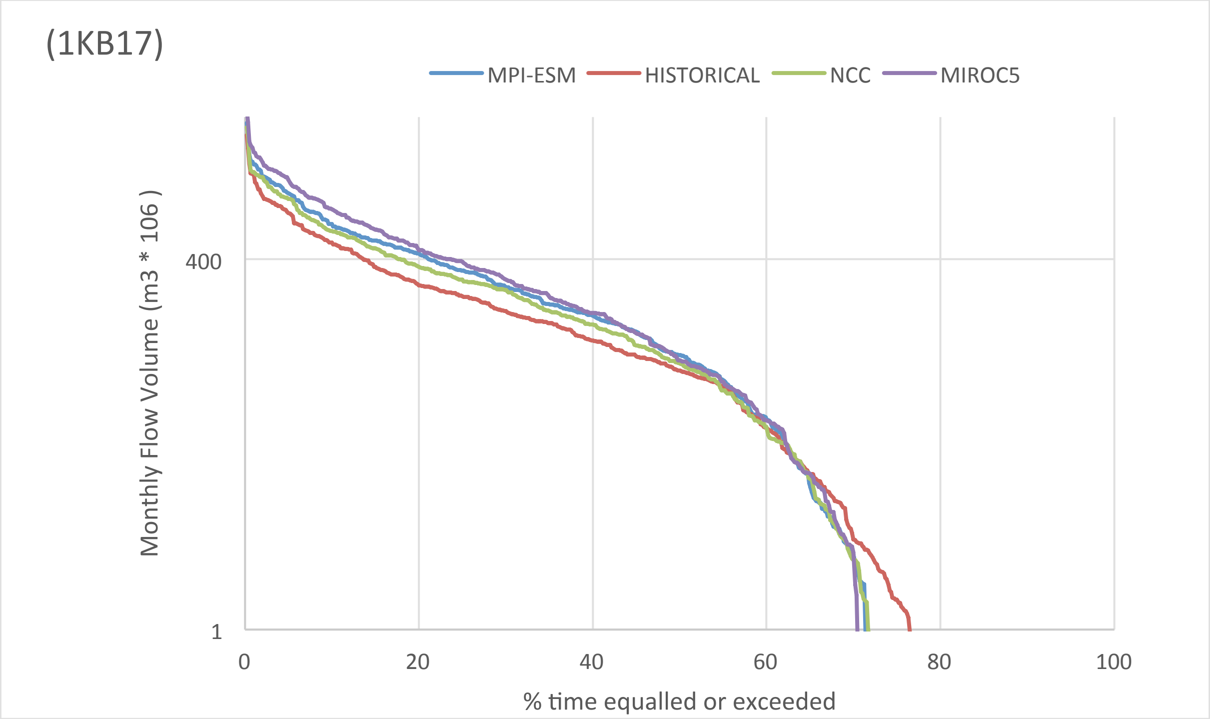


Figure 24: **Flow duration curve plotted with logarithmic indicating the historical and near future stream flows for sub-basin 1KB17. The red continuous line is the historical stream flow for the period (1976-2005)**

5.6 Summary

The impacts of hydrological changes resulting from projected changes in climate may be particularly severe for the Kilombero system given its role as a vital area for providing food, water and livelihoods support. Although General Circulation Model (GCM) simulated temperature can be relatively consistent between GCMs, Precipitation predictions from different GCMs often disagree even in the direction of change. Therefore care should be taken in the interpretation precipitation results from GCM's/RCM. Management practices on water uses in the sub basin are encouraged to be taken under the quantified uncertainty level depending on the decided level of uncertainty of GCMs/ RCM and the uncertainty related to the hydrological model.

CHAPTER SIX
THE IMPACT OF CLIMATE CHANGE ON RICE AND MAIZE IN THE RUFIJI BASIN

6.1 Background on the vulnerability of rice and maize

6.1.1 Vulnerability of rice production

Rice (Oryza spp.) is a tropical plant that thrives in hot and warm climates. Although rice grows best in warm daytime temperatures, extreme heat events over 35°C for even a few hours can damage plant processes and lead to lower yields and sterility (Figure 25). Rice is also sensitive to cold temperatures, which can slow growth and damage the plant causing smaller or failed harvests. Warmer nighttime (minimum) temperatures also reduce yields; it is estimated that yields decline 10% for every 1°C rise in minimum temperatures (Laborte *et al.* 2012; Welsh *et al.* 2010).

With climate change, temperatures are steadily warming in the Rufiji Basin. Hot temperatures over 35°C are becoming more frequent, and minimum temperatures are rising faster than maximum temperatures. Unless there are adaptation approaches to reduce these impacts, rice may be increasingly susceptible to warmer and extreme temperatures. On the other hand, higher elevation zones are warming rapidly and they may become more favorable for rice production.

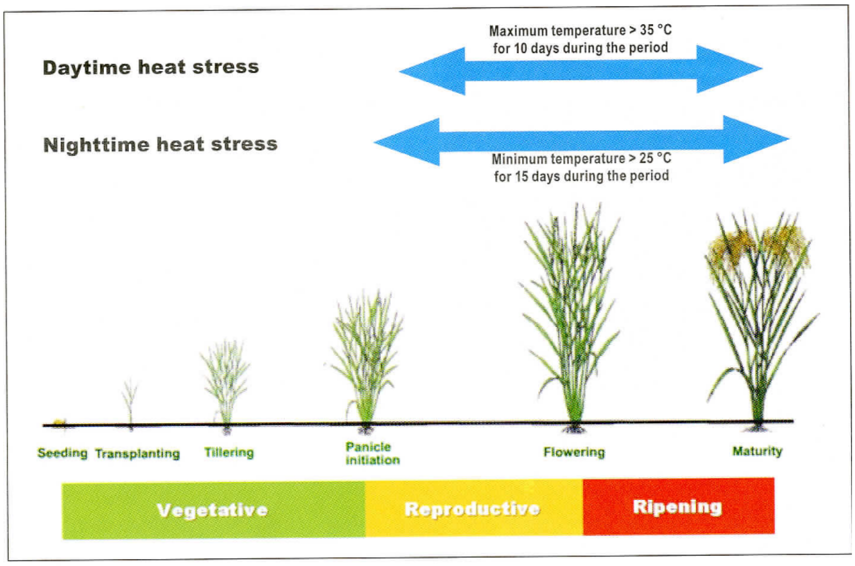


Figure 25: **Temperature Thresholds at Critical Growth Stages of Rice**

Source: Laborte *et al.,* 2012.

Rice is also demanding of water, requiring substantially more than maize or other grain crops grown in Tanzania. Although it does not require continuously saturated soil, it grows very poorly if it is water stressed particularly during its transplanting and reproductive stages. Most of the rice grown in the Rufiji Basin is under rainfed conditions with minimal irrigation, so precipitation amounts and timing are critical. Depending on the variety (especially the duration of its growing cycle), it can require between 450 and 700 mm during its growing season, or between 900 to 2,250 mm/day (FAO, 1985).

Increasingly, large and small-scale farmers are growing two seasons of rice per year by irrigating during the dry period in different parts of Rufiji basin. The area under rice cultivation is also expanding rapidly (Figure 26). The area under rice that was identified with 1997 satellite images, therefore, has greatly expanded, perhaps doubled (Figure 27).

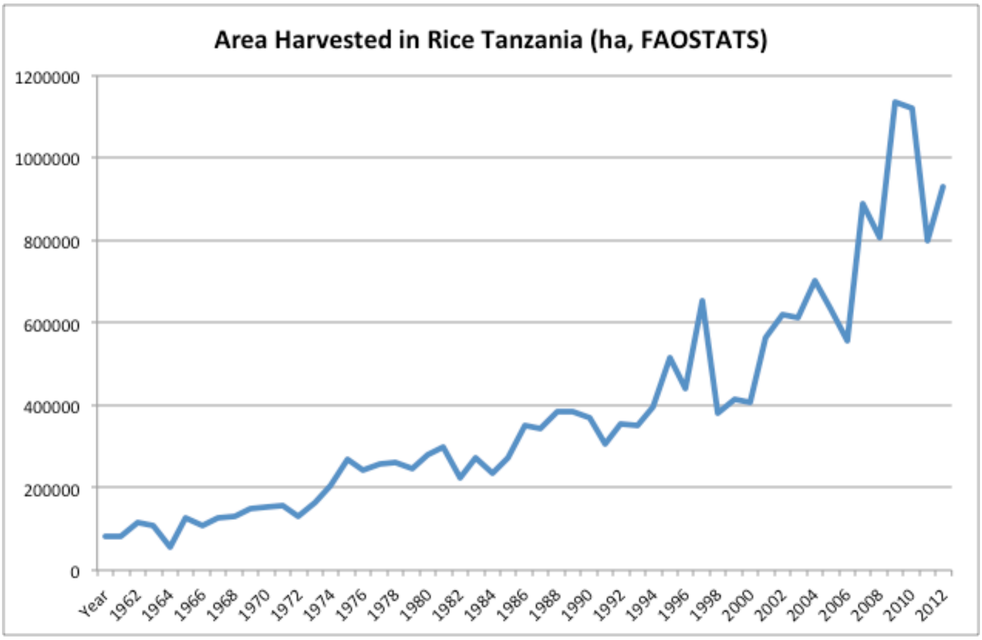


Figure 26: **Area (ha) Harvested Under Rice in Tanzania, 1962 to 2012.**

Data source: FAO, 2014.

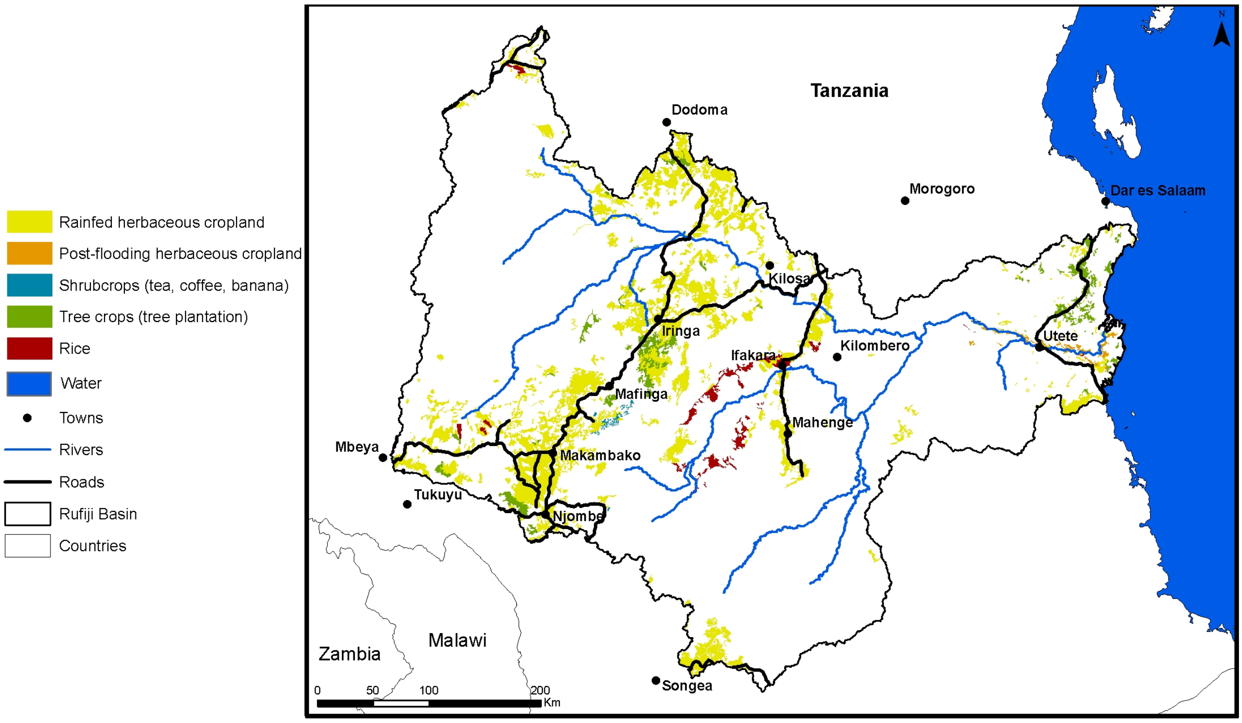


Figure 27: **Agricultural Land Use in 1997**

Data source: Africover-Tanzania (Lathan *et al.,* 2002).

This expansion and intensification of rice production is leading to a rising demand for irrigation water. Climate change is, however, expected to negatively impact water availability for rice during the rainy season due to alterations in total amount, irregular distribution of precipitation and the possible shortening of the rainy season. Rainfall events are becoming fewer but more intense, which would lead to less infiltration and more runoff, so less water available for the plants. Similarly, longer dry spells in the rainy season could lead to periods of water stress affecting particularly the transplanting and reproductive stages.

6.1.2 Vulnerability of Maize production

Maize (Zea Mays) is a tropical grass, yet is vulnerable to climate change. Its temperature range is greater than for rice, especially its ability to withstand cooler temperatures (note distribution of the class “rainfed herbaceous crop”, which is mostly maize, in cool highland zones in Figure 16). However, its growth and yields are also affected by hot temperatures over 35°C; temperatures above 35°C are considered inhibitory at whatever stage of growth. Generally, the warmer the temperature, the faster the plant completes its development (phenology). In warm temperatures such as in Tanzania, the more rapid phenology leads to lower yield as the plant matures rapidly before grains are large. Like rice, warmer nighttime temperatures reduce its yield while increasing its water demand (FAO 2013). Recent temperature trends in Rufiji—more frequent hot days, warmer nighttime temperatures, and generally warmer temperatures—would thus negatively affect maize growth and reduce maize yields.

Water requirements for maize vary greatly depending on variety, soil and temperature, but generally it does best between 500 to 800 mm/growing season. However, yields are very sensitive to water deficits during the flowering period. Severe water deficits during that period, particularly at the time of silking and pollination, may lead to little or no yield, or to a reduction in the number of grains per cob (FAO 2013).

Maize is thus particularly vulnerable to breaks, or dry spells, in the rainy season that occur during flowering. Farmers in Rufiji have noticed an increase in the length and frequency of dry spells in the season, and this could threaten yields. Other changes in precipitation, particularly in growing season amounts and length, would also affect growth and yield. Warming temperatures, with associated more rapid phenology and higher evapotranspiration and water requirements, combined with declining precipitation, could significantly affect maize yield in the Basin.

6.2 Methodology

Crop models simulate the growth of crops such as rice and maize under various conditions. They can replicate the impact of individual or a combination of changes in temperature, water, nutrients or other management factors on crop growth and production. Dynamic crop growth models in particular, which simulate the daily growth patterns responding to daily changes in the plant's environment, are useful in identifying the impact of dry spells, extreme temperature events or other within-seasonal events.

For this project, we selected two dynamic crop growth models, the CERES Maize and the CERES rice model embedded in the Decision Support System for Agrotechnology Transfer (DSSAT) crop modeling framework (Hoogenboom *et al.,* 2010). DSSAT version 4.5 was used in this project. The DSSAT crop models have been extensively tested in many parts of the world. Jones et al. (2003) refer to 15 studies in Africa that involved detailed crop model calibration and validation, several of which involved the testing of CERES-Maize in the study region (Muchena and Iglesias, 1995; Thornton et al., 1995, 2009; Wafula, 1995; Schulze, 2000).

The challenge with crop models is calibrating the model to best replicate local conditions and observed plant growth and yield. This process is generally difficult in Africa and many other places due to limitations of available environmental data (soil characteristics and daily climate), detailed cultivar information, and measured plant growth and yield statistics. Our approach was to obtain as much data as available for Tanzania or for similar locations, use globally available datasets as appropriate, and communicate with modeling and agronomic experts to respond to our results.

We conducted two types of analyses—the impact of historical (observed if possible) climate variability on yield, and the impact of projected future climate change on yield. For the historical analysis, 17 meteorological stations in the Rufiji River Basin were selected based on data availability and distribution across the Basin. Their elevation ranges from over 2000 meters to near sea level (see Table 11). For the purposes of this report, results from seven of those locations (in bold and italics) are provided. They were chosen for their importance in rice production and because of availability of meteorological station data.

Table 11: **Selected Meteorological Stations in Rufiji River Basin**

S_N	STN_NO	NAME_TOWN	STATION_NAME	LAT_DD	LONG_DD	ELEV_M
32	9635011	Dodoma Rural-1	Ilangali	-6.80	35.08	762
31	9635010	Dodoma Rural-2	Kinunguru	-6.90	35.47	972
25	9635001	Dodoma Urban	Dodoma Airport	-6.17	35.77	1120
50	9734001	Iringa Rural-1	Msembe Ferry	-7.75	34.90	2600
64	9735013	***Iringa Rural-2***	Iringa Met Stn.(Nduli)	-7.63	35.77	1428
169	9835053	***Kilolo***	Dabaga Seed Farm	-8.08	35.80	1829
194	9836013	***Kilombero***	Ifakara Katrin	-8.17	36.67	251
85	9736006	***Kilosa***	Malolo	-7.33	36.58	511
4	9534000	Manyoni	Manyoni District Office	-5.73	34.83	1248
120	9834010	Mbarali-1	Kimani	-8.83	34.17	1189
116	9834006	***Mbarali-2***	Igawa Maji	-8.77	34.38	1067
49	9636039	Mpwapwa-1	Chipogolo Pr. School	-6.87	36.03	1037
88	9736017	Mpwapwa-2	Mtera	-7.10	36.00	113
161	9835039	***Mufindi-1***	Mafinga National Service	-8.32	35.30	2072
148	9835021	Mufindi-2	Kidope Mufindi	-8.62	35.25	1890
89	9738004	***Rufiji***	Kibiti	-7.70	38.92	152
204	9836027	Ulanga	Mahenge Met. Station	-8.67	36.72	1106

The input climate data used in the historical modeling was from three sources. The first is CHIRPS version 1.8, a daily spatial precipitation dataset developed with 0.05° resolution satellite imagery and meteorological observed station data (Funk et al. 2014). This is a new dataset that is still being refined; however the project team has tested earlier versions of it in collaboration with Funk, and feels that it is comparable if not superior to similar datasets. CHIRPS was combined with daily temperature and solar radiation data from NASA's Prediction of Worldwide Energy Resource for the modeling (POWER) (NASA 2014).

For comparison, a second series of point-location modeling was done using 1-km interpolated climate grid for the globe named WorldClim (Hijmans et al., 2005). It represents current climatic conditions (covering the period 1960–1990). To obtain daily data for the 30 year period, we used the weather generator MarkSim (Jones and Thornton, 2000). Please note that the 30 year WorldClim results do *not* represent the weather from particular, actual years, but simulate climate variability during that period. The team hopes to obtain daily observed meteorological station data for the Basin. When it does, it will conduct the same crop modeling process using that data.

The soil property data for the historical point-based modeling was obtained from a fairly new soils dataset for Africa with a 1 km resolution. It was created by ISRIC World Soil Information based on soil profile and other existing data (ISRIC 2013). For the spatial analysis we used representative soil profiles from the International Soils Reference and Information Centre's World Inventory of Soil Emission Potentials (WISE) database (Batjes and Bridges, 1994), as modified and reformatted by Gijsman et al. (2007).

For the spatial crop modeling, the climate data came from two sources: WorldClim representing current climate conditions, and four downscaled AR4 GCMs with SRES scenario A1B (moderately aggressive growth). The downscaling was conducted using thin plate smoothing splines via the ANUSPLIN V4.3 software (Hutchinson,2002). In future crop modeling, we plan to use climate datasets from the IPCC AR5 models described above.

The DSSAT CERES maize model was calibrated for two maize cultivars grown in the region –Katumani Composite, a short-duration OPV bred for drought resistance, and the hybrid H614, a longer-duration higher yielding cultivar that requires more water and responds more to nutrients (results only for Katumani Composite are in this report). This report provides results of rainfed maize, simulated under different nutrient (Nitrogen) applications. One application is very low to no nitrogen application (common among especially poorer farmers), and the highest (100 kg/ha) is closer to the recommended amount.

The rice model was calibrated to two cultivars grown in the region, the short duration Poussa 33 which is generally planted during the dry season, and Kilombero, a long duration cultivar grown in the rainy season. The results provided in this report simulate growth only during the rainy season. The model was run with conditions that twenty-day old seedlings were transplanted into plots on November 20th, and the new transplants were provided irrigation water that day. No irrigation water was further applied, so growth thereafter was rainfed. Three nitrogen fertilizer levels were simulated: very low to no nitrogen application (not uncommon among poorer farmers), a split 25kg/ha at transplant + 25kg/ha (50 kg/ha total), and double that amount for the highest level (100 kg/ha), which is closer to the recommended amount.

The crop models are designed to replicate conditions similar to agricultural research stations with good management and few problems from pests or diseases, so that the effects of individual climate or other conditions are better seen. There are, therefore, differences in yields between crop models and stations, and farmers' fields. In the Rufiji Basin, this yield gap has been attributed to:

1. Tillage. Farmers don't do deep tillage.
2. Spacing. Farmers plant too few seeds, and plant randomly, traditionally.
3. Weeding is a big problem.
4. Inadequate fertilizer application
5. Pests, such as maize strike
6. Soil degradation and erosion.[4]

The combination of these and other factors, with climate change, thus affects yields and food security. This report focuses on the impact of climate change and variability on maize and rice production, and examines the application of nutrients as a possible adaptation. Future analyses will consider other adaptation practices, including improved water and land management, as well.

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[4] Personal communication, David Kigosi, Kilosa District Agricultural Officer. 2 Feb. 2014.

6.3 Results

In this section, findings on the impact of recent (termed “historical”) climate variability on rice productivity will be first examined. Secondly, analytical results of the impact of projected future climate on rice and maize productivity will be provided.

6.3.1 Impact of Historical Climate Variability on Rice Productivity

Seventeen meteorological stations in the Rufiji River Basin were selected for our historical analyses based on their distribution across the basin, and availability of data (Figure17). This report provides a summary table and graphs of the results of the crop modeling conducted with climate data from a selected seven of these locations (circled in Figure 17) that are key rice production areas or provide a climatic contrast. The locations cover different climates in the basin, from cool and wet zones in the highlands (e.g., Iringa Rural-2), and warm and wet locations in the Basin (e.g., Kilombero). Temperatures follow elevation closely and the highlands are usually wet, but the lower elevation zones can be either dry or wet. Typically inter- and intra-seasonal precipitation is more variable in drier zones, so these locations could be expected to have more yield variability. Maize in particular would be vulnerable due to its sensitivity to dry spells during silking.

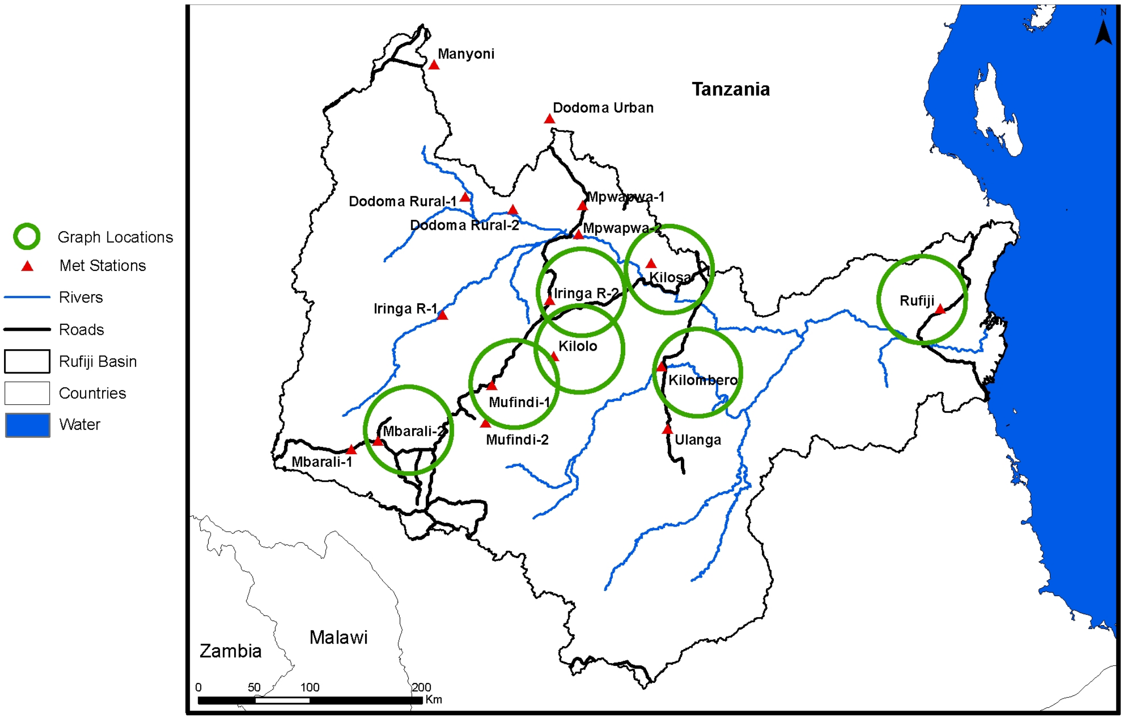

Figure 28**: Selected Meteorological Station and Point Crop Modeling Locations**

6.3.1.1 Rice Modelling Results

a) Site Level Rice Modelling

The selected sites are key rice production areas or provide a climatic contrast to current rice growing areas, or where our field work has been conducted, The locations cover different climates in the basin, from cool and wet zones in the highlands (e.g., Iringa Rural-2), and warm and wet locations in the Basin (e.g., Kilosa). Temperatures follow elevation closely and the highlands cool and usually wet, whereas the lower elevation zones are warm and can be either dry or wet (Figure 29). Typically inter- and intra-seasonal precipitation is more variable in drier zones, so these locations could be expected to have more yield variability.

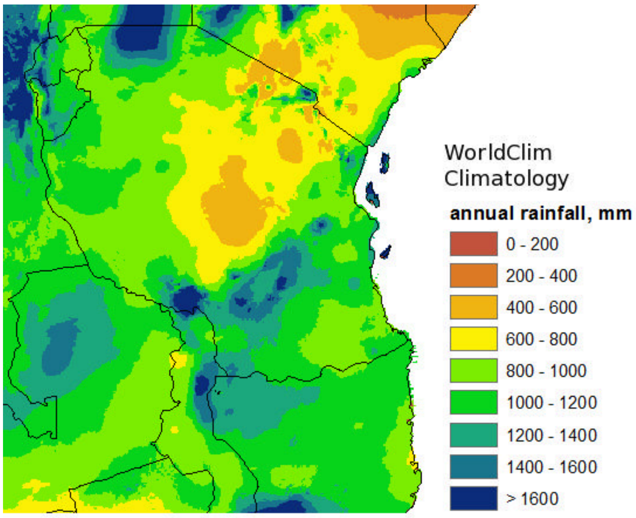

Figure 29: **Map of current annual precipitation in Tanzania**

Data source: WorldClim.

Table 12 provides a statistical summary of rice productivity over 30 years of historical climate data for each site. The sites are in order from low to high elevation. Results are provided for two rice cultivars, Kilombero (long duration) and Pousa 33 (short duration), and for two climate datasets (CHIRPS and WorldClim). See methodology section for details. Two globally available climate datasets were used because the team does not yet have daily observed meteorological station data.

Comparing the sites provides information on the effect of elevation, or temperature. Mean rice yields appear to be highest in a moderate elevation site (Kilosa, elevation 531 m). Simulated yields are optimal when TMax ranged from 28°C to 30°C and TMin ranged from 20°C to 23°C. Yields decline as one moves lower and temperatures warm, or as one moves higher and temperatures decline. With climate change, the zone of highest yield will thus move up the elevation gradient. The lowest zones can be expected to become too warm for optimal yields.

Table 12: Statistical analysis of simulated rice yields in sites in Rufiji River Basin.[5]

Rufiji (152 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm	Kilombero Variety					Pussa 33				
Mean	4947	30.2	23.1	465	330	4132	30.3	23.1	400	305
SD	558.8	0.7	0.5	105.7	22.7	679.2	0.8	0.5	96.5	30.7
CV%	11.3	2.2	2.0	22.7	6.9	16.4	2.5	2.2	24.1	10.1
CHIRPS	Kilombero Variety					Pusa 33				
Mean	4652	30.6	22.0	572	428	4373	30.6	22.0	476	406
SD	1143.9	1.1	0.6	141.2	32.1	1034.2	1.1	0.6	127.4	43.5
CV%	24.6	3.5	2.7	24.7	7.5	23.6	3.6	2.7	26.8	10.7

Kilombero (251 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm	Kilombero Variety					Pussa 33				
Mean	4637	29.6	23.1	651	281	3628	29.8	23.2	576	261
SD	336.5	0.9	0.5	142.0	27.3	540.2	0.9	0.5	125.3	26.5
CV%	7.3	3.1	2.2	21.8	9.7	14.9	2.9	2.1	21.7	10.1
CHIRPS	Kilombero Variety					Pusa 33				
Mean	4686	27.9	19.6	772.2	427.1	4490	28.0	19.7	660.9	414.9
SD	646.8	1.3	0.8	159.2	27.3	518.4	1.3	0.8	160.5	30.9
CV%	13.8	4.6	3.9	20.6	6.4	11.5	4.7	3.9	24.3	7.4

Kilosa (511 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm	Kilombero Variety					Pussa 33				
Mean	5724	28.9	19.9	642	399	4962	29.0	19.9	556	375
SD	868.4	0.6	0.5	133.5	22.2	738.3	0.7	0.6	124.5	28.0
CV%	15.2	2.2	2.4	20.8	5.6	14.9	2.4	2.8	22.4	7.5
CHIRPS	Kilombero Variety					Pusa 33				
Mean	6113	27.2	18.6	609	485	5435	27.4	18.6	534	464
SD	875.3	1.0	0.4	87.3	23.9	888.0	1.1	0.5	101.6	29.3
CV%	14.3	3.8	2.4	14.3	4.9	16.3	4.0	2.5	19.0	6.3

Mbarali-2 (1067 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm	Kilombero Variety					Pussa 33				
Mean	4709	27.5	16.5	715	418	4498	27.7	16.6	669	409
SD	819.7	0.6	0.7	207.4	31.9	644.0	0.6	0.7	206.5	31.7
CV%	17.4	2.1	4.0	29.0	7.6	14.3	2.2	4.2	30.9	7.8
CHIRPS	Kilombero Variety					Pusa 33				
Mean	5265	25.4	17.3	581	475	5176	25.5	17.4	557	481
SD	574.3	1.1	0.4	72.3	23.9	220.6	1.2	0.5	76.0	24.1
CV%	10.9	4.5	2.5	12.4	5.0	4.3	4.6	2.7	13.6	5.0

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[5] Abbreviations: Yield (kg/ha); TMax (maximum temperature, °C); TMin (minimum temperature); PRCP (precipitation, mm/growing season); ET (evapotranspiration, mm); SD (standard deviation) CV% (coefficient of variation).

Table 12 (cont.). Statistical analysis of simulated rice yields in sites in Rufiji River Basin

Iringa Rural 2 (1428 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm			Kilombero Variety					Pussa 33		
Mean	3950	24.4	15.3	677	369	4033	24.6	15.4	643	372
SD	570.1	0.7	0.6	200.0	16.8	551.9	0.7	0.6	181.2	23.1
CV%	14.4	2.7	3.8	29.5	4.5	13.7	2.9	3.6	28.2	6.2
CHIRPS			Kilombero Variety					Pusa 33		
Mean	4720	26.5	17.7	538	459	4651	26.5	17.8	511	462
SD	914.4	1.2	0.4	96.8	29.0	892.2	1.2	0.4	88.4	27.5
CV%	19.4	4.5	2.2	18.0	6.3	19.2	4.4	2.3	17.3	6.0

Kilolo (1829 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm			Kilombero Variety					Pussa 33		
Mean	3733	22.7	13.5	826	372	3929	22.9	13.7	816	385
SD	605.5	0.6	0.8	225.9	22.4	776.3	0.6	0.7	223.2	22.6
CV%	16.2	2.7	5.9	27.3	6.0	19.8	2.4	5.0	27.4	5.9
CHIRPS			Kilombero Variety					Pusa 33		
Mean	5667	25.7	17.8	742	474	5183	25.8	17.9	657	464
SD	558.6	0.8	0.6	116.8	24.3	416.8	0.8	0.6	112.1	22.7
CV%	9.9	3.0	3.5	15.8	5.1	8.0	3.2	3.6	17.1	4.9

Mufindi (2072 m alt)

	Yield	TMAX	TMIN	PRCP	ET	Yield	TMAX	TMIN	PRCP	ET
WorldClm			Kilombero Variety					Pussa 33		
Mean	3029	21.6	12.2	905	379	3605	22.1	12.9	869	390
SD	733.5	0.7	1.0	192.6	25.7	797.8	0.7	0.7	183.6	25.9
CV%	24.2	3.2	8.0	21.3	6.8	22.1	3.0	5.3	21.1	6.6
CHIRPS			Kilombero Variety					Pusa 33		
Mean	5860	25.7	17.8	721	482	5257	25.9	17.9	640	467
SD	334.8	0.8	0.6	106.5	20.0	249.5	0.8	0.6	95.8	22.7
CV%	5.7	3.0	3.4	14.8	4.2	4.7	3.1	3.5	15.0	4.8

To better understand the effect of fertilizer on yield, simulations were conducted with three levels of nitrogen fertilizer (5, 50 and 100 Kg N/ha) (Table 13). Rice yields simulated with 5 Kg N, which is not an uncommon application, were very marginal yet similar to many farmers' yields (Ephrem Mwelase, District Irrigation Officer, Kilosa, and Kisawasawa Village Extension Officer). However, simulated rice yields responded well to higher rates of N in all locations.

Simulated yields under 50 kg N/ha were similar to or a bit higher than yield obtained by small scale farmers applying fertilizer and using improved varieties (pers comm David Kigosi, District Ag. Officer, Kilosa District and others), and simulated yields with 100 kg N/ha, up to 7 tonnes/ha, are similar to the highest yields obtained by commercial rice growers in the region using intensive cultivation practices (pers comm General Manager, Kilombero Plantations Limited). Simulated yield was also in line with published results from neighboring areas (e.g., Kanyika *et al.,* 2007). In general, then, the rice model appeared to perform adequately. The results point to the importance of fertilizer application for yield in the Basin.

Table 13: **Simulated rice yield (mean ± SD) using WClim climate data under 3 Nitrogen levels**

Site	5 Kg N/ha	50 kg N/ha	100 kgN/ha
Rufiji	334±96	2820±385	4947±558
Kilembero	63±57	2058±511	4637±336
Kilosa	675±170	3766±785	5724±868
Mbarali	77±64	2116±653	4709±819
Iringa	76±71	1365±521	3950±570
Kilolo	102±191	1056±522	3733±606
Mufindi	69±95	767±474	3029±734

Lastly, the impact of climate variability on growing season precipitation and yield was examined. Results are provided in Table 13 and illustrated as graphs of precipitation and yield over 30 years using the two historical climate datasets, and for the two rice varieties (Figure 30). For the purposes of illustration, the graphs from the Rufiji site is shown.

As expected, the site with the lowest precipitation and warmest temperatures, Rufiji, shows the highest inter-annual precipitation and yield variability among the sites. CHIRPS precipitation was more variable than WorldClim's (coefficient of variation or CV of 25%) compared to WorldClim precipitation (CV of 23%). Variation in growing season precipitation under CHIRPS resulted to higher inter-annual variability of simulated mean yield of 4652 kg/ha with a CV of 24.6% compared to WorldClim's 4947 kg/ha with a CV of 11.3%. When daily observed climate data becomes available, a similar analysis will be conducted.

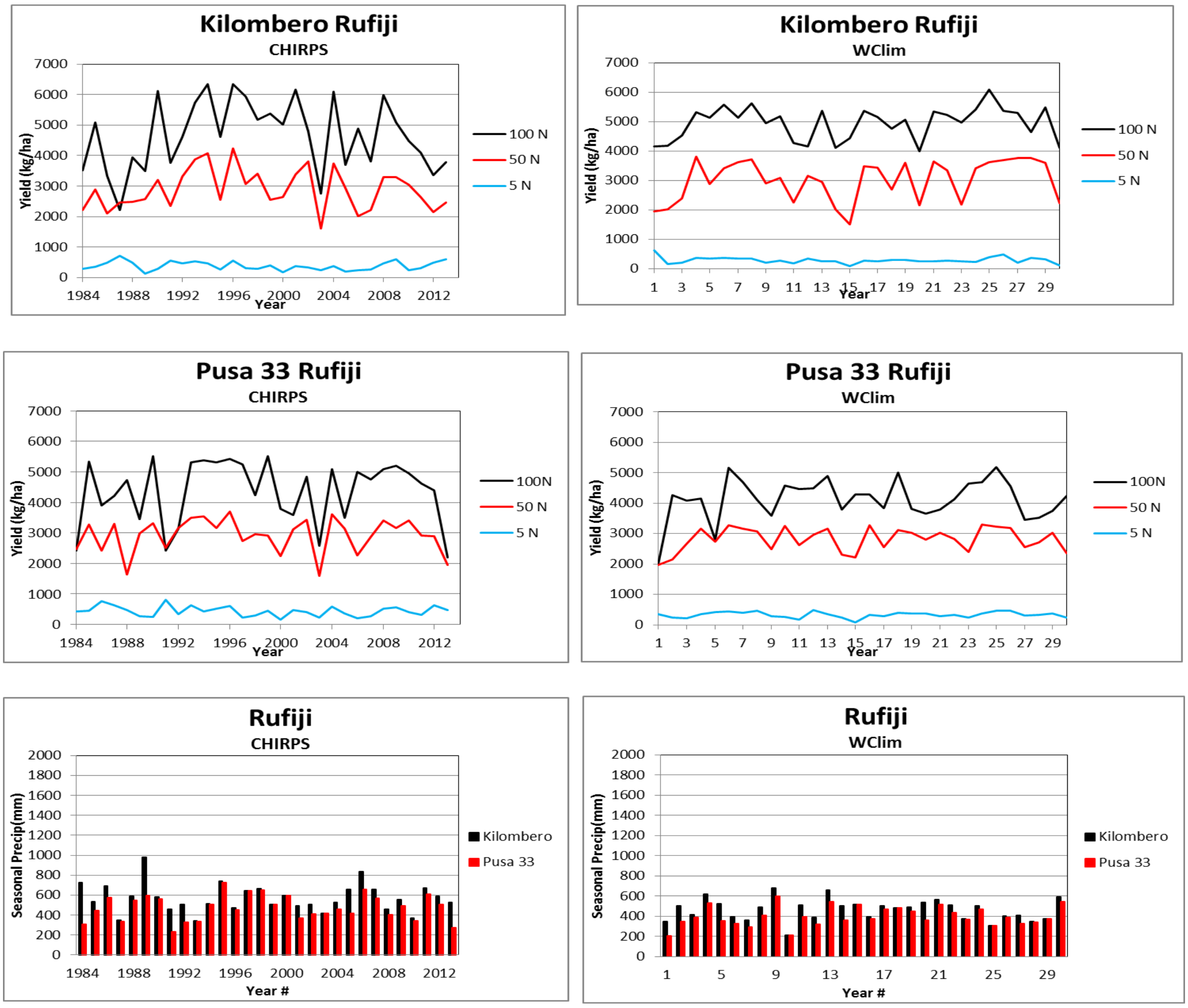


Figure 30: **Inter-annual variation of simulated yield in Rufiji Sation under three nitrogen fertilizer levels (5, 50, and 100 Kg N/ha) and two rice cultivars (Kilembero and Pusa 33) over 30 years.**

b) Spatial rice modelling

The productivity of rice was further examined by modeling its growth across the Basin. To better reveal the effects of climate, relatively high amounts of nitrogen fertilizer and rainfed conditions were assumed. Both the long duration Kilombero and shorter duration (and thus lower yield) Poussa 33 were modeled under the management practices described in the crop modeling methodology section.

The results show that spatial pattern of rice yield (Figure 31) is highly sensitive to temperature and precipitation (Kilombero variety illustrated). Indeed, temperatures (Figure 32) exerts a large influence on yields in the Basin. The cooler temperatures in the Highlands rapidly inhibit yield. The highest yields occur where the minimum temperatures do not fall below 22° C nor are higher than 24°C, and the maximum temperatures are below 35°C. These results mirror the point-level modeling results.

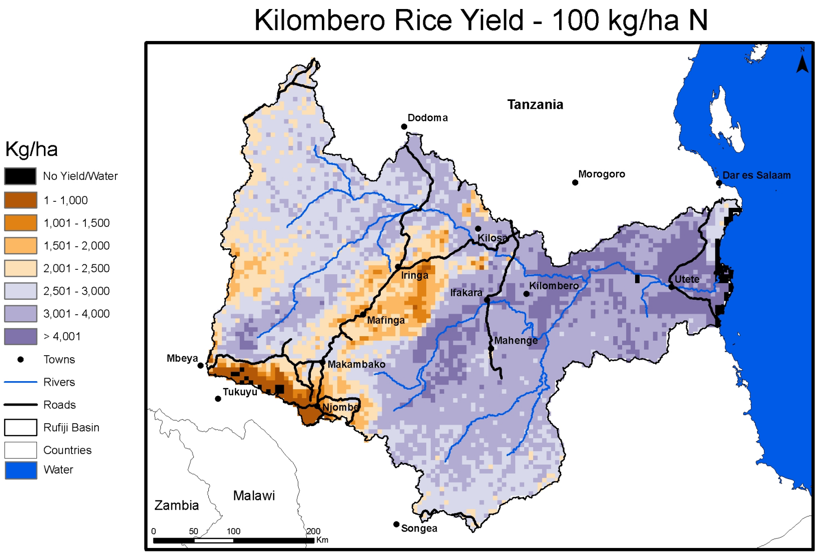


Figure 31: **Rice yield of Kilombero variety under current climatic conditions.**

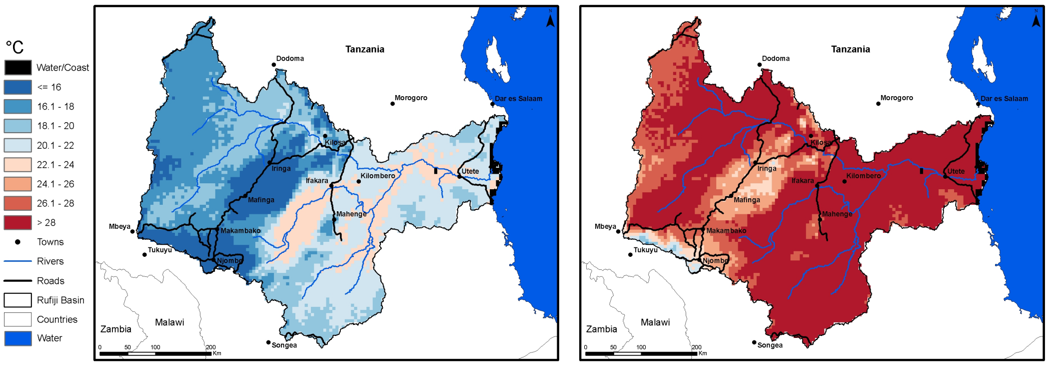


Figure 32: Minimum (left) and maximum (right) temperatures under current climate in the Rufiji River Basin.

The warming temperatures expected in the future may lead to a shift in growing conditions for rice, in which the foothills of the highlands become viable and locations that become too hot (particularly high minimum temperatures) will experience declining yields. Higher evapotranspiration and declining precipitation would exasperate this temperature-induced yield decline. The impact of projected future climate change will be explored when we couple projected climate data to the rice growth model.

6.3.1.2 Maize modelling results

Changes in maize yield reflect the impact of several climatic factors, including changes in minimum and maximum daily temperature, length of rainy season, amount of rain falling during the rainy season, and solar radiation. These all affect plant growth and development. Rising temperatures, for example, increase evapotranspiration, which under limited water conditions can cause water stress. Warmer temperatures also lead to accelerated phenology in which the maize matures faster. The accelerated phenology reduces the time available for the plant to produce biomass and large kernels, and yields decline.

This section provides results of the impact of projected future climate change on maize growth and productivity. Data from four CGMs representing the current and mid-century were used as inputs to the maize crop model (see methodology section for details). The projections of all four GMCs indicate drier and much warmer conditions in the Basin (Figures 33, 34 and 35).

Temperatures are expected to rise substantially, particularly minimum (nighttime) temperatures. The temperatures in the Highlands will rise more than in the lowlands. Three of the four models indicate that precipitation during the growing season will decline, particularly in the Highlands where it is expected to decline by 150 or more mm/ growing season by 2050. Only the CSIRO model projects modest increases in precipitation in the foothills and lowlands.

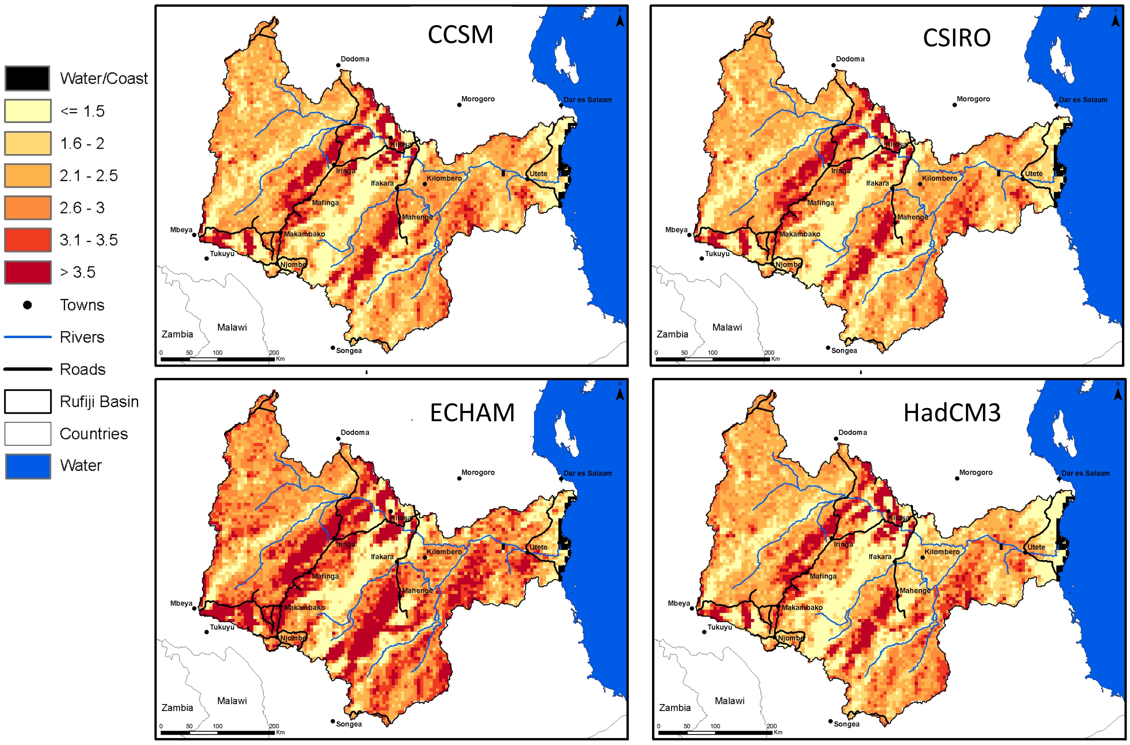


Figure 33: **Change in minimum temperature (C°) between 2000 and 2050 in the Rufiji River Basin.**

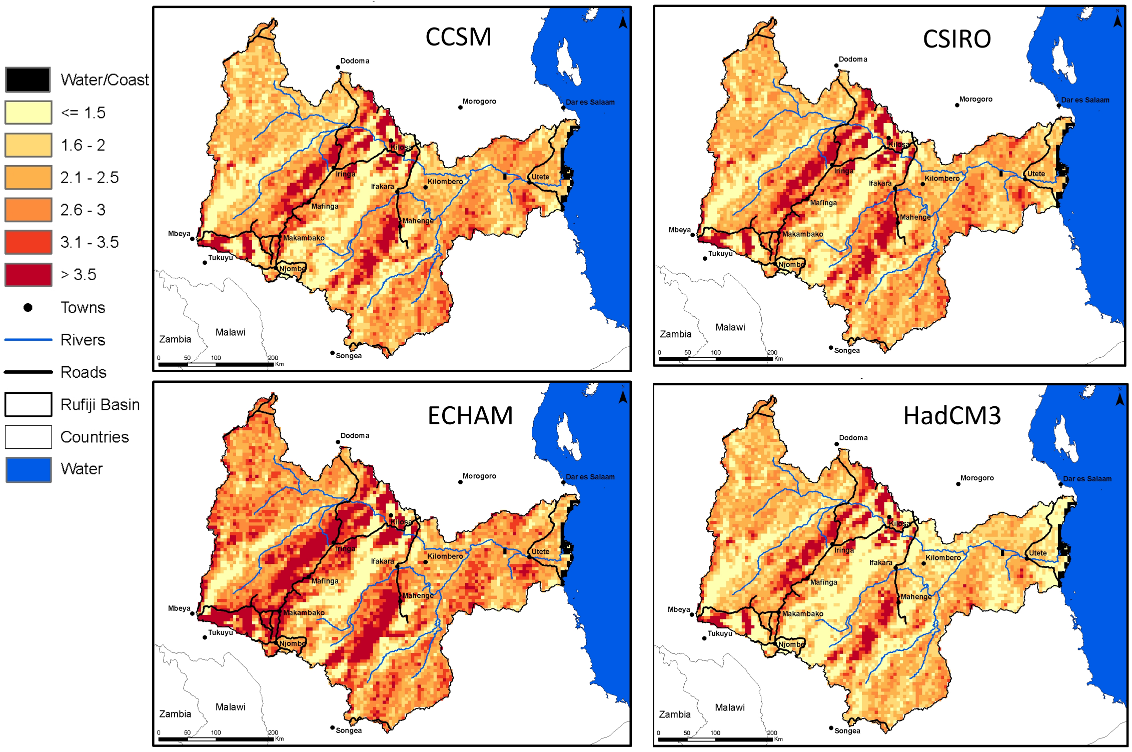


Figure 34: **Change in maximum temperature (C°) between 2000 and 2050 in the Rufiji River Basin**

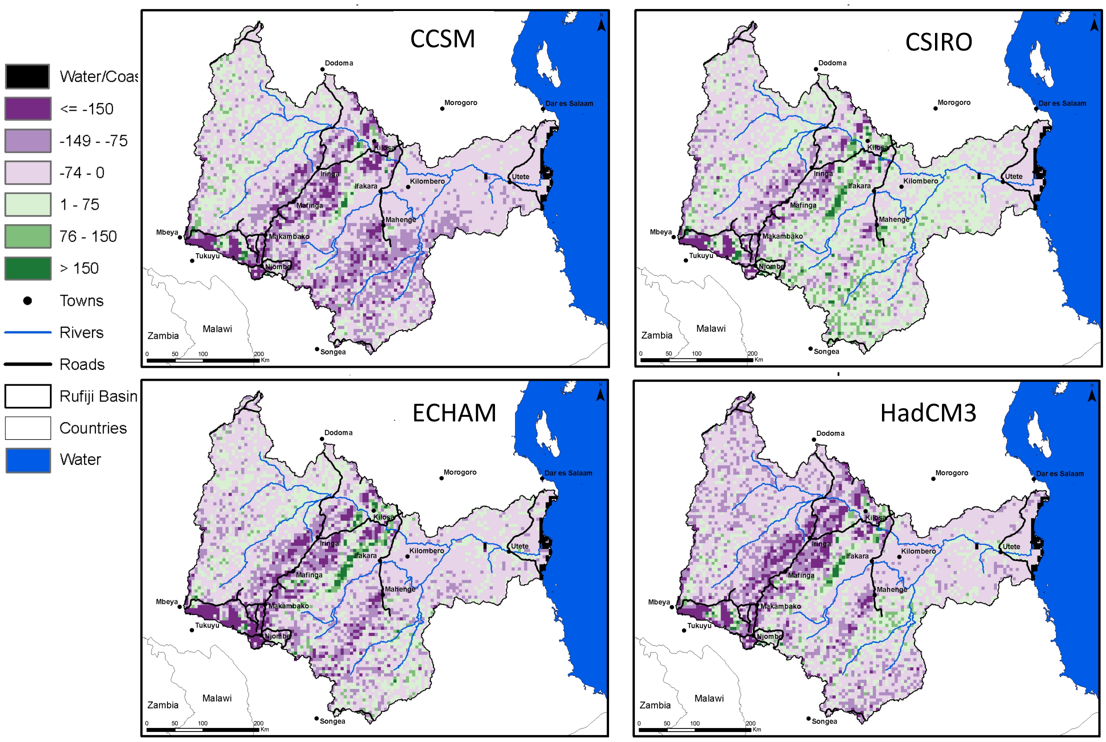


Figure 35: **Change in growing season precipitation (mm) between 2000 and 2050 in the Rufiji River Basin**

In some of the lower elevation zones of Rufiji River Basin, the warming temperatures would lead to additional water stress and more rapid plant phenology. These changes, particularly in hotter and/or drier areas, would lead to declining yields. Where yields are already low due to limited rainfall, in the future maize yields may fall below economic viability.

However, results for the Highland zones (around the Iringa-Njombe road) in general indicate that climate change would lead to increases in maize yield. The cool temperatures in these highlights are currently a limiting factor; with warmer temperatures, maize in these zones with their good soils and sufficient precipitation will have higher production. These warmer temperatures are, however, expected to reduce coffee and tea productivity.

These results show variable impacts of climate change on yields across the Basin. The analysis revealed localized effects of climate change on yields. Local topography and soils play an important role determining how climate change is expected to affect crop growth and development.

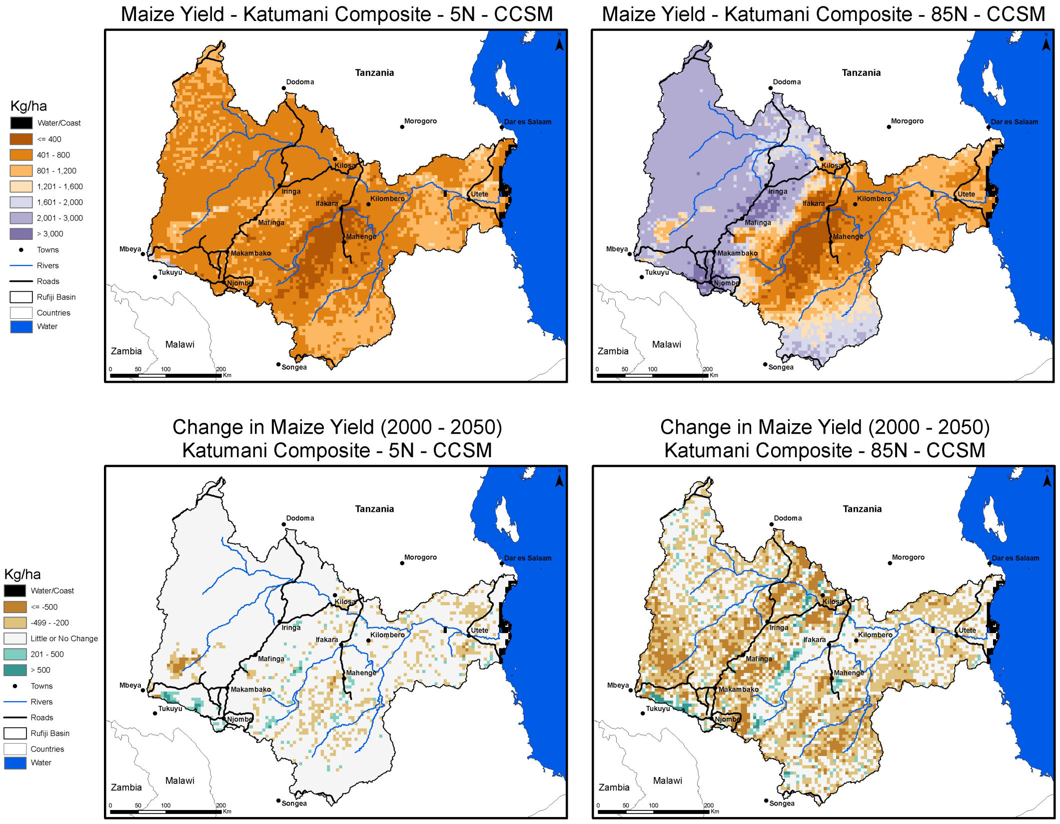
The team conducted sensitivity experiments to examine how maize growth and production would be affected by management practices under current and projected climate conditions.

Three of the most important adaptation practices being considered currently in Tanzania are 1) short-season or drought-resistant maize varieties so that the maize is less vulnerable to highly variably rainy seasons and to water stress due to the higher temperatures with no change or declining precipitation, and 2) better management practices, especially fertilizer application, to reduce the plant's susceptibility (the so-called no regrets option), and 3) irrigation.

The maize variety modeled, Katumani composite is a short-season variety developed for Kenya's sub-humid or semi-arid conditions. Even under good conditions, its yields are low compared to longer duration varieties but it may do better than other varieties under warmer and drier conditions (note: results for a longer duration hybrid maize cultivar will be provided in the future).

Illustrated are the results from two nitrogen fertilizer application rates: a low rate of 5 kg/ha which reflects many small-holders' practices, and a moderately high level of 85 kg/ha. The basic question being examined is, "is fertilizer an effective adaptive strategy for coping with climate change?" Where (i.e. highlands) large doses of fertilizers will be an effective adaptation strategy health and environmental cautions should be taken. This is because, environmental and health problems of excessive fertilizers usage for rice and maize production will likely result into water and soil pollution through leaching. Therefore, training on appropriate usage of fertilizers and organic farming are important to extension workers and smallholder farmers. This would conserve the environment and protect the health of the consumers.

The two maps in Figure 36 (using mid-century CCSM data) and Figure 37 (using mid-century CSIRO data) illustrates the yield differences between the two fertilizer levels. The response to nitrogen is large across the Highlands and much of the lowlands (note: the authors will investigate the results of low yields east of the Highlands; we would expect yields there to be similar to those north of the Highlands). With low nitrogen, yields are only in the 400 to 1,000 kg/ha whereas with additional 85 kg/ha nitrogen added, yields increase to 1,600 to higher range. Other maize cultivars show an even larger increase in yield.



Maize Yield - Katumani Composite - 5N - CCSM

Maize Yield - Katumani Composite - 85N - CCSM

Change in Maize Yield (2000 - 2050)
Katumani Composite - 5N - CCSM

Change in Maize Yield (2000 - 2050)
Katumani Composite - 85N - CCSM

Figure 36: **Simulated maize yields (kg/ha) of Katumani Composite maize with CCSM climate data. Upper left: 2050 yields with low nitrogen (N) fertilizer. Upper right: 2050 yields with higher N. Lower left: Change in yields between 2050 and 2000 with low N. Lower right: Change in yields between 2050 and 2000 with higher N.**

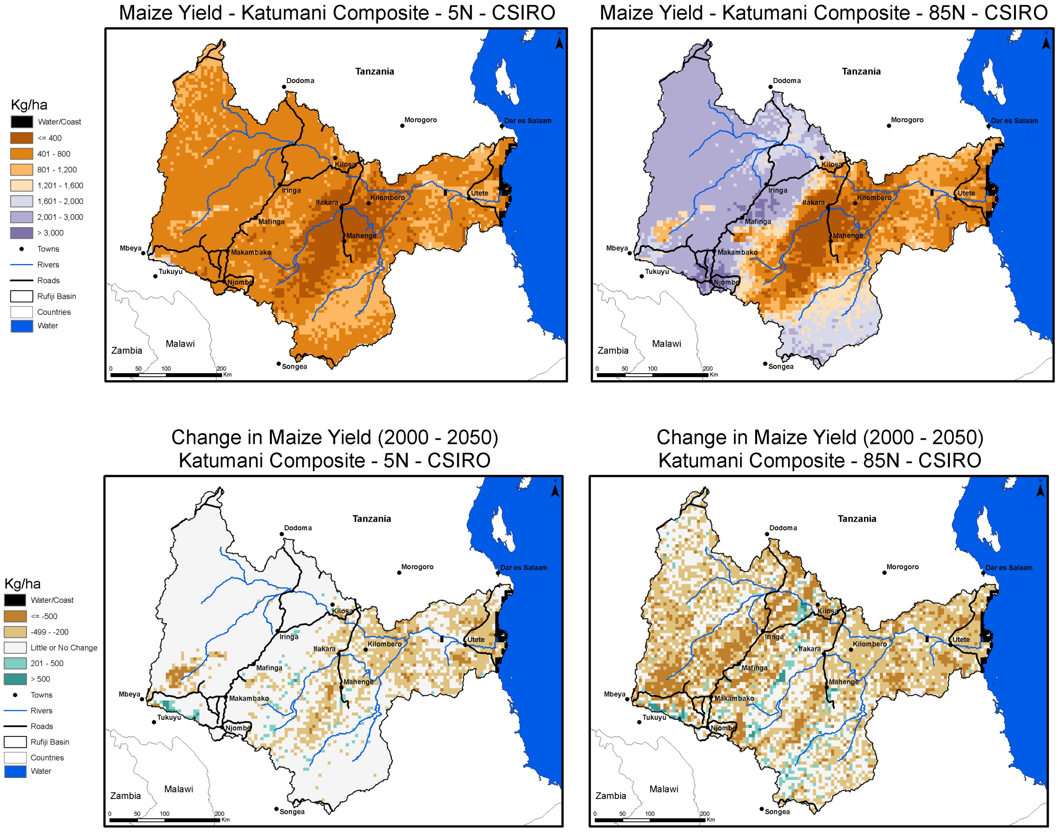


Figure 37: **Simulated maize yields (kg/ha) of Katumani Composite variety with CSIRO climate data. Upper left: 2050 yields with low nitrogen (N) fertilizer. Upper right: 2050 yields with higher N. Lower left: Change in yields between 2050 and 2000 with low N. Lower right: Change in yields between 2050 and 2000 with higher N.**

This fertilizer response pattern holds under both current and future climate conditions pointing towards fertilizer potentially being an important "no regrets" option for climate change. However, climate change moderates the fertilizer response. To examine the effect of climatic change on maize yield and the effectiveness of fertilizer as an adaptation strategy, we compared the change in yields of the low and higher fertilizer levels under current and projected climates. The results for both CCSM and CSIRO models (the lower maps of Figure 25 and 26) are that projected climate change would lead to larger yield losses with the higher fertilizer levels than for low fertilizer levels. This is the case across most of the Basin.

This counter-intuitive finding is explained by the fact that when nutrient levels are high and do not restrict yields, then water can become the critical limiting factor. The projected warmer temperatures and declining or no change in precipitation leads to additional water stress which would inhibit growth in plants otherwise doing well. Additional water stress would have less of an impact on plants already undergoing extreme nutrient limitation stress (i.e., those receiving low dose of nitrogen). On the other hand, the cool Highlands show some additional yield increases with the higher fertilizer levels because the projected warmer temperatures permitting maize to thrive.

The conclusion is that the adoption of short duration maize varieties and the application of fertilizer themselves are unlikely to be a sufficient coping strategy against climate change. The climate of most of the Basin will be getting warmer and drier, and water stress will increasingly limit production. In sum:

1. Under the current and future climates, additional application of N fertilizer even at moderate levels dramatically increases maize yield.
2. Future climate impacts on maize grown with moderate fertilizer levels varies across the Basin:
    a. Higher elevation areas showed a positive response of higher yield due to warming temperatures and the Highlands becoming more suitable for maize.
    b. Most of the Basin would experience yield declines even with fertilizer because water stress becomes more of a limiting factor (the impact of higher temperature and declining or no change in precipitation).
3. Therefore, application of fertilizer and adoption of short duration, drought resistant maize varieties by themselves are unlikely to be a sufficient adaptation strategy. In the lowlands, water can be expected to increasingly become a critical limiting factor affecting maize production.

CHAPTER SEVEN

CONCLUSION

These chapters provided background information and research results concerning climate change and its impacts on surface water and on rice and maize productivity. Agriculture in the Rufiji River Basin is vulnerable to the impacts of climate change in several ways. Warming temperatures, declining precipitation and changes in the rainy season are already affecting water availability and plant growth. Rice is sensitive to temperature, and although warming temperatures will permit it to expand its distribution to higher elevations, yields can be expected to decline in lower elevations as they become hotter and drier.

The results indicate that rice yields respond well to nitrogen fertilizer applications across the Basin, and that even relatively low doses can lead to improved yields. Maize is particularly vulnerable to two aspects of climate change in the Basin: warming temperatures and increased water stress causing declining yield across the lowlands, and increased precipitation variability including dry spells in the rainy season during the plant's reproductive stage. Maize, too, responds well to even small amounts of fertilizer (particularly in multiple applications) in the Basin, but the response will be muted as water stress becomes more widespread and intense.

Vulnerability assessment report, which is the subsequent milestone will also refine and better calibrate the models under this report with additional, observed data including meteorological station data, stream flow measurements, land use/land cover change, and water management practices. In addition, the new AR5 GCM and other datasets will be incorporated into the hydrological and crop models to provide more information on the impact of projected future climate change on water availability and crop yields. Results of the hydrological model will inform new modeling of irrigated rice, and how precipitation variability and change will affect irrigation water availability and crop productivity.

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APPENDICES

APPENDIX 1: FOCUS GROUP DISCUSSION PARTICIPANTS IN THE PROJECT VILLAGES

A. KISANGA VILLAGE

S/NO	NAME	OCCUPATION/Committee
1.	Hamadi Nelem	Village Executive Officer
2.	David Kigosi	Agriculture Field Officer
3.	Robsert Kalale	Secretary-Water Committee
4.	Hilda Kalave	Farmer
5.	Michael Kigomba	Farmer
6.	Bahati Maguza	Farmer
7.	Lemi Kinyengwe	Member-Environmental committee
8.	Erica Mnzeru	Farmer
9.	Charles Paulo	Farmer
10.	Pudensia Mkumbae	Treasurer- Water committee
11.	Rosemary John	Chairperson-Water Committee
12.	Mariam Kiwanga	Chairperson-Environmental Committee
13.	Agustino Simbeye	Farmer
MALOLO ‘B’		
1.	Yohana Rajabu Magoza	Village Executive Officer
2.	Constantine Mgambwa	Ward Executive Officer
3.	Mwinyimbegu Iddi	Agricultural Field Officer
4.	Mahamud Kasuke	Member- Irrigation Committee
5.	Iddi Rashid Kihande	Farmer
6.	Omari Daudi Ngulali	Member- Irrigation Committee
7.	Salima Nyagawa	Member- Irrigation Committee
8.	Asha Nzala	Farmer/irrigator
9.	Mwaine R. Kahemega	Member- Irrigation Committee
10.	Felista Komba	Farmer/Irrigator
11.	Evalado Mgalela	Member- Irrigation Committee
12.	Norest Philimon Mwikanu	Assistant Village Executive Officer
MANG’ULA ‘A’		
1.	Deograsias F.Kadanga	Village Executive Officer
2.	Grace E.Mella	Agriculture Field Offocer
3.	Reonalo Ngalama	Farmer
4.	Valeliana Mhiche	Farmer
5.	Cosmas Mwadua	Farmer
6.	Kaitani Kamile	Farmer
7.	Praxeda John	Farmer
8.	Suna Kulolela	Farmer
KISAWASAWA		
1.	Ramadhan J Athman	Acting Village Executive Officer
2.	Salum R. Mbaga	Village Agricultural Extension Officer-Kanolo
3.	Kasian Kombania	Chairperson- Irrigation Committee
4.	Mess Msaliboko	Farmer
5.	Rukia Kinjwamu	Member-Irrigation Committee
6.	Halima Sanga	Member-Irrigation Committee
7.	Justen Hamis	Farmer
8.	Musa Kuduya	Member-Irrigation Committee
9.	Deo Likalagala	Secretary-Irrigation Committee
10.	Omary Kipolelo	Member-Irrigation Committee

APPENDIX 2: KEY INFORMANTS CONSULTED IN THE PROJECT SITES

S/NO	NAME	OCCUPATION	ORGANISATION
1.	Abel A Mchome	PAFO	Kilosa District Council
2.	Waziri Thabit		Kilosa District Council
3.	Tatu Kachenje	DAICO	Kilosa District Council
4.	Munga J.Mohid	DAFO	Kilosa District Council
5.	Charles Mengo	Environmental Engineer	Rufiji Water Basin Office
6.	Godfrey Sanga	Technician	Rufiji Water Basin Office
7.	Idris Msuya	Water Basin Officer	Rufiji Water Basin Office
8.	Hawa Ngapanya	Extension Officer	Kilombero District Council
9.	Saplina Swai	Forest Officer	Kilombero District Council
10.	Christopher Mnguu	Crop Officer	Kilombero District Council
11.	Athuman Mahundu	Statistician	Kilombero District Council
12.	Godfrey Christopher	Project Coordinator-Climate Change Adaptation Project	Kilombero Valley Environmental and Development Organisation (KIVEDO)
13.	Adrea Nyahuzi	Conservation Project Coordinator	KIVEDO
14.	Hamza Ngaposa	Executive Director	KIVEDO