UNIVERSITY OF DAR ES SALAAM
INSTITUTE OF RESOURCE ASSESSMENT (IRA)

SPECIAL TECHNICAL REPORT

ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON CROP AND WATER AVAILABILITY, AND CONSIDERATION OF POTENTIAL ADAPTATION PRACTICES FOR THE RUFIJI RIVER BASIN, TANZANIA

A REPORT SUBMITTED TO THE UNIVERSITY OF DAR ES SALAAM
AND USAID-TANZANIA

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ABBREVIATIONS

AR4, AR5: Fourth and Fifth Assessment Report of the IPCC

ASDS: Agricultural Sector Development Strategy

CanESM2: The Canadian Centre for Climate Modelling and Analysis Earth System Model, version 2,

CCSM: The “Community Climate System Model” GCM developed by the National Center for Atmospheric Research in Boulder, Colorado.

CCSM4: Community Climate System Model, version 4 from the National Centers for Environmental Research, National Center of Atmospheric Research, USA,

CERES:Crop Estimation through Resource and Environment Synthesis

CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data

CSIRO: A GCM developed by the Commonwealth Scientific and Industrial Research Organization of Australia.

DSSAT:The Decision Support System for Agrotechnology Transfer is a process-based crop model (i.e., models the entire phenology or life-span of the crop) that has inputs such as soil characteristics, radiation, fertilizer inputs, planting date, crop cultivar characteristics and daily temperature and rainfall. It thus facilitates comparing simulated crop yields across different locations, climate, management, and/or cultivar characteristics.

ECHAM: A GCM developed by the Max Planck Institute for Meteorology in Hamburg, Germany.

FTP: File Transfer Protocol

GCM: Global Climate Model, or General Circulation Model (used interchangeably). This is the general term for climate models developed to simulate global atmospheric circulation patterns over space and time including the impact of enhanced GHG.

GHG: Greenhouse gases, including water vapor, carbon dioxide, methane, nitrous oxide and ozone, which absorb and emit radiation in the atmosphere.

GMO: Genetically Modified Organism

HadCM3: A “Hadley Centre Coupled Model,” a GCM developed by the UK Meteorology Office in Exeter, UK.

HWSD: Harmonized World Soil Database

IPCC: Intergovernmental Panel on Climate Change

IIASA: International Institute for Applied Systems Analysis

IPSL-CM5A-LR: Institut Pierre Simon Laplace Coupled Model 5A, France,

MPI-ESM-LR: Max Planck Institut für Meteorologie Earth System Model, Germany,

MRI-CGCM3: Meteorological Research Institute, Japan.

MSU: Michigan State University

NASA POWER: National Aeronautical and Space Administration Prediction of Worldwide Energy Resource

NBS: National Bureau of Statistics

RBWO: Rufiji Basin Water Office

RRB: Rufiji River Basin

SAGCOT: Southern Agricultural Growth Corridor of Tanzania

SOTER: Soil and Terrain based Programme

SSA: Sub-Saharan Africa

UCSB: University of California, Santa Barbara

UDSM: University of Dar es Salaam

WorldClim: A spatially explicit global database representing the “average” monthly climate based on modeling several years (1950-2000) of available meteorological station data. In our project, it represents current climate.

WUE: Water Use Efficiency

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Recent and projected changes in the Tanzanian climate and population suggest that adaptation strategies will be increasingly necessary to meet the crop production and water use requirements of people in the Rufiji River Basin (RRB). Adaptation strategies may include modifications to help smallholder farmers rise their crop yields and improve water management for irrigation. At the Basin level, climate change adaptations will involve various levels of water management in order to provide sufficient clean water for consumption and sanitation for urban and rural populations. Recent policies and public-private partnerships like SAGCOT represent a push to address these needs by modernizing agriculture and improve food security and economic stability. However, to meet the projected requirements for food and income, yields of major crops will need to improve and irrigated areas within the Rufiji River Basin (RRB) will need to expand, and significantly, water use efficiency will need to be very high. The influence of climate change on power generation across the basin is an important consideration of current and future water requirements. Currently, power generation is operating at approximately 20% of required demand due to an insufficient water level in hydro-generating power stations.

This report provides results of extensive modeling in a GIS framework and data analysis to identify vulnerabilities to agriculture due to climate change across the entire Rufiji River Basin. It focuses on the productivity of two major food security and cash crops in the region, rice and maize, and then examines the impact of management variables on water resources available for irrigation, domestic use, and other uses. This has been accomplished by calibrating crop and hydrological models to Rufiji River Basin conditions, running the model under current and future climate conditions, and under various management options such as irrigation technologies or fertilizer applications. The results provide new information on the

potential impact of climate change and human management decisions on crop productivity and water resource availability for the Basin.

The main questions being addressed in the analysis are:

a. How is climate projected to change in the Rufiji River Basin?
b. What is the expected impact of climate change on crop growth rates and productivity across the Basin? What areas in the Basin will be most affected, or most vulnerable? What would be the impact of different technologies to improve crop productivity?
c. What is the status of surface water use and availability across the Basin? What would be the effect of land use change, population change, climate change and improved irrigation technologies on water available for irrigation or other uses?

The analysis was conducted using numerous datasets, four types of models (climate, crop, hydrological and land use) and statistical analysis. Calibration of the models to local, observed or measured data was conducted as much as possible, and the sources of the data are provided in the methodology section. However, the calibration and validation of the models was hampered by the limited amount of observed data available (particularly observed crop yield, daily meteorological, stream flow, water abstraction and irrigation technologies). Because of this, the results should be considered preliminary. The model results will be refined as additional data and information is incorporated. The current results regarding climate adaptation strategies and scenarios will be discussed with University of Dar es Salaam and other project personnel. The revised modeling and scenarios will be completed in Y3 of the project.

1. INTRODUCTION

Climate change across Tanzania and the Rufiji River Basin (RBB) and its effects on agricultural production and food security are critical to the Tanzanian people, government officials, and Tanzania's plans for the future. SAGCOT, *Kilimo Kwanza*, ASDS, and many other policies, government institutions, and public-private partnerships are trying to both modernize agriculture and provide for an increasing population while also developing infrastructure to supporting new industries and commercial efforts.

Currently, a large percentage of the population is primarily involved in agricultural production as smallholder farmers producing crops for sustenance and profit. A shift in scale from the traditional smallholder to the modernized, large holder / commercial farming operation may occur as modernization policies move forward across Tanzania. There is also room for community-based smallholder cooperatives to form to replicate the large holders' gain in the economy of scale and infrastructure benefits available when farming at scale. Larger agricultural operations and the SAGCOT concept of agro-industrial clusters benefit from efficiencies in irrigation, purchasing power for seed, chemicals, and fertilizer, and selection for capital improvements such as efficient irrigation schemes, power distribution, road construction, grain warehousing and storage, and market access for products.

This report provides results of extensive modeling to identify vulnerabilities to agriculture due to future climate change across the entire Rufiji Basin. It focuses on the productivity of two major food security and cash crops in the region, rice and maize, and examines the impact of resource management on water resources available for irrigation, domestic use, and other water uses.

The report provides new results of modeling and analysis, revised from the earlier Milestone 1.5 report,[1] based on additional data, information and feedback. For example, new crop modeling was conducted using a different rice cultivar, new IPCC AR5 climate model datasets were used to inform the crop and hydrological models, newly available 2012 population census data was used to inform water and land use projections, additional stream flow data was incorporated, and information on planned future irrigation and other water abstractions were considered.

This report is divided into five chapters. Chapter 1 provides an introduction. Chapter 2 discusses the methodology, including the datasets upon which the analysis is based. Chapter 3 presents findings regarding the impact of climate change on rice and maize productivity. Chapter 4 presents results of the hydrological and land use models regarding available water resources. Finally, chapter 5 provides a conclusion.

2. METHODOLOGY

A combination of different models was used to obtain information on how climate change would affect crops and water availability. In short, historical climate datasets and future climate projections based on climate models were used as input data for both the crop and hydrological modeling. The results of the rice modeling in regards to the amount of daily water required for irrigating the rice also informed the hydrological model. The results of the hydrological model will in turn provide information on how much and where the land is that can be under irrigation. Figure 2.1 provides an overview of the coupled modeling approach and the datasets used in the analyses.

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[1] Milestone 1.5 Technical Report on Climate Change Linkages and Impacts in the Medium Term. Report Submitted to USAID Tanzania, February, 2015 by the University of Dar es Salaam Institute of Resource Assessment (IRA).

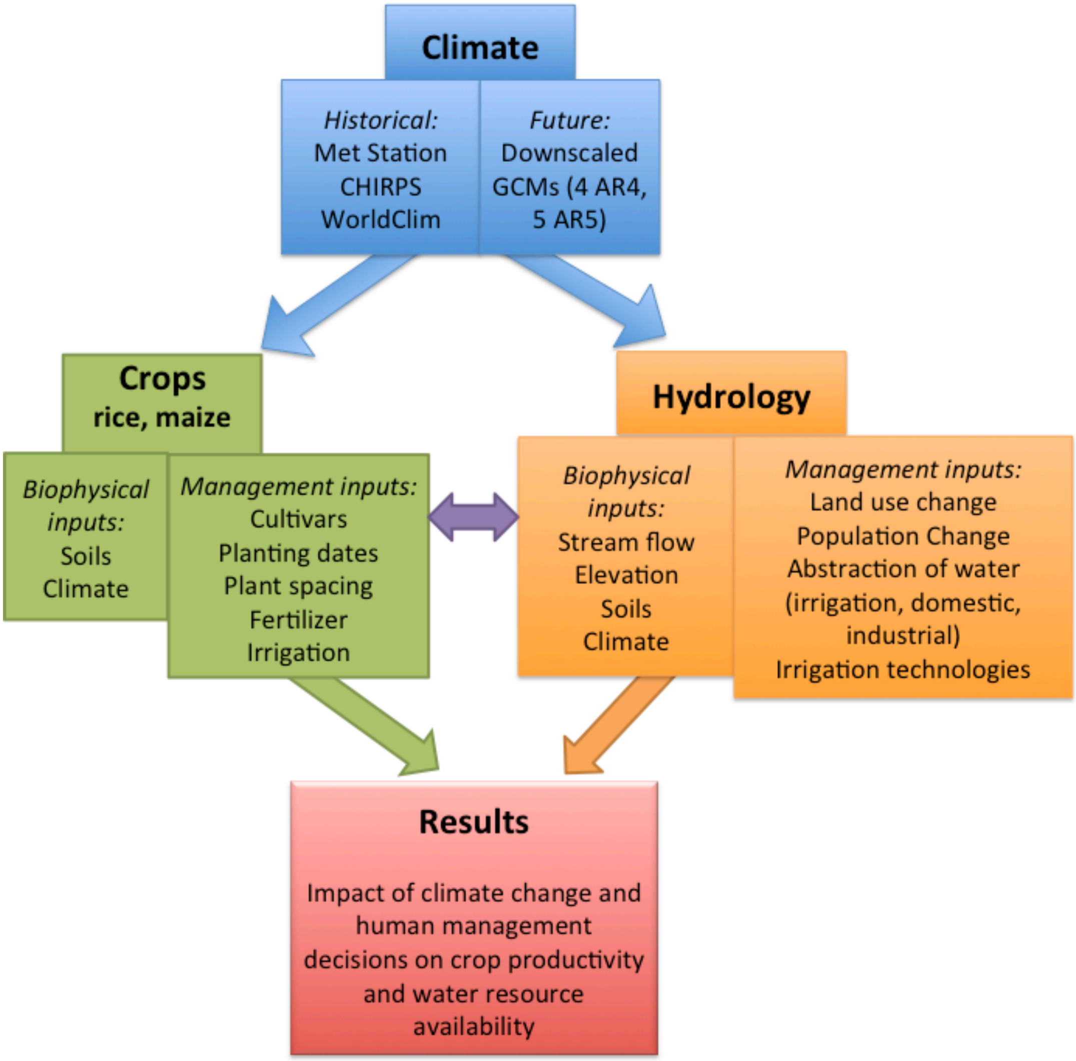

Figure 2.1. Schematic of the coupled modeling approach followed in this research.

2.1 Climate Datasets and Climate Models

Historical, or recent, climate datasets were used to examine observed trends in precipitation, to calibrate the crop and the hydrological models, and as inputs to the crop and hydrological models to examine the impact of recent climate variability on crop production and water availability (see these results in an earlier report, Milestone 1.5). In this report, the historical datasets were again used as baseline climate data and as inputs in the crop and hydrological models. The historical climate dataset used in these analyses include:

a. Observed meteorological station data from the Tanzania Meteorological Agency. 17 stations with sufficient length and quality of precipitation in the Rufiji Basin were selected for precipitation analysis and to run in the crop and hydrological models (historical crop-climate results in Milestone 1.5 report).

b. WorldClim (Hijmans et al., 2005) which represents current climatic conditions. It is a spatial dataset with monthly means covering the period 1960–1990. To obtain daily data for the 30 year period for the crop model, we used the weather generator MarkSim (Jones and Thornton2000).

c. CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data, Funk et al. 2014) version 1.8. CHIRPS is a high-resolution, daily time series, spatial precipitation dataset from FEWSNET/UCSB covering the period 1983 to 2014. A version ready for use in Tanzania became available recently. The team conducted extensive testing of earlier versions and the latest version against observed data and found that the latest version was in general sufficient for our purposes, and superior to other available spatial time series precipitation datasets. The dataset is large—over 180 gigabytes for the daily precipitation dataset at 1 km resolution for Africa. Using it for our purposes has involved writing computer programs and communicating regularly with UCSB and others. The team has begun switching from WorldClim to CHIRPS in the crop and hydrological models (this switch is not entirely complete).

d. NASA Power (NASA 2014) is a satellite-derived spatial, time-series product. The team compared it to other available spatial time series datasets and found it, despite being coarse resolution, to be superior to other datasets. NASA Power’s minimum and maximum temperatures, and solar radiation variables were used in the crop and hydrological models.

Global Climate Models (GCMs) provided future climate simulation results. The Intergovernmental Panel on Climate Change (IPCC) has endorsed new AR5 models that are considered an improvement over the AR4 models (Flato et al. 2013). The team had been using the AR4 models and they are the basis for the Milestone 1.5 report. For this report, the new simulations became available it was felt important to switch and use the latest models (the maize simulations presented in this report were conducted before the switch and are based on the AR4 models). Five AR5 models were selected for the Rufiji Basin region based on their ability to simulate observed spatial and temporal climate trends (Otieno and Anyah (2013), and to provide a level of comparison between GCMs. The simulations are from the high or runaway (RCP8.5) Representative Concentration Pathways (RCPs) or levels of greenhouse emissions. The GCMs selected and whose simulations are represented in this report are:[2]

a. CCSM4: Community Climate System Model, version 4 from the National Centers for Environmental Research, National Center of Atmospheric Research, USA,
b. MPI-ESM-LR: Max Planck Institut für Meteorologie Earth System Model, Germany,
c. CanESM2: The Canadian Centre for Climate Modelling and Analysis Earth System Model, version 2,
d. IPSL-CM5A-LR: Institut Pierre Simon Laplace Coupled Model 5A, France,
e. MRI-CGCM3: Meteorological Research Institute, Japan.

Because these models were run within a framework for inter-comparison, the model configurations and other relevant information for these simulations are all referenced in Taylor et al. (2012). The data were downscaled to 6 km and bias-corrected to daily time steps using a MATLAB program developed by Oregon State University College of Engineering

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[2] "We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals."

(http://globalclimatedata.org/) and modified to suit our needs. Historical data sources were based on CHIRPS v 1.8 for rainfall data and interpolated daily station data for historical temperature surfaces done for the hydrological modeling. Monthly perturbations were applied to daily time series for the years 2010-2060.

2.2. Crop Modeling Methodology

Full details of the crop model, soils data used and other crop modeling methodological information are listed in Milestone 1.5 report, so an abbreviated version is provided here. The rice and maize modeling was conducted with the Decision Support System for Agrotechnology Transfer (DSSAT) model, a process-based crop model (i.e., models the entire phenology or life-span of the crop) that has inputs such as soil characteristics, fertilizer inputs, planting date, crop cultivar characteristics and daily temperature, rainfall and solar radiation.

CERES Maize of DSSAT was prepared using locally available soils and climate datasets, and calibrated with several local maize cultivars. The high-yielding, slightly longer duration hybrid H-614 variety was selected for illustrating the impact of climate change in the Rufiji Basin for this report (the earlier report provided results for the Katumani Composite maize cultivar, which is now less commonly grown). The simulations had the maize planted during September to November and grown during the rainy season. To examine the potential for irrigation and fertilizer to reduce the negative effect of climate change, and thus be useful as adaptation technologies, maize simulations were conducted using different nitrogen fertilizer levels, and under rainfed for maize and both rainfed and irrigated situations for rice, for both current and future climate conditions. The climate datasets used for the maize simulations were WorldClim to represent current conditions, and four AR4 GCMs (CCSM, EchHAM, CSIRO and HadCM3) to provide future climate perturbation simulation information.

The rice model had earlier been calibrated to two cultivars grown in the region, the short duration Pusa 33 which is generally planted during the dry season, and Kilombero, a long duration cultivar grown in the rainy season. Based on feedback recently received that newer cultivars are becoming more commonly used, a third cultivar was calibrated and simulated, the higher yielding TXD-85. This cultivar was simulated under rainfed and irrigated conditions, and with moderate nitrogen fertilizer (50 kg/ha applied at transplanting, and an additional 50 kg/ha applied after 30 days (note that the Milestone 1.5 report has results showing the effect of different nitrogen fertilizer levels on rice yield).

The rainfed simulations had twenty-day old seedlings transplanted into plots near the start of the rainy season on December 2nd, and the new transplants were provided irrigation water that day. No irrigation water was further applied, so growth thereafter was entirely rainfed and so low rainfall could potentially affect yield.

The irrigated simulations had twenty-day old seedlings transplanted into plots after the rainy season crop would have been harvested, on June 2nd, and the plants grew during the dry (winter) season. The plants were provided irrigation water when soil moisture fell below 50% of plant available soil moisture in top 30 cm of soil profile. The climate datasets used for the spatial rice simulations presented here are WorldClim to represent current climate conditions, and five AR5 models (CCSM4, MPI-ESM-LR, CanESM2, IPSL-CM5A-LR and MRI-CGCM3) to provide future climate perturbation simulation information.

2.3 Hydrological model methodology

In order to fully explore all factors related to climate change and water resources, a calibrated model of the Rufiji basin has been created to quantify historical hydrologic response across the basin. This model includes simulation of the basin from 1983 through 2014 using available data from Tanzanian Meteorological office as ground truth stations, CHIRPS V2.0

precipitation data (Funk et al. 2014), and NASA(2014) POWER-based temperature and solar radiation data. Currently, additional climate change based projections are being processed for inclusion in this work including rainfall, maximum and minimum temperature, and solar radiation data.

Using the calibrated hydrologic model, projections of water use and water resources planning will be made when evaluating proposed climate adaptation strategies. At the same time the model will incorporate changes in population and capital improvements across the basin. These changes will include new irrigation schemes proposed by a number of different programs and additional dams. Adaptation strategies, when implemented, will improve current water use and remove much of the uncertainty associated with changes in the climate. In addition, new forecasting technologies will also aid in the optimal timing of farming practices, greatly reducing the risk associated with weather extremes. Since irrigation of crops, mostly rice, is the largest consumer of water in the Rufiji basin, a significant portion of this document will focus on techniques that can improve irrigation efficiency. In addition to irrigation water use, household domestic use of water both in urban and rural settings is also considered.

The objectives of the hydrological work are the following:

1. Develop a calibrated hydrologic model of the Rufiji basin including cropping scenarios from 1983 - 2014.
2. Compile historical water use permitting based on RBWO data provided by the Basin Office.
3. Calculate consumptive uses of water within the basin for irrigation, domestic water use, and water storage in the basin for additional uses, such as hydropower generation facilities.
4. Compile land use projections for modeling water uses in the Rufiji basin through 2060.

5. Calculate projections of population and increases in irrigation area per both capital projects / irrigation schemes and irrigation of cropped areas by households (smallholders) in the basin.
6. Develop climate adaptation strategies and scenarios for inclusion in modeling of the basin to be evaluated with UDSM and other project personnel for accuracy. This modeling will be completed in Y3 of the project.

2.3.1 Rufiji Basin and Hydrologic Model Configuration

In this study, the Soil and Water Assessment Tool (SWAT) was used to simulate the hydrology of Rufiji river basin. As with our previous work with SWAT on this project the watershed was subdivided into subbasins with careful attention being paid to delineate subbasins that corresponded to observed flow stations so that proper calibration of the model could be performed. In this work, the basin was subdivided into 33 subbasins (Figures 2.2-2.3). We originally chose 13 river gaging stations to use as part of this calibration work. This work represents the current conditions within the watershed given current land use and agricultural practices, water use conditions and climate. This modeling setup will be used as a starting point to include the future land use, water use, and climate change scenarios.

The SWAT model was set up to run given the inputs described earlier and with guidance for agricultural cropping parameters performed with the DSSAT model. The input layers into the model included land use, soil type and the digital elevation model. Daily weather data (rainfall, solar and max/min temperature) over the period from 1989 – 2010 was used to drive the model. A weather data file was created for each subbasin.

Of the 13 original river gaging stations, a total of 6 were ultimately used. They include the stations (1KA15A, 1KA11A, 1KA32A, 1KA31, 1KA59 and 1KB32). These stations were chosen because they contained data within our modeling timeframe of interest (1990 – 2010) and within them they contain long periods of observed data without interruptions. It was noticed that the data was more available without gaps from about the year 2000 to 2010 so most of the sites displayed in this report cover that period. Stage-based gauging stations were combined with the appropriate flow-based rating curves used at each station so that watershed discharge data could be calculated. It is appropriate in this modeling work to examine the data on a more coarse time step so the daily observed data was aggregated to a monthly average flow value. In turn, the SWAT model was set to output flow values on a monthly value. Additionally, with the exception of station 1KB32, the river gaging station data was located within the Great Ruaha River basin upstream of the Mtera Reservoir. Data within other areas of the watershed such as the Kilombero river or the main branch of the Rufiji River were unavailable to us or their time period did not cover into our modeling period of 1990 – 2010. Unless more observed data can be made available for other locations, this modeling work will be required to be mostly focused in the Great Ruaha basin.

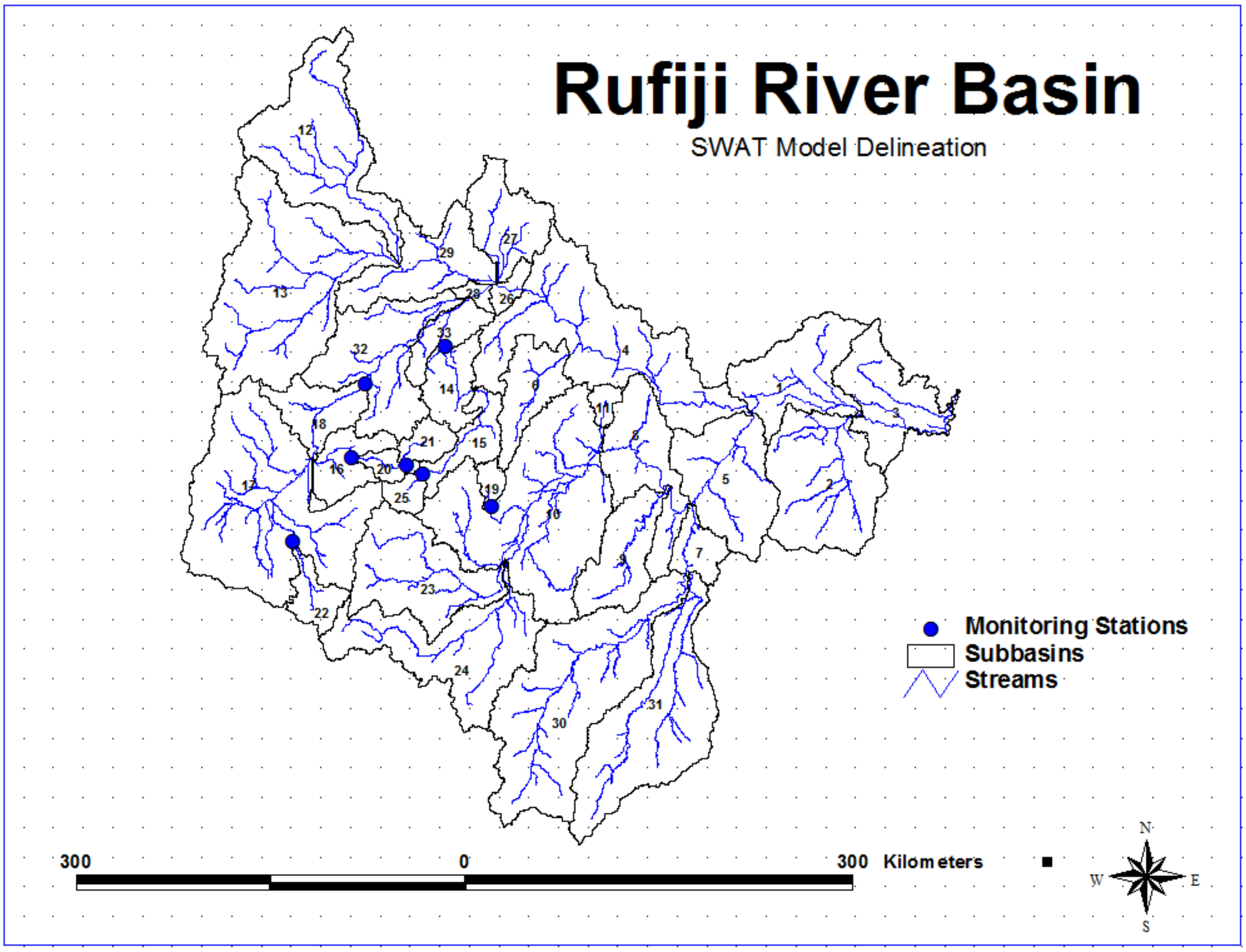


Figure 2.2. Map of basins and RBWO monitoring stations.

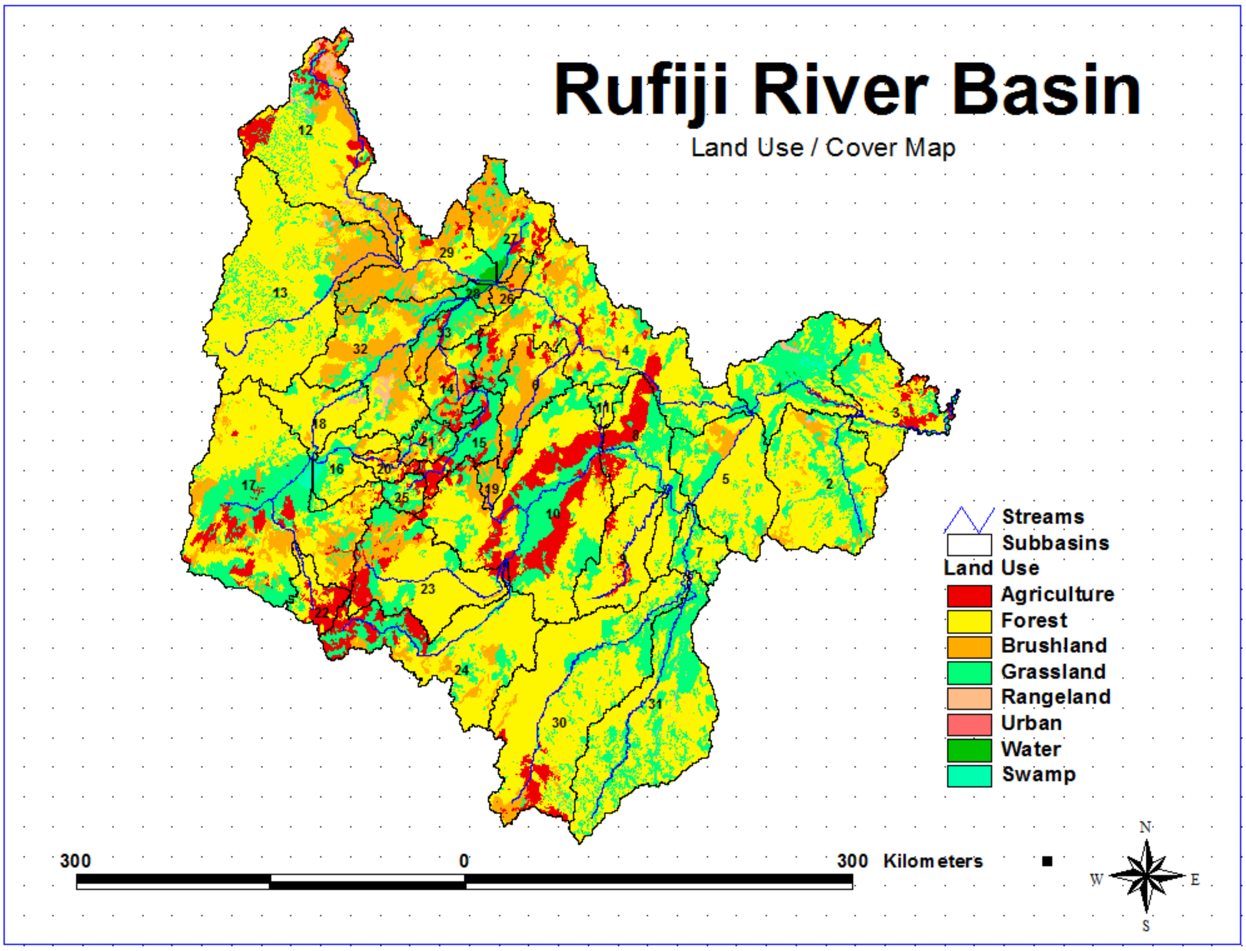


Figure 2.3. Map of basins showing land use.

2.3.2 Meteorological, Soil, and Land use Data

Meteorological data for the period 7/1/1983 through 12/31/2014 were compiled for calibration of the model against observed station values. The time-series begins on July 1st because that was the earliest availability of all necessary variables from each data source.

CHIRPS V2.0 was chosen as the source for precipitation data. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) "incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring" (Funk et al. 2014). The incorporation of in-situ data to complement the remotely-sensed data and the series of quality-control measures make this product preferable to other potential data sources. The dataset resolution equates to approximately 5 kilometers, surpassing other comparable datasets. The data are provided as GeoTIFF raster files via an FTP server. These raster files were all clipped to the extent of the study area.

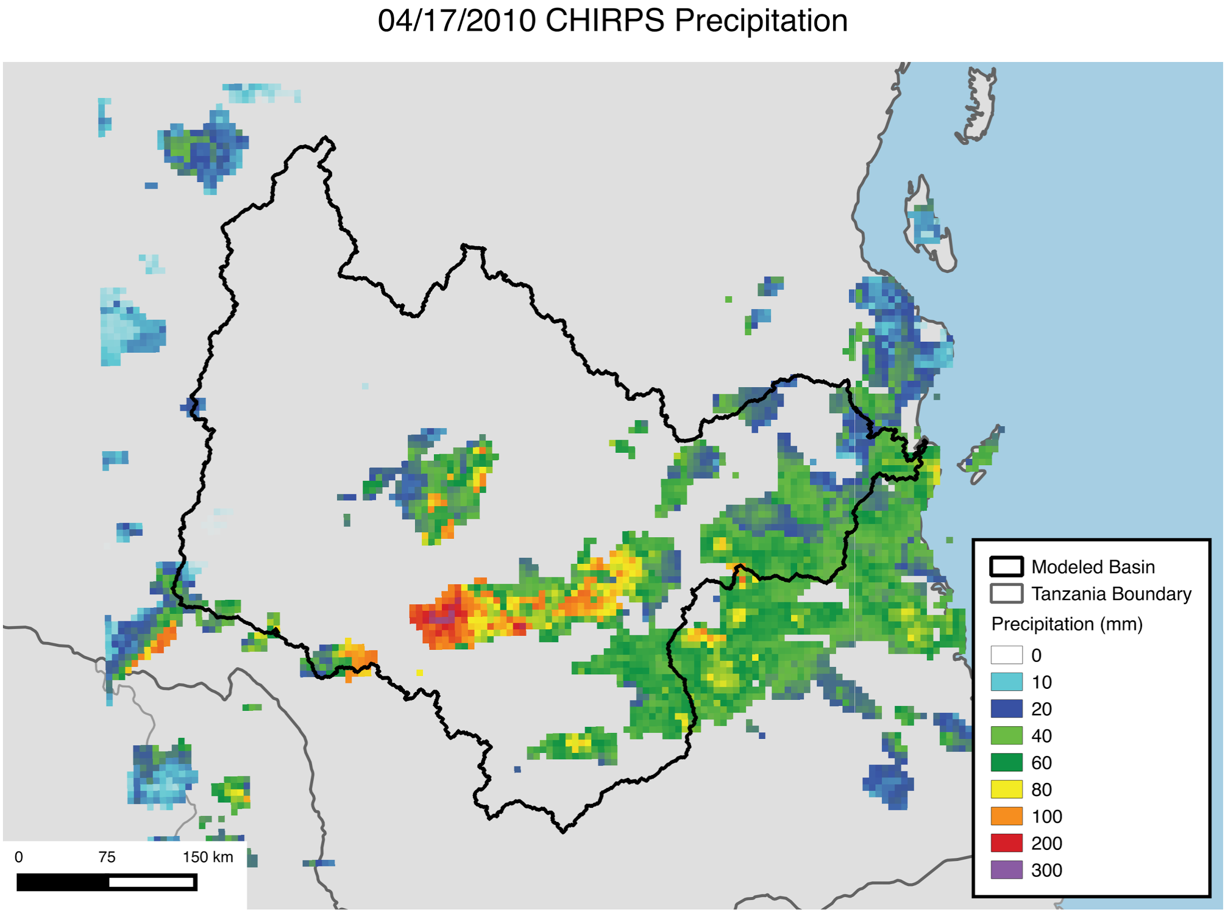


Figure 2.4. An example precipitation raster overlaid on the study area based on CHIRPS data.

The NASA POWER (Prediction of Worldwide Energy Resource Project) Agroclimatology dataset was chosen as the source for temperature minimum, temperature maximum, and solar radiation. The dataset combines a number of sources for each variable as necessary to assemble a long, historic time-series. The dataset provides global coverage on a 1° latitude by 1° longitude grid. Although this resolution is coarse in comparison to the CHIRPS precipitation, these variables are less localized than precipitation and the hydrological model is less sensitive to them. These data are available as text output from a web query based on an input coordinate. Each 1° latitude by 1° longitude grid cell was queried and the results for each variable were converted into daily GeoTIFF raster files. These raster files were then resampled to match the resolution and extent of the precipitation raster files.

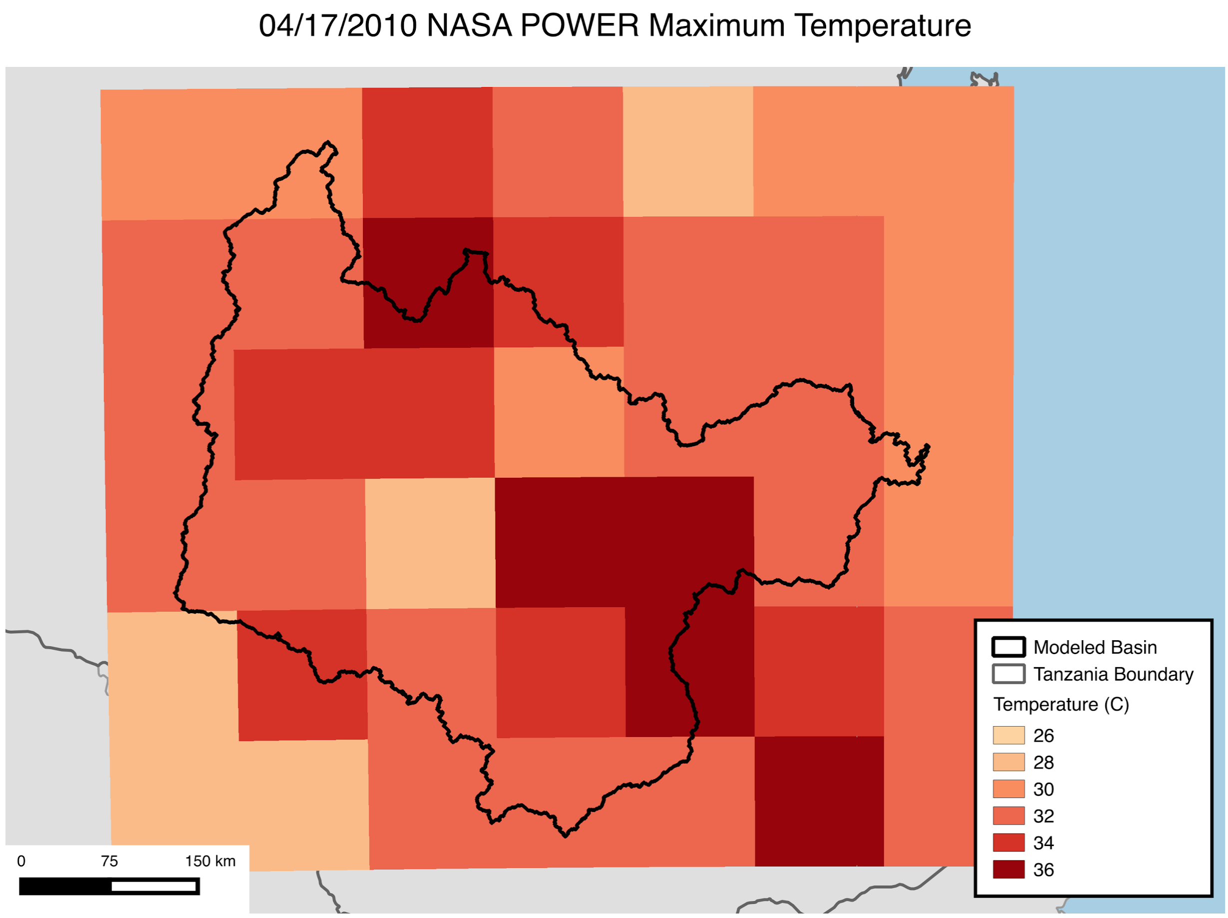

04/17/2010 NASA POWER Maximum Temperature

Figure 2.5. An example temperature maximum raster file overlaid on the study area.

With the sub-basins already determined from the monitoring stations, these meteorological data were used for calibration purposes. To accomplish this, a daily mean for each variable was computed from the raster grid cells contained within the vector extent of each sub-basin.

The Harmonized World Soil Database (HWSD) was the source of the soils data used in this analysis. HWSD is provided by the Food and Agriculture Organization of the United Nations

(Fischer et al., 2008) and the International Institute for Applied Systems Analysis (IIASA). As the name implies, this dataset is actually a compilation of four regional and global soil datasets placed into a common schema. The source for Tanzania within HWSD is the Soil and Terrain Database (SOTER) Programme. However, rather than use SOTER directly, HWSD was preferred based on previous familiarity and a more easily parsed schema. HWSD has been compiled at a resolution of one kilometer.

2.3.3 Land Use and Land Cover Data Analysis and Compilation

Vector land use classification files for 1996 and 2013 were provided by the Center for Climate Change Studies at the University of Dar es Salaam. An analysis of the change in hectares of cultivated land between the two files was performed for each of the sub-basins. The basin as a whole averaged a 6.3% increase in cultivated land per year. There were 620,010 hectares of cultivated land in 1996, increasing to 1,602,722 in 2013. This analysis served as the basis for future projections of cultivated land.

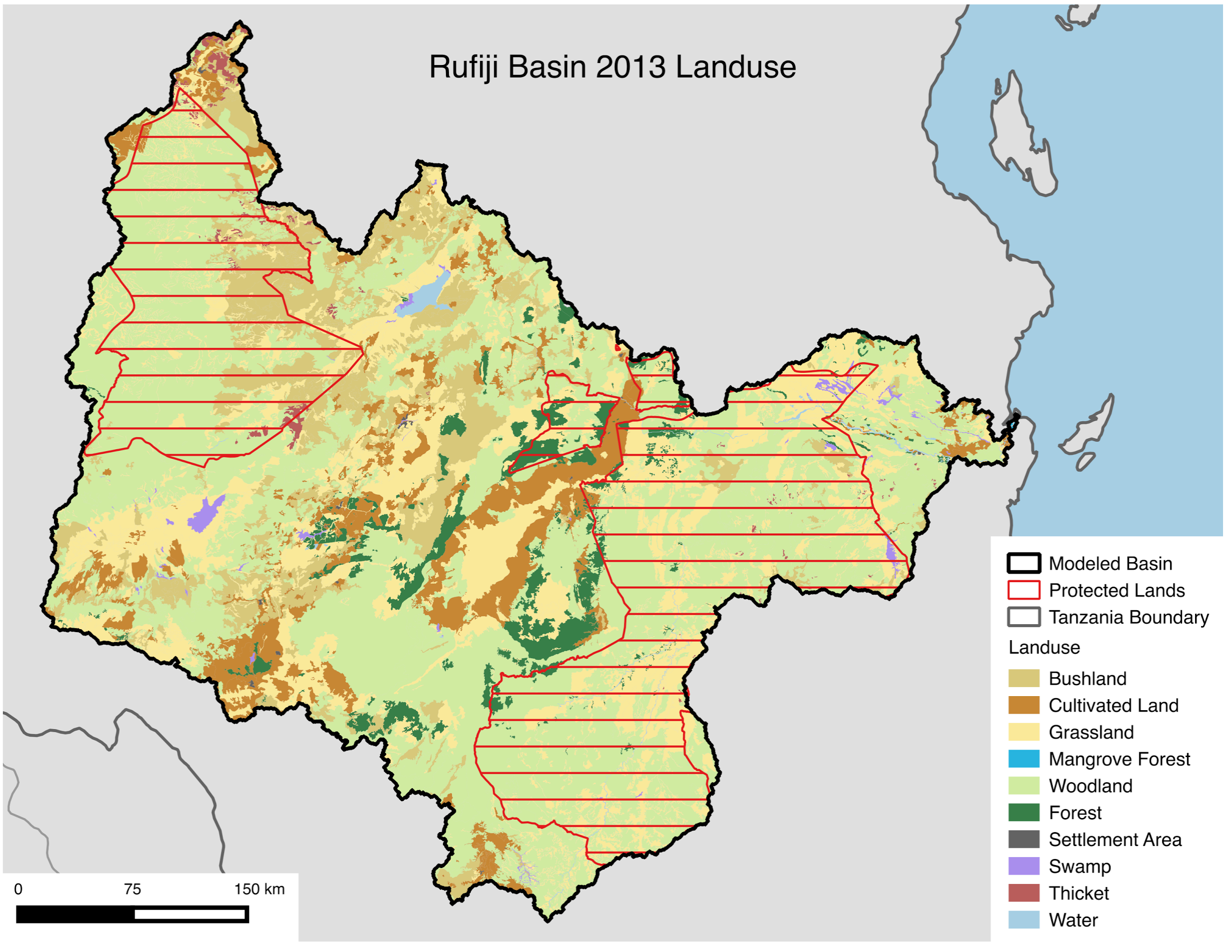


Figure 2.6. Land use classification within the modeled basin in 2013. 1,602,722 hectares of cultivated land.

A recently released 30 meter land cover product, GlobeLand30, from the National Geomatics Center of China (2014) was also chosen for this project. This global dataset is useful primarily because it can be used for national-level analyses as opposed to analyses solely within the Rufiji basin. This dataset contains ten land cover classes derived from circa 2010 Landsat and HJ-1 imagery. HJ-1 is a three member Chinese satellite constellation equipped with multispectral sensors. Other freely available land cover datasets are approximately one kilometer in resolution and are considerably older.

2.3.4 Population Projections and Water Use Estimation

Population data were obtained from the National Bureau of Statistics (NBS) population censuses for the years 2002 and 2012. Because of changes to administrative boundaries between censuses a data product was selected to which an alignment was performed. These data contain regional tabulations for both urban and rural populations.

Annual percent change in each population for each region was calculated. Of the regions the modeled basin crosses, the average annual urban percent change was 4.2%, and the annual rural percent change was 1.0%.

Because these data were available at the regional level, populations must be assigned to each sub-basin. First, the number of urban classified pixels from the Tanzanian raster land cover product contained within the entirety of each Region was determined. The urban population per pixel was then calculated. Using this figure for each region the total urban population was determined by multiplying by the pixels intersecting each region and sub-basin. Rural areas are not well-represented in the land cover product so a different approach was implemented. The amount of habitable land in each region was determined by eliminating regions where slope and land use would not allow for habitation at significant levels. Next, a population density figure was determined for each region. Using the habitable area of each region within the intersecting sub-basins the rural population could be totaled. The total population of the basin was approximately 1,400,000 in 2002 according to the RBWO. Our approach is in agreement with this figure. In 2012 the urban population of our modeled basin was 966,062 and the rural population was 895,879 totaling 1,861,941.

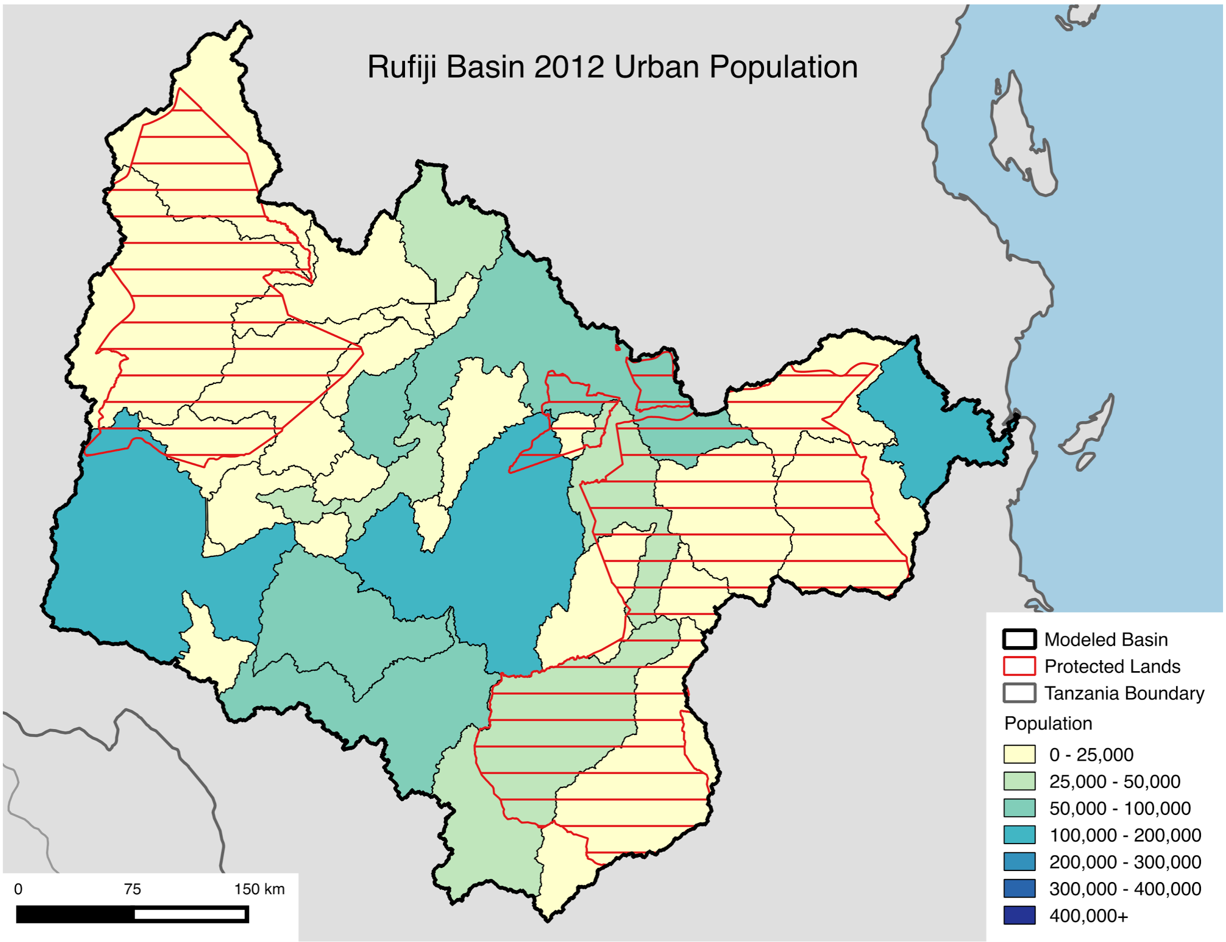


Figure 2.7. 2012 urban population within the modeled basin. Total population of 966,062.

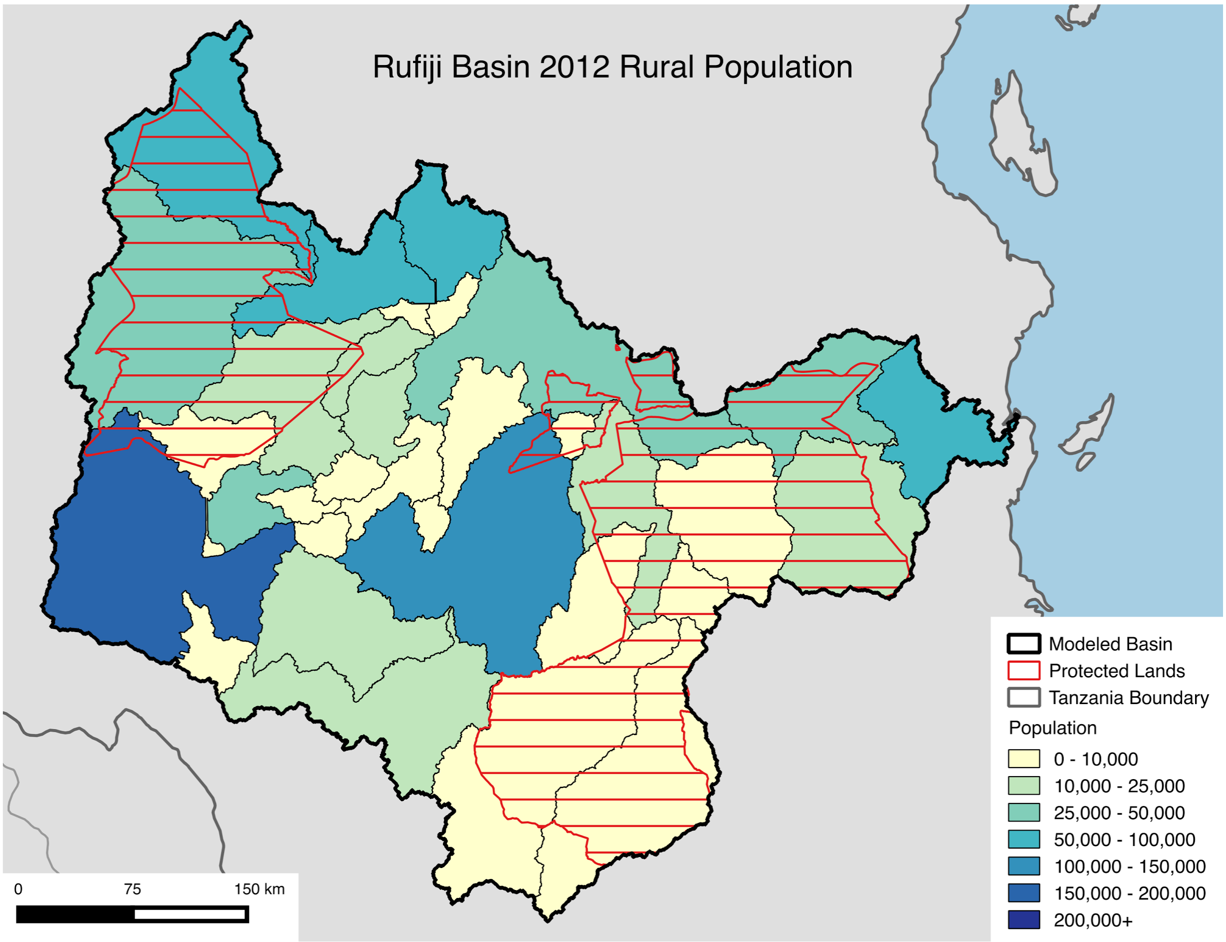


Figure 2.8. 2012 rural population within the modeled basin. Total population of 895,879.

2.3.5 Domestic Water Use

Domestic water use across the basin was determined based on the population estimates detailed in the previous section. Using domestic water use requirements developed from the Design Manual for Water Supply and Waste Water Disposal (as detailed in Ministry of Water - URT, 2014) of 25 liters per capita-day for rural residents and 70 liters per capita-day for urban residents, projections of water use were included for every month of the simulation for the historical calibration period. Projections were also included for use in the climate change periods of 2010-2040 and 2040-2060.

2.3.6 Future Scenario Planning

Current land use, population, irrigation schemes from small and large holder growers, and domestic water use estimates were used to calculate the current water resource conditions in the Rufiji basin. Future scenarios were compiled and presented in the results section of this document. After confirmation of a number of projections with the team during our end of year 2 section of the study (scheduled November 10th - 13th 2015) , these scenarios combined with population, irrigated area, irrigation efficiency, and land use conversion projections will determine water resource availability combined with climate projections from a number of the climate models configured by MSU colleagues (ongoing work). In year 3 of the study, these scenarios include improvements in irrigation efficiency and increased amounts of irrigation across the basin, alterations in the composition of small-holder to large holder growers and industrialization of agriculture in the basin promulgated by the policies of the Tanzanian government, improvements in irrigation methods and management, inclusion of additional water storage and rainfall harvesting, and climate-based forecasting of planting conditions and other agronomic decision making. Finally, scenarios based on increasing land use and water efficient agronomic practices will be included in this year's report.

3. RESULTS

This chapter will present the results of the various modeling and analysis. It starts with presenting results of projected changes in temperature and precipitation using the AR5 GCM model datasets for the Rufiji River Basin during the crop growing season. It then examines the projected impact of climate change on rice and maize, and considers the potential for improved management practices to assist in adapting to climate change impact. It then considers the results of the modeling and analysis of water resources in the Basin, including the effects of land use change, population change, and improved irrigation technologies.

3.1. Projected Future Climate Change During the Growing Season

Rice, maize and other especially grain crops are sensitive to changes in minimum (night-time) and maximum (day-time) temperatures, and to changes in precipitation. We therefore focus on these changes that are projected to occur during the crop growing season (mid-December to June). The results are in the form of maps of these climate variables for current climate conditions (represented by WorldClim data), projected future 2050 climate conditions (represented by downscaled GCMs to a 6 km resolution), and the projected change in climate between those time periods.

The Rufiji Basin has a wide range of temperatures, from extremely warm in the lowlands near the coast, to cold minimum temperatures averaging below 16°C in the Rubeho Mountains, Iringa Highlands, Mbarika Mountains and Kipengere Range (thereafter jointly referred to as the Highlands). The plains north of the Iringa Highlands are somewhat cooler than those south of the Highlands, where even minimum temperatures average over 25°C (Figure 3.1A and 3.2A). Under these conditions, rice is restricted to lower elevation areas where minimum temperatures are at least 16 or 18°C, and maize to lower and mid-elevation zones where minimum temperatures are above 10°C.

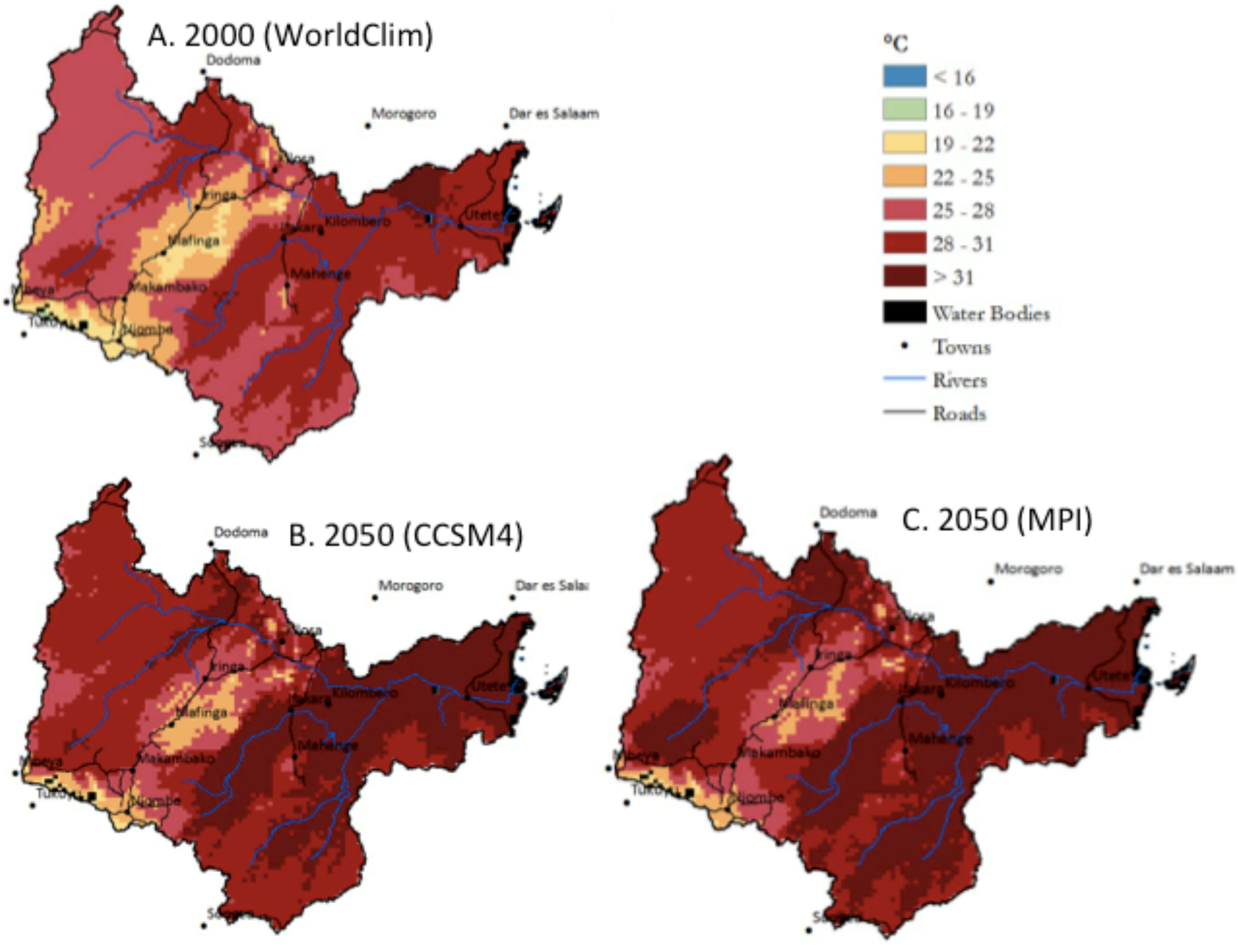


Figure 3.1. Average maximum temperature during the growing season under current climate conditions (A), and GCM projected futures of CCSM4 (B) and MPI (C).

Climate change is already raising temperatures in the Rufiji Basin (Figures 3.1, 3.2 and 3.3). All selected GCMs project an increase of an additional 1.5 to 3.5°C or higher, depending on location in the Basin and GCM. Generally the minimum temperatures are rising faster than the maximum temperatures. The GCM MPI projects more warming than CCSM4, which is somewhat cloudier.

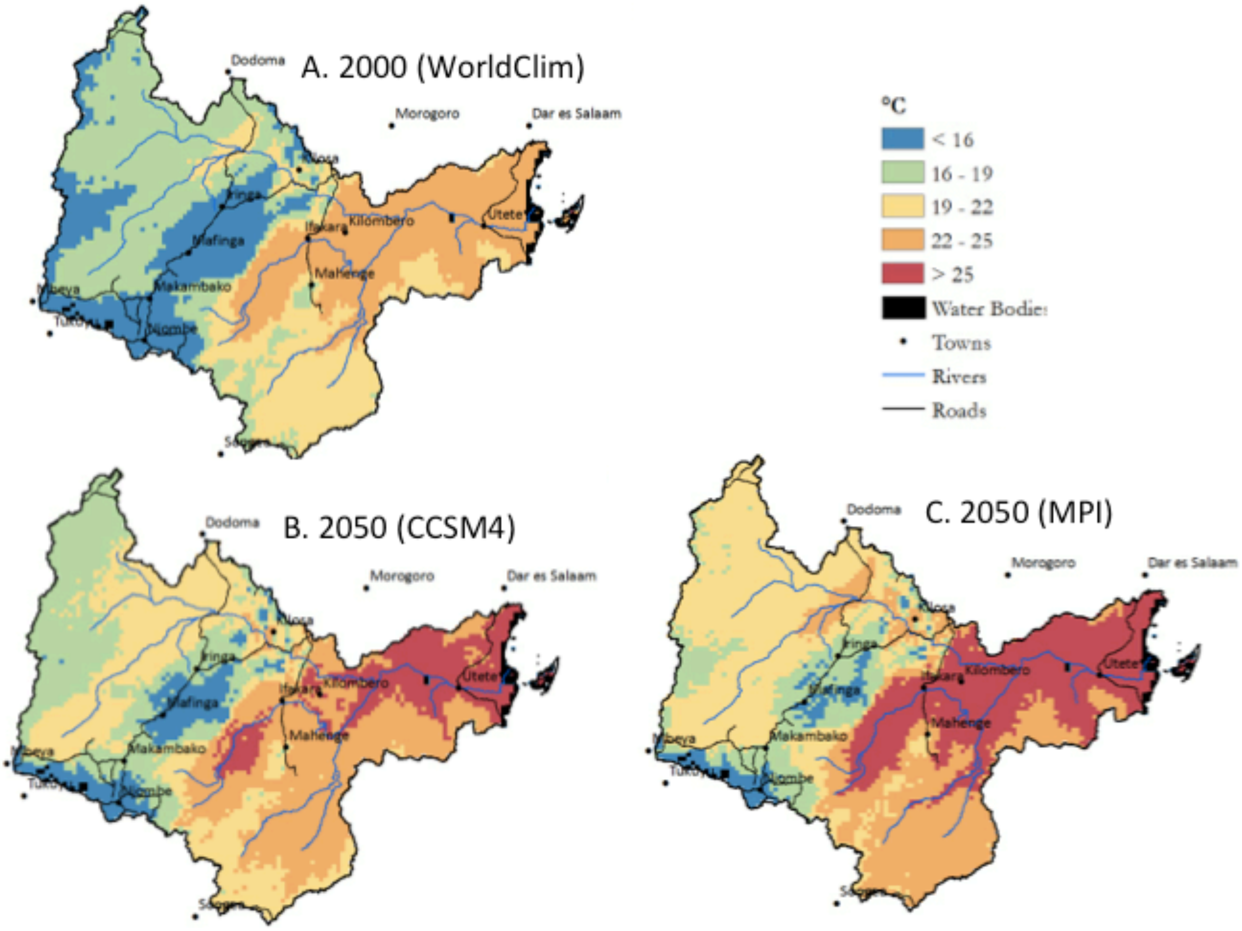


Figure 3.2. Average minimum temperature during the growing season under current climate conditions (A), and in 2050 CCSM4 (B) and MPI (C) GCMs.

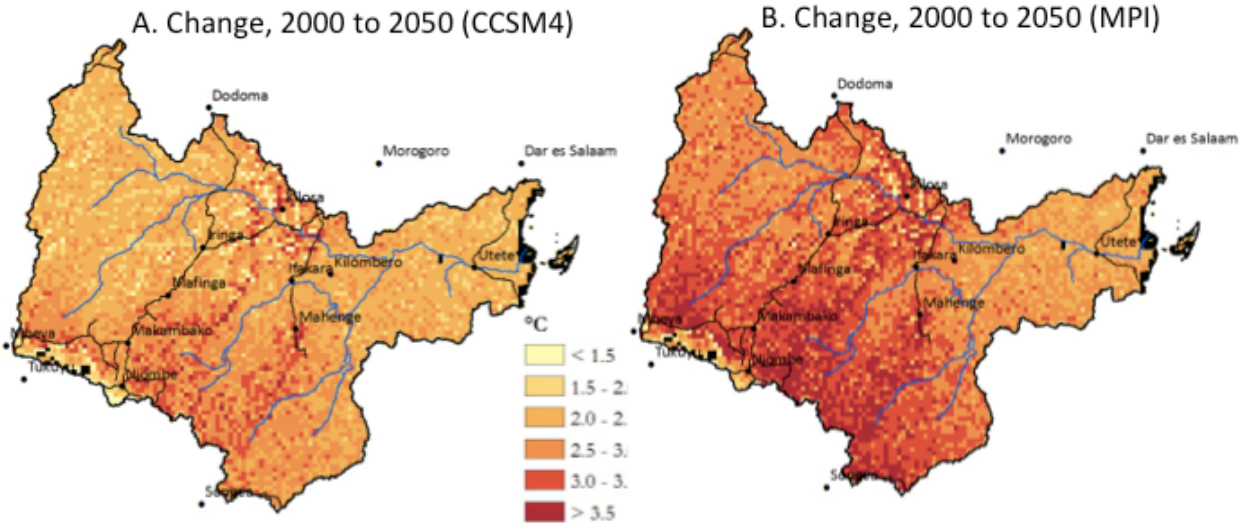


Figure 3.3. *Change* in maximum temperatures during the growing season between the current and 2050 time periods projected by CCSM4 (A) and MPI (B) GCMs.

Precipitation patterns in the Basin are similarly varied across space (Figure 3.4A). The areas with less precipitation are in the lowlands, particularly in the Mbeya plains north of the Highlands, because the mountains prevent much moisture from reaching there (the orographic effect). The lowlands south of the Highlands also receive less precipitation than the extremely wet Highlands that receive an average of over 1,000 mm/growing season. However, most of the lowlands are relatively less wet for rainfed rice and maize during the average year. Some of the driest areas in Mbeya are marginal, but most of the Basin generally receives sufficient precipitation for crops.

Precipitation is projected to change as well, although the projected changes are not large (generally between -250 and +250 during the growing season) (Figure 3.4 and 3.5). The five GCMs indicate somewhat differing amounts of change, with CCSM4 projecting the most decline, MRI the least change, and CanSM2 the most increase. All five, however, agree that generally the Mbeya area north of the Highlands are expected to receive more precipitation and the Highlands less precipitation. They disagree on the direction of change in precipitation amounts for the area south of the Highlands, with three GCMs projecting moderate declines, and two moderate increases.

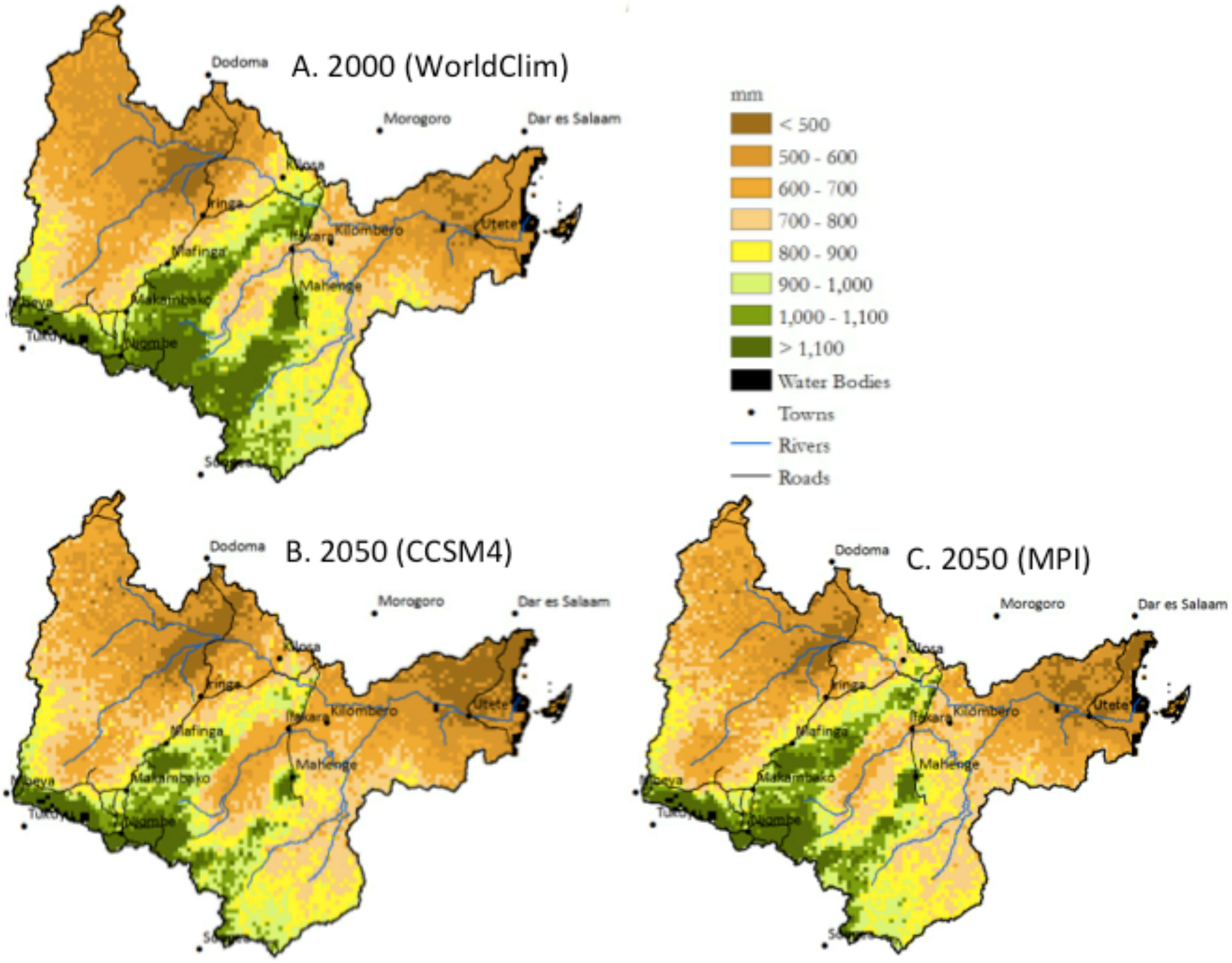


Figure 3.4. Average precipitation during the rice growing season (Dec-Jun) under current climate conditions (A), and projected 2050 futures by CCSM4 (B) and MPI (C).

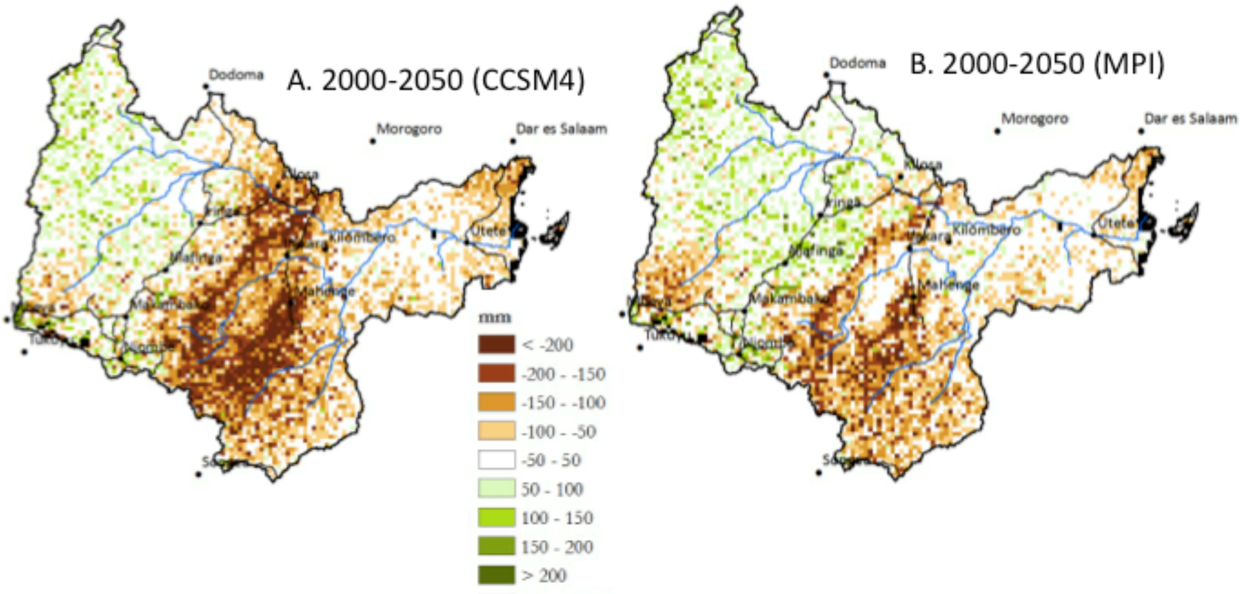


Figure 3.5. *Change* in growing season precipitation between the current and 2050 time periods as projected by CCSM4 (A) and MPI GCMs (B).

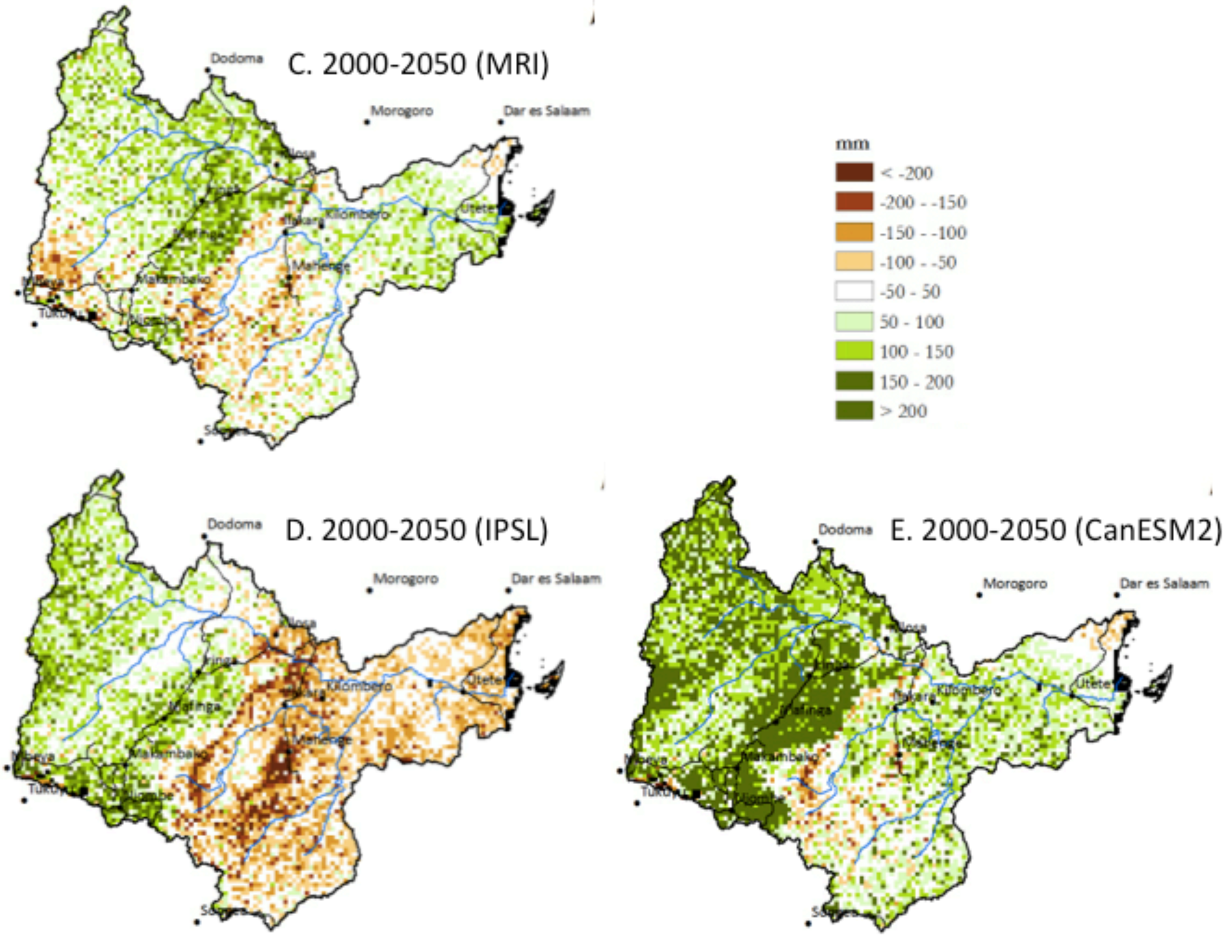


Figure 3.5 (cont.). *Change* in growing season precipitation between the current and 2050 time periods as projected by MRI (C), IPSL (D) and CanESM2 (E) GCMs.

Despite the projected decline in precipitation in the Highlands, the amount of precipitation falling there during the growing season there is projected to remain above 800 mm, or sufficient for most crops. In the drier lowlands, the projected average change in precipitation is not very large in most GCMs (although precipitation variability is expected to worsen, which is a major climate change impact not yet well reflected in GCMs). However, the rise in temperature in both zones can be expected to significantly affect both rice and maize growth and production. The next section will examine this more closely.

3.2. Impacts of Climate Change on Rice and Maize

3.2.1. Vulnerabilities of Rice and Maize to Climate Change

This section discusses the vulnerabilities of rice and maize to climate change. Both crops, like all plants, have optimum and inhibitory temperatures for growth and reproduction, and minimal and optimal water requirements. As the Basin temperatures warm and precipitation changes with climate change, this will affect the growth of the crops, and where in the Basin that they may grow well and produce grain.

3.2.1.1. Rice climate sensitivities

Rice (Oryza spp.) is a tropical plant with particularly warm temperature requirements. Most varieties, including those grown in Rufiji Basin, thrive in warm climates and do not produce in cooler temperatures. During the vegetative stage (from germination to panicle stage), cold temperatures below 10° C. slow down and can stop plant development. Growth is fastest at maximum (day-time) temperatures of around 25° C., and growth again slows if temperatures rise above 30° C. The plant is even more sensitive during the reproductive stage, from panicle initiation to flowering. Extreme heat events over 35°C for even a few hours can damage reproductive plant processes and lead to lower yields and, if lasting 10 days or more, complete sterility. Cold temperatures during this phase are equally harmful and more common. Minimum (night-time) temperatures below 25°C will slow reproductive processes, but minimum temperatures below 18°C will generally cause sterility and those below 16°C will lead to 100% sterility (Laborte et al. 2012; Wopereis et al., 2009). For this reason, our mapped results exclude areas with minimum temperatures below 16°C. Minimum temperatures over 30°C during the reproductive stage 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 are expected to become more favorable for rice production. Our results illustrate this change in where in the Basin rice may do well.

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 poorly if water stressed particularly during 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 important. 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)

3.2.1.2. Maize climate sensitivities

Maize (Zea Mays) is a tropical grass yet does best under moderate temperatures and is vulnerable to warming. Its temperature range is greater than for rice, especially its ability to withstand cooler temperatures. Ideal maximum (day-time) temperatures are between 27 to 30°C, and minimum (night-time) temperatures are 21 to 27°C. Temperatures above that, especially those above 35°C, lead to lower productivity. Like rice, warmer minimum temperatures reduce its yield while increasing its water demand. Warm minimum temperatures lead to higher respiration and less dry matter accumulation (Hoeft et al. 2000). Also, 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, reducing yields (FAO 2013).

Extreme warm temperatures, over 35°C, are are inhibitory at whatever stage of growth and yields fall off rapidly. 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. Cool temperatures below 10°C affect maize at all stages, reducing germination during early stages and delaying and reducing grain harvest and later stages. As the Highlands warm, their currently cool temperatures will become more conductive for maize.

Water requirements for maize vary greatly depending on variety, soil type 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.

3.2.2. Impact of Climate Change on Rainfed Rice

Rice is, as explained above in Chapter 2, very sensitive to both maximum and minimum temperatures. This sensitivity, combined with the wide variation in temperatures across the Rufiji Basin, leads to differing effect of temperature changes on rice growth and productivity across the region.

The maximum temperature affects rice growth in several ways—optimum, warm temperatures lead to good vegetative growth but, above a certain threshold around 30°C, hot temperatures cause the plant to slow or to stop growth (Welsh et al. 2010). Starting from more moderate temperatures, warming maximum temperatures speeds up the plant's phenology, or time to maturity, and if too rapid this reduces the time for the plant to produce biomass to support high grain yields. Thus maximum temperatures directly affect the rapidity of time to maturity and the amount of biomass produced.

Minimum temperatures affect rice growth and yield somewhat differently. When too cold, below 25°C, the reproductive processes will slow. Indeed, minimum temperatures below 18°C will generally cause sterility and those below 16°C will lead to 100% sterility (Wopereis et al., 2009). Warm minimum temperatures over 30°C during the reproductive stage also reduce yields. Thus minimum temperatures can be said to directly affect yield.

Figure 3.6 reflects the impact of temperature on the length of growing season across the Rufiji Basin under current climate conditions (6A), and two future climate GCM conditions (6B and 6C). The darker blue indicates a longer time to maturity, and the lighter blue indicates a faster time to maturity. Black indicates areas that are too cold for rice to produce, with minimum temperatures below 16°C. Comparing the length of growing season with the temperature maps (Figures 1 and 2), the geographical distribution of time to maturity under current conditions appears to mirror the maximum temperature, with the most rapid maturity times of under 120 days in the warmer eastern zones. The area north of the Highlands has more moderate temperatures, and the days to maturity are mostly in the 140 to 160 day range. But the higher elevation zones have cool temperatures that are reaching the point of being too cold for rice, and the time to maturity lengthens to over 160 days. Indeed, the minimum temperatures in the higher elevation zones that too cold, below 16°C, cause sterility, no yield and these areas are indicated in black.

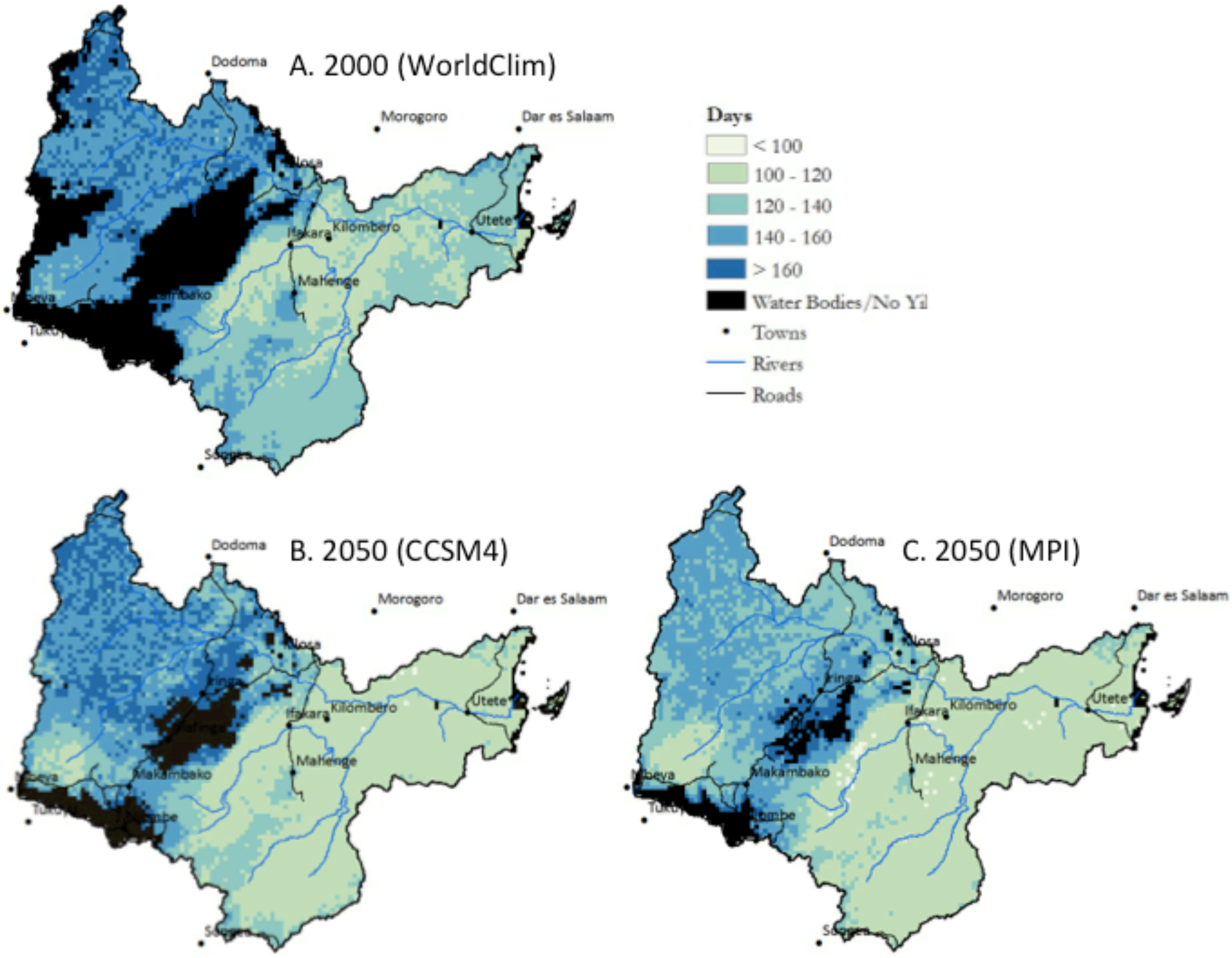


Figure 3.6. Length of growing season for TXD-85 rice transplanted in December under current climate conditions (A) and two future projected GCM climates, CCSM4 (B) and MPI (C).

With projected warming, the length of the growing season can be expected to shorten. This process affects the rice in regions differently. The already very warm east and southern area is projected to get even warmer, with minimum temperatures averaging over 25°C (red color in Figure 3.2) and maximum temperatures averaging over 31°C (darkest color in Figure 3.1) in some places. These warmer temperatures do somewhat reduce the already short length of the growing season, which would affect yield. The temperatures also have reached the threshold where frequent hot temperatures would negatively affect the amount of growth and the fertility of the plant. Both effects could be expected to reduce yield.

In contrast, the area north of the Highlands in Mbeya has more moderate current temperatures. The projected warming would, therefore, have a significant impact on the length of the growing season, shortening it by up to 40 days depending on location and GCM model. This would directly reduce plant production and yield. It would remain, however, relatively cool for rice production.

Finally, the rice in the Highlands is under cold stress under current climate conditions, and only small areas of the Highlands are warm enough to have any rice production. The zones with minimum temperatures too cold for rice, illustrated in black in Figure 6, cover most of the Highlands. With the projected warming in the future, however, minimum temperatures will increase significantly and the area too cold for rice under current conditions will shrink. Even if rice can be grown there, however, the length of the growing season is still very long, over 160 days.

The impact of projected climate change on rice yield in the Rufiji Basin, therefore, would be the result of the combination of initial temperatures and projected rise in temperatures, and the initial precipitation and projected change in precipitation. Indeed, the maps of yield under current climate conditions, and under projected future climate conditions (Figure 7), and maps of the change in yield between current and mid-century (Figure 8) illustrate the varied yield across the region, and varied impacts of climate change.

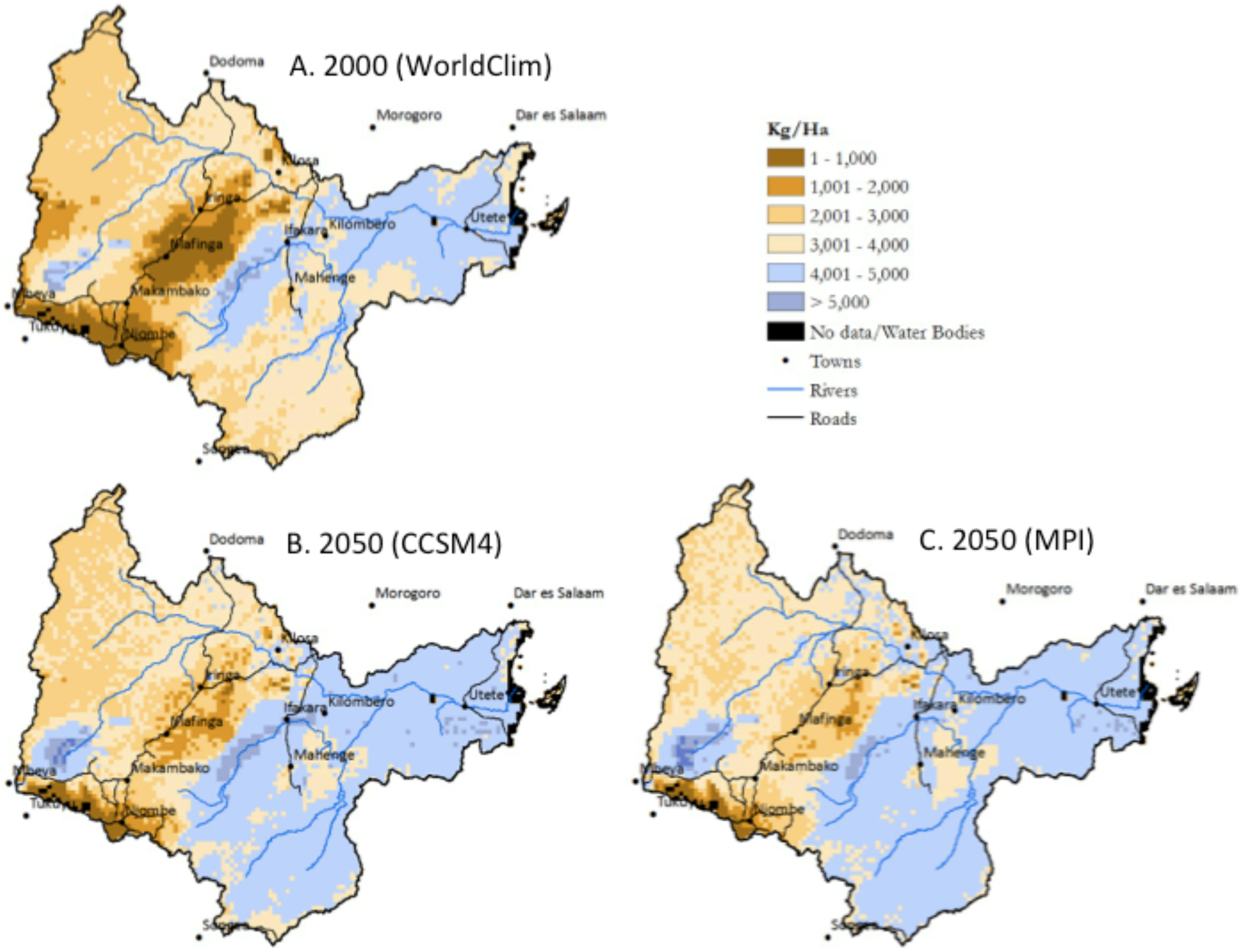


Figure 3.7. Yield (kg/ha) of TXD-85 rainfed rice with 100 kg/ha nitrogen transplanted in December under current (A) and two future projected GCM climates (B and C).

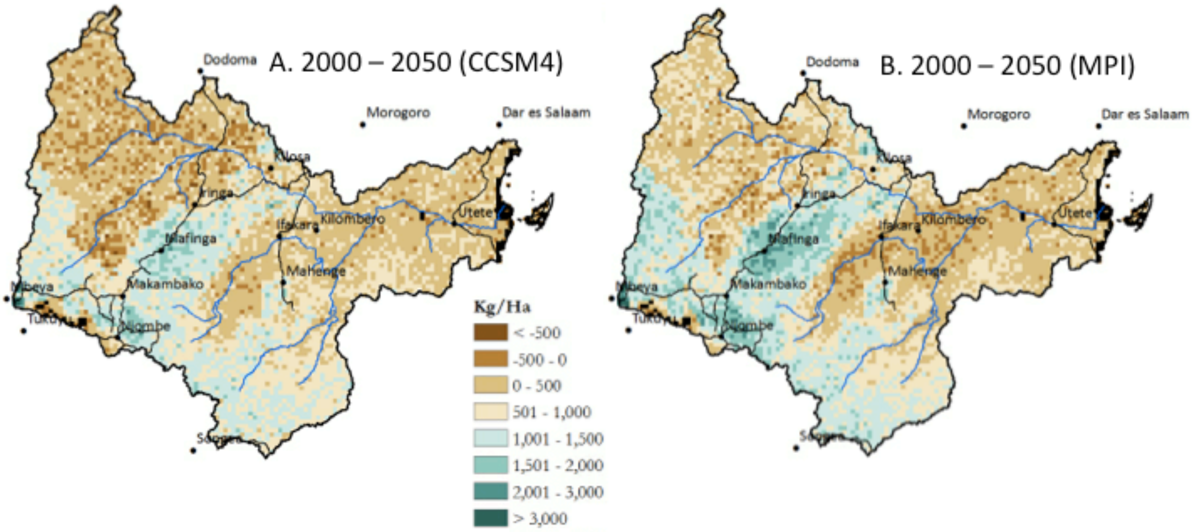


Figure 3.8. *Change* in yield (kg/ha) between current and two mid-century GCMs: CCSM4 (A) and MPI (B). TXD-85 rainfed rice with 100 kg/ha nitrogen transplanted in December.

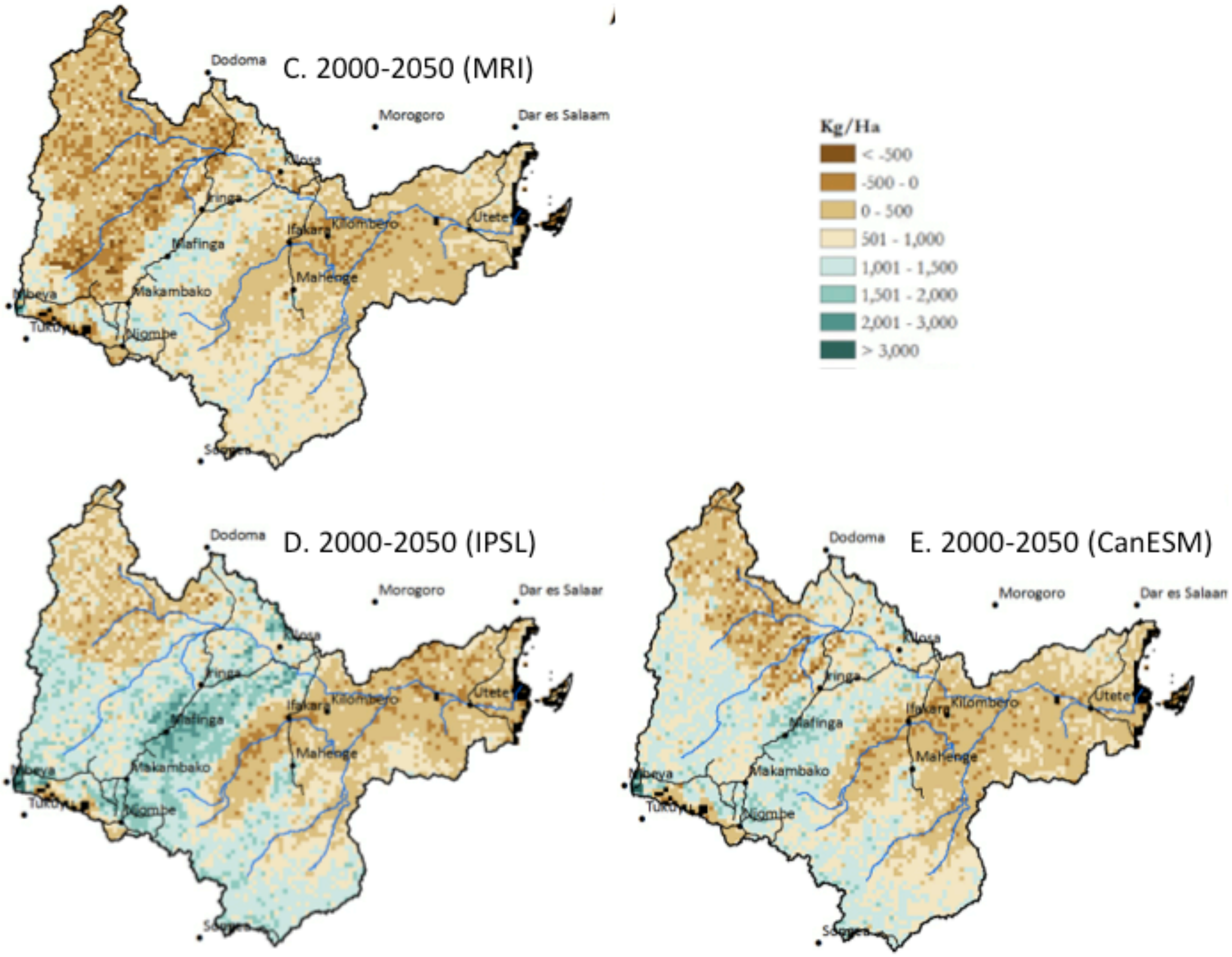


Figure 8 (cont). *Change* in yield (kg/ha) between current and three mid-century GCMs: MRI (C), IPSL (D) and CanESM (E). TXD-85 rainfed rice with 100 kg/ha nitrogen transplanted in December.

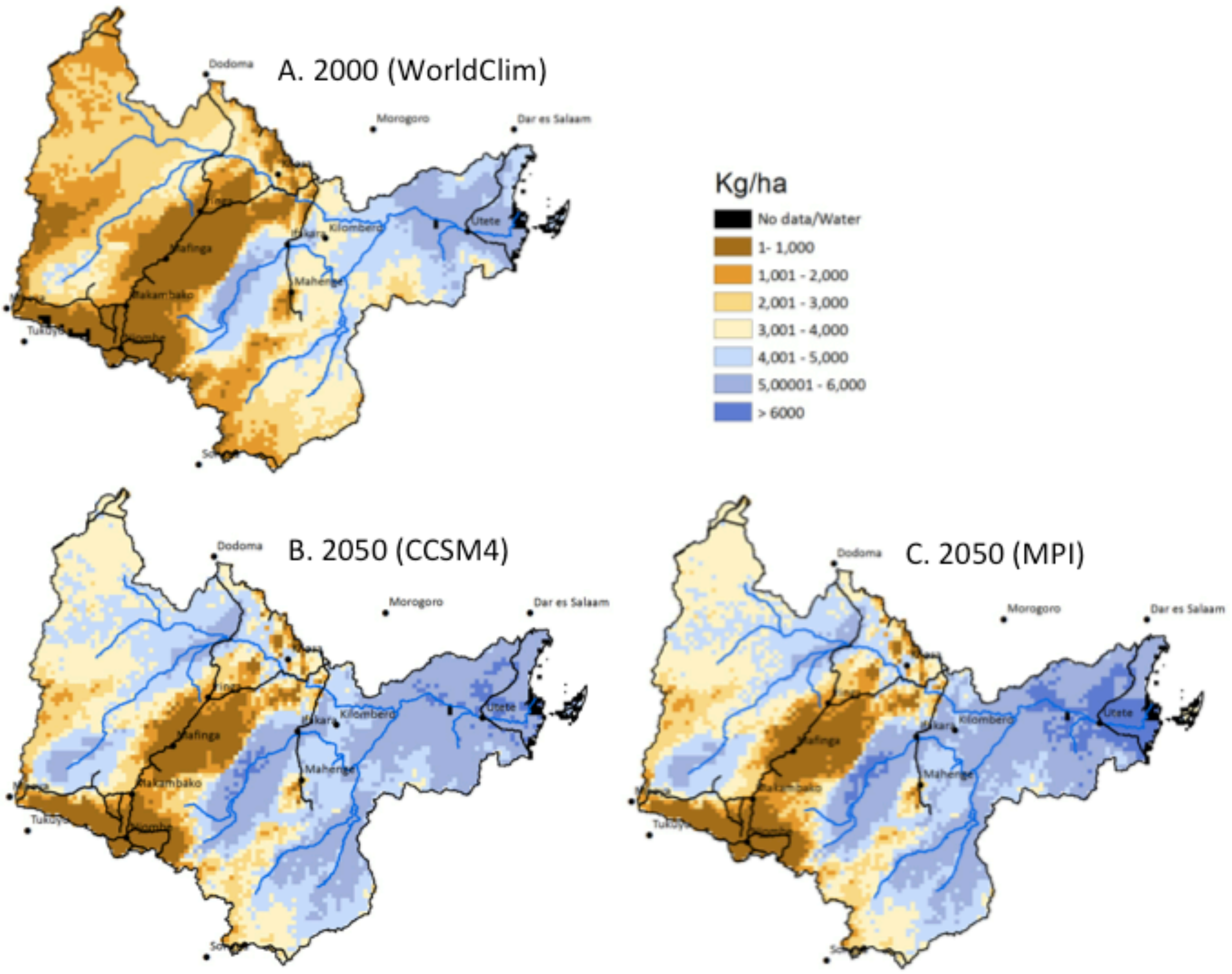
The yield maps indicate a high degree of variation in yield, with the highest yields in the warmest zones. These areas have ideal conditions for rice, with their warm temperatures and sufficient precipitation. Simulated yields are over 5,000 kg/ha (note: on-farm yields rarely attain these types of simulated yields because simulations do not reflect plant disease, lower nutrient levels, pest, weeds, etc.). Yield are lower in the cool plains and especially the Highlands, where cool temperatures restrict growth and yield.

Projected warming temperatures, therefore, can be expected to improve yields in the more moderate temperature zones in the plains, and in the Highlands. The projected change in precipitation is not sufficient to cause most areas to experience water deficits that would affect yield. The only exception is in the northwest of the Basin which will experience low levels of deficits under some GCM simulations.

Indeed, the results shown in Figure 8 do indicate that yields rise in the Highlands, where the warmer temperatures will reduce cold stress and be more conductive to rice (though the cold will continue to suppress yields). However, the projected little change or even declines in rice yield in the moderate temperature zone north of the Highlands illustrates the impact of the shrinking length of growing season, and some increase in water deficits. Even though the warmer temperatures will be conductive to rice, they will cause more rapid maturity and lower yields. In the warmest zones east and south of the Highlands, simulated yields remain the same or decline. There, the warming temperatures don't lead to much change in the growing season length, but they reach the threshold where hot temperatures can suppress plant growth and yield.

3.2.3. Impact of Climate Change on Irrigated, Winter Rice

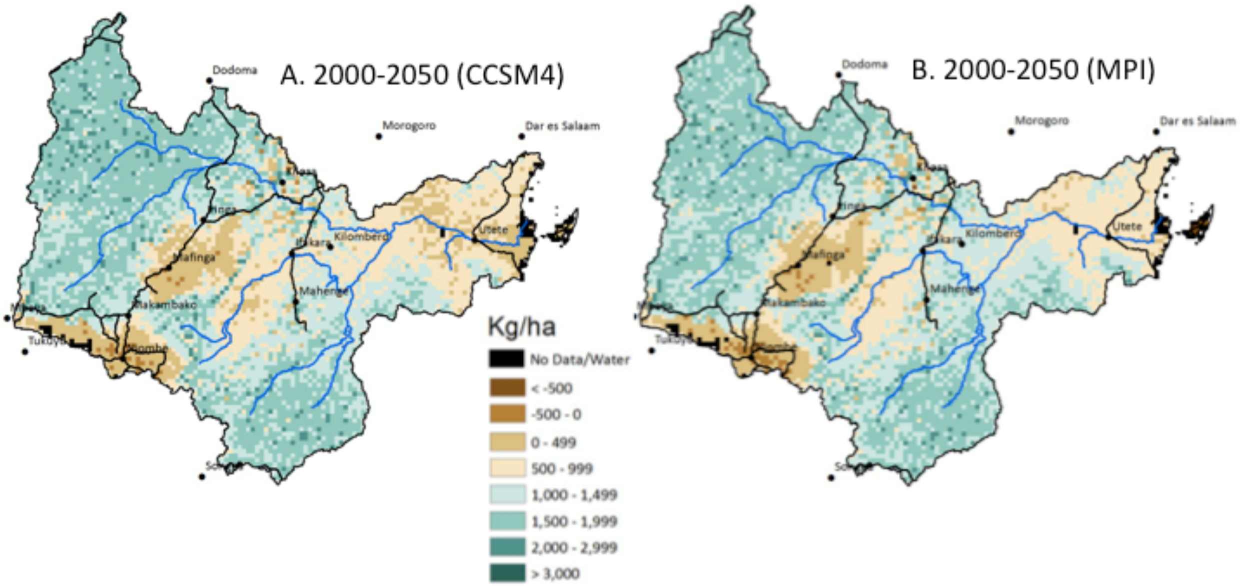
During the "winter", or dry season from around June to September, many farmers in the Rufiji Basin grow irrigated rice. Climate change can be expected to impact this rice production, as well, even if precipitation amounts would not affect it. The dry, winter season is cooler than the main growing rainy season and the warming temperatures could be expected to improve yields. The rice simulations were conducted during this period under irrigation, so the simulated plants would not have experienced water deficits. Temperatures would have the largest effect.


A. 2000 (WorldClim)

B. 2050 (CCSM4)

C. 2050 (MPI)

Figure 3.9. Yield (kg/ha) of TXD-85 irrigated rice with 100 kg/ha nitrogen transplanted in June under current (A) and two future projected GCM climates, CCSM4 (B) and MPI (C).


A. 2000-2050 (CCSM4)

B. 2000-2050 (MPI)

Figure 3.10. *Change* in irrigated rice yield (kg/ha) planted in June between current and two future projected GCM climates, CCSM4 (A) and MPI (B).

Figure 3.9 illustrates irrigated, winter rice yield under current climate, and two future climate simulations. Under current temperatures, much of the region is too cool for rice to obtain its maximum yield. Only the Kilombero Valley and closer to the coast are temperatures ideal. In the future, especially under the warmer MPI GCM, the warming temperatures indeed increase the area that receives the higher yields. Indeed, the change in yield maps, Figure 10, illustrate that especially the currently cooler zones can expect winter rice yields to somewhat increase. The areas currently with optimal temperatures in the winter will actually see some declines in yield, as the warmer temperatures cause the length of growing season to shorten.

Results presented in the Milestone 1.5 report included tests of the impact of different nitrogen fertilizer levels on rainfed rice yield in seven sites across the Rujifi Basin. The question being addressed was whether nitrogen (N) fertilizer could reduce the variability of yield, and where in the Basin it would have the largest impact. The results are summarized here because of their potential to provide insight into climate change adaptation practices. As expected, the driest site with the warmest temperatures, Rufiji, shows the highest inter-annual precipitation and yield variability among the sites. Kilosa, the site with warm but not hot temperatures and with sufficient precipitation, had the highest yield, and the cooler and wettest sites (Mufindi, Kilolo) had the lowest yield. Production under three levels of nitrogen fertilizer (5, 50 and 100 kg/ha) were examined. Yield returns to N were high in all sites, indicating that N application would be a good “no regrets” option. In the drier, warmer sites, returns declined after 50 kg/ha N compared to the 5 to 50 kg/ha yield improvement. However in the wetter sites the yield return increased substantially between 50 and 100 kg/ha N. These results indicate that with the warming temperatures, the yield returns to N will be less than what they currently are in the warmest areas because other conditions (heat, shorter length of growing season) restrict yields. Where the temperatures are not too warm and water sufficient, however, N applications can be expected to continue to provide large returns.

In summary, the impact of climate change on rice growth and productivity in the Rufiji Basin is complex and varies across the Basin. The warming temperatures projected in the future are expected to lead to a shift in growing conditions for rice during the rainy season. The foothills of the Highlands may become viable for rice as their cool temperatures warm. However, elsewhere in the Basin during the rainy season, temperatures are currently optimum or too warm for rice, and the warming temperatures of the future are expected suppress yields. Yields will decline due to a shortening of time to maturity (the length of the growing season) as the phenology quickens. Especially in the warmer areas to the east and south of the Highlands, the more frequent hot temperatures will also depress yields, and returns to nitrogen fertilizer will decline. During the dry, winter season, however, the warming temperatures will affect rice less because current temperatures are much cooler. Indeed, yields may rise across the Basin in the winter except in the warmest locations.

3.2.4. The Impact of Climate Change on Maize

Maize has a larger temperature range than rice, particularly its ability to withstand cooler temperatures. Most varieties also require less water than rice. These environmental variables, as well as socioeconomic reasons (labor requirements, yield, food preferences) result in maize being a major crop in the Rufiji Basin. Climate change is expected to affect maize production in the Basin because the warming temperatures will reduce the time to maturity and lower yield, hot temperatures above 35 °C are inhibitory at whatever stage of growth, and warmer minimum temperatures reduce its yield while increasing its water demand. In warm locations with high water demand, the precipitation may be insufficient and water deficits can lower yields.

Results were provided in the Milestone 1.5 report on the simulated impact of climate change on the Katumani Composite maize variety, but subsequent feedback indicated that farmers are now growing newer, higher yielding varieties. The team thus conducted additional maize simulations using the hybrid H-614 maize cultivar for Tanzania (not just the Rufiji Basin).[3] The results presented here are thus for H-614, and for the sake of simplicity, simulations from one AR4 GCM (HadCM3). The question being addressed was, "Would adaptation practices reduce the negative impact of climate change on maize productivity?" Examined first are the impact of water deficits and the potential benefits of irrigation under current and future climate conditions, and secondly the impact of nitrogen stress and potential for nitrogen fertilizer under current and future climate conditions.

Perhaps the most important yield limiting factor in the region is water. Water deficits mostly mirror yields, confirming its critical nature (Figure 11). In Rufiji, yield are suppressed due to water deficits in some of the warmest areas. The Highlands have sufficient water but the highest elevation areas are too cool for maize. To examine the impact of water deficits and the potential of irrigation to increase yields, maize simulations were conducted assuming unlimited water, no water deficits. The results, in Figure 12, show the potential yield of maize. In this simulation, the main limiting factor on yields is cool or hot temperatures.

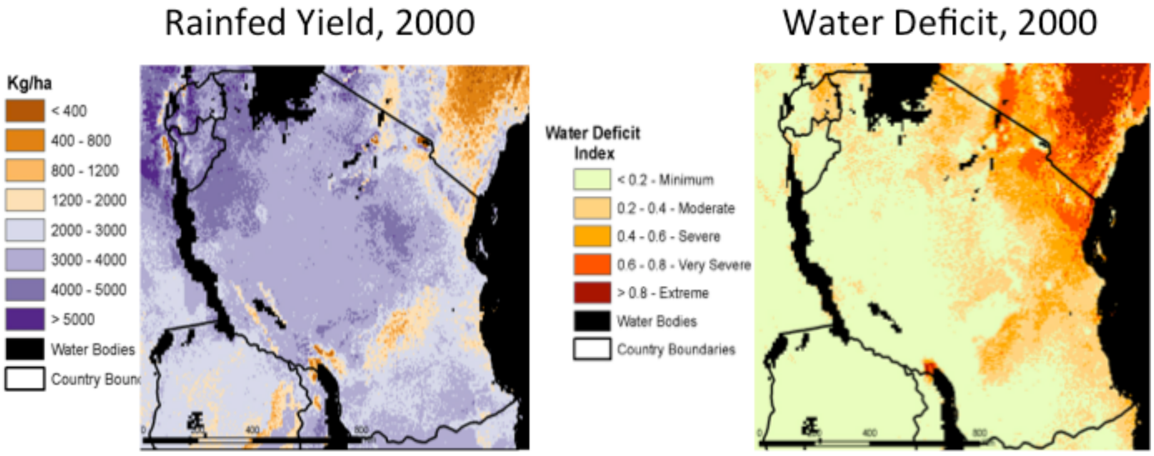


Figure 3.11. *Left*: H-614 maize variety simulated rainfed yield, current climate (WorldClim), 85 kg/ha N. *Right:* Simulated water deficit for maize, current climate (WorldClim).

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[3] The maize simulations were partly supported by USAID Associate Award AIDOAA-LA-11-00010 under Food Security III, CDG-A-00-02-00021-00.

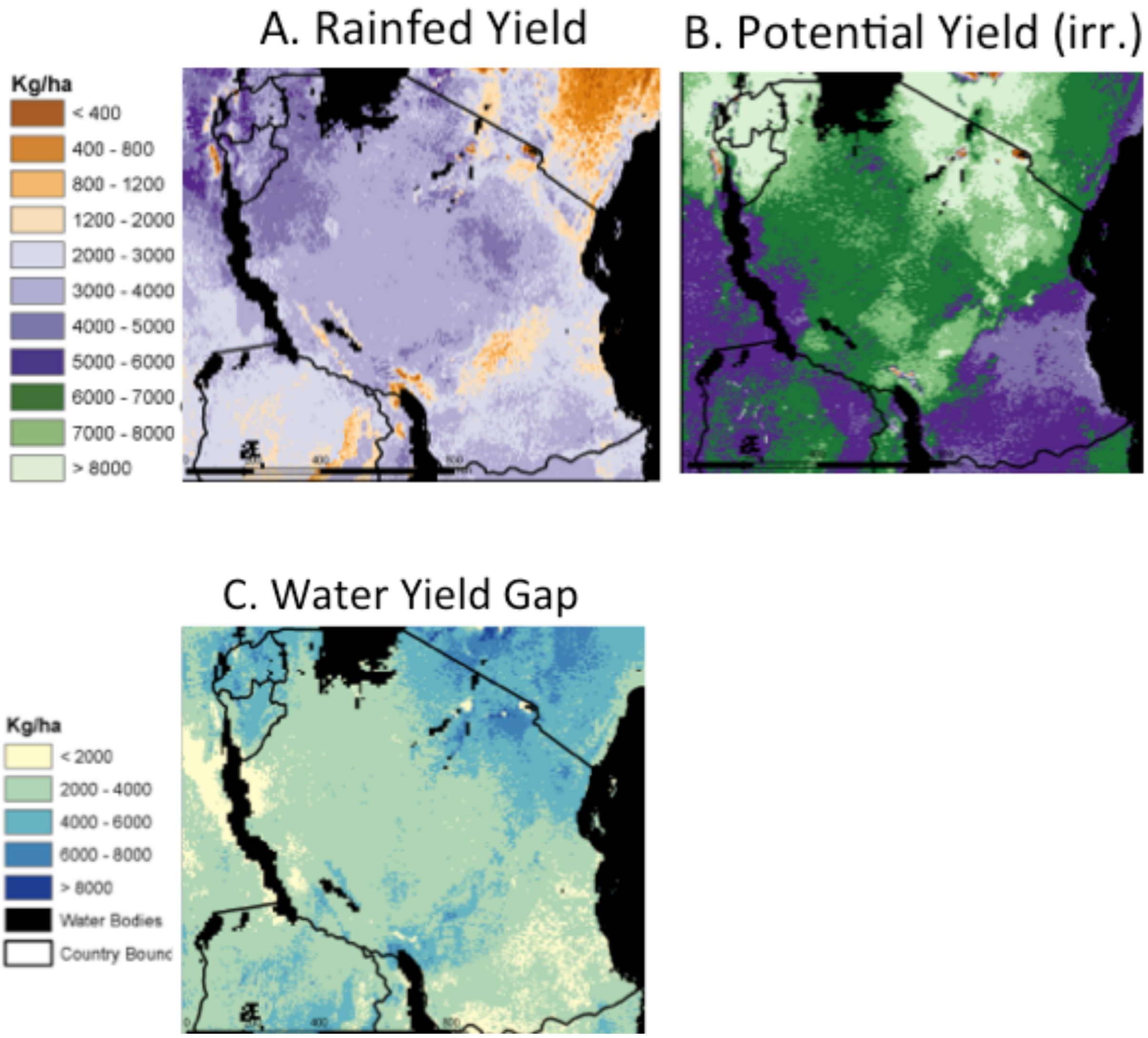
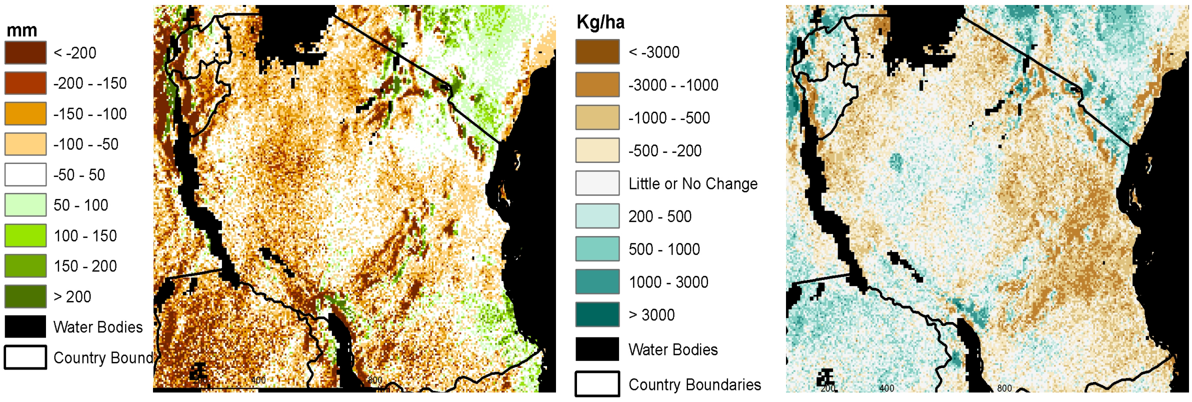


Figure 3.12. **A.** Rainfed yield: H-614 maize variety simulated rainfed yield, current climate (WorldClim), 85 kg/ha N. **B.** Potential yield: 614 maize variety simulated with no water deficit (as per with irrigation), 85 kg/ha N, current climate (WorldClim). **C.** Water yield gap: the amount of additional yield obtained with irrigation (i.e., yield of map A subtracted from map B).

Figure 12A is again rainfed yield, but Figure 12B is the potential yield, or the yield that could be obtained with irrigation and sufficient nutrients. The potential maize yield in the hotter eastern and southern part of the Rufiji area is up to 6,000 kg/ha, and in the cooler plains north of the Highlands yields reach over 8,000 kg/ha. The additional maize yield that could be obtained by providing irrigation is called the Water Yield Gap, and is calculated by subtracting the rainfed from the potential yield. The yield gap reflects where irrigation would provide the largest benefit. In Tanzania, the gap is highest in moderate temperature, dry areas. In hotter areas (such as near the coast) or the cooler wetter Highlands, the amount of additional yield that could be obtained by irrigation is smaller.

Climate change, however, will alter this. GCMs project growing season temperatures increases of between 1.5° and 3.5° C by 2050. According to the HadCM3 in Figure 13A and other GCMs, moderate precipitation increases or decreases can be expected in the Basin.



A. Change in Precipitation (2000 to 2050, HadCM3)

B. Change in Rainfed Yield (2000 to 2050)

C. Change in Water Deficit (2000 to 2050)

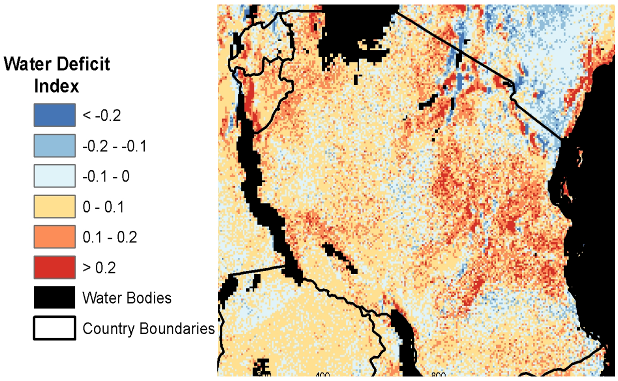


Figure 3.13. **A.** Change in the growing season precipitation from the current (WorldClim) to mid-century (HadCM3) climates. **B**. Change in rainfed maize yield from current to mid-century. **C**. Change in the rainfed maize water deficit index between current and mid-century.

The warmer temperatures combined with little change in precipitation would raise maize water demand, worsen maize water deficits and reduce yields especially in water-limited areas. As shown in Figure 13B, only in the Highlands would maize yields improve because the warmer temperatures would moderate the current cold. Elsewhere, especially where temperatures are already warm and precipitation projected to decline, maize yields generally decline by around 1,000 to 3,000 kg/ha. The change in water deficit index map, Figure 13C, reflects the worsening situation except where precipitation is projected to increase.

The full impact of climate change is revealed in projected declines in potential yield between current and mid-century (Figure 14, browns indicate declining yield). The warming will lower yield by between 1,000 and 3,000 kg/ha even under optimal water and nutrient conditions, due to shorter times to maturity and the impact of hot temperatures suppressing yields. Again, only in the cold, high elevation areas will maize will produce better in the future. This map, more than any other, indicates the challenges faced under climate change.

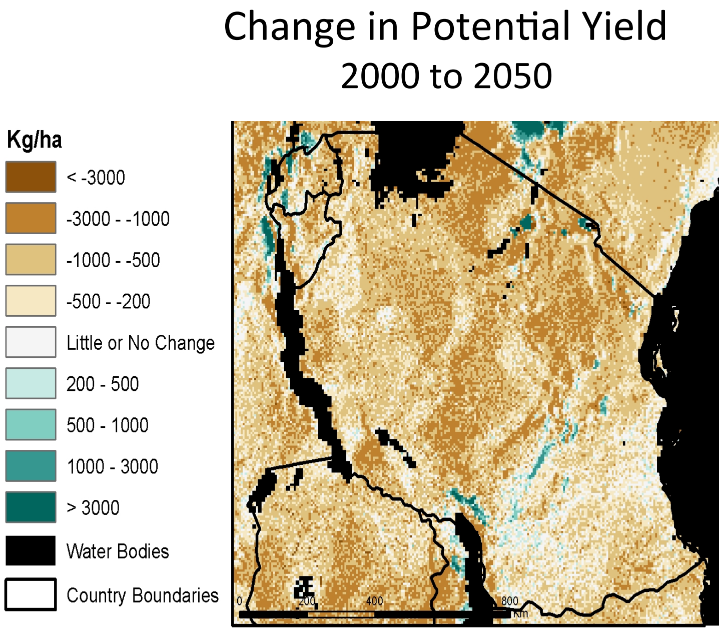


Figure 3.14. Change in potential yield of H-614 maize between 2000 (WorldClim) and 2050 (HadCM3) (no water or nutrient deficits).

The second important limitation to maize yield in this region is plant nutrients, especially nitrogen and phosphorus. This study focused on nitrogen (N). Figure 15 illustrates maize yield under two N application levels: 5 kg/ha (very low but what many farmers apply) and a moderate 85 kg/ha. The difference in obtained yield between these two N applications is illustrated in C. The benefits to N application are generally large across the region. Only in the cold Highlands with their volcanic soil, or in very dry or hot areas, is the N yield gap small. In these areas, N fertilizer would not provide as much much benefit.

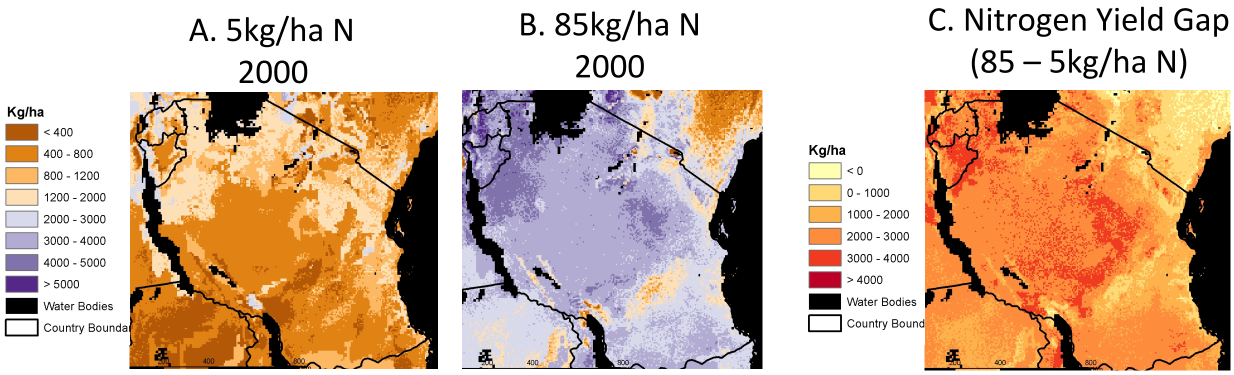


Figure 3.15. **A**. H-614 rainfed maize yield under 5 kg/ha N application, current climate (WorldClim). **B.** Same as A, but with 85 kg/ha N. **C.** Nitrogen yield gap, or the difference between maps A and B.

In the future, the nitrogen yield gap, or the difference between yields obtained using low and high N applications, is projected to be smaller (Figure 16, purple color indicates less yield benefit due to N). In the future, N fertilizer will not be able to increase yields as much it currently does because of the impacts of hot temperatures and worsening water deficits constraining maize yields. Like irrigation, the benefits to N will decline in the future.

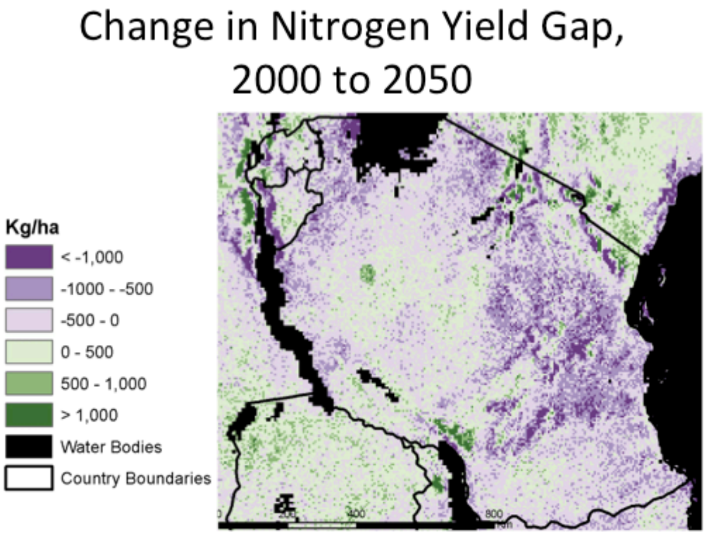


Figure 3.16. . Change in the nitrogen yield gap of H-614 rainfed maize between 2000 (WorldClim) and 2050 (HadCM3).

In summary, the analysis of the potential of irrigation and N applications to reduce the negative effect of climate change on maize yields indicates:

a. The Rufiji region has highly variable yield responses to water and N under current and future climates, which calls for locally adapted management recommendations. However, under the current and future climates, additional application of N fertilizer even at moderate levels dramatically increases maize yield.
b. Most maize growing areas are already water limited, and climate change is expected to worsen water deficits. Unfortunately yield benefits to supplemental water will decline in the future due to hotter temperatures.
c. Nitrogen is also very limiting, and yield benefits to N applications are high especially in locations that are not too cold, hot or dry. However, the yield benefits to N will shrink in the future as temperatures clime and water deficits worsen.
d. N fertilizer application is likely to most benefit wetter, cooler areas where temperatures remain under 40° C.

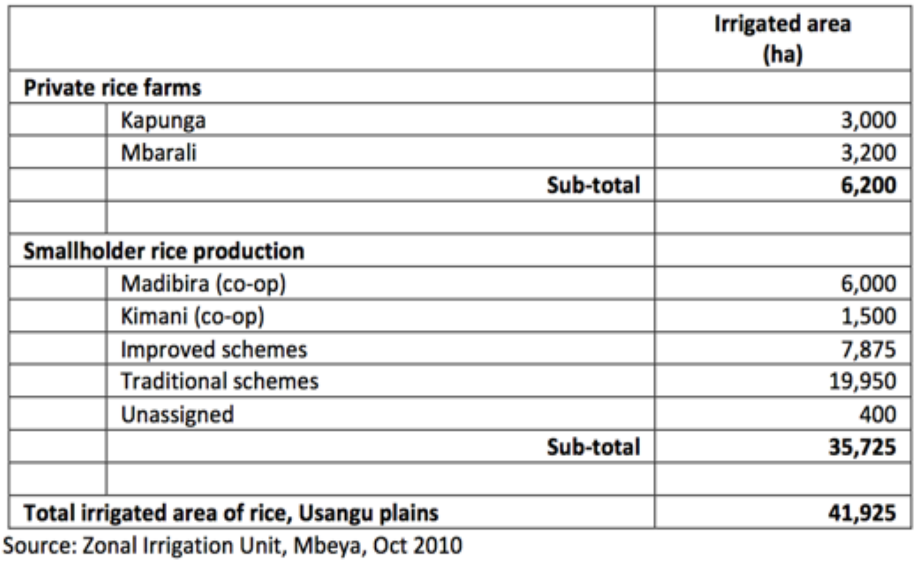
3.3. Water Resources in the Rufiji River Basin

3.3.1. Basin-Wide Water Resources Demand

Basin-wide water resources demand is critically affected by amounts of irrigation. Water demand from consumptive use by people is an incredibly small portion of the total water use. Based on data from the Tanzanian Census of Agriculture (both regional, for example, Mbeya Region Agricultural Census, 2007/8 - URT, 2012 and national), irrigated areas were compiled and assigned to each basin. While classified land use data indicate what might be cultivated areas versus other land uses, the amount of irrigated area is much more difficult to geo-locate accurately with the exception of planned irrigation schemes, which in many ways can be. In addition, these irrigated areas do not accurately reflect the reality of what is actually occurring. For example, the primary agricultural areas noted by the census of agriculture or other irrigation estimates for the Mbarali area of Mbeya Kapunga Farm and Mbarali State Farm often do not include the small holder section of Kapunga Farm and other miscellaneous schemes. Only a case study of the realities of irrigation in this critical area conducted by SAGCOT (SAGCOT, 2015 referencing data from the Zonal Irrigation Unit, Mbeya) showcases the universe of the irrigation area in the Usangu plains of the Mbarali area. An excerpt is shown in Table 3.1.

SAGCOT (2015) describes the usage in the basin as varying incredibly based on wet or dry years and varying from 22,000 ha (dry year) to 42,000 ha (in an average year). The maximum irrigable area using flood irrigation is approximately 55,000 ha. These numbers are more than double those reported by the census of agriculture. We speculate that these totals also do not include all amounts of household based irrigation requirements, which might not be considered as irrigation by zonal irrigation units or census data collectors.

Table 3.1. Excerpted from SAGCOT (2015) - Rice Irrigation in the Usangu Plains



		Irrigated area (ha)
Private rice farms		
	Kapunga	3,000
	Mbarali	3,200
	Sub-total	**6,200**
Smallholder rice production		
	Madibira (co-op)	6,000
	Kimani (co-op)	1,500
	Improved schemes	7,875
	Traditional schemes	19,950
	Unassigned	400
	Sub-total	**35,725**
Total irrigated area of rice, Usangu plains		**41,925**

Source: Zonal Irrigation Unit, Mbeya, Oct 2010

Data were processed for all permitted uses based on data from the RBWO. When totaling these water uses and comparing them to a few values found in other sources, larger schemes were accurate in terms of permitted use; however, when totaling these usages across the basin, it was readily apparent that either the permitted water uses were over-permitted or that a number of the permits are no longer used by the people to whom they were issued. This was based on the year of some of the active permits, which were registered to individuals even for small water uses. Additional work will be required to ensure accuracy when using these data.

When totaling all irrigated areas and combining with the 500 mm of water required by the rice crop (the largest crop water requirement compared to maize - from MSU collaborator work), incorporating low levels of irrigation efficiency, and including domestic consumptive water use, our calibrated watershed model was overestimating water availability based on hydrologic data from RWBO gauges for basins after significant irrigation schemes and cultivated areas. For headwater basins where these uses were minimal, our calibrated model of these basins was incredibly accurate in reproducing outflow gauge data from the RWBO network including baseflow amounts in the river network. In order to fully account for water use in the agriculturally-dominant basins, water withdrawals were increased to minimize the difference between model outflows and gauge data from RWBO. We suspect that the significant amount of water being used in these primary areas is comprised of low irrigation efficiencies, permitted uses, unregulated and un-permitted use, and diversions for use with no return flow. Noting the difference between official census estimates of irrigated areas and those reported in the Usangu Plains document (SAGCOT, 2015), it is clear that significant discrepancies exist between published amounts of water use and actual amounts of water use. Completing the partitioning of this water use into components will be the focus of the next and final stage of the project. This significantly affects future planning.

3.3.2 Projected Land Use

Projections of land use are shown in Figures 3.17 - 3.18 and detailed in Table 3.2. Each sub-basin was assumed to continue expanding its cultivated land at the annual rate observed between 1996 and 2013, that rate was not allowed to exceed 6.3%. Rates higher than that are likely unsustainable and may be the result of changes in the classification between the datasets and not actual on the ground changes.

An algorithm was created to select lands for conversion based on certain criteria. Only land use classifications of Bushland, Grassland, Natural Forest, Thicket, and Woodland could be converted. No lands within protected areas could be converted. Additionally, any lands to be converted fall within a soil suitable for cultivation and have a mean slope of less than 10%. The combination of all of these conditions was combined with a 100 hectare grid to simplify the selection process. The algorithm then iteratively selected lands for conversion. Upon reaching the years 2025 and 2050 output files were created depicting the extent of cultivated land at those points in time. These years were chosen because they represent the midpoints of each of the future periods. These layers will be used to represent the entirety of their respective periods.

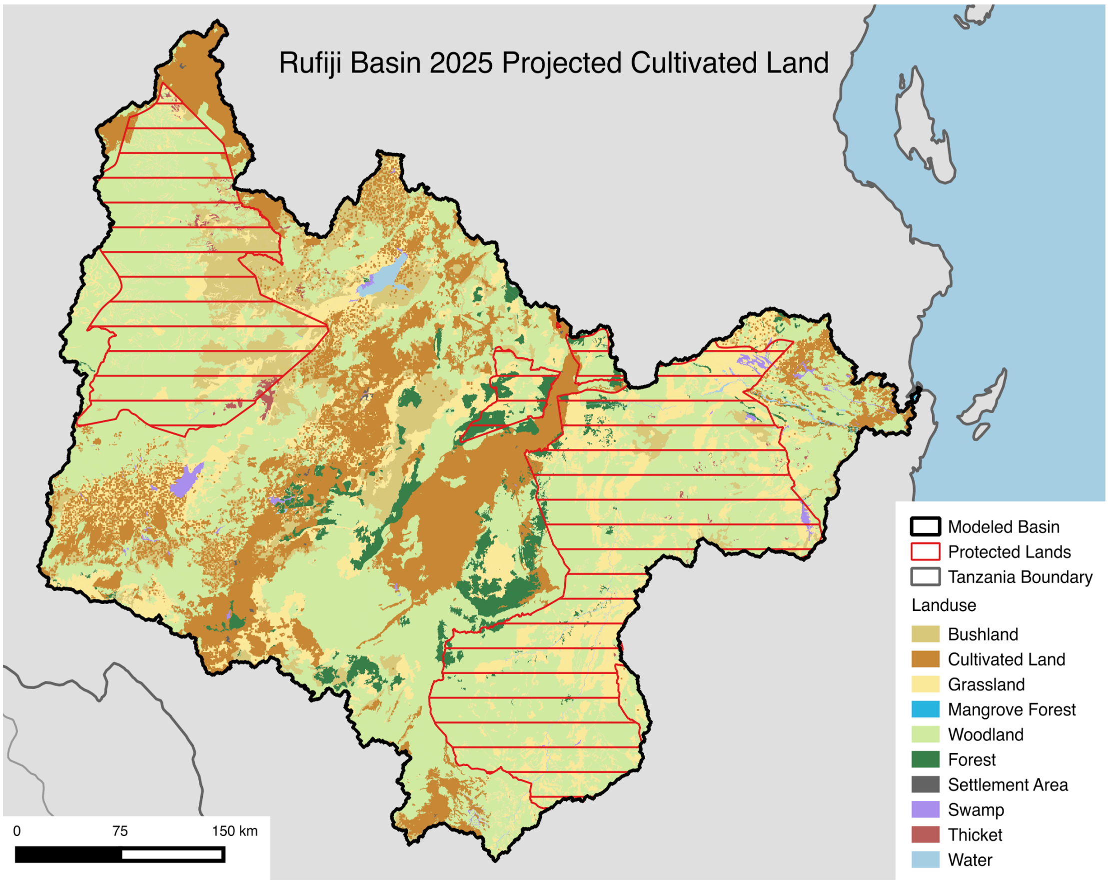


Figure 17. Projected cultivated land within the modeled basin in 2025. 2,961,812 hectares of cultivated land.

In 2013, the total cultivated land within the modeled basin was 1,602,722 hectares. In 2025, the total cultivated land within the modeled basin is projected to reach 2,961,812 hectares. This represents an 85% increase from 2013, averaging 5.25% annually. In 2050, the total cultivated land within the modeled basin is projected to reach 3,618,640 hectares representing a 22% increase from 2025, averaging a mere 0.8% annually. This slowdown can be attributed to the lack of lands available for conversion. Significant portions of land that could be converted otherwise are within protected regions.

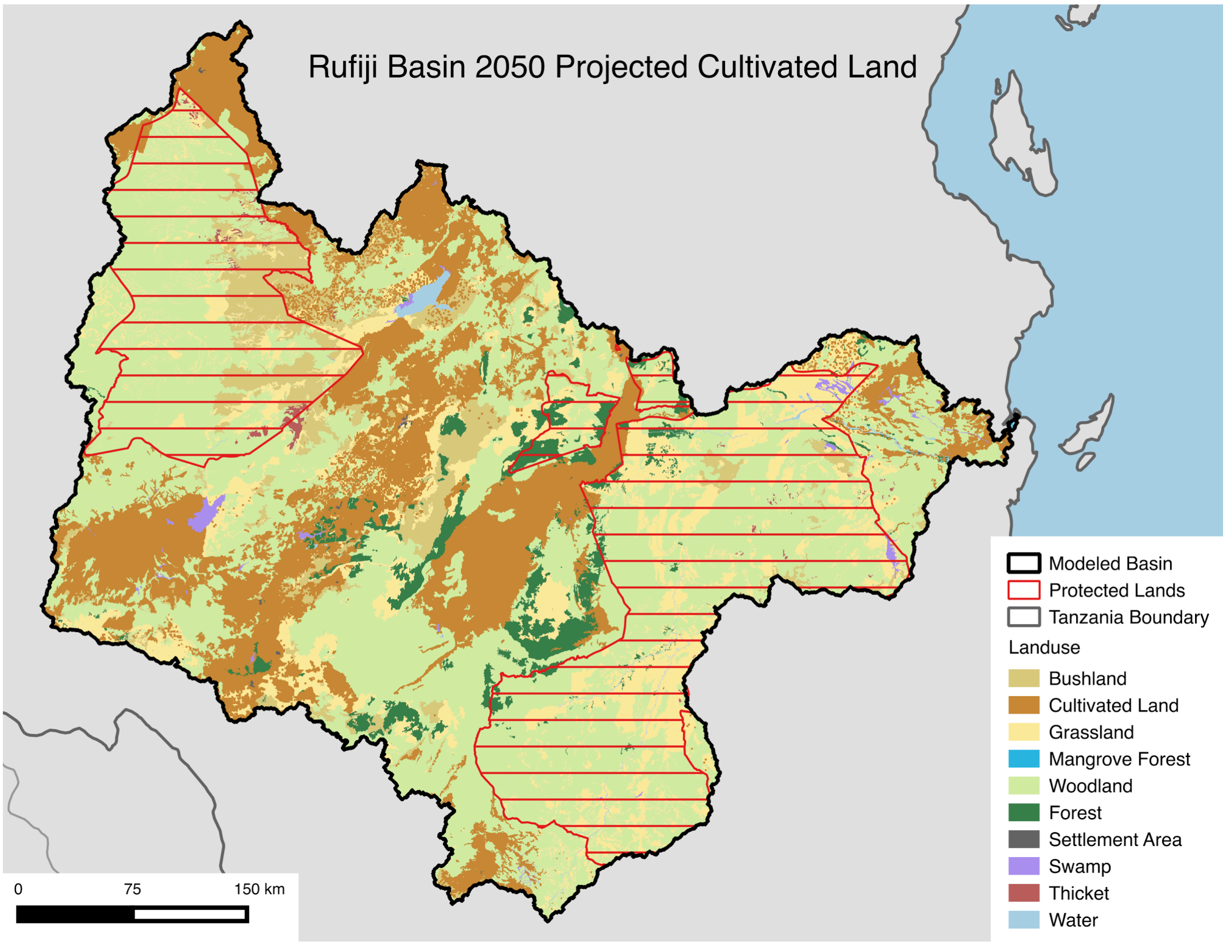
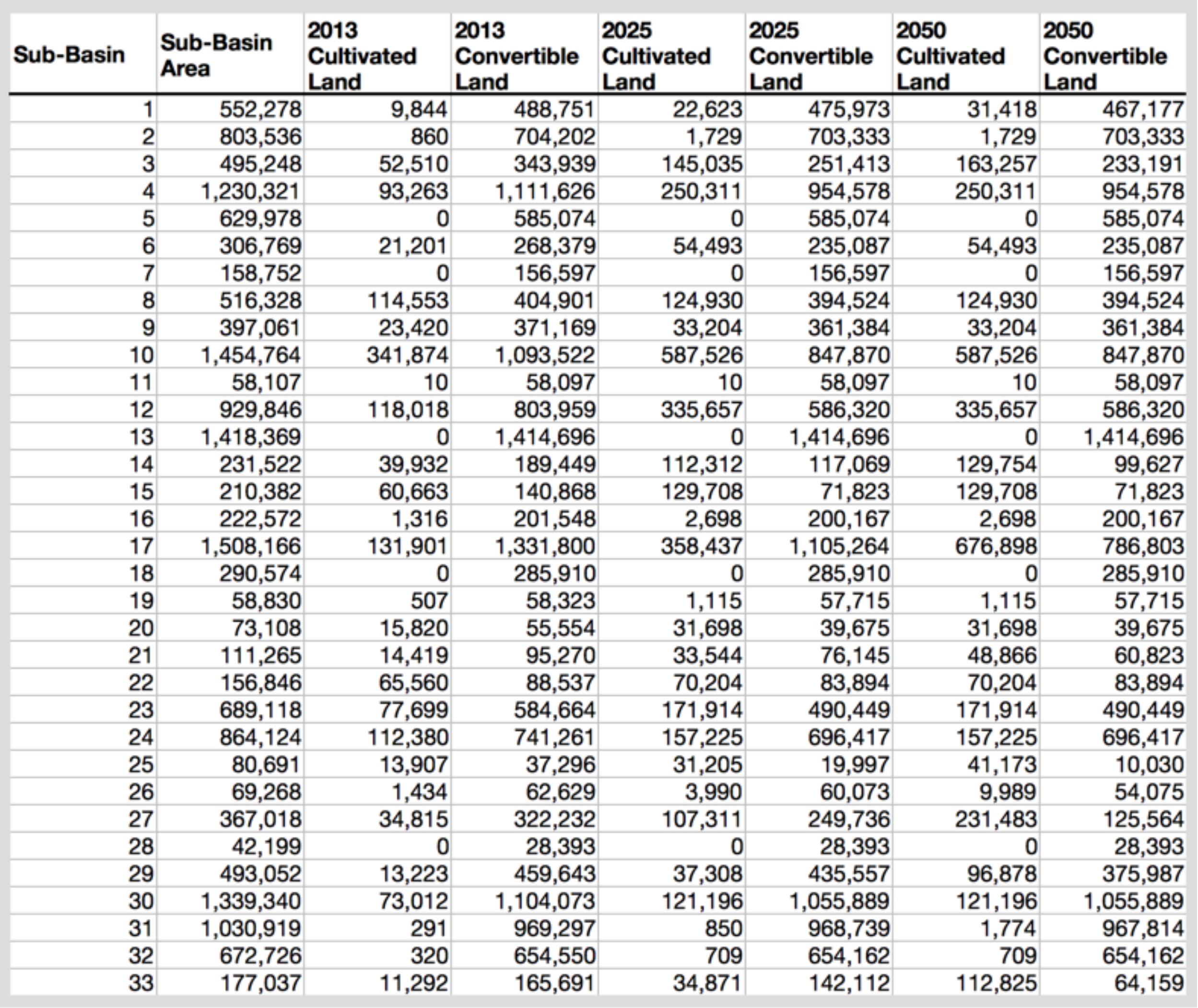


Figure 3.18. Projected cultivated land within the modeled basin in 2050. 3,618,640 hectares of cultivated land.

Table 3.2. 2013 and projected hectares of cultivated land and convertible land for each modeled sub-basin.



Sub-Basin	Sub-Basin Area	2013 Cultivated Land	2013 Convertible Land	2025 Cultivated Land	2025 Convertible Land	2050 Cultivated Land	2050 Convertible Land
1	552,278	9,844	488,751	22,623	475,973	31,418	467,177
2	803,536	860	704,202	1,729	703,333	1,729	703,333
3	495,248	52,510	343,939	145,035	251,413	163,257	233,191
4	1,230,321	93,263	1,111,626	250,311	954,578	250,311	954,578
5	629,978	0	585,074	0	585,074	0	585,074
6	306,769	21,201	268,379	54,493	235,087	54,493	235,087
7	158,752	0	156,597	0	156,597	0	156,597
8	516,328	114,553	404,901	124,930	394,524	124,930	394,524
9	397,061	23,420	371,169	33,204	361,384	33,204	361,384
10	1,454,764	341,874	1,093,522	587,526	847,870	587,526	847,870
11	58,107	10	58,097	10	58,097	10	58,097
12	929,846	118,018	803,959	335,657	586,320	335,657	586,320
13	1,418,369	0	1,414,696	0	1,414,696	0	1,414,696
14	231,522	39,932	189,449	112,312	117,069	129,754	99,627
15	210,382	60,663	140,868	129,708	71,823	129,708	71,823
16	222,572	1,316	201,548	2,698	200,167	2,698	200,167
17	1,508,166	131,901	1,331,800	358,437	1,105,264	676,898	786,803
18	290,574	0	285,910	0	285,910	0	285,910
19	58,830	507	58,323	1,115	57,715	1,115	57,715
20	73,108	15,820	55,554	31,698	39,675	31,698	39,675
21	111,265	14,419	95,270	33,544	76,145	48,866	60,823
22	156,846	65,560	88,537	70,204	83,894	70,204	83,894
23	689,118	77,699	584,664	171,914	490,449	171,914	490,449
24	864,124	112,380	741,261	157,225	696,417	157,225	696,417
25	80,691	13,907	37,296	31,205	19,997	41,173	10,030
26	69,268	1,434	62,629	3,990	60,073	9,989	54,075
27	367,018	34,815	322,232	107,311	249,736	231,483	125,564
28	42,199	0	28,393	0	28,393	0	28,393
29	493,052	13,223	459,643	37,308	435,557	96,878	375,987
30	1,339,340	73,012	1,104,073	121,196	1,055,889	121,196	1,055,889
31	1,030,919	291	969,297	850	968,739	1,774	967,814
32	672,726	320	654,550	709	654,162	709	654,162
33	177,037	11,292	165,691	34,871	142,112	112,825	64,159

3.3.3. Projected Population

From the 2012 population figures resulting from the baseline analysis, future projections for 2025 and 2050 were calculated (Figure 3.19 - 3.20 and Table 3.3). Urban and rural populations are predicted to increase within each sub-basin according to the regional growth rates for the region in which they are contained. A minimum annual growth rate of 0.5% and a maximum growth rate of 3.0% were set. It was assumed that over such long periods high growth rates outside of an upper bound of 3% would not be sustainable in rural areas and medium sized urban areas located in rural areas. In 2025, the projected urban population of our modeled basin was 1,408,872 and the projected rural population was 1,061,953, totaling 2,470,825. From the 2012 figures the urban population grew 46% (3% on average annually) and the rural population grew 18.5% (1% on average annually). In 2050, the urban population of our modeled basin was 2,912,657 and the rural population was 1,506,761 totaling 4,419,418. From the 2025 projections the urban population grew 106% (3% on average annually) and the rural population grew 42% (1.4% on average annually).

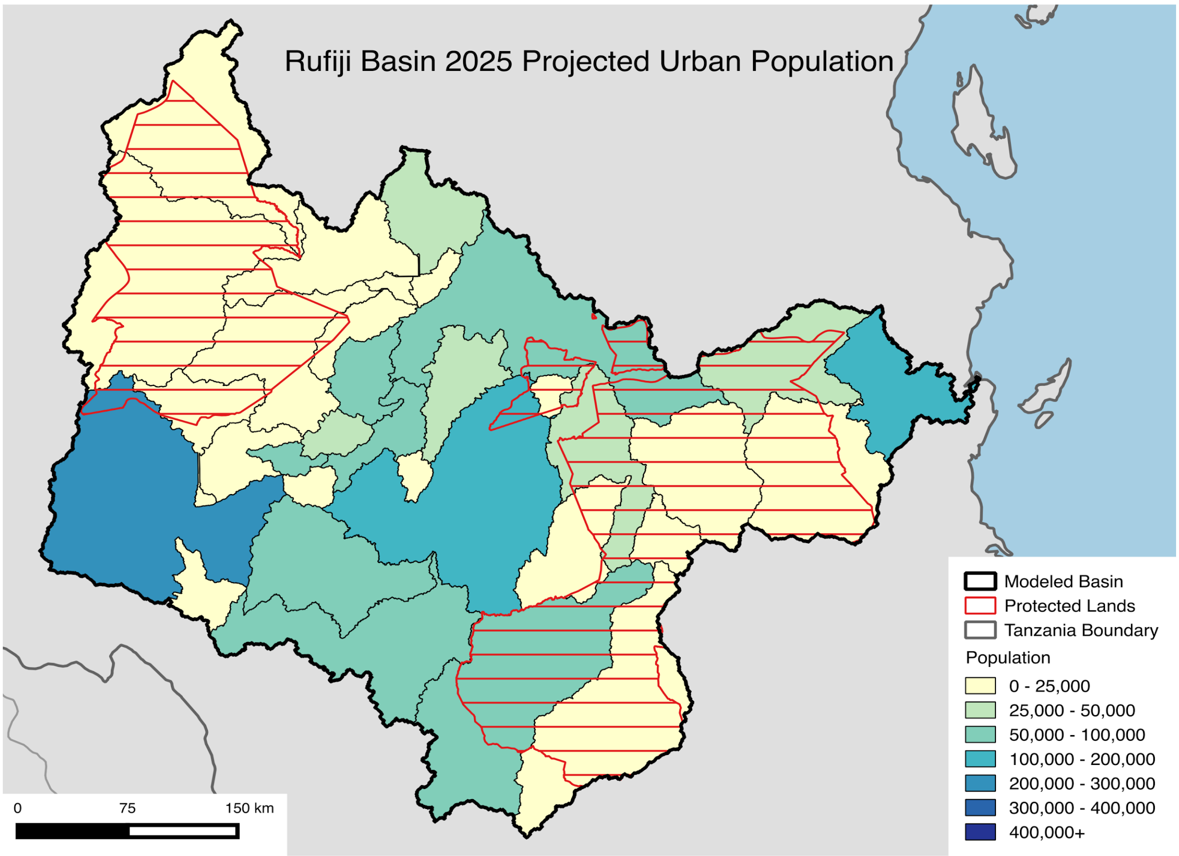


Figure 3.19. 2025 projected urban population. Total population of 1,408,872.

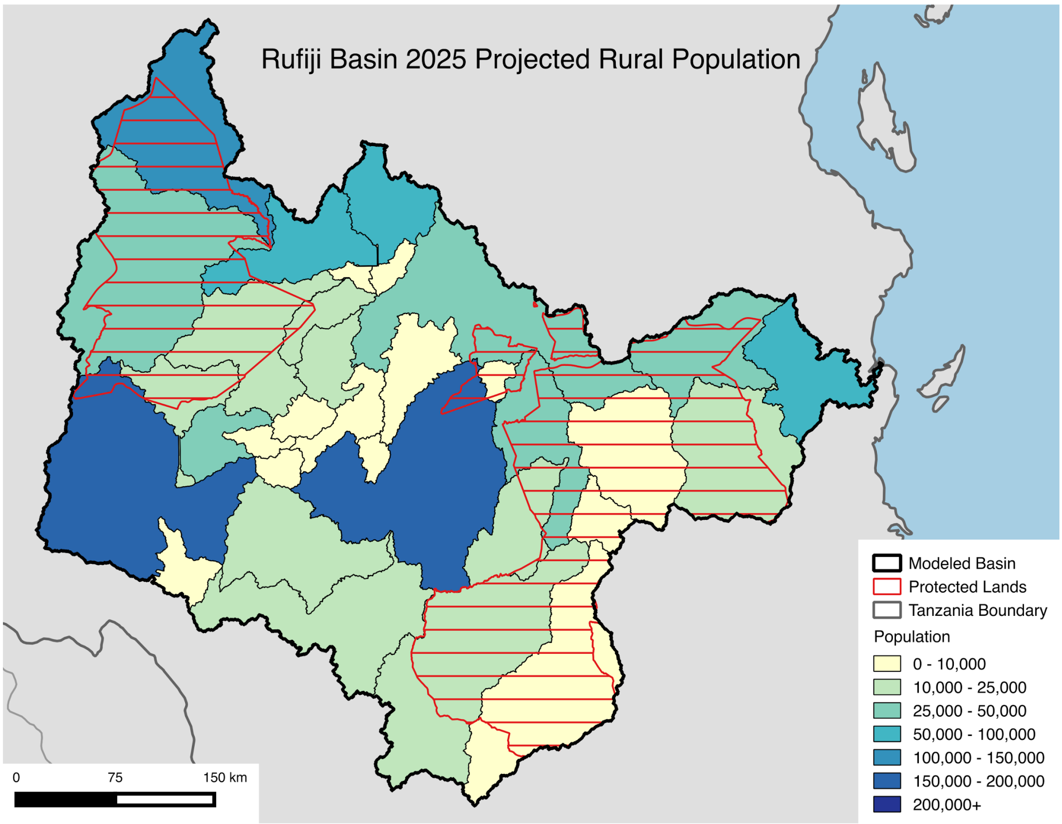


Figure 3.20. 2025 projected rural population. Total population of 1,061,953.

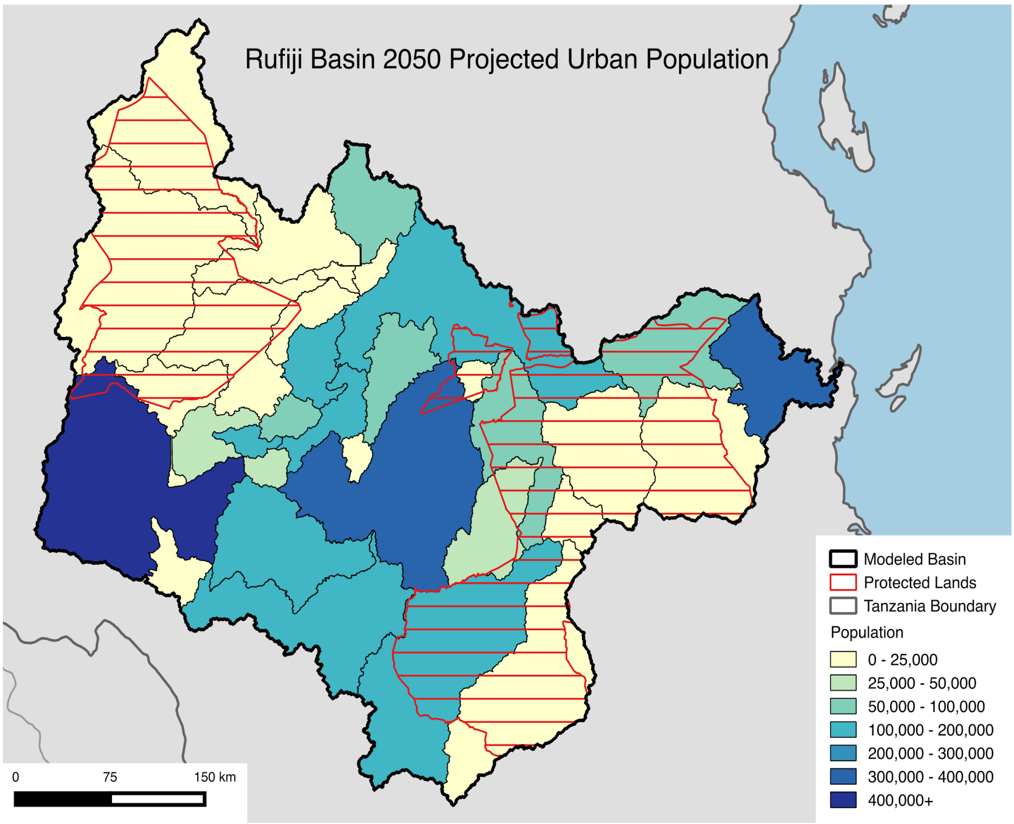


Figure 3.21. 2050 projected urban population. Total population of 2,912,657.

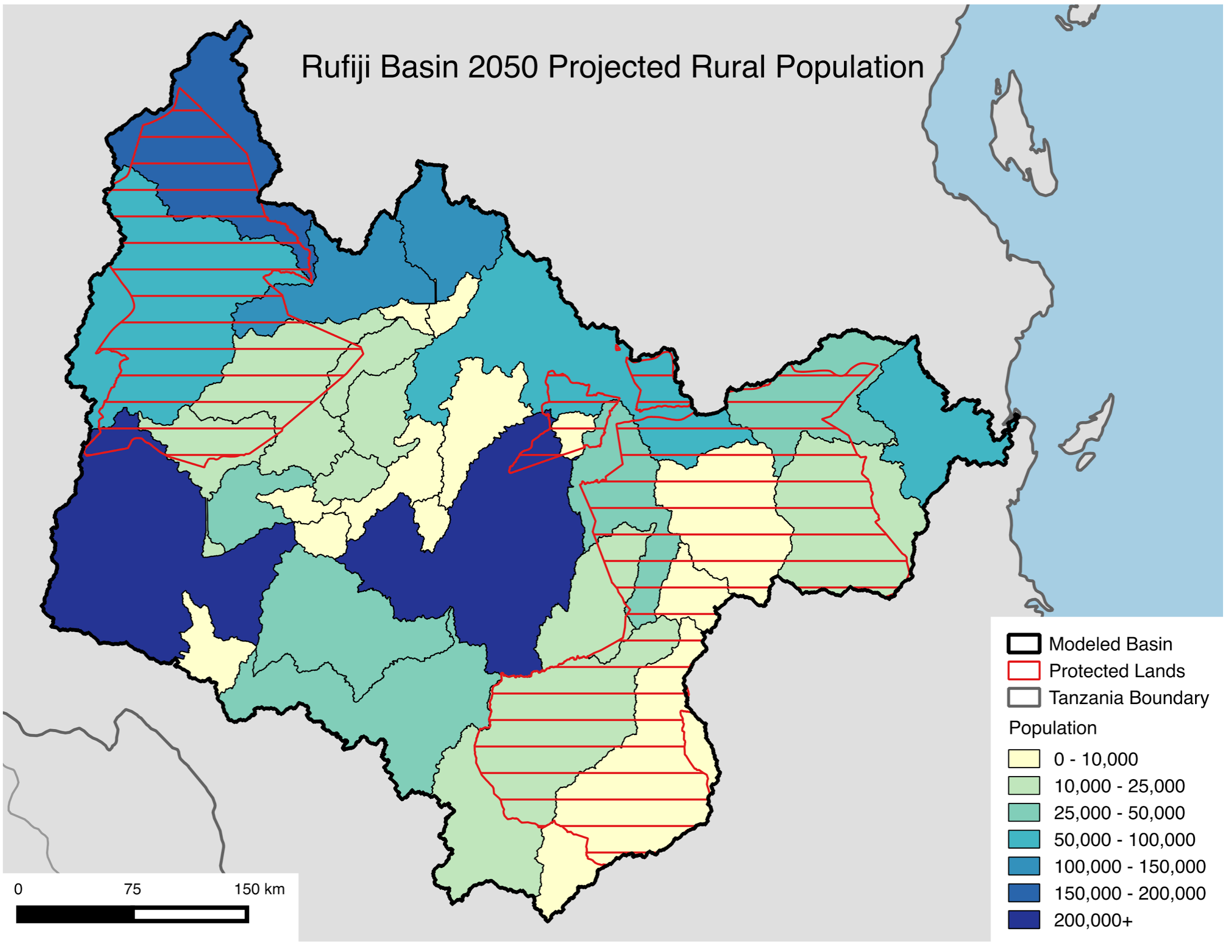
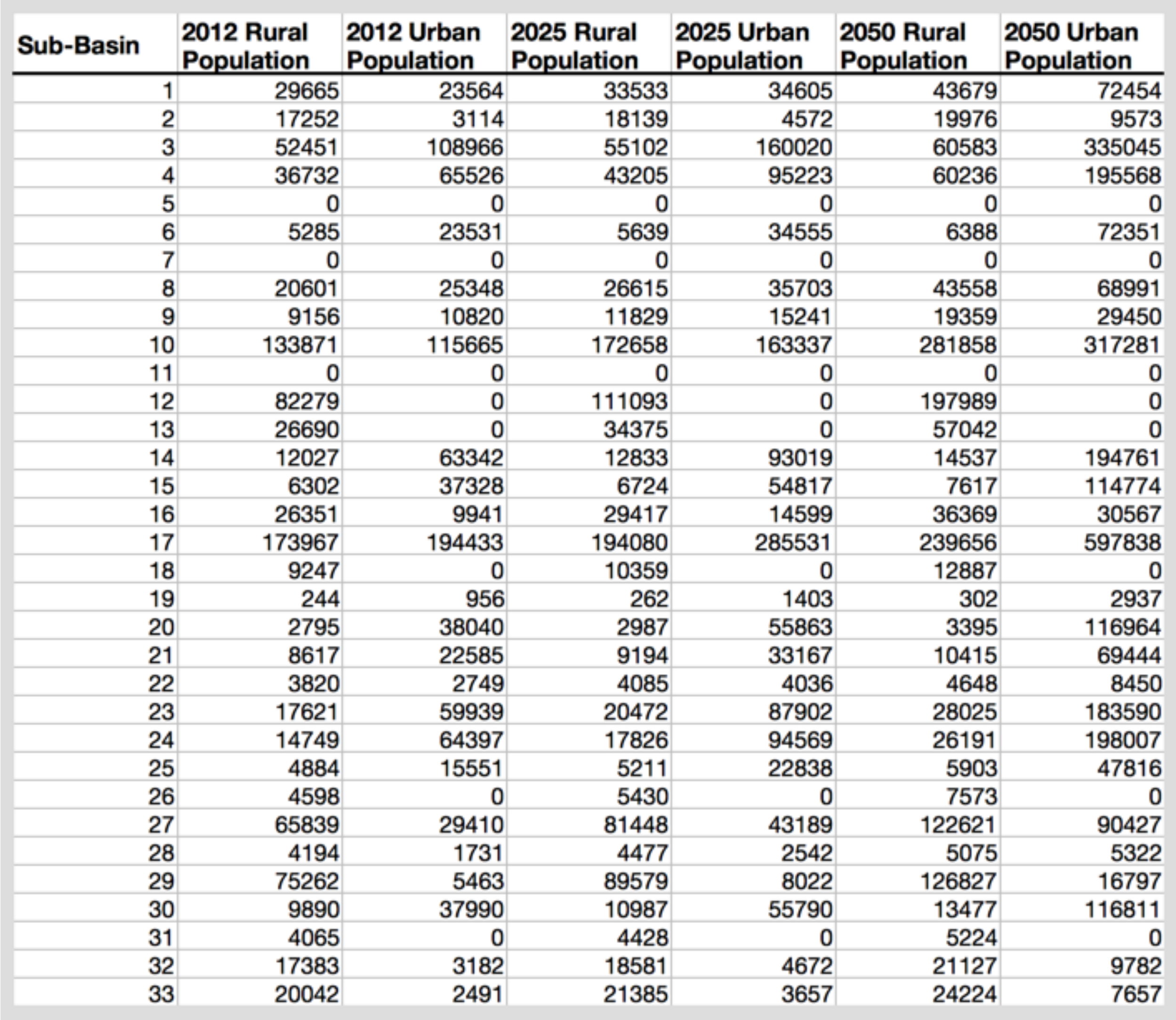


Figure 3.22. 2050 projected rural population. Total population of 1,506,761.

Table 3.3. 2012 and projected rural and urban population for each modeled sub-basin.



Sub-Basin	2012 Rural Population	2012 Urban Population	2025 Rural Population	2025 Urban Population	2050 Rural Population	2050 Urban Population
1	29665	23564	33533	34605	43679	72454
2	17252	3114	18139	4572	19976	9573
3	52451	108966	55102	160020	60583	335045
4	36732	65526	43205	95223	60236	195568
5	0	0	0	0	0	0
6	5285	23531	5639	34555	6388	72351
7	0	0	0	0	0	0
8	20601	25348	26615	35703	43558	68991
9	9156	10820	11829	15241	19359	29450
10	133871	115665	172658	163337	281858	317281
11	0	0	0	0	0	0
12	82279	0	111093	0	197989	0
13	26690	0	34375	0	57042	0
14	12027	63342	12833	93019	14537	194761
15	6302	37328	6724	54817	7617	114774
16	26351	9941	29417	14599	36369	30567
17	173967	194433	194080	285531	239656	597838
18	9247	0	10359	0	12887	0
19	244	956	262	1403	302	2937
20	2795	38040	2987	55863	3395	116964
21	8617	22585	9194	33167	10415	69444
22	3820	2749	4085	4036	4648	8450
23	17621	59939	20472	87902	28025	183590
24	14749	64397	17826	94569	26191	198007
25	4884	15551	5211	22838	5903	47816
26	4598	0	5430	0	7573	0
27	65839	29410	81448	43189	122621	90427
28	4194	1731	4477	2542	5075	5322
29	75262	5463	89579	8022	126827	16797
30	9890	37990	10987	55790	13477	116811
31	4065	0	4428	0	5224	0
32	17383	3182	18581	4672	21127	9782
33	20042	2491	21385	3657	24224	7657

3.3.4. Hydrologic Modeling and Calibration

The model was calibrated for each observed gaging station location by altering the hydrologic curve number value and base flow recessional curve. For each subasin, we calculated from agricultural census data the amount of irrigation for crop acreage and applied this as a monthly water use. This water use was a combination of consumption use by the population and irrigation use (adjusted for system inefficiencies). In order to get the model to best fit the observed data, it was required in increase the monthly water use in each basin to greater than the documented water use. This is especially apparent at gaging station 1KA59, where often times during the dry season the entire Great Ruaha River is reduced to zero flow. It is still apparent in Figure 3.27 that the simulated flow still does not match the observed flow. More investigation will be performed on this subbasin to get a better understanding of the water use in that area prior to flowing into the Mtera Reservoir. In the next stage of the project, if more observed gaging station data becomes available, we will also include it in this analysis.

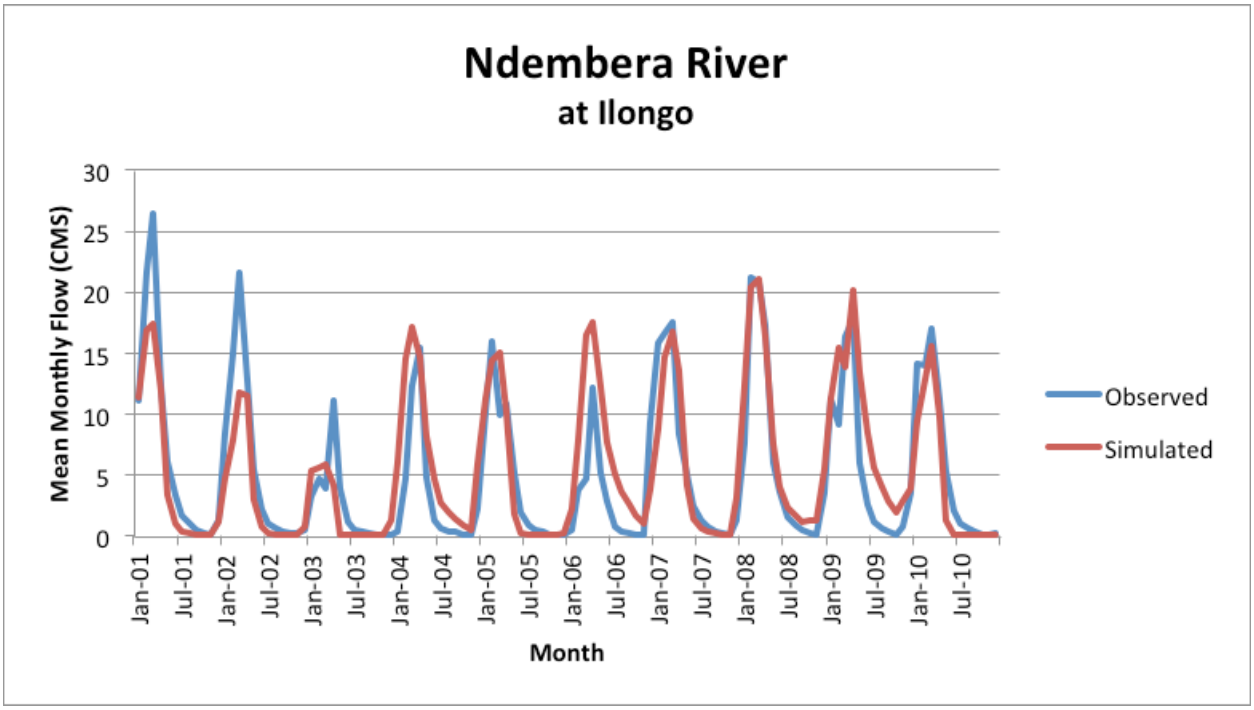


Figure 3.23. Calibrated flow for Ndembera River. Station 1KA15A

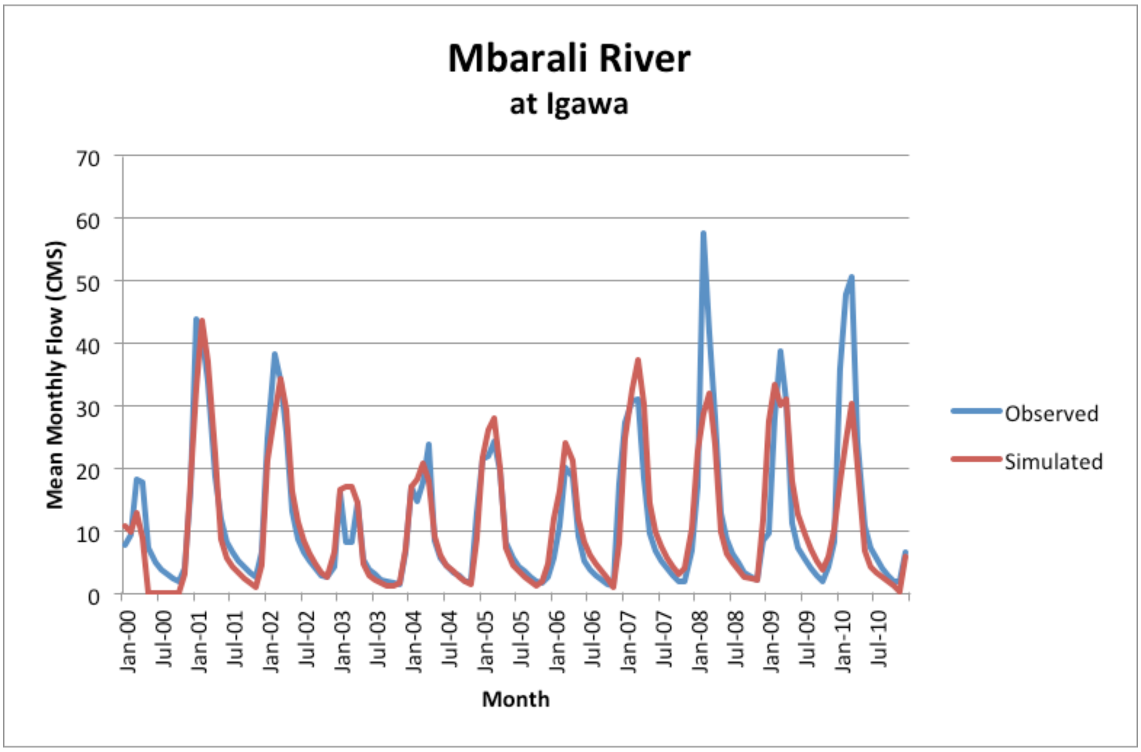


Figure 3.24. Calibrated flow for Mbarali River. Station 1KA11A

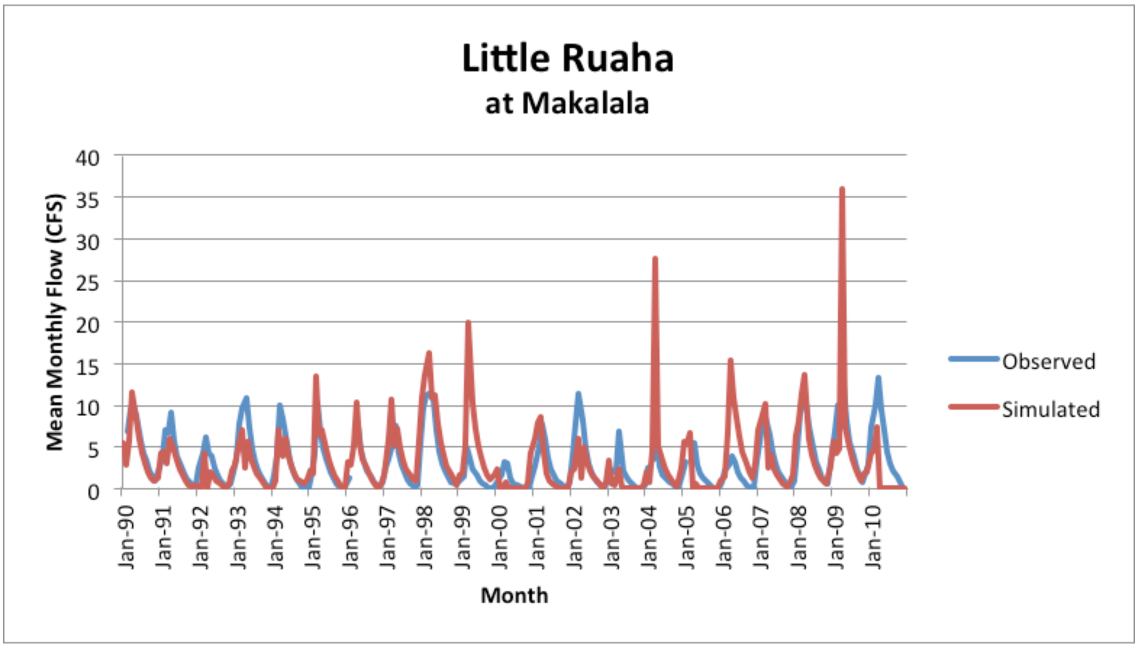


Figure 3.25. Calibrated flow for Little Ruaha River at Makalala. Station 1KA32A.

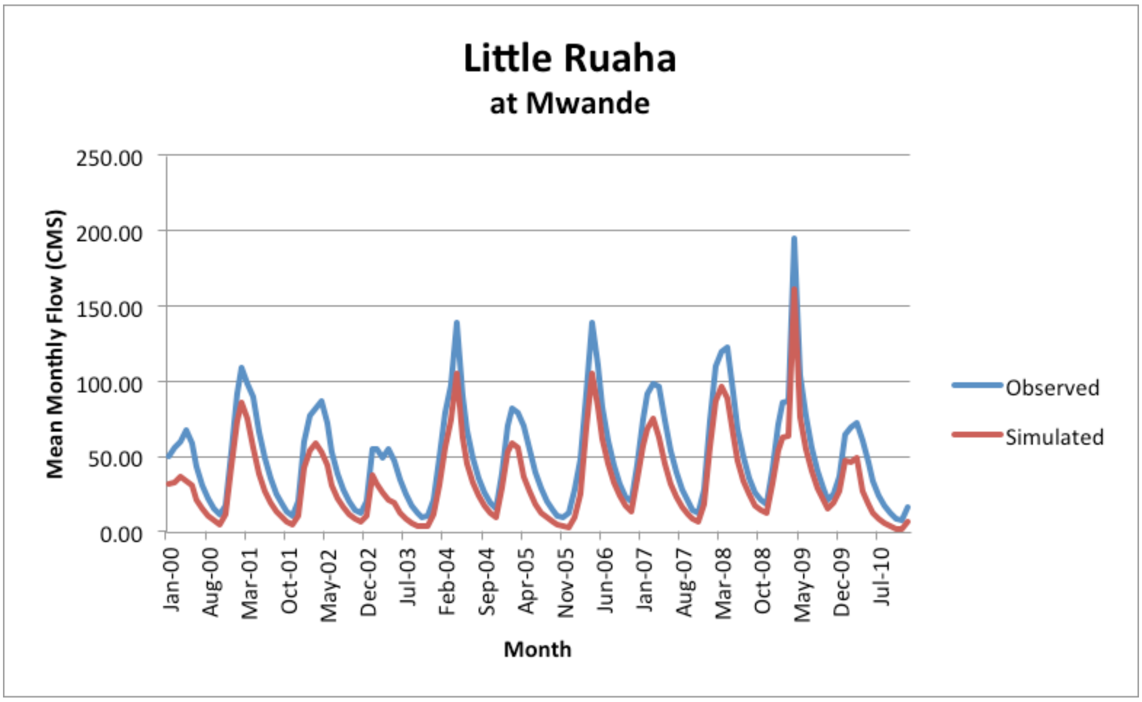


Figure 3.26. Calibrated flow for Little Ruaha River at Mwande. Station 1KA31

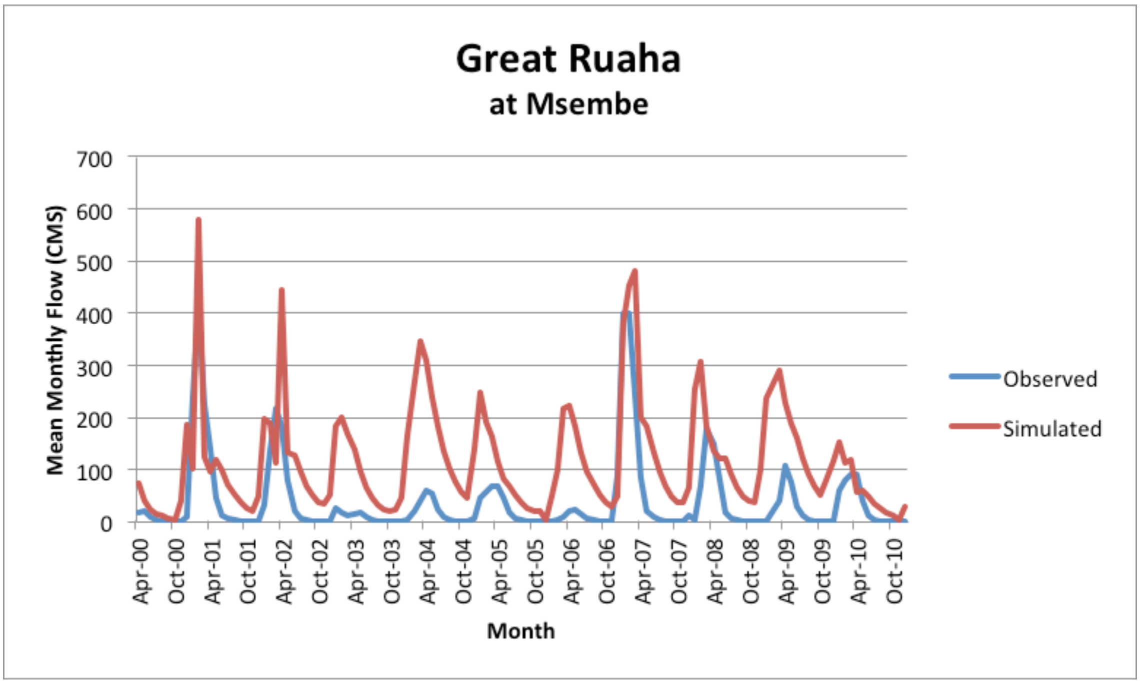


Figure 3.27. Calibrated flow for Great Ruaha River at Msembe. Station 1KA59

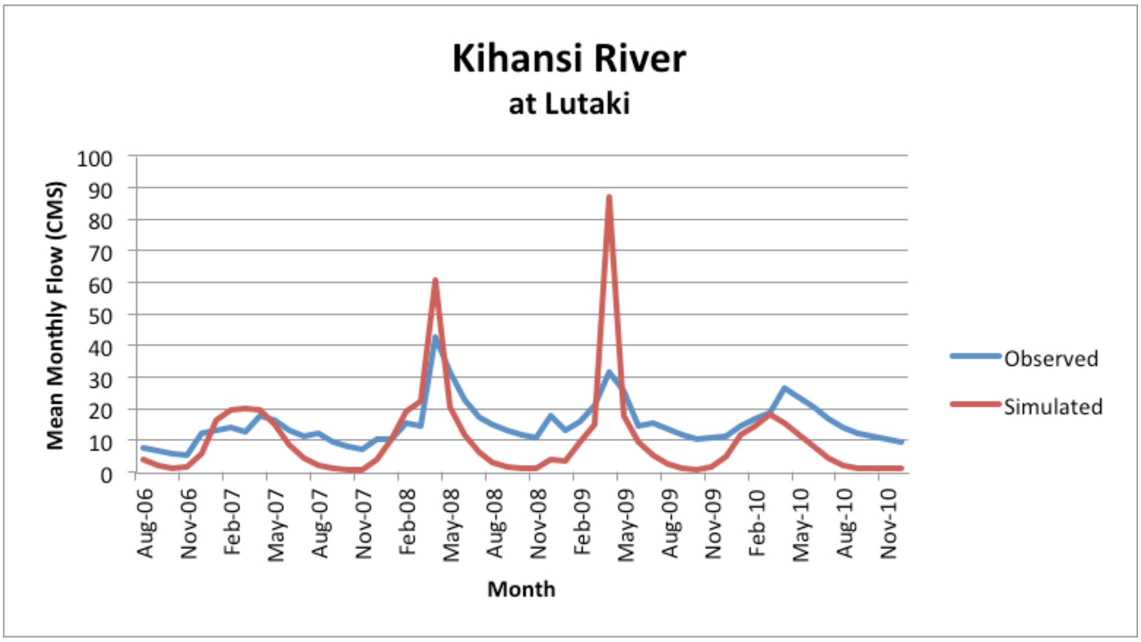


Figure 3.28. Calibrated flow for Kihansi River at Lutaki. Station 1KB32.

3.3.5 Future Scenarios and Plan for Climate Projection-based Modeling

3.3.5.1 Scenario 1: Improved Irrigation Efficiency + Increased Irrigation Levels

Current irrigation systems

Very little is known regarding efforts by landholders over the last decade to improve irrigation strategies across the Rufiji River Basin. While we know a few details regarding some of the water use permits across the basin, these sources do not indicate the types or methods of irrigation and water use that are permitted beyond a broad distinction of either irrigation or domestic water use.

However, as it currently stands, traditional furrow and flood (paddy or ‘basin’) technique-based irrigation is in widespread use. These methods have low levels of irrigation efficiencies and employ surface-based irrigation water distribution systems using canals (bunds) most often built of soil. Short canals built of heavier soils lead to higher irrigation efficiencies while longer canals built of light (sandy) soils leads to lower efficiencies. Efficiency ranges from 36%-54% for unlined, soil only, systems. Poorly maintained irrigation components - leaking or no irrigation gates, excessive flooding, and very little return flow, can contribute an additional loss of up to 50% of the values presented above (FAO, 1989). Some of the loss results from standing water percolating deep into the soil and other losses result from evaporation from the surface of the water. If weeds are permitted to grow in canals they not only impeded water flow but remove water from the system via transpiration. According to MoWI (2008) as discussed by Ndomba et al. (2013), the existing irrigation infrastructure in Tanzania is both inefficient and improperly operated (including diversions with no return flow, improper flow control, and other problems). These problems lead to very low efficiencies in the range of 15-20%.

Improving the efficiency of current flood/furrow irrigation systems.

One of the most important practices that can be adopted is to line primary and secondary canals with concrete. Lining surface water irrigation canals increases the efficiency of distribution of water by reducing the potential for siltation of channels and the opportunity for weeds to obstruct water flow. Lined channels have been shown to increase the efficiency from 54% to 59%, depending on length of run. However, lining canals has no effect on how efficiently the water is used when it reaches the fields. Other approaches must also be encouraged or implemented to improve irrigation efficiency in the field. They include the following;

1. utilize metering devices and pay-per-use to discourage over-watering
2. grade land slope for best soil wetting with minimal erosion and runoff
3. channel excess water to return to source to reduce standing water evaporation
4. provide accurate weather forecasts to help improve irrigation timing and amounts

5. encourage a randomized water allocation method for smallholders to reduce the risk of tail-end fields being allocated water ‘out-of-season’
6. encourage the transplanting of rice (vs direct seeding) to minimize seasonal water use
7. encourage the adoption of short season rice varieties to minimize seasonal water use
8. eliminate ‘cascade’ flow (field to field) irrigation for non-rice crops
9. demonstrate to farmers proper furrow depth and width for optimal soil wetting
10. size gates, spiles, siphon tubes or bund cuts to insure proper soil wetting across field width for furrow irrigation systems
11. install effective gates that provide proper ‘head’ for spiles or siphon tubes.

Where basin (flood) irrigation is used for rice, it is common for an excessive amount of water to be maintained over the field throughout the growing season, and where furrow irrigation is used upslope fields may be irrigated first then runoff water from that field is used to irrigate adjacent downslope fields (cascade flow). Both of these procedures are in use by smallholder farmers and both accelerate water losses. Other reports indicate that smallholders owning fields at the tail-end of irrigation system may not get irrigation water early enough in the season to insure planting is done at optimal times. This means that tail-end fields may not get planted at all, or when planted late may require extra water to complete maturity during the dry season. Using a water allocation method that monitors the amount of water used and more equitably distributes water among fields near and far from the source should improve the efficiency of water use among farmers.

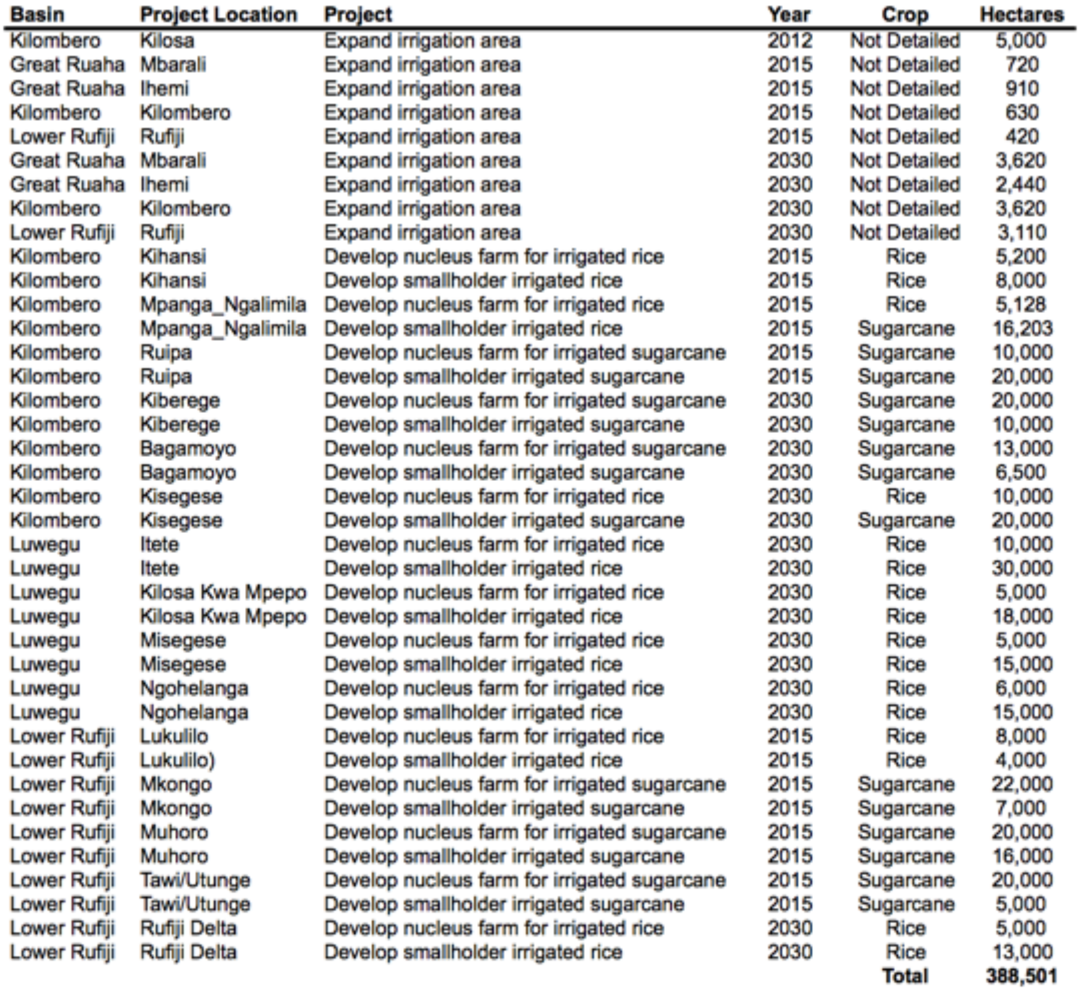
Sprinkler irrigation systems (for non-rice crop areas)

In the Rufiji basin, sprinkler irrigation is used to a limited extent and that primarily on sugarcane. Compared to flood or furrow irrigation, sprinkler irrigation tends to require more of an initial investment, takes more fossil fuel energy to operate, and requires a more technical approach to maintenance. However, once established it tends to be less labor intensive. A principal advantage of sprinkler irrigation methods is that it can be used over sloping or undulating topography. A disadvantage of sprinkler systems is that heavily silted water may plug spray nozzles, cause excessive pump wear, and coat the crop with sediment. Sprinkler irrigation systems include: center pivot, wheel line, stationary pipe, rain guns, and movable pipe or flex-line. Establishing or expanding sprinkler irrigation systems requires a relatively clean and reliable source of water and a system to supply fuel and maintenance for the diesel or gasoline powered pumps. Because of the investment required sprinkler systems are adopted initially by larger farms. However, it is feasible that smallholder co-ops might be able to employ sprinkler systems as well. Sprinkler irrigations system efficiencies are generally equal to or slightly better than a well operated surface irrigation scheme. However, their efficiencies will depend on wind, temperatures, and effective and timely operation of the equipment.

Increasing irrigated areas in the RRB

The SAGCOT investment Blueprint (SAGCOT, 2011) provides an overview of proposed irrigation projects and the changes in infrastructure that will be essential to their implementation. The objective of adding to the hectarage currently being irrigated is to expand the agricultural base and improve the ability of the agricultural sector to provide sufficient food for the future. It is self-evident that existing irrigation systems cannot simply be extended, they must be expanded in such a way as to establish an infrastructure that distributes and utilizes irrigation water in an efficient manner. Since water will be the limiting resource for the foreseeable future, it is imperative that existing water resources be used as efficiently as possible and that new sources of water be tapped to bring added irrigated hectarage on line. The following table provides an overview of proposed projects and those currently under development.

Table 3.4. Projected expansions of irrigation across the watershed.



Basin	Project Location	Project	Year	Crop	Hectares
Kilombero	Kilosa	Expand irrigation area	2012	Not Detailed	5,000
Great Ruaha	Mbarali	Expand irrigation area	2015	Not Detailed	720
Great Ruaha	Ihemi	Expand irrigation area	2015	Not Detailed	910
Kilombero	Kilombero	Expand irrigation area	2015	Not Detailed	630
Lower Rufiji	Rufiji	Expand irrigation area	2015	Not Detailed	420
Great Ruaha	Mbarali	Expand irrigation area	2030	Not Detailed	3,620
Great Ruaha	Ihemi	Expand irrigation area	2030	Not Detailed	2,440
Kilombero	Kilombero	Expand irrigation area	2030	Not Detailed	3,620
Lower Rufiji	Rufiji	Expand irrigation area	2030	Not Detailed	3,110
Kilombero	Kihansi	Develop nucleus farm for irrigated rice	2015	Rice	5,200
Kilombero	Kihansi	Develop smallholder irrigated rice	2015	Rice	8,000
Kilombero	Mpanga_Ngalimila	Develop nucleus farm for irrigated rice	2015	Rice	5,128
Kilombero	Mpanga_Ngalimila	Develop smallholder irrigated rice	2015	Sugarcane	16,203
Kilombero	Ruipa	Develop nucleus farm for irrigated sugarcane	2015	Sugarcane	10,000
Kilombero	Ruipa	Develop smallholder irrigated sugarcane	2015	Sugarcane	20,000
Kilombero	Kiberege	Develop nucleus farm for irrigated sugarcane	2030	Sugarcane	20,000
Kilombero	Kiberege	Develop smallholder irrigated sugarcane	2030	Sugarcane	10,000
Kilombero	Bagamoyo	Develop nucleus farm for irrigated sugarcane	2030	Sugarcane	13,000
Kilombero	Bagamoyo	Develop smallholder irrigated sugarcane	2030	Sugarcane	6,500
Kilombero	Kisegese	Develop nucleus farm for irrigated rice	2030	Rice	10,000
Kilombero	Kisegese	Develop smallholder irrigated sugarcane	2030	Sugarcane	20,000
Luwegu	Itete	Develop nucleus farm for irrigated rice	2030	Rice	10,000
Luwegu	Itete	Develop smallholder irrigated rice	2030	Rice	30,000
Luwegu	Kilosa Kwa Mpepo	Develop nucleus farm for irrigated rice	2030	Rice	5,000
Luwegu	Kilosa Kwa Mpepo	Develop smallholder irrigated rice	2030	Rice	18,000
Luwegu	Misegese	Develop nucleus farm for irrigated rice	2030	Rice	5,000
Luwegu	Misegese	Develop smallholder irrigated rice	2030	Rice	15,000
Luwegu	Ngohelanga	Develop nucleus farm for irrigated rice	2030	Rice	6,000
Luwegu	Ngohelanga	Develop smallholder irrigated rice	2030	Rice	15,000
Lower Rufiji	Lukulilo	Develop nucleus farm for irrigated rice	2015	Rice	8,000
Lower Rufiji	Lukulilo)	Develop smallholder irrigated rice	2015	Rice	4,000
Lower Rufiji	Mkongo	Develop nucleus farm for irrigated sugarcane	2015	Sugarcane	22,000
Lower Rufiji	Mkongo	Develop smallholder irrigated sugarcane	2015	Sugarcane	7,000
Lower Rufiji	Muhoro	Develop nucleus farm for irrigated sugarcane	2015	Sugarcane	20,000
Lower Rufiji	Muhoro	Develop smallholder irrigated sugarcane	2015	Sugarcane	16,000
Lower Rufiji	Tawi/Utunge	Develop nucleus farm for irrigated sugarcane	2015	Sugarcane	20,000
Lower Rufiji	Tawi/Utunge	Develop smallholder irrigated sugarcane	2015	Sugarcane	5,000
Lower Rufiji	Rufiji Delta	Develop nucleus farm for irrigated rice	2030	Rice	5,000
Lower Rufiji	Rufiji Delta	Develop smallholder irrigated rice	2030	Rice	13,000
				Total	**388,501**

3.3.5.2 Scenario 2: Improve Local Water Harvesting and Storage

Improvements in onsite water storage and harvesting from on-farm water tanks and groundwater systems (such as ponds and small dams where applicable) can be critical to help protect yields from climate variability during critical periods of grain fill and crop development. Storage of water in an elevated structure typically requires a significant expenditure of energy to pump water and to install a pumping infrastructure; however, recent developments in solar-based pumping technology and advances in water storage approaches make these types of irrigation technologies reasonable for the small community or even by smallholders. Recent development of new technologies offer possibilities for increasing irrigation efficient approaches utilizing solar powered pumps like the majipump, which require very little infrastructure (only a solar panel - no battery required). Development of additional reservoirs for water resource management at the local or basin scale is also critical. While this is could be capital intensive for certain areas, these types of improvements can be completed by smallholder communities as part of their water management.

As part of determining the water storage requirements for these types of systems from the smallholder to the large commercial growers, accurate predictions of climate can be critical to an understanding of agronomic requirements as well as water availability for domestic or industrial uses. As part of this work, Agrible will evaluate forecast-based prediction analytics to help in agronomic-based decisions, such as time of planting and irrigation scheduling for optimal vegetative growth.

3.3.5.3 Scenario 3: Land Use Changes

As the population continues to increase in Tanzania, additional land will need to be brought into cultivation. Half of the total landmass of the country, about 44 million hectares are arable, although serious obstacles to production agriculture exists in some areas due to recurring drought, tsetse fly infestations, or distance from potable water. Approximately 10 million hectares are estimated to be cultivated at this time with less than 3 million hectares planted to annual crops. A comparison of land use allocation from 1996 and 2013 revealed an increase in cultivated land of 6.3% per year on average. Future conversions of land will likely include unprotected shrubland, grassland, and forested areas. As part of the hydrologic modeling, projections for changes in land use within the Rufiji basin will be made for each sub-basin. Projected land use will be determined based on the rate of conversion for each sub-basin as constrained by the arable land available in the sub-basin.

“Approximately 95% of the 2.1 million hectares that are under crop production in the southern corridor is farmed by smallholders using traditional rain-fed methods, primarily for subsistence farming. In general, agricultural yields are low, with grain and pulse yields averaging less than 1.5 MT/ha. Despite its huge potential there is currently very limited large scale irrigated farming in the southern corridor. Of the 7.5 million hectares of arable land, less than 2% is farmed under irrigation (these being mainly public irrigation schemes for smallholder rice production).” (Interim Report SAGCOT SRESA 12-02.pdf pg 26)

Land Use Scenario: Protected lands remain untouched: It is possible that the status of these lands will be maintained and they will remain untouched. Under this scenario, once other convertible lands have been exhausted no others will be disturbed.

Land Use Scenario: Shrub land, grassland, and other unprotected land converted: Approximately 300,000 hectares of productive agricultural land is slated to be brought under cultivation to meet SAGCOT Investment Blueprint objectives by 2030. This amount compares to the estimated base of 40,000 hectares currently in production.

3.3.5.4 Scenario 4: Agronomic Practices to Improve Water Use Efficiency

One certain means of improving the efficiency of water use while expanding agricultural production is to adopt agronomic practices that conserve water. A number of these practices currently exist and others are being aggressively developed in countries around the world. This section addresses many of the most appropriate technologies and examines briefly their limitations and advantages.

Background: Approximately 2 million hectares of maize are currently planted in Tanzania with 85% of production being done by smallholders (Lyimo, 2014). Average maize production in the Rufiji basin is .67 MT/ha (11 bu/a) while yields for Tanzania as a whole were determined to be between 1 to 1.5 MT/ha (16 to 25 bu/a) (Barreiro-Hurle, 2012). Similarly, rice yields in the basin average about 1.2MT/ha which compares to about one third the average yields of rice in the US. It would appear at first glance that a great deal of progress on production could be achieved by widespread adoption of advanced hybrids, effective pesticide practices, appropriate irrigation scheduling, and a good fertilizer program. However, expanding production with both rice and maize includes both opportunities and challenges.

Improved hybrid maize and rice varieties: Modern maize hybrids in Tanzania have been estimated to have the potential to yield 4.5 to 11 MT/ha (72 to 175 bu/a, Lyimo, 2014) under improved management systems that would include the use of pesticides and a robust fertility program. However, many farmers maintain a practice of replanting seed using seed from open-pollinated (non-hybrid) varieties for periods of from five to ten years, (Kaliba, 1998) and for hybrid varieties for 1 to 5 years. Drought, low market prices, pests and diseases, and high input prices are important constraints for adopting newer hybrids. The high costs of improved seed, poor availability and lack of knowledge were additional reasons why farmers did not use improved maize seed (Lyimo, 2014). Rice yields are also hampered by grower’s preference for lower yielding varieties that are market favorites. However, breeding rice lines with desirable traits is a promising means of increasing rice yields goals.

Fertilizer and soil amendments: While modern maize hybrids and rice varieties have characteristics that allow them to take advantage of lower levels of nutrients in the soil, soils that are not fertilized sufficiently cannot produce substantially increased yields. Nutrient deficiencies are compounded by a possible pH imbalance that would prohibit major and micronutrients from being optimally (or nominally) available to the plant. Although research on fertilizers has been conducted within the basin, currently there is little information on soil nutrient status in the RRB that would provide a suitable foundation for nutrient recommendations on specific sites.

Maize and rice Insects: Maize has several pests in the East African region that are devastating to crop yields. The principal pests include stalk borers (*Busseola fusca, Chilo partellus, Sesamia camistis*), armyworms (*Spodoptera exempta*) and the greater grain borer *Prostephanus truncatus* and the lesser (*Rhizopertha dominica)* grain borers. There is currently little information to indicate that these pests would be attenuated sufficiently by plant based genetically modified organism traits (GMOs), nor does their life cycle suggest that a GMO trait would be feasible to develop as timing of gene expression would be difficult to coincide with insect appearance. Except for larger farms, pesticide use is also minimal in the RRB. The hazards associated with the use of many pesticides mandates training, equipment, and protective gear that creates a significant burden to smallholders. No surveys have been done to provide reliable data on the scope of pest distribution, severity, or resultant losses.

Rice and maize diseases: Crop diseases in Tanzanian maize and rice are likely to be similar to those found in the US and other developed countries. This would include seedling blights and rots, foliar diseases, and ear and kernel diseases. Adoption of hybrids and varieties with good disease tolerance is likely to improve yields significantly. However, insect pests are known to favor the lush vegetation resulting from improved hybrids, potentially resulting in greater than normal losses from insects. Without the necessary insecticides receipt of the full benefits of an improved hybrid is unlikely.

Crop storage pests: Katinila (1998) reported the loss of stored maize in Tanzania to be as high as 30% due to insects. The two most destructive insects, the greater and lesser grain borers, are very difficult to eliminate from stored grain. An insecticide treatment does exist (Actellic Super), but correct application of the product requires a degree of sophistication that becomes an obstacle to smallholders wishing to use the pesticide (Katinila, 1998). Other insects pests are also endemic in stored grain as well as ear and kernel diseases that can continue to develop in storage if grain is not dried sufficiently. Some kernel diseases found in stored grain can produce toxic compounds that make the grain unfit for consumption by humans or livestock. Cleaning of grain at the time of harvest, drying of the grain before storage, and proper use of insecticides is critical to preventing loss of stored grain.

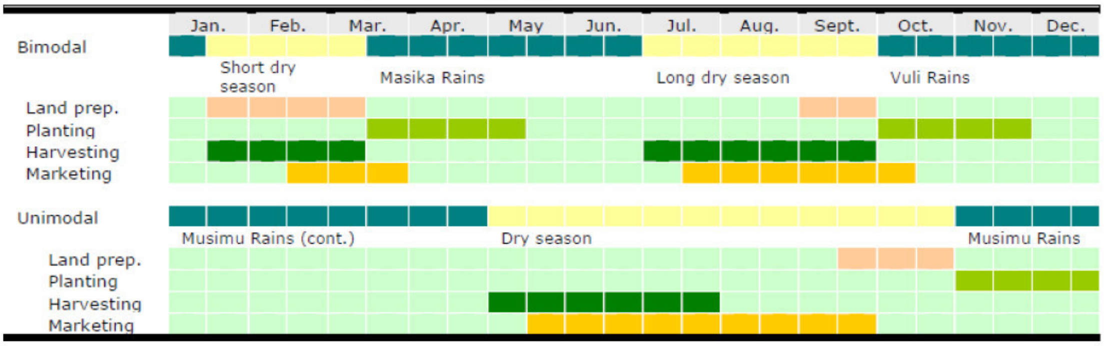
Weeds: Elimination of weeds is often the first consideration for improving crop yields as they tend to be the most visible obstructions to yield. However the physical labor required to control weeds in a 2 ha plot (size of the average smallholder plot) is a necessary task that takes substantial effort and time throughout much of the growing season. Here again, herbicides would appear to the the solution except for the hazards associated with their toxicity, misapplication, and off-target movement, and the complex demands for technical training and equipment.

Water use efficient varieties and hybrids: Planting rice varieties and maize hybrids which use water more efficiently than those currently planted is a desirable goal with practical aspects. The principal drawback to this approach is that desirable traits, such as disease resistance, grain quality, or standability, may take time and resources to breed into the seed stock and receive acceptance by farmers. However, researchers in many countries are making progress on developing varieties with improved drought resistance and water use efficiencies and the benefits of introducing those varieties and hybrids should not be overlooked.

Adoption of water-saving alternative crops: Other drought tolerant and water use efficient crops could be adopted as a means of increasing grain production while reducing water consumption. Such crops might include sorghum, spring wheat, spring barley, and perhaps soybeans. These crops have the same challenges as maize and rice, but their production may also have the additional challenges of resistance by farmers who lack the knowledge of how they can be produced and the uncertainty of how market prices would support production.

Use of conservation tillage or no-till: The advantages of conservation till and no-till are well known. They include a reduction in evaporation of moisture from the soil surface, greater retention of rainwater, and a reduction in the amount of energy and equipment necessary to prepare the soil for planting. In cases of prolonged dry weather during planting season conservation tillage may provide an improved seedbed that facilitates earlier crop germination. Except for the need for some specialized equipment for seed planting these practices would appear to be ideal methods of improving water use efficiency, although the improvement in efficiency is quite variable depending on topography, soil type, and rainfall patterns. In Tanzania and across the Sub Saharan area, a marked disadvantage of conservation tillage is that crop residue left on the surface provides an ideal reservoir for insect and diseases. Some of the advantage of conservation tillage can be reserved by finely chopping the residue to expose insects and destroy breeding sites. However, shearing crop residue does little to reduce diseases. Some weeds may also be a greater concern in conservation tillage regimes. Any reduction in tillage will require a commensurate increase in labor by smallholders who may not have ready access to herbicides, and an increase in pesticide use by small and large operations that do have access. Farmers should expect some increase in pest pressure from weeds, insects, and crop diseases when using conservation tillage practices which may necessitate an increase in pesticide use. The use of conservation tillage methods should be encouraged in the RRB, although with some consideration for obstacles to its adoption.

Optimizing plant population and planting time: Assuming the use of common agronomic practices among smallholders, planting early has been reported as the most significant yield boosting practice for maize in Tanzania (Katinila 1998, Goodbody, 1990). A chart showing field operations in Tanzanian unimodal and bimodal seasons is in the figure below (Barreiro-Hurle, 2012). The principal reason for the maize early planting success can be explained in that its reproductive stages benefit avoid moisture stress as the rainy season transitions to the dry. Although early planting of maize is a preferred practice, at times dry weather before planting can make soils difficult to work, necessitating a delay in planting until soils become more workable after a rain. Katinila (1998) suggests an optimum plant population for maize of 44,000 plants per hectare (18,000/a). This plant population would not be unusual considering the low fertility rates and unimproved hybrids currently being used. However, the expected plant population for well fertilized and watered modern hybrids would be about 88,000/ha. Use of modern hybrids at higher populations, in addition to improved fertility and pest control would undoubtedly prove to be more efficient in water use, as evaporation from soil and irrigation systems would be less significant compared to the increase in production.



Cropping seasons in Tanzania

Source: WFP, 2010.

Optimize fertilizer use to efficiently produce yield: The current use of fertilizer averages 8.7 kg/ha/yr across all growers (Abate, 2014) whereas the recommended fertilizer rate for Southern Tanzania is about 20 kg N/ha and 20 kg P_2O_5/ha. On smallholder parcels, when fertilizer is used it is dropped in a furrow or in a hole next to the planted seed (Katinila,1998). The rate of 20kg/ha dropped in a furrow is equivalent to a broadcast rate of approximately 60kg/ha (55lbs/a) if the fertilizer is utilized efficiently by the plant. However, it is unlikely that many smallholders regularly apply any fertilizer and that the average given above represents figures heavily weighted to large landholders. Even so, a rate of 8.7 kg/ha is unlikely to satisfy the high nutrient demands of maize, nor will such low rates build soil fertility over time. However, to maximize water use efficiency by the rice or maize crop it will be critical to build soil fertility levels. WUE by the crop will depend on a Return On Investment for fertilizer and can only be realized by adequate market price for the grain.

Soil erosion and pollution prevention: To our knowledge, there are no current surveys of soil erosion or erosion control practices found in the RRB. Terraces, cover crops, windbreaks, filter strips, buffer strips, are proven technologies that can help maintain crop productivity and reduce runoff of fertilizers and pesticides under both excessively wet and very dry conditions. As modern agronomic practices are implemented more widely and dryland and irrigation areas expanded, erosion control and pollution prevention must accompany development.

Rice seeding methods: On many fields within the RRB paddies are flooded as much as thirty days prior to planting to facilitate tillage and land leveling. Many farmers also apply a higher level of water on rice than is necessary to reduce the frequency of irrigation, control weeds, and insure against irregularities in water distribution. These practices are wasteful of water in that they encourage losses due to percolation and evaporation (Akinbile, 2011).

Furrow row planting of rice for water conservation: Planting rice within a furrow has promise to reduce irrigation water use on rice. Research indicates an improvement in Water Use Efficiency of about 40% by reducing evaporation and percolation (Atta, 2008).

Plant water use efficient rice varieties: Research has indicated that the inclusion of the Arabidopsis HARDY gene in rice varieties improves both salt and drought tolerance. Success on improving water use efficiency (WUE) via breeding and advanced means of genetic selection in several rice lines is being reported by a company titled Mahyco. Efficiency increases are probably in the low double digits. (Karaba, 2007)

Use a shorter season rice crop: The use of some Basmati rice varieties, which matures in 120 days instead of the 140 to 160 days, could save on water use because the period of essential flooding will be shorter (WWF, 2010).

Direct seeding rice: One technique that has proven to be a water saving procedure for rice is to transplant rice rather than direct seed. This involves obtaining transplants from a community nursery or for farmers to establish their own nursery by setting aside a small area in their basin to germinate seedlings. Carangon (2002) reported that water demand decreased 15% for transplanted rice compared to that which was direct seeded. Transplanting allows a delay in flooding the basin, which reduces evaporation, and also gives farmers additional time for field preparation. Although transplanting rice takes additional labor, it can also facilitate stand management and reduce the risk of delayed planting or emergence which can result from water availability or weather issues.

Addition of insect resistant traits in rice via GMO: Several important pests (rice stem borers) could potentially be controlled through the adoption of Bt rice varieties. How effective these GMO varieties may be, and how acceptable GMO traits may be to markets are issues of concern. Traits such as Bt proteins may not be sufficiently expressed when seedlings are small and yet infestation of insects are at destructive levels. They may also lose their effectiveness when insects develop resistance to the gene. This may occur in some areas of the Rufiji basin more rapidly than other due to rice being double cropped in dry season irrigation areas as a monocrop.

Agronomic practices summary: In the aggregate, a consideration of all the above is necessary to achieve a significant increase in grain production and more efficient water use.

No one mitigation practice (fertilizer, pesticides, improved hybrids, GMO trait, etc.) implemented independently is as likely to result in a significant improvement as would an approach that combines several of these elements.

3.3.5.5 Scenario 5: Policy and Demographic Changes

It is government policy to recognize and respect local tribal rights, customs, and land ownership concepts. However, the main goal of Climate Adaptation Strategies is to foster efficiencies in resource use and to increase agronomic production via economies of scale. These objectives are often at odds with one another throughout much of past efforts. While it is easy to comprehend how traditional pastoral-agricultural systems have been sustainable, the changes proposed here are intended to greatly expand agricultural production while improving water use efficiency. These changes do not necessarily have a clearly defined path to similar sustainability, as they will require concurrent infrastructure improvements as well as significant policy changes.

4. CONCLUSIONS

The Tanzanian government has a number of policies favoring the modernization agriculture. These include agronomic practices to increase crop yield and the expansion of irrigation, transport and other infrastructures to permit improved production and marketing. This report examined the potential of some of these in light of expected climate, demographic and population changes. Although the report should be considered interim, as the authors continue to refine the models and conduct scenarios, some initial conclusions can be drawn.

Agronomic management implications of the crop-climate modeling include the following.

Rice:

a. Because of the warming temperatures, rice yields will improve somewhat in the Highlands, but the highest yields will remain in the lowlands.
b. However, rainfed rice yields are expected decline in the future in the lowlands because of the impacts of hot temperatures on plant growth and, in some areas, worsening water deficits. Without supplemental irrigation during the rainy season, yields may decline.
c. During the winter (June) planting, if the rice plants have sufficient irrigation and nutrients, yields will remain the same or even rise in the future.
d. Rice yields greatly benefit from N applications, but the benefits are less in the very warm or drier areas.

Maize:

a. Low fertilizer levels significantly limit current yields. With climate change, the benefits of fertilizer will decline, since its ability to increase yields diminishes with water deficits. Fertilizer will remain a critical management practice, however, especially in medium and high potential areas.
b. Irrigation in moderate temperature areas would generate very large benefits
c. Hot areas, and of course wetter and cold areas, would benefit much less from irrigation.

d. Benefits from irrigation will decline in the future due to hotter temperatures.
e. Maize, rice other crop varieties will need to be tolerant of warmer temperatures and extreme heat. Grain varieties will need to be resistant to the acceleration of plant maturity due to warmer temperatures.
f. In areas of low and declining precipitation, varieties and crops resistant to within-growing season dry spells, especially during flowering, will produce more reliably.

From the hydrological analyses, it was found that almost all water is already being used in the primarily agriculturally dominant areas of the Rufiji basin. While increases in rainfall may be a part of future climate change in some areas of Tanzania, recent years also show that low rainfall years are also prevalent. Agricultural production in these basins also increase in wet years using up to two times the amount of water in a dry year. These uncontrolled increases in usage make future predictions difficult. Increasing amounts of cultivated land and increases in irrigation schemes also favor even more water usage across the basin. Meanwhile, achieving planned gains in agricultural production would require large and small holder Basin growers to adopt a combination of a wide range of practices, many of which may not be economically or otherwise practical under current conditions.

Meanwhile, the team will continue to test the potential impact of different technical and other changes in GIS-based scenarios to compare their impact on water resources and agriculture. In order to project future water resources, current water usage will be partitioned into different kinds of water usage. This requires the aid of UDSM collaborators and others in understanding what is reasonable and not reasonable to assume. Once we have set these ranges, we can adjust the amount of irrigation efficiencies, smallholder and large holder proportion of growers, different types of irrigation schemes with efficiency increases, and changing land use and water usage. Future work will also include ongoing delta method-based climate projections from MSU collaborators.

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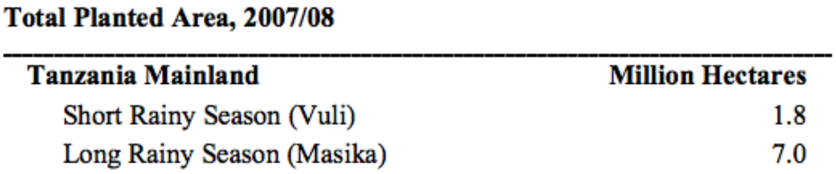
APPENDIX I

SOURCES OF VARIOUS PUBLIC DATA USEFUL TO THE STUDY

These data were compiled by Agrible and project personnel. In most cases these are screen captures of tabular data. Reference is listed in each section - in many cases more than one table of data were extracted from the document shown in the header.

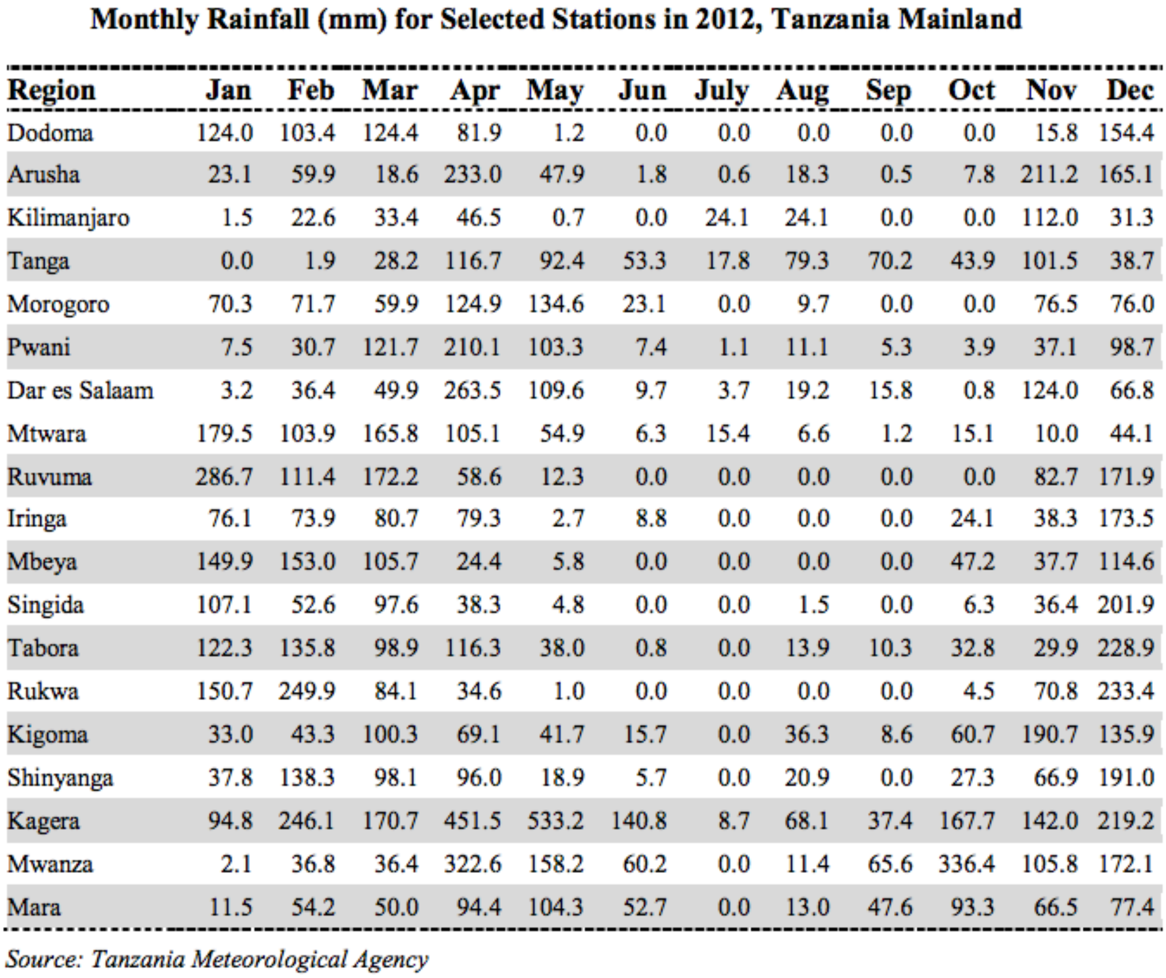
Table. Planted hectares from Tanzanian National Bureau of Statistics (2013).



Total Planted Area, 2007/08

Tanzania Mainland	Million Hectares
Short Rainy Season (Vuli)	1.8
Long Rainy Season (Masika)	7.0

Table. Monthly Rainfall from Selected Stations in 2012 from Tanzanian National Bureau of Statistics (2013).



Monthly Rainfall (mm) for Selected Stations in 2012, Tanzania Mainland

Region	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Dodoma	124.0	103.4	124.4	81.9	1.2	0.0	0.0	0.0	0.0	0.0	15.8	154.4
Arusha	23.1	59.9	18.6	233.0	47.9	1.8	0.6	18.3	0.5	7.8	211.2	165.1
Kilimanjaro	1.5	22.6	33.4	46.5	0.7	0.0	24.1	24.1	0.0	0.0	112.0	31.3
Tanga	0.0	1.9	28.2	116.7	92.4	53.3	17.8	79.3	70.2	43.9	101.5	38.7
Morogoro	70.3	71.7	59.9	124.9	134.6	23.1	0.0	9.7	0.0	0.0	76.5	76.0
Pwani	7.5	30.7	121.7	210.1	103.3	7.4	1.1	11.1	5.3	3.9	37.1	98.7
Dar es Salaam	3.2	36.4	49.9	263.5	109.6	9.7	3.7	19.2	15.8	0.8	124.0	66.8
Mtwara	179.5	103.9	165.8	105.1	54.9	6.3	15.4	6.6	1.2	15.1	10.0	44.1
Ruvuma	286.7	111.4	172.2	58.6	12.3	0.0	0.0	0.0	0.0	0.0	82.7	171.9
Iringa	76.1	73.9	80.7	79.3	2.7	8.8	0.0	0.0	0.0	24.1	38.3	173.5
Mbeya	149.9	153.0	105.7	24.4	5.8	0.0	0.0	0.0	0.0	47.2	37.7	114.6
Singida	107.1	52.6	97.6	38.3	4.8	0.0	0.0	1.5	0.0	6.3	36.4	201.9
Tabora	122.3	135.8	98.9	116.3	38.0	0.8	0.0	13.9	10.3	32.8	29.9	228.9
Rukwa	150.7	249.9	84.1	34.6	1.0	0.0	0.0	0.0	0.0	4.5	70.8	233.4
Kigoma	33.0	43.3	100.3	69.1	41.7	15.7	0.0	36.3	8.6	60.7	190.7	135.9
Shinyanga	37.8	138.3	98.1	96.0	18.9	5.7	0.0	20.9	0.0	27.3	66.9	191.0
Kagera	94.8	246.1	170.7	451.5	533.2	140.8	8.7	68.1	37.4	167.7	142.0	219.2
Mwanza	2.1	36.8	36.4	322.6	158.2	60.2	0.0	11.4	65.6	336.4	105.8	172.1
Mara	11.5	54.2	50.0	94.4	104.3	52.7	0.0	13.0	47.6	93.3	66.5	77.4

Source: Tanzania Meteorological Agency

National Panel Survey (NPS)

Results from the 2010/11 NPS show that access to electricity had increased from 13 percent to 17 percent between 2008/09 and 2010/11. However, the increase is not significant particularly in rural areas where access to electricity was only 5.3 percent.

Percentage of Households with Access to Electricity

Area	NPS 2008/09	NPS 2010/11
Tanzania	**13.0**	**17.0**
Rural	2.4	5.3
Urban	42.8	43.4
Mainland	**12.4**	**16.4**
Dar es Salaam	61.1	68.9
Other Urban	31.4	32.6
Other Rural	2.0	4.2
Zanzibar	**33.9**	**39.7**

Source: National Panel Survey 2010/11

Percentage of Households with Access to Safe Drinking Water

Area	Rainy Season		Dry Season	
	NPS 2008/09	NPS 2010/11	NPS 2008/09	NPS 2010/11
Tanzania	**43**	**43**	**44**	**50**
Rural	33	32	33	40
Urban	73	66	73	74
Mainland	**42**	**42**	**43**	**49**
Dar es Salaam	78	75	81	78
Other Urban	67	62	67	71
Other Rural	32	30	32	38
Zanzibar	**81**	**86**	**80**	**84**

Source: National Panel Survey 2010/11

HOUSEHOLD BUDGET SURVEYS

Key Indicators from the Household Budget Surveys

Indicators	**1991/92**	**2000/01**	**2007**
Housing, Water and Sanitation, Communication (%)			
Households with modern roofs	36.0	43.0	55.0
Households with modern walls	16.0	25.0	35.0
Households with electricity	9.0	12.0	13.0
Households with protected water sources	46.0	55.0	52.0
Household within 1 Km of drinking water	50.0	55.0	57.0
Households using toilets	93.0	93.0	93.0
Household owning radios	37.0	52.0	66.0
Households owning telephones	1.0	1.0	25.0
Education and Health (%)			
Adults men with any education	83.0	83.0	83.0
Adults women with any education	68.0	67.0	71.0
Literate adults	-	71.0	73.0
Primary school net attendance ratio	-	59.0	84.0
Children aged 7-13 years studying	57.0	61.0	86.0
Secondary net enrolment ratio (forms I-IV)	-	5.0	15.0
Households within 6 km of primary health	75.0	75.0	76.0

Source: Household Budget Surveys 1991/92, 2000/01 and 2007

Household Indicators	**2007/08**		
	Tanzania	**Mainland**	**Zanzibar**
Percentage of households not owning Assets			
Radio	33	33	31
Bicycle	49	50	48
Iron	76	76	84
Wheelbarrow	93	93	97
Mobile phone	68	68	50
TV/ Video	97	97	90
Vehicle	95	95	97
Landline phone	99	99	99
Percentage of households and Sources of Energy for Lighting			
Wick Lamp	67	67	72
Hurricane Lamp	24	24	11
Pressure Lamp	4	4	3
Firewood	2	2	1
Mains Electricity	2	2	12
Candles	0	0	0
Solar	1	1	0
Gas(Biogas)	0	0	0
Percentage of households and Sources of Energy for Cooking			
Firewood	95	95	95
Charcoal	4	4	4
Crop Residues	1	1	1
Paraffin / Kerosene	0	0	0
Mains Electricity	0	0	1
Bottled Gas	0	0	0
Solar	0	0	0
Livestock Dung	0	0	0
Gas (Biogas)	0	0	0
Percentage of households and Access to Drinking Water (Less than one Km)			
Wet Season	66	76	99
Dry Season	57	56	98

HOUSEHOLD BUDGET SURVEYS

Key Indicators from the Household Budget Surveys

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Households within 6 km of primary health	75.0	75.0	76.0

Source: Household Budget Surveys 1991/92, 2000/01 and 2007

Crop Indicators

	2007/08		
	Tanzania	**Mainland**	**Zanzibar**
AGRICULTURAL HOUSEHOLDS			
Number of Rural Agricultural households	5,838,523	5,706,329	132,193
Number of Households Growing Crops only	3,508,581	3,422,072	86,509
Number of Households Growing Crops and livestock	2,268,255	2,224,410	43,844
Number of Households with Livestock only	57,770	55,929	1,840
Number of Households doing Pastoralism	3,917	3,917	0
LAND ACCESS & OWNERSHIP			
Land allocated to smallholders (ha)	14,810,368	14,684,721	125,647
Average allocated land per agricultural household	2.5	2.5	0.9
Average Utilized Area per agricultural household	2.0	1.98	0.91
Land Insufficiency Rate (%)	63	63	56
Land Utilization Rate (%)	78	78	96
Average planted area of annual Crops per crop growing household	1.5	1.6	0.4

		2002/03			2007/08		
		Tanzania	**Mainland**	**Zanzibar**	**Tanzania**	**Mainland**	**Zanzibar**
PRODUCTION IN TONNES							
Cereals	Vuli	755,060	753,517	1,544	1,458,979	1,451,911	7,068
	Masika	2802,832	2,790,438	12,394	6,173,797	6,140,629	33,168
Roots & Tubers	Vuli	141,207	137,078	4,129	160,215	150,441	9,774
	Masika	2,342,987	2,268,055	74,932	1,670,380	1,537,462	132,918
Pulses	Vuli	138,702	138,192	510	214,181	213,249	932
	Masika	266,550	266,361	189	512,358	512,022	337
Oil Crops	Vuli	24,876	24,692	185	36,024	35,845	180
	Masika	215,420	215,217	203	608,814	608,308	506
Vegetable	Vuli	74,371	71,509	2,864	152,126	148,396	3,730
	Masika	153,806	150,233	3,572	285,033	281,003	4,030
PRODUCTION OF PERMANENT CROPS IN TONNES							
Cashew nut			183,419		134,998	134,997	1
Banana			2,205,673		1,889,570	1,795,230	94,339
Coffee			61,602		186,250	186,250	-
Mango			336,028		190,402	180,291	10,111
Pigeon pea			26,615		44,942	44,358	584
Coconut			102,458		120,619	106,105	14,514
Oranges			186,695		197,522	186,583	10,938
Sugar Cane			404,694		190,147	186,500	3,647
Palm Oil			51,109		12,217	12,217	-
IRRIGATION PRACTICE							
Percentage Irrigated Area							
Vuli		3.3	3.2	12.3	4.8	4.7	9.9
Masika		2.6	2.6	1.2	2.8	2.8	3.5
Percentage of households using Irrigation Facilities							
Dams			5		0.9	0.7	13
Canals			28		10.5	10.2	27
Well			15		1.5	1.4	12
Rivers			49		52.7	52.9	36
Lake			2		5.5	5.6	0
Pipe water			1		27.6	27.8	11
Borehole			1		1.3	1.3	0

Input Usage

	2002/03			2007/08		
	Tanzania	Mainland	Zanzibar	Tanzania	Mainland	Zanzibar
INPUT USAGE: ANNUAL CROPS						
Percentage Area Planted on Improved Seeds	-	16	-	16.9	17	7.4
Percentage Area planted with fertiliser application	28.09	24.23	0.15	-	-	-
Percentage Area planted with Farm Yard Manure application	18.4	15.95	0.04	-	-	-
Percentage Area planted with Compost application	2.97	2.48	0.07	-	-	-
Percentage Area planted with Inorganic fertiliser application	6.73	5.79	0.04	6.7	6.7	6.9
CROP EXTENSION						
Percent of Households Receiving Crop Extension Services	-	34	-	67	67	34
FARM IMPLEMENTS						
Percent of Households Using hand hoe as the main Farm Implement	-	98	-	97.6	97.8	89.5
Percent of Households Using OXEN PLOUGH as the main Farm Implement	-	24	-	14.1	14.4	0.3
Percent of Households Using Tractor as the main Farm Implement	-	3	-	0.8	0.8	1.4

APPENDIX II:

CONSUMPTIVE WATER USE

Ministry of Water, URT, 2014: Integrated Water Resources Management and Development Plan for Lake Rukwa Basin, Final Interim Report II, Volume I: Water Demand Projections (2015 – 2035), developed by WREM International Inc., Atlanta, Georgia, USA, 96pp.

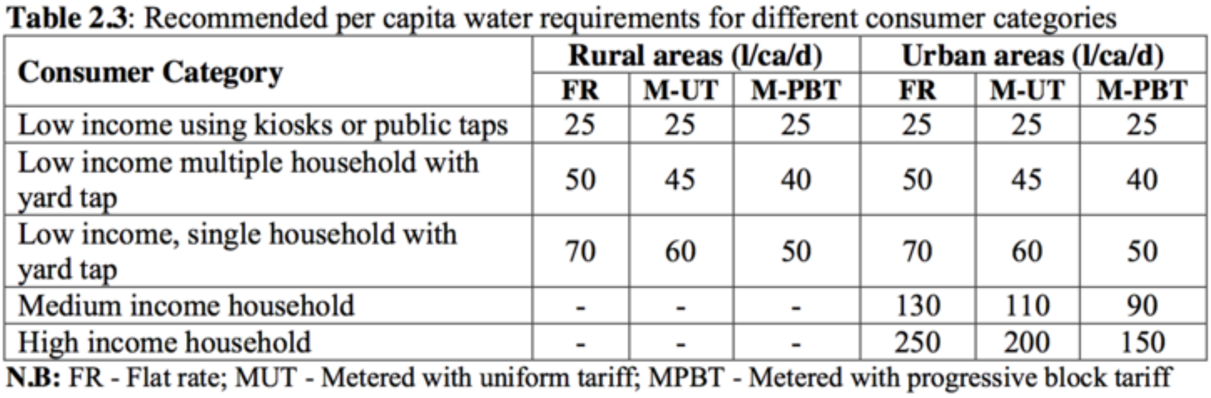

Table 2.3: Recommended per capita water requirements for different consumer categories

Consumer Category	**Rural areas (l/ca/d)**			**Urban areas (l/ca/d)**		
	FR	**M-UT**	**M-PBT**	**FR**	**M-UT**	**M-PBT**
Low income using kiosks or public taps	25	25	25	25	25	25
Low income multiple household with yard tap	50	45	40	50	45	40
Low income, single household with yard tap	70	60	50	70	60	50
Medium income household	-	-	-	130	110	90
High income household	-	-	-	250	200	150

N.B: FR - Flat rate; MUT - Metered with uniform tariff; MPBT - Metered with progressive block tariff