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

DECISION SUPPORT TOOL




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SECTION ONE

INTRODUCTION

1.0 Background

Significant changes in climate on a global scale are likely impact agricultural production and consequently affect the world's food security. Recent and projected future changes in Tanzanian climate and agriculture suggest that adaptation strategies will be increasingly necessary to meet crop production and water use requirements in the Rufiji River Basin and indeed throughout Tanzania. The Rufiji River Basin has great potential to produce large amounts of rice, maize and other crops, and to support livestock. However, climate change and rising demand for water is challenging the planned expansion of irrigated rice and other crops.

The Decision Support Tool (DST) is composed of interactive tools that permit the user to query the effectiveness of selected adaptation technology scenarios under the current and future climate conditions. The DST was designed with stakeholders' input, and is based on the project's climate, crop, land use and hydrological modeling, fieldwork and data analysis.

It is important to note that, Rufiji Basin is very heterogeneous, and the effectiveness of adaptation technologies varies across the basin depending on local climatic, soil, relief, elevation and other conditions. The DST recognizes this, with results presented as spatially differentiated maps and data reflecting these differences. The working model of the DST is found at: http://www.rsgis.msu.edu/dmoy/dashboard2/index.php. Once the tool has been fully populated (including the content for the water availability section) and comments from stakeholders incorporated, the address will change to be a University of Dar es Salaam and a Michigan State University URL.

1.1. Objective of the Decision Support Tool

The objective of the DST is to provide users information on how climate change is expected to impact crop productivity and water availability for irrigation, and how selected adaptation technologies and improved crop and water management practices may help to reduce the negative climate change impacts. The tool is interactive, and intended to enable River Basin Officers, Government officers and other stakeholders to use the results of the project's research and modelling for better decision-making related to climate change impacts and adaptation to climate change.

SECTION TWO
METHODOLOGY

2.1 General approach

DST provides focused information on how climate change would affect crops and water availability for irrigation, and the potential of different adaption technologies to reduce the negative effects of climate change and to increase productivity, as well as taking on board of the associated positive implications. The DST was created using data sets, four sets of models, and stakeholders' input developed during the wider stakeholders' consultations.

To produce the maps and other results presented in the DST, a combination of different models and statistical analyses were used. These are future described in the publications in the reference section by Olson et al. (2015), Alagarswamy et al. (2015) and Moore et al. (2012). Historical climate datasets and future climate projections based on Global Climate Models (GCMs) were used as input data for both the crop and hydrological modelling. The results of the rice modelling in regards to the amount of daily water required for irrigating the rice also informed the hydrological model. Household survey data and focus groups provided information on agricultural and water management practices.

The analysis was thus conducted using 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. However, the calibration and validation of the models was hampered by the limited amount of observed data available. Because of this and because of the inherent uncertainty of future climate change and Global Climate Modelling, the results should be considered indicative and should not be interpreted as certain. The modelling results and DST will be refined and expanded as additional data and information is incorporated. Figure 1 provides an overview of the coupled climate, crop and hydrology modelling approach and the datasets used in the analyses.

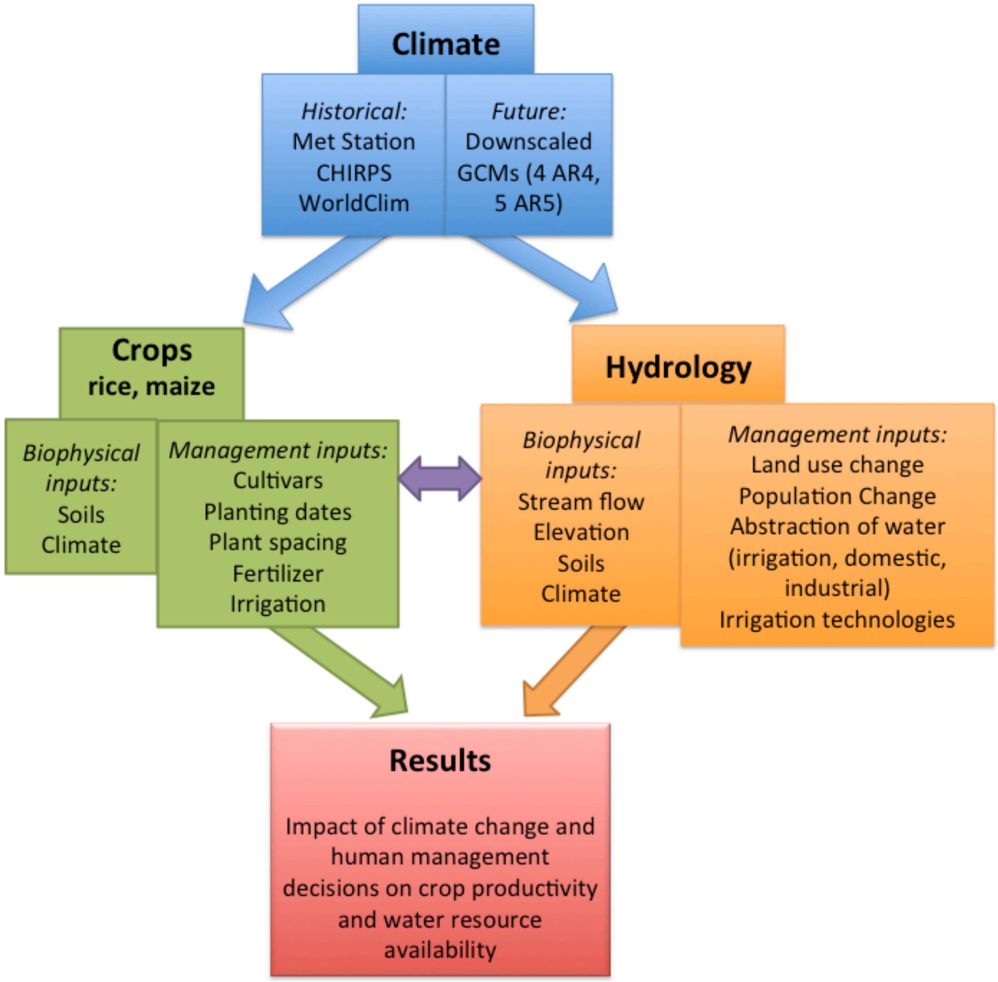

Figure 1: The coupled modelling approach and main datasets used. Source: Olson et al. 2015.

2.2 Climate Analysis and Modelling

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 (Moore *et al.* 2012). The historical climate dataset used in these analyses include:

a. Observed meteorological station data from the Tanzania Meteorological Agency for 17 stations that had sufficient length and quality of precipitation in the Rufiji Basin were selected for precipitation analysis and to run in the site-specific crop model.

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 years period for the crop model, we used the weather generator MarkSim (Jones and Thornton 2000).

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.

d. NASA Power (NASA 2014) is a satellite-derived spatial, time-series product. 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. Four 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:[1]

a. CCSM4: Community Climate System Model, version 4 from the National Centres for Environmental Research, National Centre 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. MRI-CGCM3: Meteorological Research Institute, Japan.

The data were downscaled to 6 km and bias-corrected to daily time steps using a MATLAB program (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.

In the DST climate section, results from the four GCMs are provided to illustrate the range of projected changes in temperature and precipitation of GCMs; this is common practice in climate change science due to the inherent uncertainty of modeling future climate. Although the four

[1] "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."

GCMs were chosen for their ability to simulate current trends in East Africa, it is not possible to compare them for their accuracy in projecting the future. It is hoped that the users of the DST thus recognize that the future climate and other projections are not certain and take the results as indicative trends to inform policy and practice. However, in the crop and hydrology sections of the DST, maps are presented in which modelling results are based on only one or two GCMs driving the crop or hydrology models (although the team conducted crop and hydrology modelling using multiple GCMs and these are presented in technical reports). This decision was made to promote clarity and to reduce the number of maps the user needs to examine. The GCMs used to illustrate the impact of climate change on crops and water availability are "middle of the road" GCMs that best represent current climatic trends.

2.3 Crop Modelling

For this project, two dynamic crop growth models, the CERES Maize and the CERES rice model were embedded in the Decision Support System for Agrotechnology Transfer (DSSAT) crop modeling framework (Hoogenboom *et al.,* 2010). DSSAT version 4.5 was used. Two types of analyses were conducted—the impact of historical (observed if possible) climate variability on yield, and the impact of projected future climate change on yield. For the historical analysis, precipitation data was used from 17 stations of the Tanzania Meteorological Agency and from CHIRPS for point level modeling, and WorldClim was used in the spatial crop modeling. They were combined with daily temperature and solar radiation data from NASA's Prediction of Worldwide Energy Resource for the modeling (POWER) (NASA 2014). GCM data was used to examine the impact of projected climate change on yield (climate datasets described above). The soil property data for the historical point-based modeling was obtained from a soils dataset for Africa with a 1 km resolution. It was created by ISRIC World Soil Information based on soil profile and other existing data. The spatial crop modeling was run using data from the FAO soils map calibrated with soil profiles from WISE database (ISRIC).

The rice model was run under rainfed conditions during the rainy season, and irrigated during the dry season. For the rainfed conditions, twenty-day old seedlings were transplanted into plots on November 20th, and the new transplants were provided irrigation water that day. Growth thereafter was rainfed. For the irrigated conditions, seedlings were transplanted on June 2nd. The plants were provided irrigation water when soil moisture fell below 50% of plant available soil moisture in top 30 cm of soil profile. Yield is measured in terms of hulled rice. In this Decision Support Tool, modeling results are provided for different management practices:

1. Two rice varieties: An older, longer duration and widely grown variety (Supa), and a variety representing a higher producing, improved variety (TXD-85).
2. Two fertilizer levels: A low application of Nitrogen fertilizer, of 5 kg/ha, and the higher application of 100 kg/ha.

The maize model was run using the same historical datasets, but with AR4 IPCC GCMs (CCSM, HadCM3, ECHam and CSIRO). We assumed current representative smallholder practices; planting was assumed to occur automatically once the soil profile received a thorough wetting at the start of the rainy season (Alagarswamy *et al.,* 2015). In this Decision Support Tool results are provided under different management conditions:

1. Two maize varieties: Katumani composite, an older short-season variety developed by the Kenya Agricultural and Livestock Research Organisation (KALRO) for medium- to low-potential zones, and H614, a longer-season hybrid suited for mid- to high-potential zones.

2. Two fertilizer levels: low application of Nitrogen fertilizer, of 5 kg/ha, and a moderate application of 85 kg/ha.

3. Rainfed and irrigated. Under the rainfed scenario, no additional water was provided so dry conditions could affect yield. Under the irrigated scenario, water was provided as needed.

2.4 Hydrology Modelling

To explore factors related to climate change and water resources, a calibrated model of the Rufiji basin was created to quantify historical hydrologic response. This model includes simulation of the basin from 1983 through 2014 using available data from Tanzanian Meteorological Agency as ground truthing stations, CHIRPS precipitation data, NASA POWER-based temperature and solar radiation data, and four GCMs. The Soil and Water Assessment Tool (SWAT) was used to simulate the hydrology of Rufiji river basin. The Rufiji River Watershed was subdivided into 33 sub-basins. Six (06) river gagging stations from the Rufiji River Basin Authority were chosen to use as part of this calibration work. They include the stations (1KA15A, 1KA11A, 1KA32A, 1KA31, 1KA59 and 1KB32).

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. 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 gagging 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. The model was calibrated using auto-calibration method by linking SWAT with the optimization algorithm, AMALGAM (Vrugt and Robinson, 2007). Auto-calibration was conducted in supercomputer facilities with 24,000 model evaluations.

The SWAT model was set up 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 sub-basin.

This work represents the current conditions within the watershed given current land use and agricultural practices, water use conditions and climate. This modeling setup includes current and future land use (land use model based on historical urban and rural population growth rates, 2013 land use, and land suitability), water use, irrigation technology and climate change scenarios. The scenarios are based on three time periods: current baseline (1990-2010, calibration), and future 2010-2040 and 2040-2060 with land use, population and climate adjustments.

Irrigation technology scenarios were also examined. Each has an estimated water efficiency rate that affects the availability of water in the local and downstream basins. As efficiency improves, more water is available for additional use.

2.5 Delivery Mechanism of the Tool

The DST will be available on two platforms. The main platform will be an online, Internet enabled website housed at Michigan State University with a mirror site at the University of Dar es Salaam. For users without Internet access, such as many people in the Basin, a version of the tool will also be available offline, as a DVD or on a flash drive.

SECTION THREE
DESCRIPTION OF THE TOOL

3.0 Introduction

The DST is an interactive tool designed to illustrate to the user the potential of various adaptation technologies under climate change and technology scenarios. The technology scenarios are generally "baseline," or the current technology of most small-scale famers, and different improved technologies that may reduce the negative effects of climate change.

The DST is structured to provide information to users on four main topics:

1. **Climate**: current and projected future minimum and maximum temperatures, and precipitation;
2. **Maize**: impacts of climate change on productivity, and benefits of improved varieties, fertilizer applications and irrigation to reduce the negative effects of climate change;
3. **Rice**: impacts of climate change on productivity of rainfed rice grown during the rainy season and irrigated rice grown in the dry season, and benefits of improved varieties and fertilizer to reduce the negative effects of climate change;
4. **Water**: impact of climate change on the availability of water for irrigation and other uses in the Basin, and effects of improved irrigation technologies and change in amount of land being irrigated on rice production, downstream water flow and the ability of downstream sub-basins to irrigated.

In addition, the DST has introduction sections, a methodology section, publications, and, in the "About" tab, information about the wider project and team members.

3.1 Crop-Climate Tool

The first tool allows the user to examine the impact of climate change on rice and maize yields, and the potential of adaptation technologies compared to baseline technology (what most small-scale farmers currently practice) to reduce the negative effects of climate change. It is based on the result of climate, rice and maize modeling and results are presented as maps of yield across the Basin and explanatory text.

Users select what topic they are interested in (e.g., climate, maize or rice), and then what technology scenario they would like to examine. Since rice is often grown in two seasons in the Basin—during the rainy season mostly as a rainfed crop, and during the cooler, dry season as an irrigated crop, results are provided for both seasons. A comparison of an older and an improved variety is also provided for both seasons, and the effect of different fertilizer levels as an adaptation technology is provided for the rainy season crop. Most maize is grown as a rainfed crop during the rainy season in the Basin. Results are provided looking at the impact of climate change on maize productivity, and then comparing the effectiveness of management practices: a comparison of two maize varieties, and different fertilizer levels.

The crop-climate section is as follows:

1. Climate
    a. Current climate
        i. TMax and TMin Temperatures during the growing season
        ii. Growing season precipitation
    b. Projected future climate (4 downscaled GCMs to 6 km)
        i. TMax and TMin Temperatures
        ii. Growing season precipitation
2. Rice scenarios, for both rainy season (rainfed conditions) and winter dry season (irrigated conditions):
    a. Variety benefit: traditional Supa versus improved TDX85. Yield under current and future climate, and the impact of climate change on yield of both.
    b. Fertilizer benefit: low versus high nitrogen fertilizer levels, rainfed. Yield under current and future climate, and the impact of climate change on yield for both low and high fertilizer application rates.

    Results include maps comparing the yield differences between the technologies under current and future climate conditions, and text explanation.
3. Maize scenarios:
    a. Impact of climate change on maize (technology held constant)
    b. Maize variety benefit: older Katumani variety versus improved hybrid H614. Yield under current and future climate, and the impact of climate change on yield of both varieties.
    c. Fertilizer benefit: low versus moderate nitrogen fertilizer application levels. Yield under current and future climate, and the impact of climate change on yield for both low and high fertilizer application rates.

d. Irrigation benefit: rainfed versus irrigated. Yield under current and future climate, and the impact of climate change on maize yield under both rainfed and irrigated technologies.

Results include maps comparing the yield impact of technologies under current and future climate conditions (e.g., a maps of the yield gained from using nitrogen fertilizer under current and under future conditions), comparing yield benefits of different technologies, and text explanations.

3.2 Water Availability Tool

The hydrology or water section of the DST allow the user to select a sub-basin, and then select the time period of interest (current or future), change the irrigation technology and amount of land under irrigation, and the result is provided in terms of changing water flow available for that sub-basin and for downstream sub-basins. The tool is based on the project's climate, crop, land use and hydrological modelling.

When the tool opens, a map of the Rufiji River Basin is shown with the sub-basins indicated. The user selects which sub-basin and which time period (current, 2025 or 2050) to simulate. The user then decides on a water management scenario—what percentage of the cropped land is under irrigation, and the level of irrigation technology being used. The tool's results are presented in a panel on the side of the screen with the amount of rice and maize produced in the selected sub-basin, and the amount of water available for irrigation in that and in downstream sub-basins. The results of each scenario can be saved for future reference.

Since water is a limited resource, the tool reflects the impact of decisions on irrigation technologies on the water available in the selected and in downstream sub-basins. For example, the user can select to expand the land under irrigation under a medium-level technology scenario and notice an increase in rice produced, but then observe declining water flows to downstream sub-basins. On the other hand, if the user selects a more water efficient irrigation technology, the amount of land being irrigated can expand to a certain extent without impacting downstream water flows. The results reflect real-world trade-offs and limits in water availability.

There are four irrigation technology levels being simulated in the tool, as described in the table below:

Irrigation Tech. Level	*Canals*	*Water use managed*	*Type of weeding*	*Water returned*	*Fields leveled*	*Flooded vs. pivot*	*% water use efficiency*
A. Business as usual	Unlined	No	Hand	No	Poor	Flooded	15%
B. Improved surface	Cement lined, gates	Yes	Hand	No	Poor	Flooded	30%
C. Semi-mechanized	Cement lined, gates	Yes	Herbicide	Some	Moderate	Flooded	60%
D. Industrial	Central lines/pipes, gates, lined	Yes	Herbicide	Yes, pumped	Good	Pivot	85%

Currently in the Basin, most small-scale farms are using the business as usual approach, although more land is being put under improved surface irrigation. Larger scale farms are using semi-mechanized or industrial technologies, although maintenance of pipes and canals (and thus water efficiency) varies. A key constraint to the Basin's current water efficiency is the lack of return flow (in which water not used by the crop is returned via canals to streams and rivers).

In the tool, it is assumed that over time small-holders will move towards managed systems with controlled water use and other efficiencies. The tool also includes the addition of new industrial-type farms, as mentioned in government planning documents that act as nuclei for the expansion of improved irrigation technologies among small holders. Other changes, including population size, land use and climate, evolve in the tool over time as well.

SECTION FOUR
CONCLUSION

The DST is a living tool. As more research and modelling are conducted, the tool will be updated and expanded. Similarly, as users become familiar with the DST, they may request additions and improvements. As such, the DST is not now and will not be in the future “finalized” but will be ever-evolving.

The DST is the first interactive tool available to users that provides visual, spatially-explicit information on climate change and on the possible effectiveness of various crop production and irrigation technologies. Even though the project focuses on future climate change impacts, the tool can be used to examine the effectiveness of these technologies under current climatic conditions as well.

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