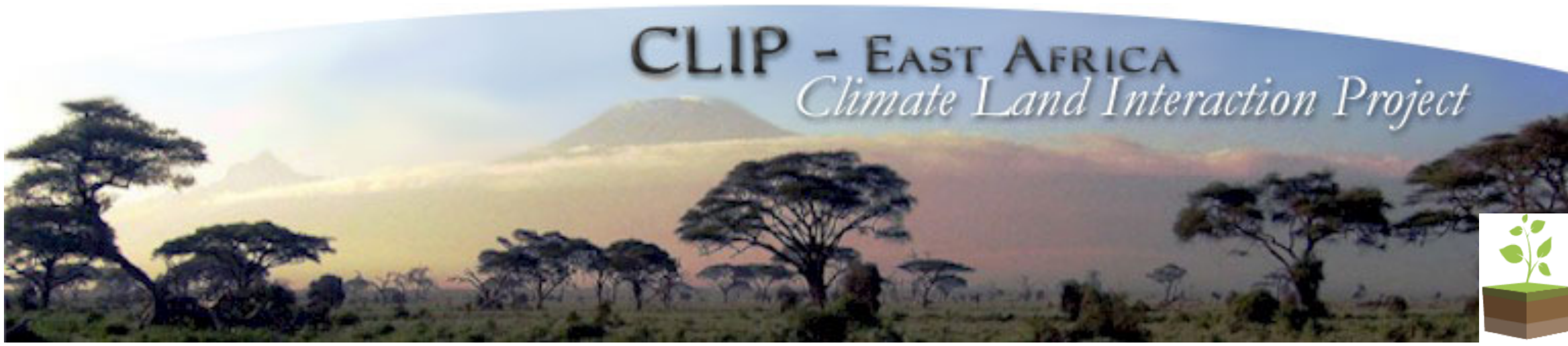
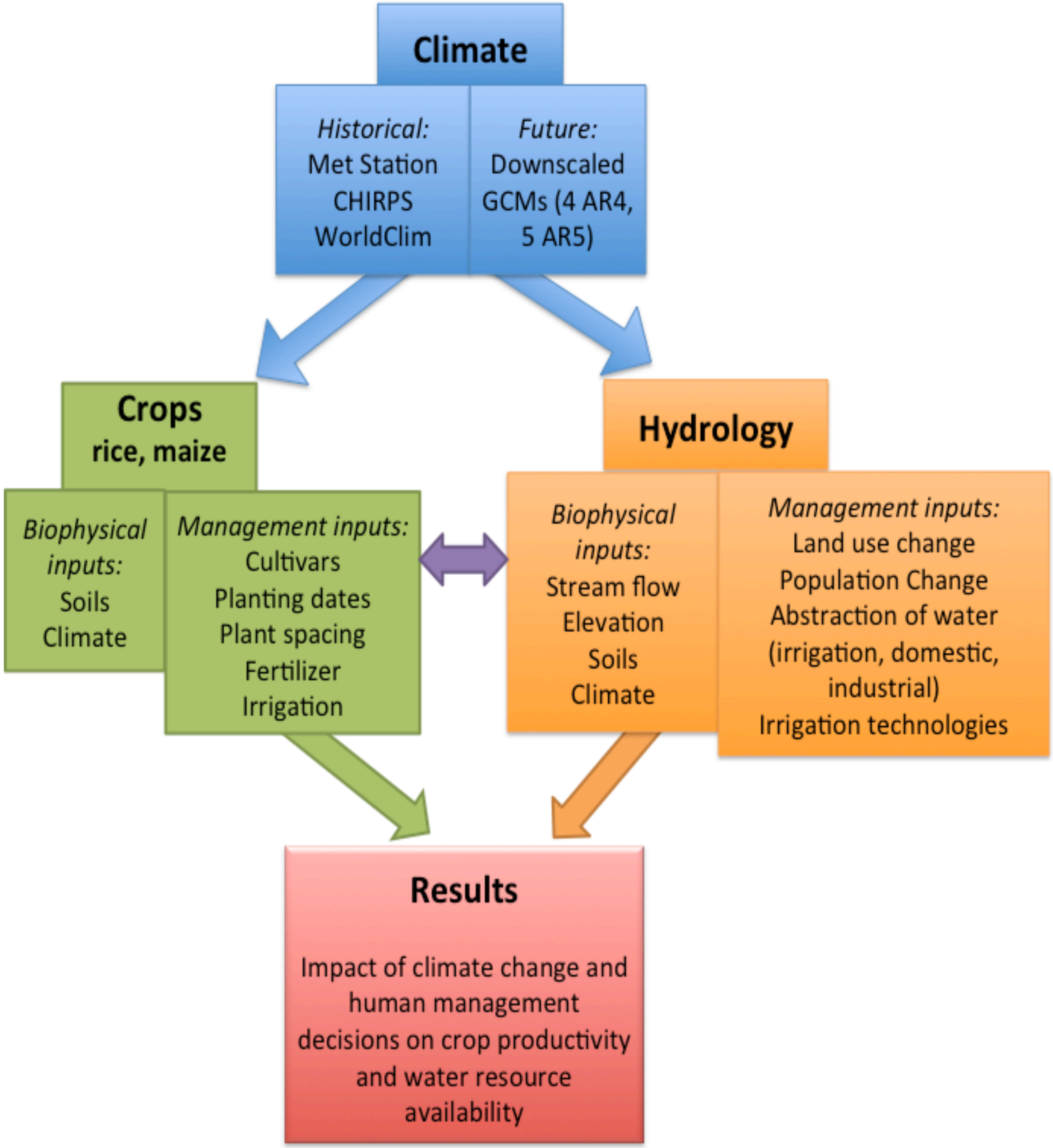


Impact of Climate Change and Adaptation Technologies on Crops and Water Availability for Irrigation in the Rufiji Basin, Tanzania

Presented at USAID, Dar es Salaam, April 28, 2016

Jennifer Olson (olsonjj@msu.edu), Jeff Andresen (andresen@msu.edu), Gopal Alagarswamy, Chad Hawkins, Samantha Horvath, Edmund Mabhuye, Paul Miller, Nathan Moore, William Northcott, Cibin Raj, Pius Yanda


Climate
Historical:
Met Station
CHIRPS
WorldClim
Future:
Downscaled
GCMs (4 AR4,
5 AR5)
Crops
rice, maize
Biophysical inputs:
Soils
Climate
Management inputs:
Cultivars
Planting dates
Plant spacing
Fertilizer
Irrigation
Hydrology
Biophysical inputs:
Stream flow
Elevation
Soils
Climate
Management inputs:
Land use change
Population Change
Abstraction of water
(irrigation, domestic,
industrial)
Irrigation technologies
Results
Impact of climate change and human management decisions on crop productivity and water resource availability

Talk's Focus

- How does climate change and technology choice affect area being cropped and irrigated, and crop productivity?
  - Crops examined: Maize and rice
  - Irrigation technologies and climate change impact on water examined: by sub-basin, on flows and land area that could be irrigated.

Scenario Approach

- Technology Scenarios
  - Irrigation: four technology levels
  - Rice: varieties, fertilizer, irrigation
  - Maize: varieties, fertilizer, irrigation
- Climate Scenarios
  - Current climate
  - Future projections

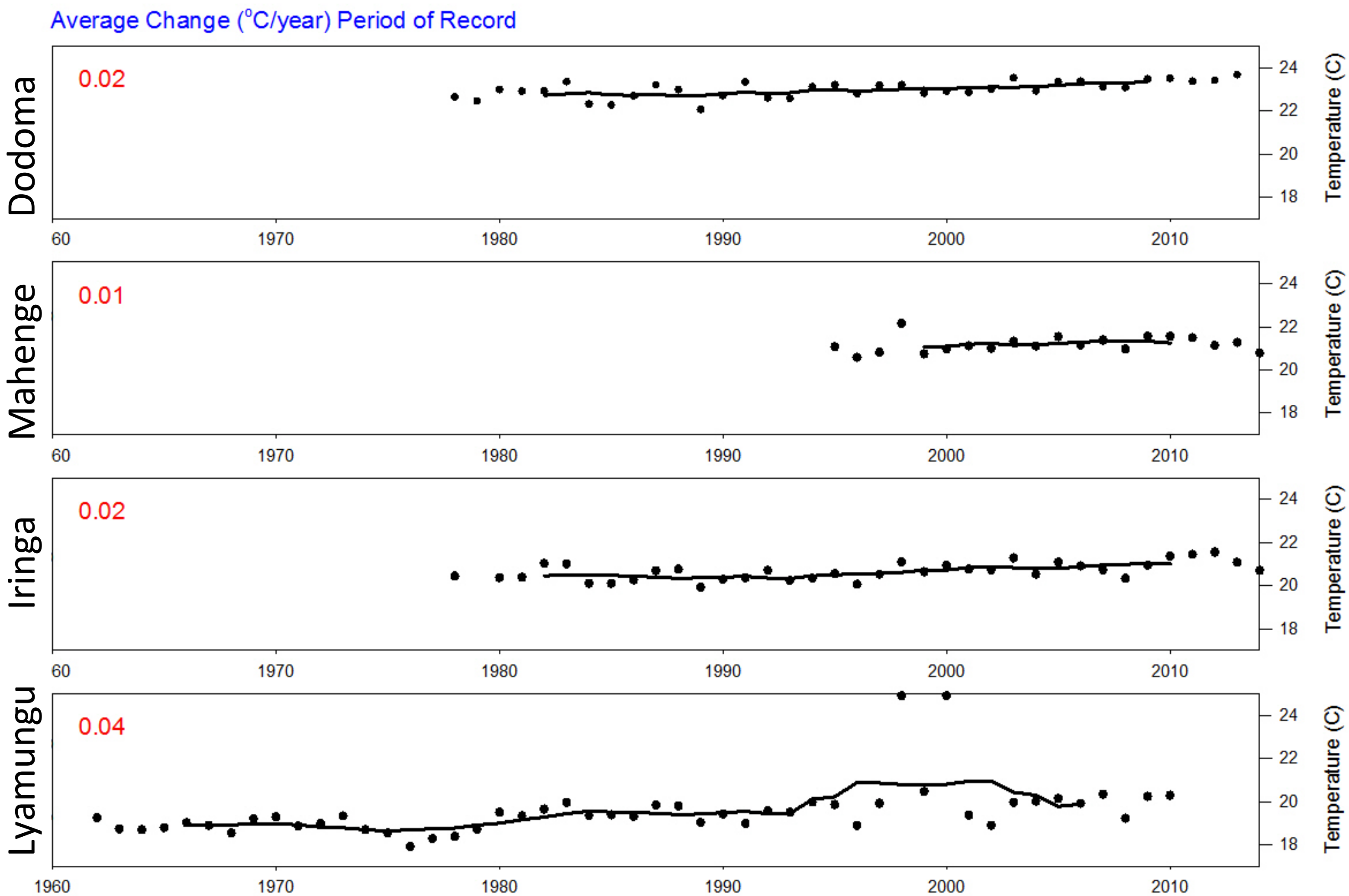
General Climatic Trends

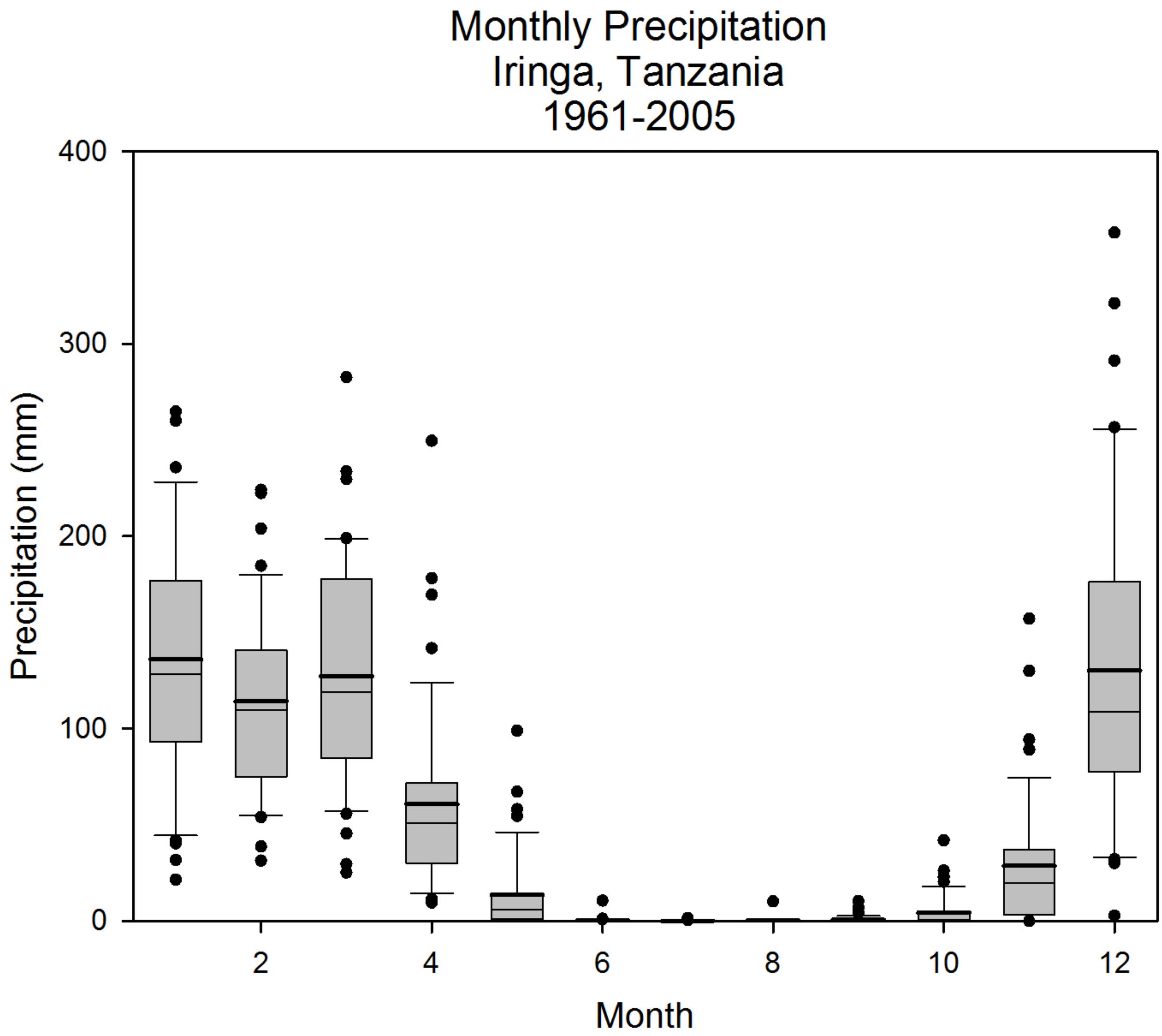
Rufiji Basin, 1950-2015

- Warmer temperatures
  - Both max. and min. temperatures increasing
- Lower annual precipitation
  - Mostly short rains (NOV-DEC)
- More erratic/variable precipitation
  - Fewer wet days, more extended dry periods
  - Increasing heavy rainfall events
- Increases in potential evapotranspiration

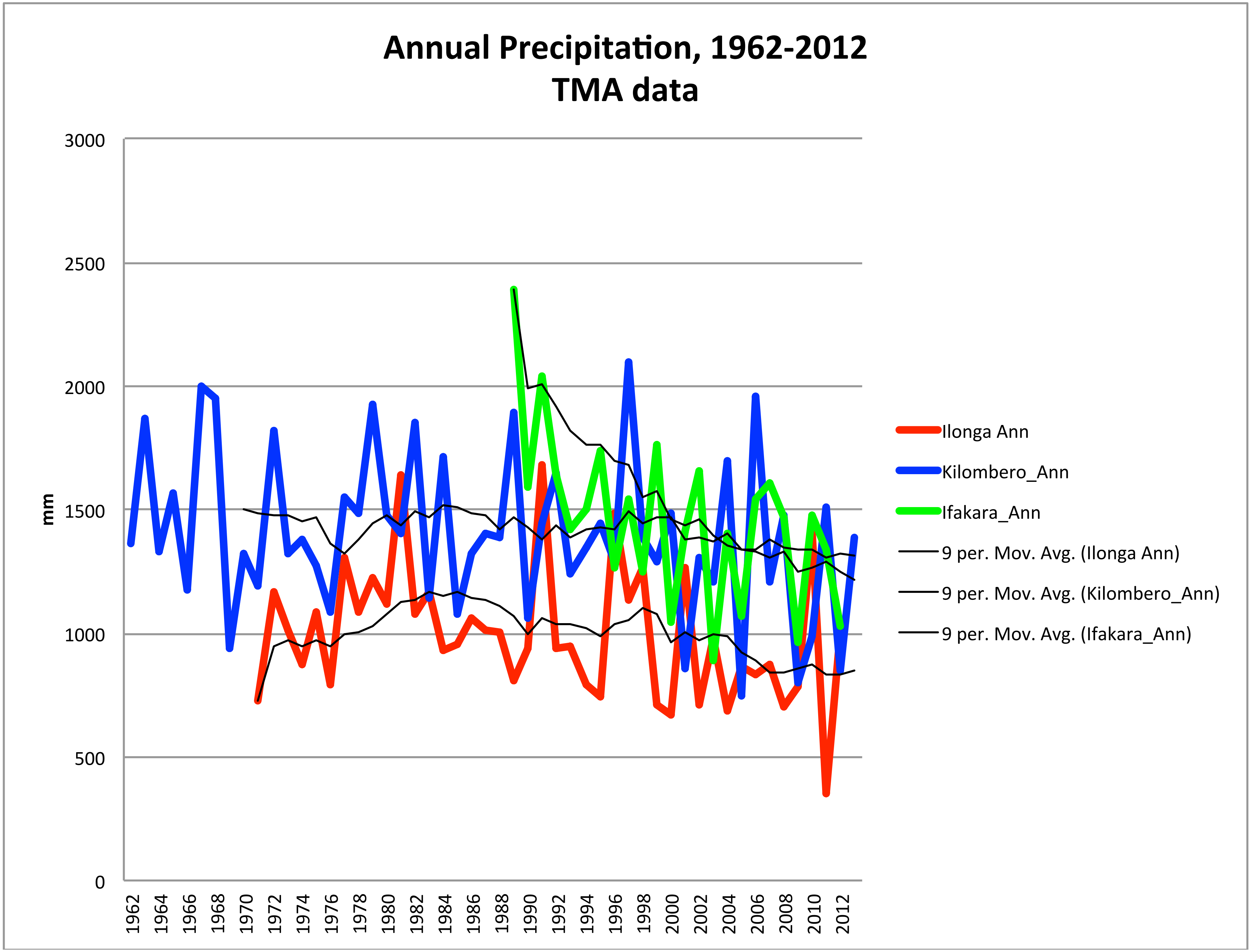
Annual Mean Temperature vs. Year

1962-2013



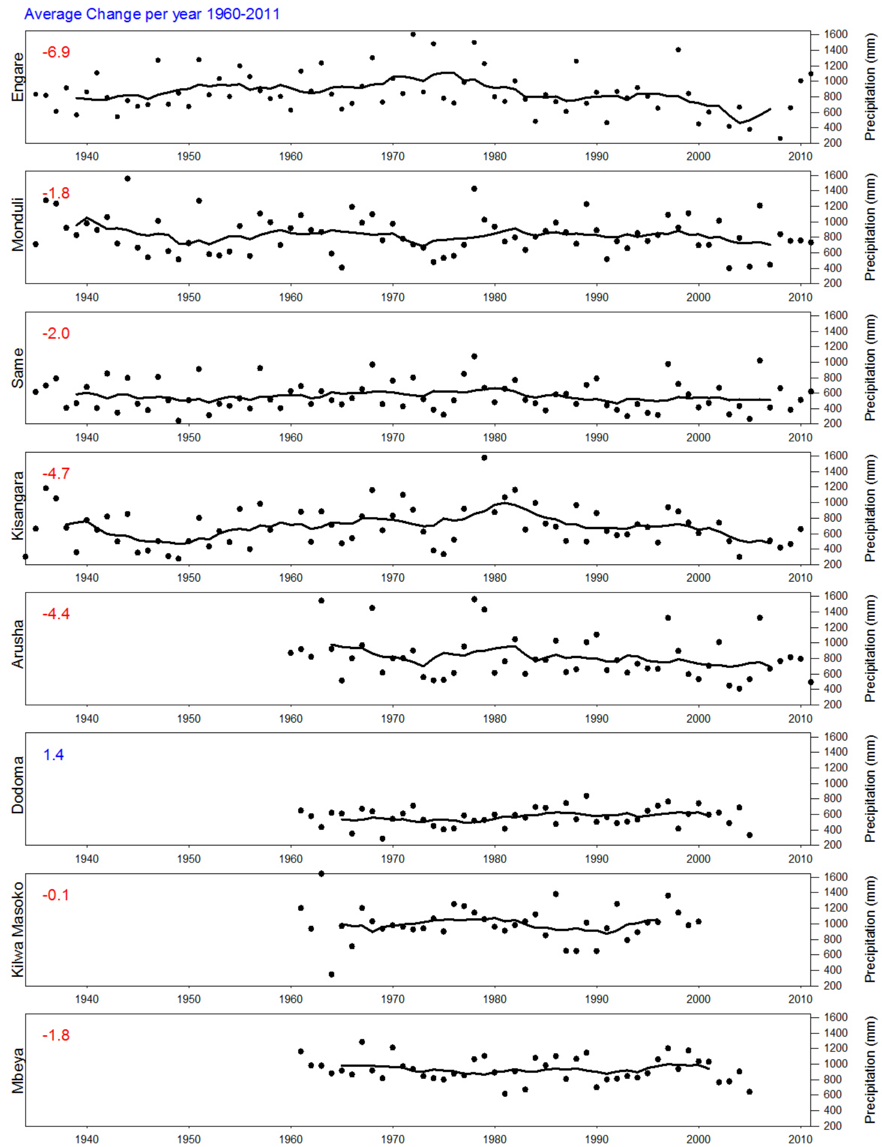


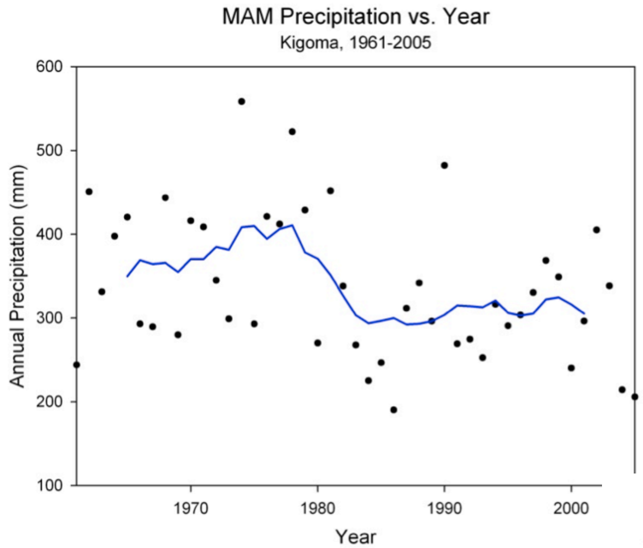
Monthly Precipitation
Iringa, Tanzania
1961-2005
Precipitation (mm)
400
300
200
100
0
2
4
6
8
10
12
Month

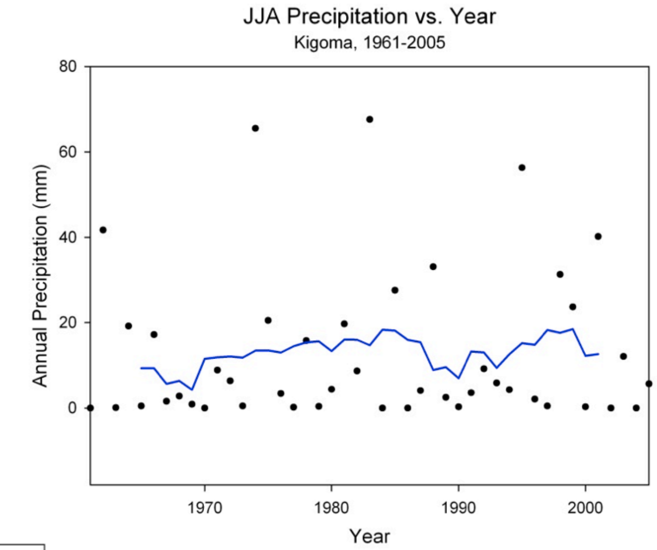

Annual Precipitation, 1962-2012
TMA data
3000
2500
2000
1500
1000
500
0
mm
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Ilonga Ann
Kilombero_Ann
Ifakara_Ann
9 per. Mov. Avg. (Ilonga Ann)
9 per. Mov. Avg. (Kilombero_Ann)
9 per. Mov. Avg. (Ifakara_Ann)

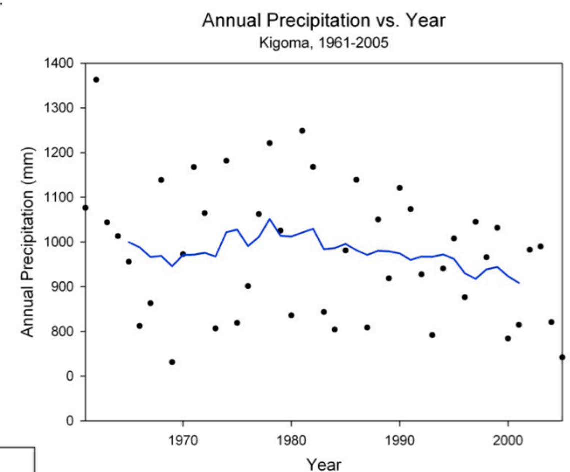
Annual Precipitation vs. Year

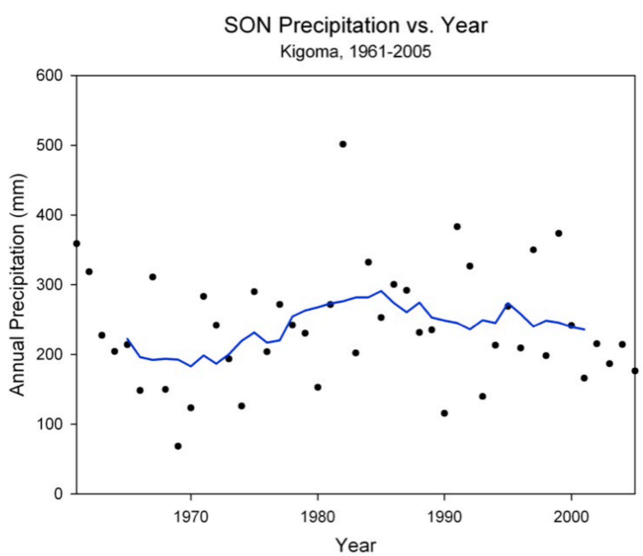
1960-2011

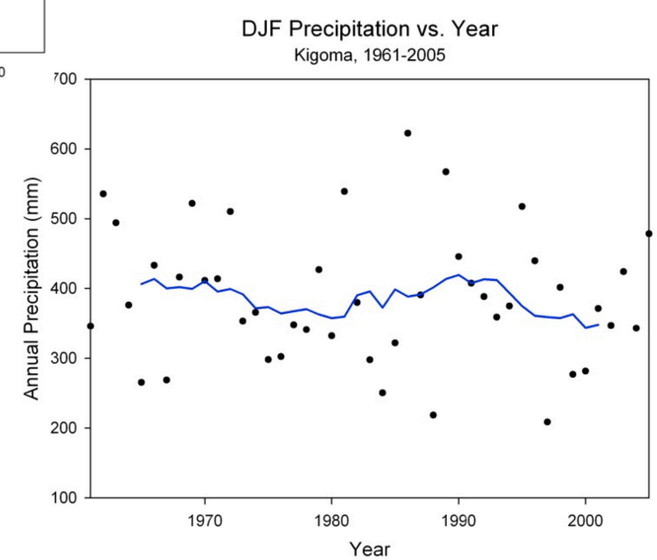


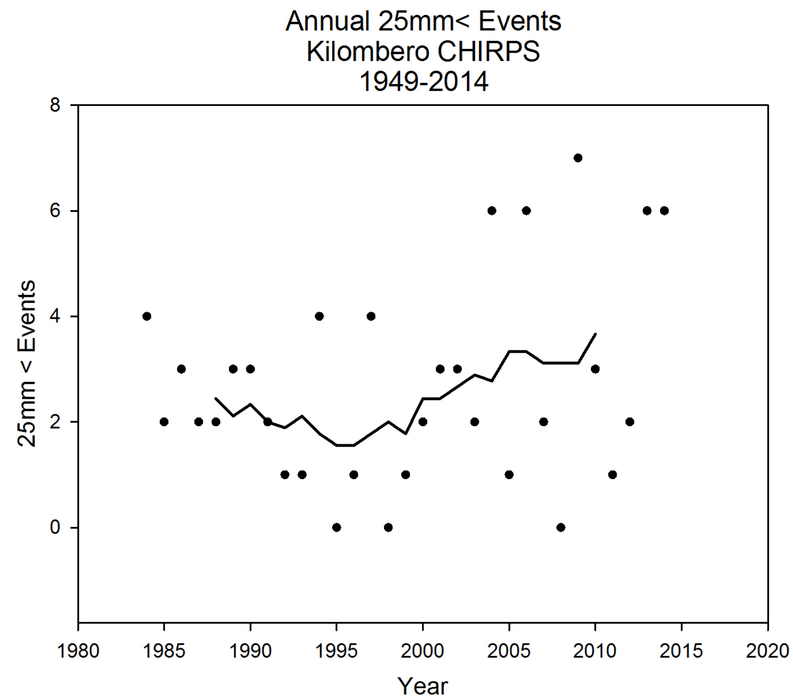

MAM Precipitation vs. Year
Kigoma, 1961-2005
Annual Precipitation (mm)
Year
100
200
300
400
500
600
1970
1980
1990
2000

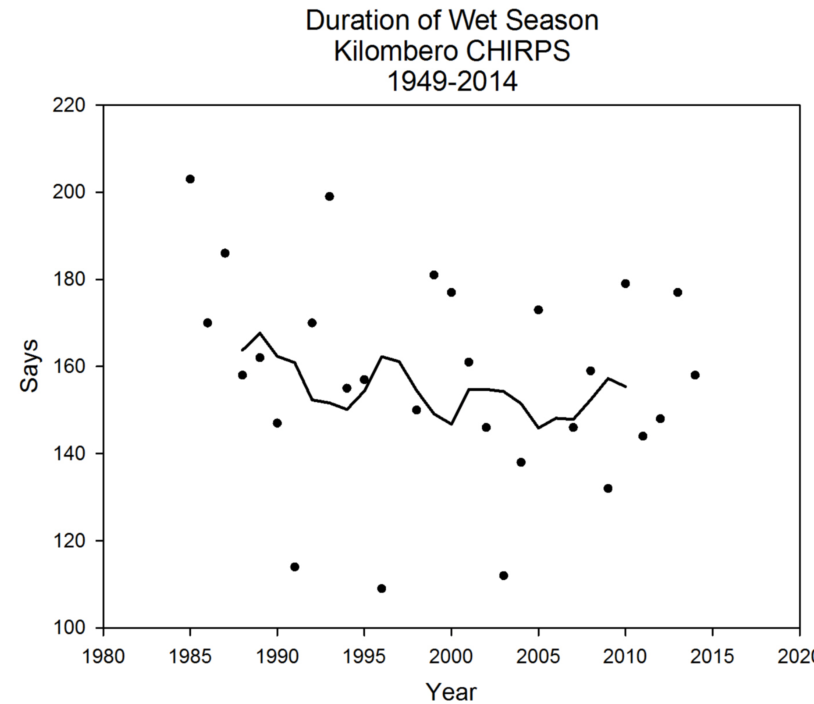

JJA Precipitation vs. Year
Kigoma, 1961-2005
Annual Precipitation (mm)
Year
0
20
40
60
80
1970
1980
1990
2000

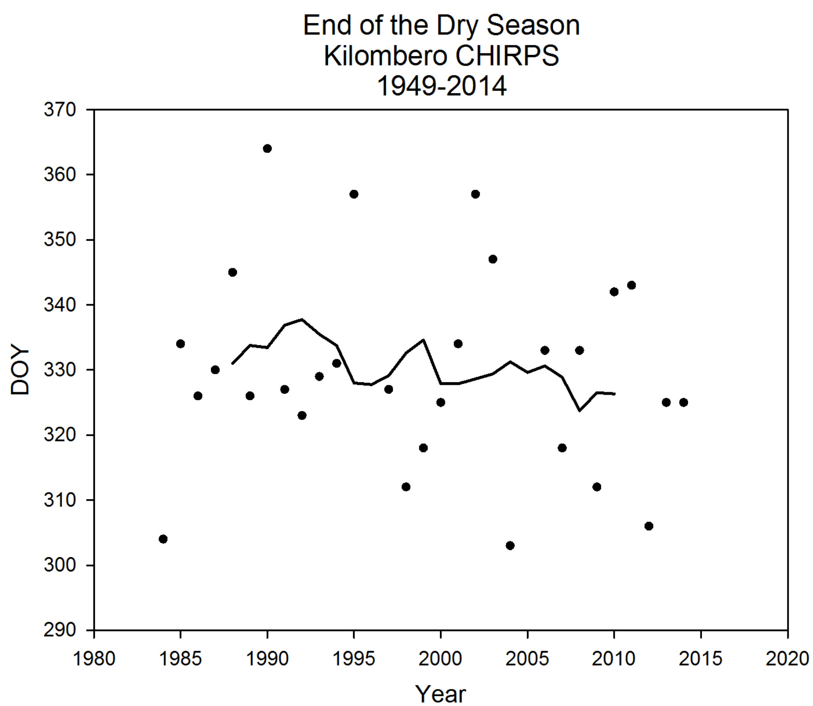

Annual Precipitation vs. Year
Kigoma, 1961-2005
Annual Precipitation (mm)
Year
0
800
900
1000
1100
1200
1300
1400
1970
1980
1990
2000

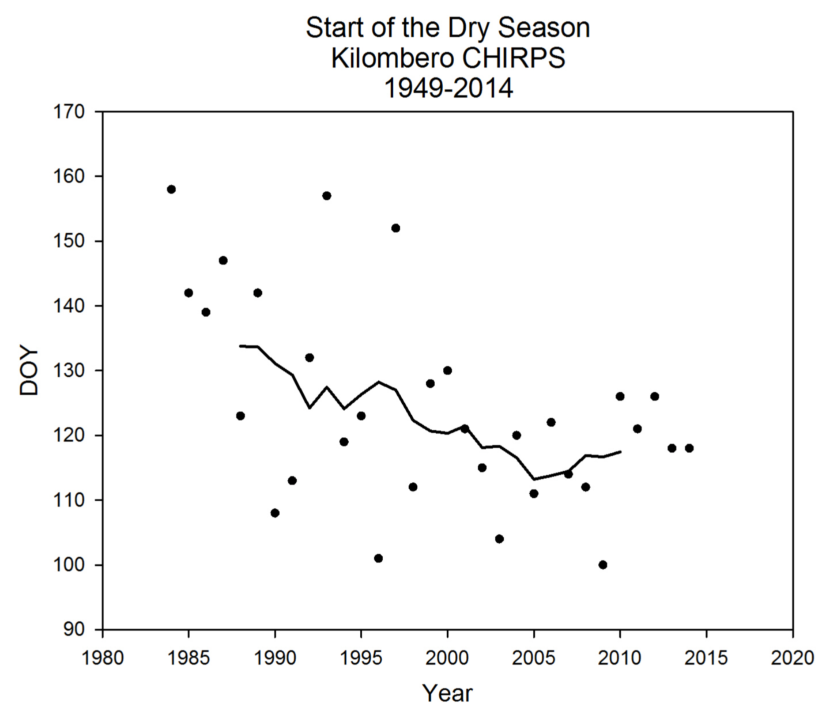

SON Precipitation vs. Year
Kigoma, 1961-2005
Annual Precipitation (mm)
Year
0
100
200
300
400
500
600
1970
1980
1990
2000


DJF Precipitation vs. Year
Kigoma, 1961-2005
Annual Precipitation (mm)
Year
100
200
300
400
500
600
700
1970
1980
1990
2000


Annual 25mm< Events
Kilombero CHIRPS
1949-2014
25mm < Events
8
6
4
2
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

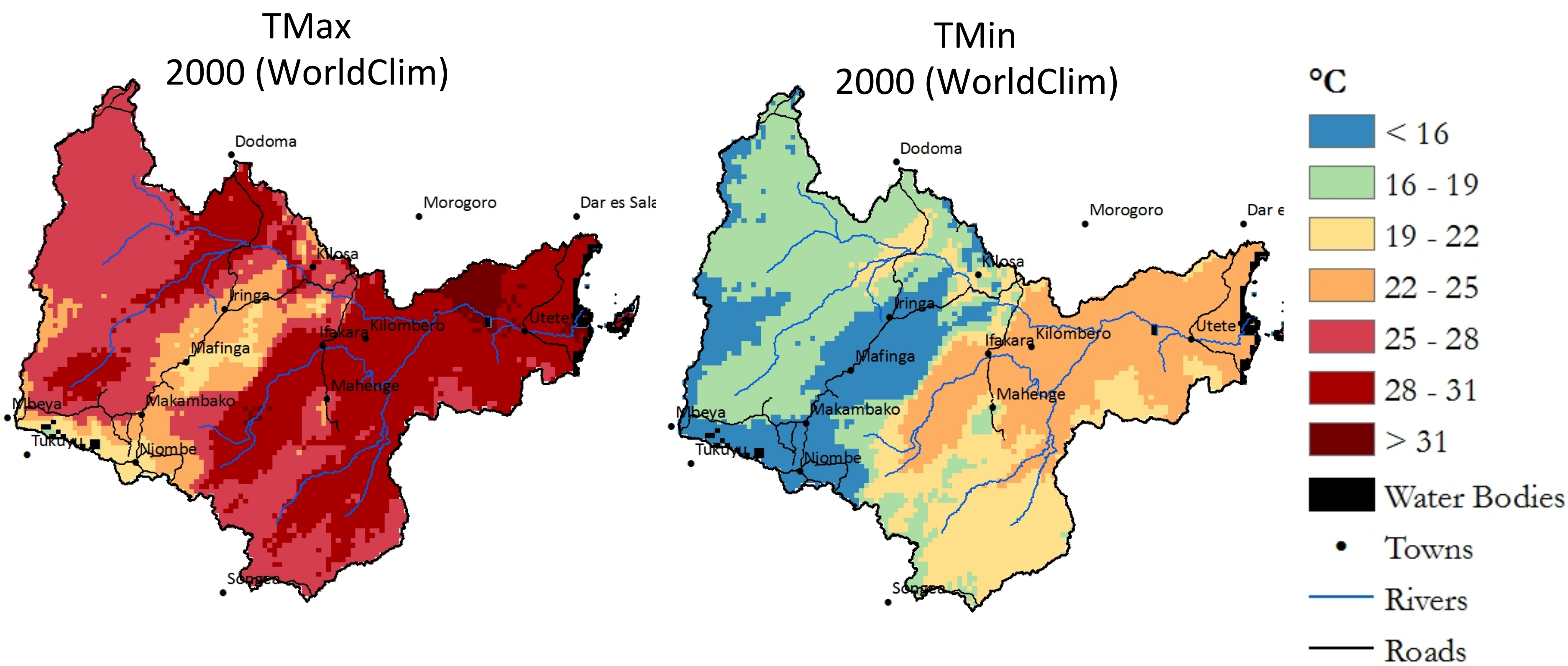

Duration of Wet Season
Kilombero CHIRPS
1949-2014
Says
220
200
180
160
140
120
100
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


End of the Dry Season
Kilombero CHIRPS
1949-2014
DOY
370
360
350
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


Start of the Dry Season
Kilombero CHIRPS
1949-2014
DOY
170
160
150
140
130
120
110
100
90
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

Future Climate Projections

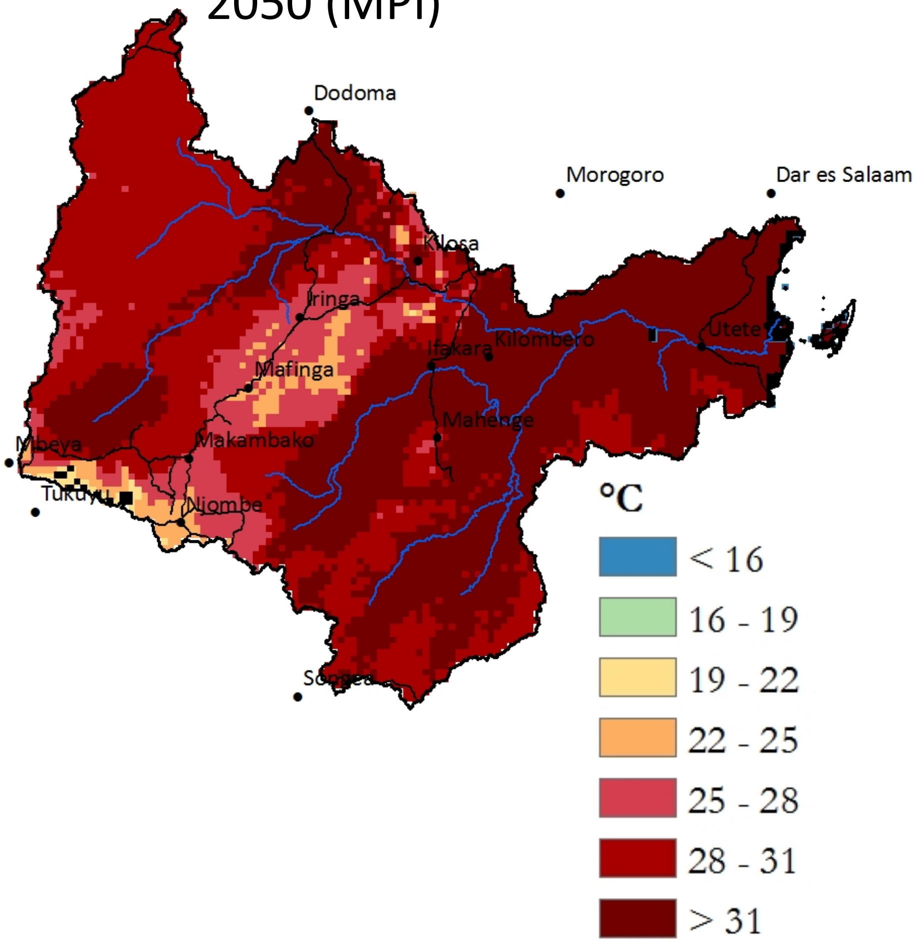
Current Tmax and Tmin Temperatures Dec-May



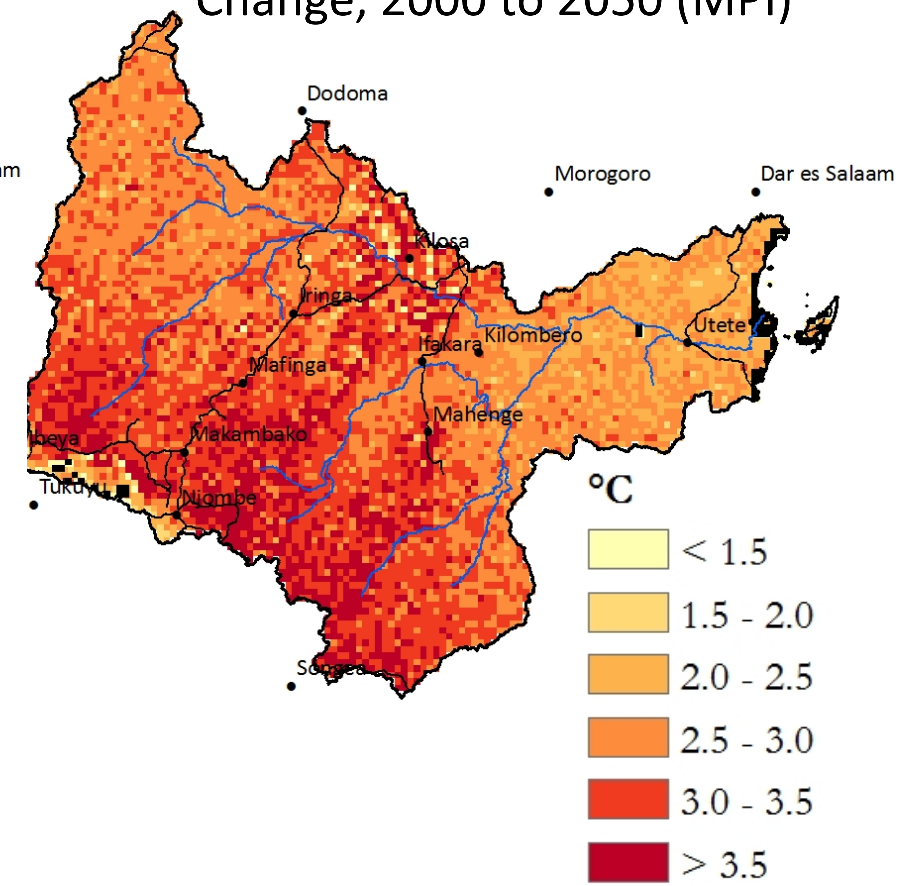
Tmax Future and Change 2000 to 2050

MPI GCM, Dec-May

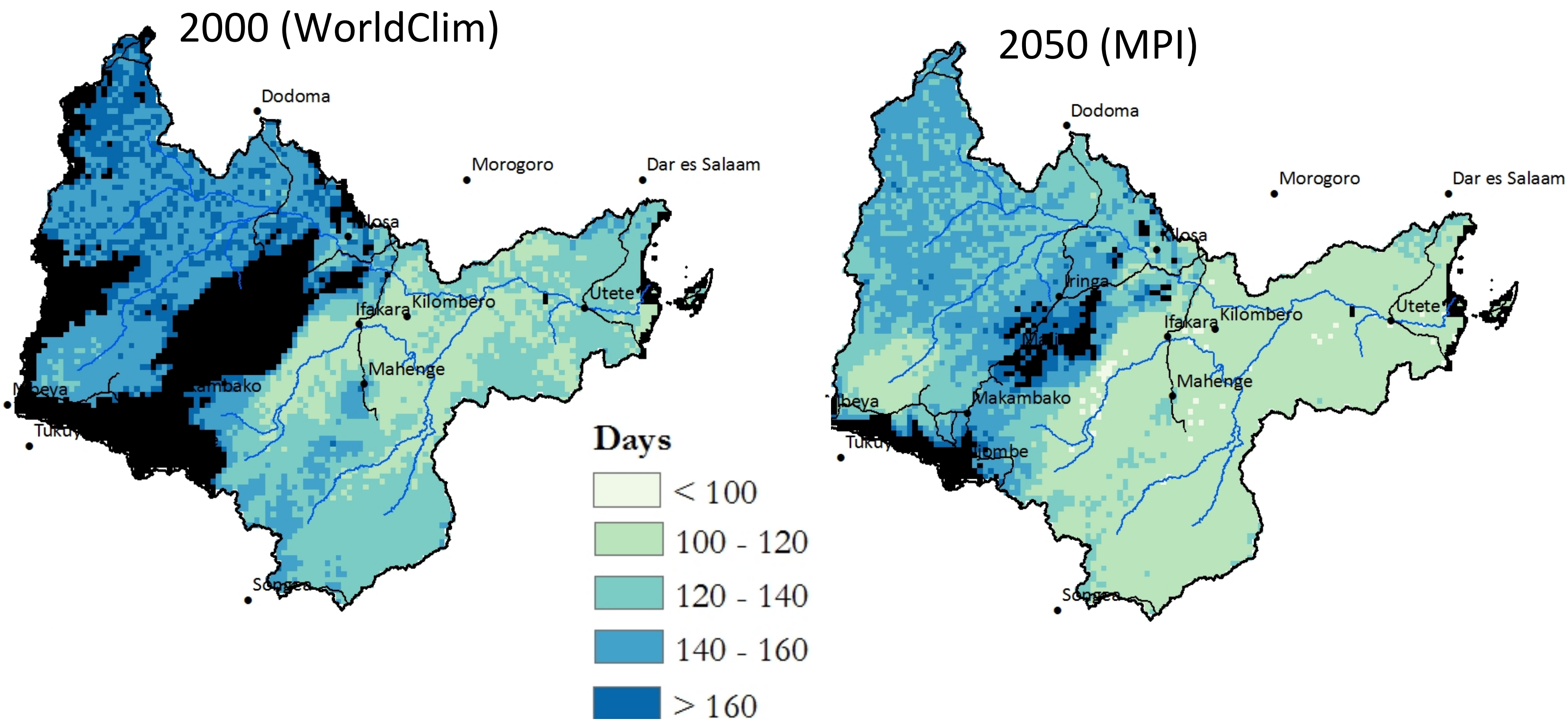
2050 (MPI)



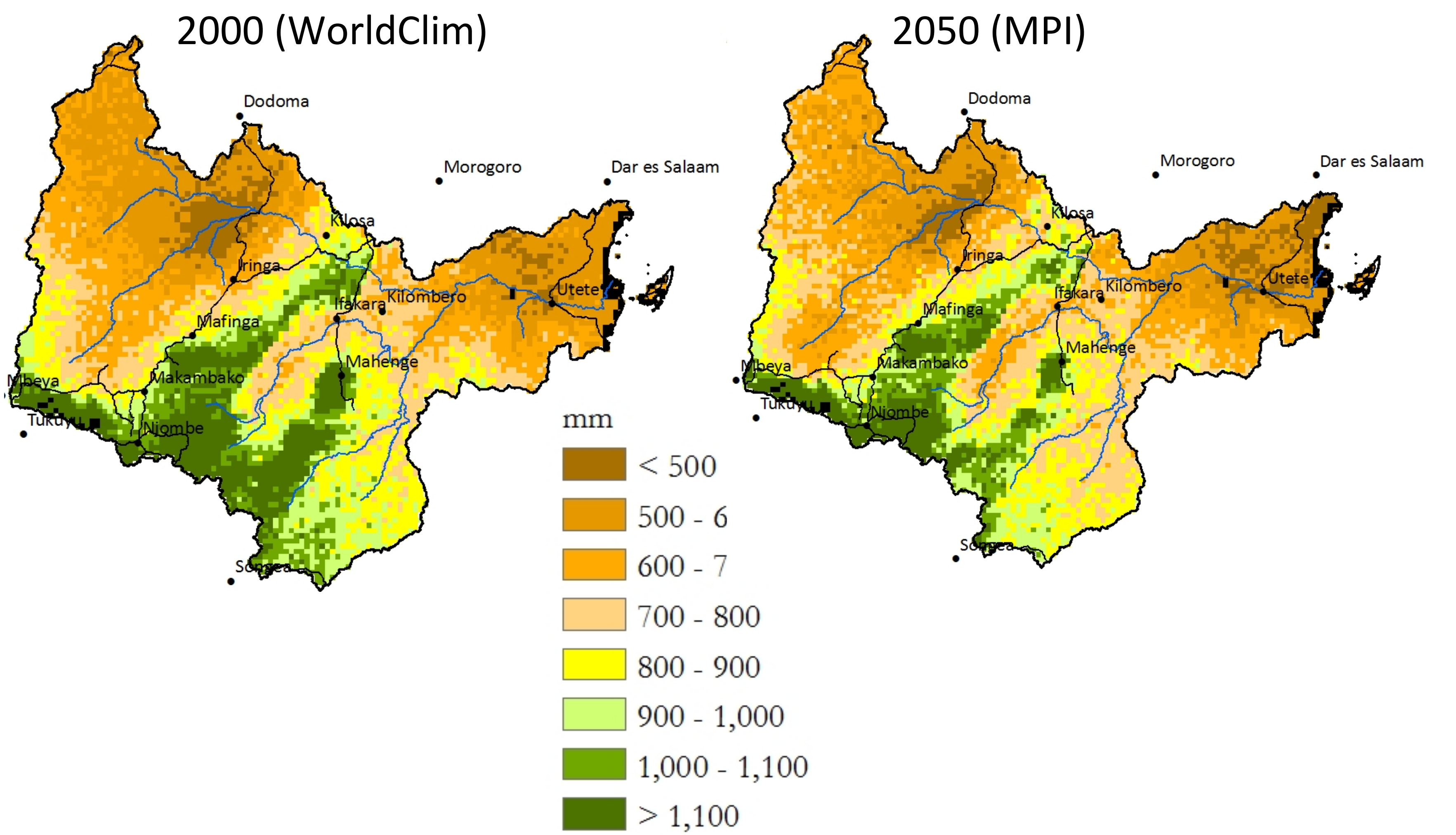
Change, 2000 to 2050 (MPI)

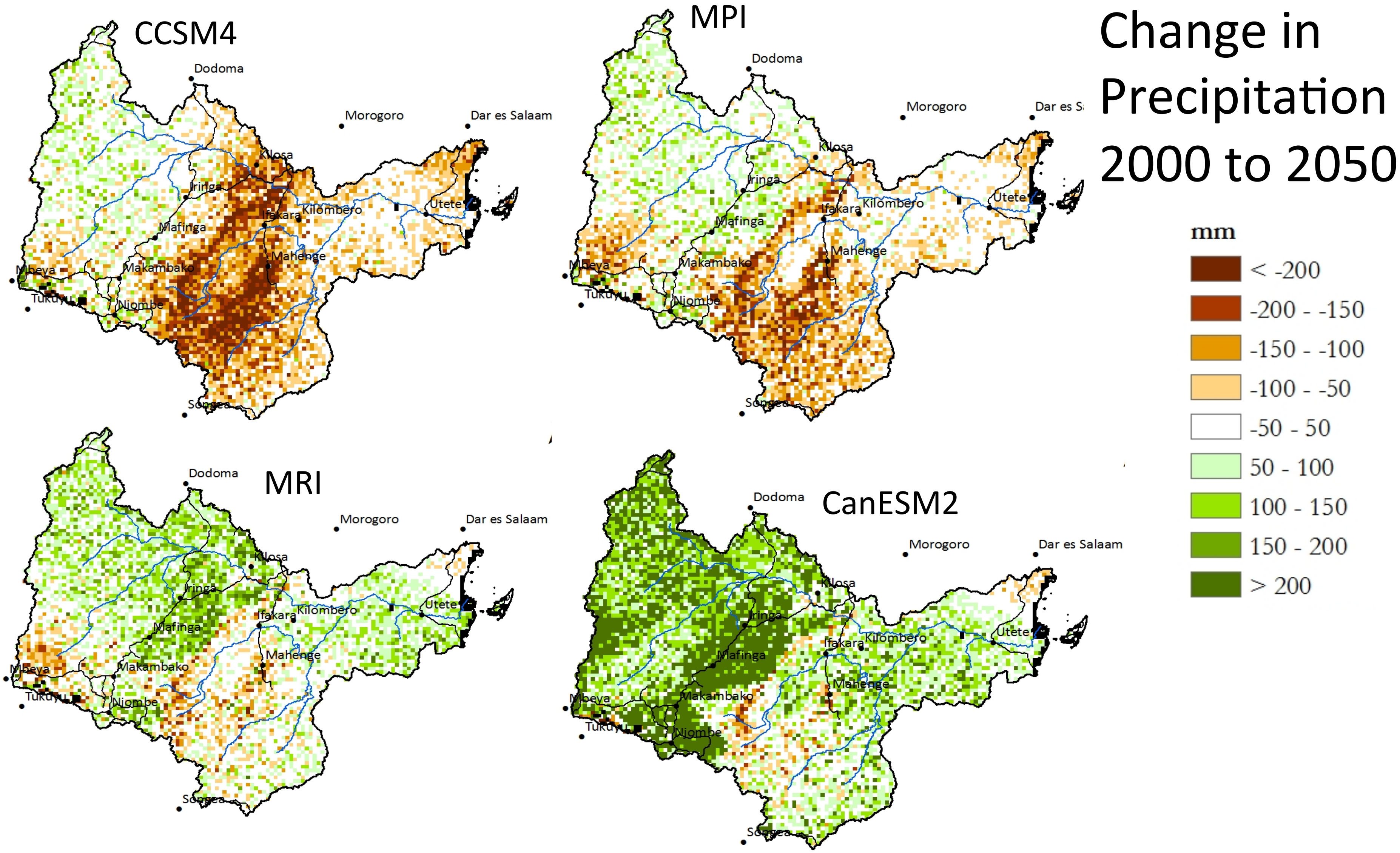


Days to Maturity of Rice (Dec. planting): 2000 & 2050



Precipitation Dec-June, 2000 & 2050 (MPI)

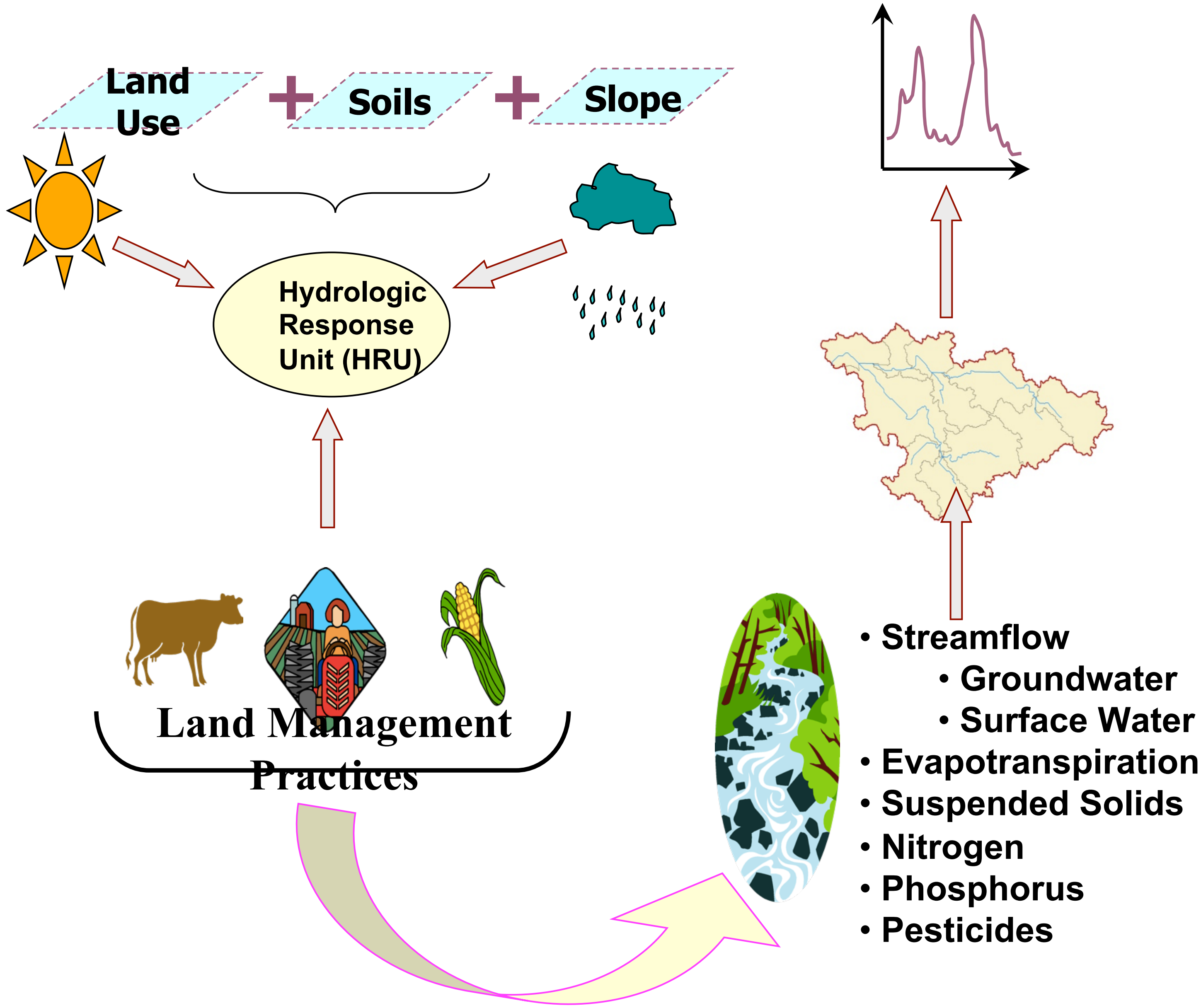


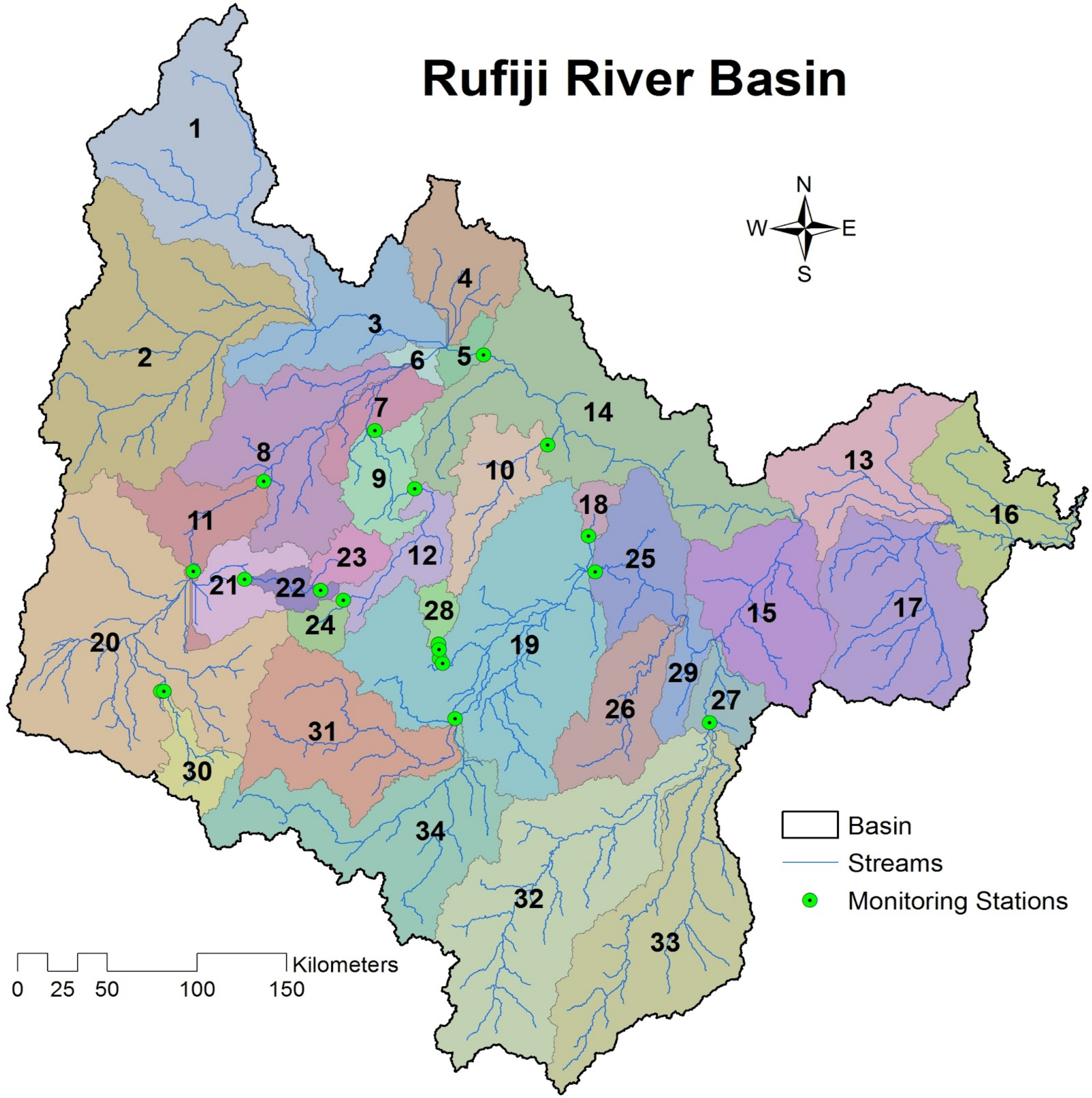

Change in Precipitation 2000 to 2050
mm
< -200
-200 - -150
-150 - -100
-100 - -50
-50 - 50
50 - 100
100 - 150
150 - 200
> 200
CCSM4
MPI
MRI
CanESM2
Dodoma
Morogoro
Dar es Salaam
Kilosa
Iringa
Kilombero
Ifakara
Utete
Mafinga
Mahenge
Mbeya
Makambako
Tukuyu
Njombe
Songea

Hydrological Modeling Methodology

1. Preparation of all data layers for modeling
   a. TMA and CHIRPS data -> model input data
   b. Land use characterization and projection to future
   c. Population characterization and projection
2. Configuration and calibration of SWAT hydrologic model
   a. Setting cropping scenarios
   b. Modeling all different soils, management, and land use combinations per basin including baseline scenario
   c. Calibration with available stream flow data
3. Scenarios and projections
   a. Development and integration of climate model based input data (GCMs)
   b. Scenario configuration and modeling
   c. Results processing and development of data structures for the DSS

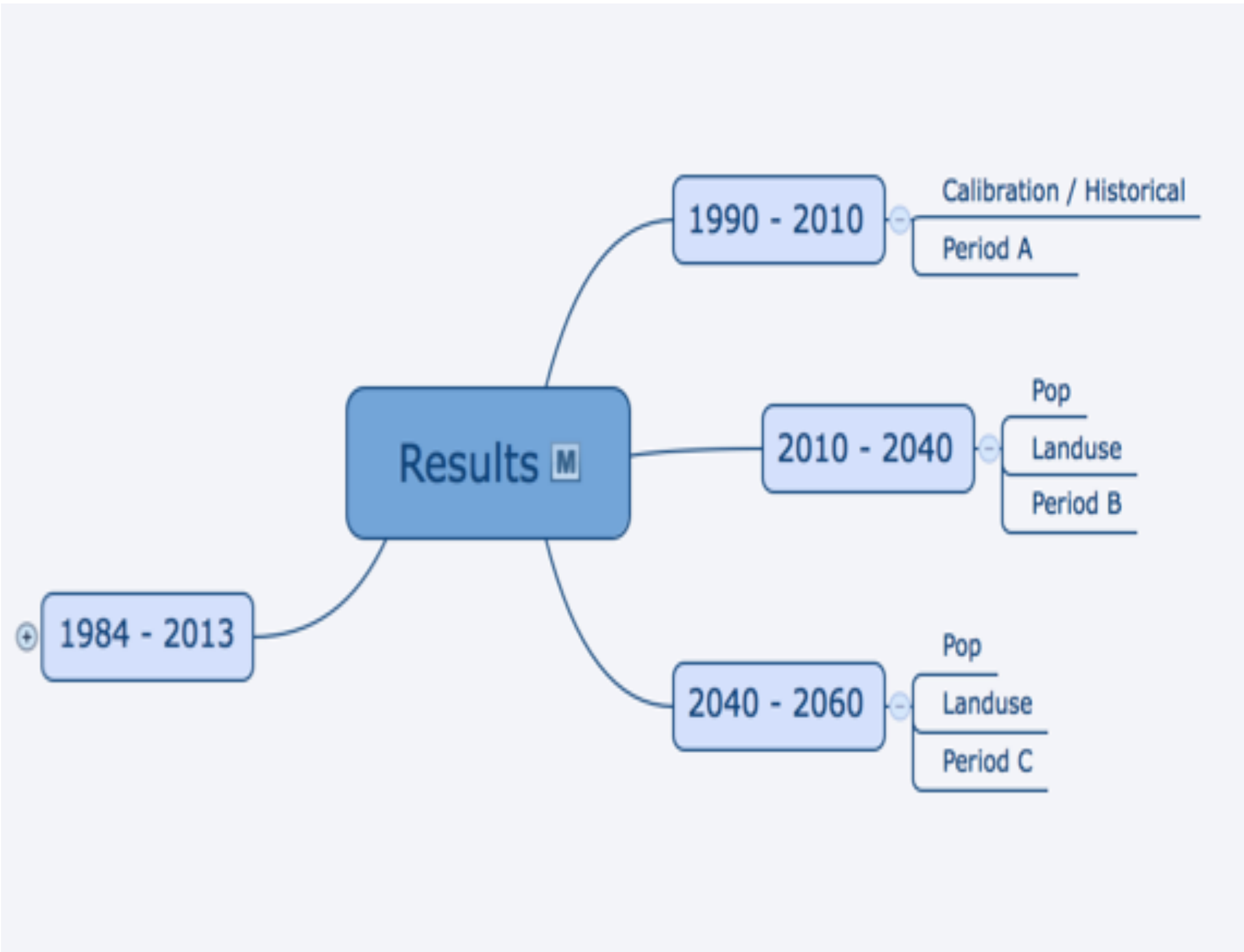
Soil and Water Assessment Tool (SWAT)





Rufiji River Basin
N
W
E
S
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
Basin
Streams
Monitoring Stations
0
25
50
100
150
Kilometers

Scenario Development

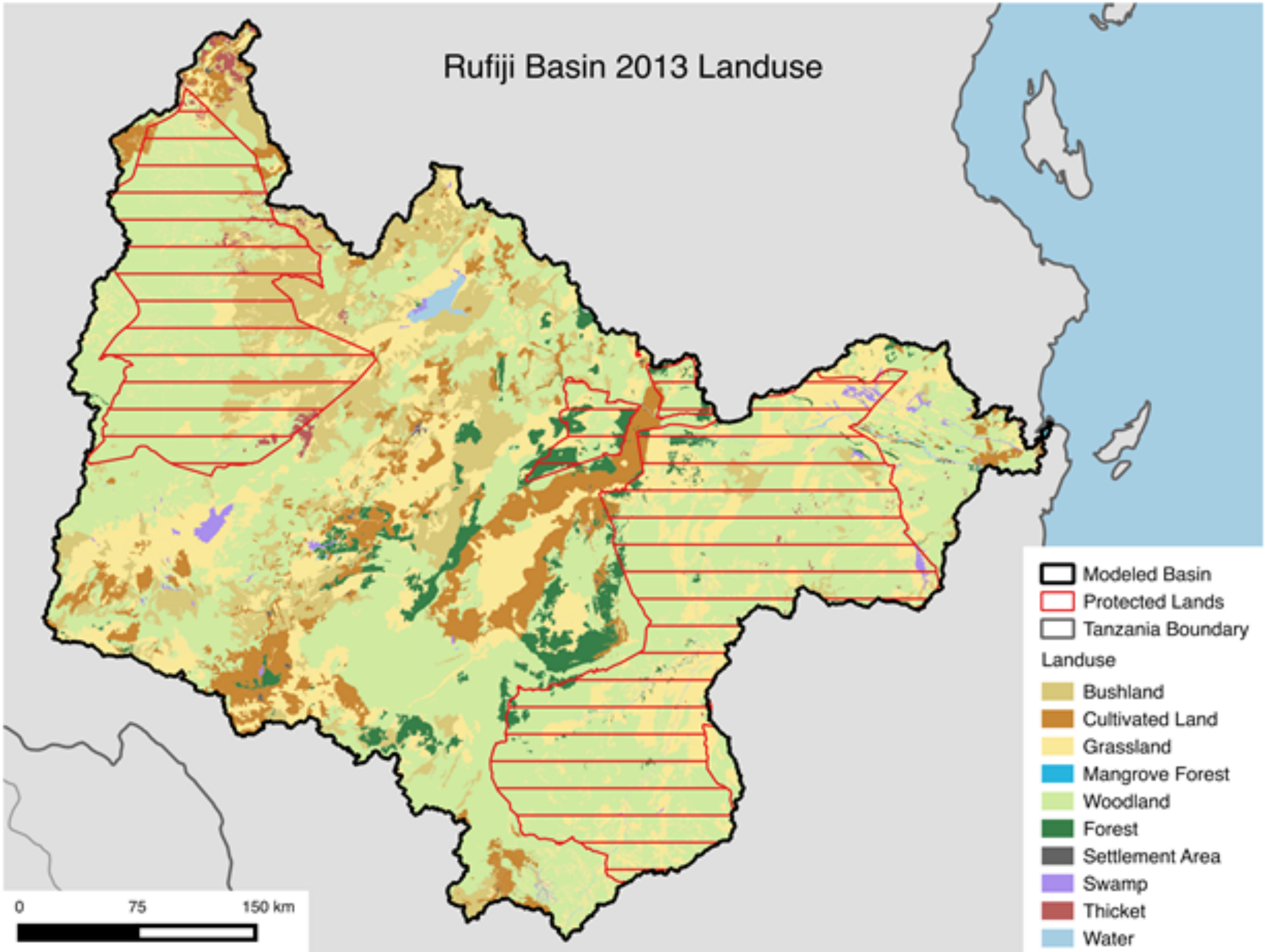


Scenario work is based on three time periods

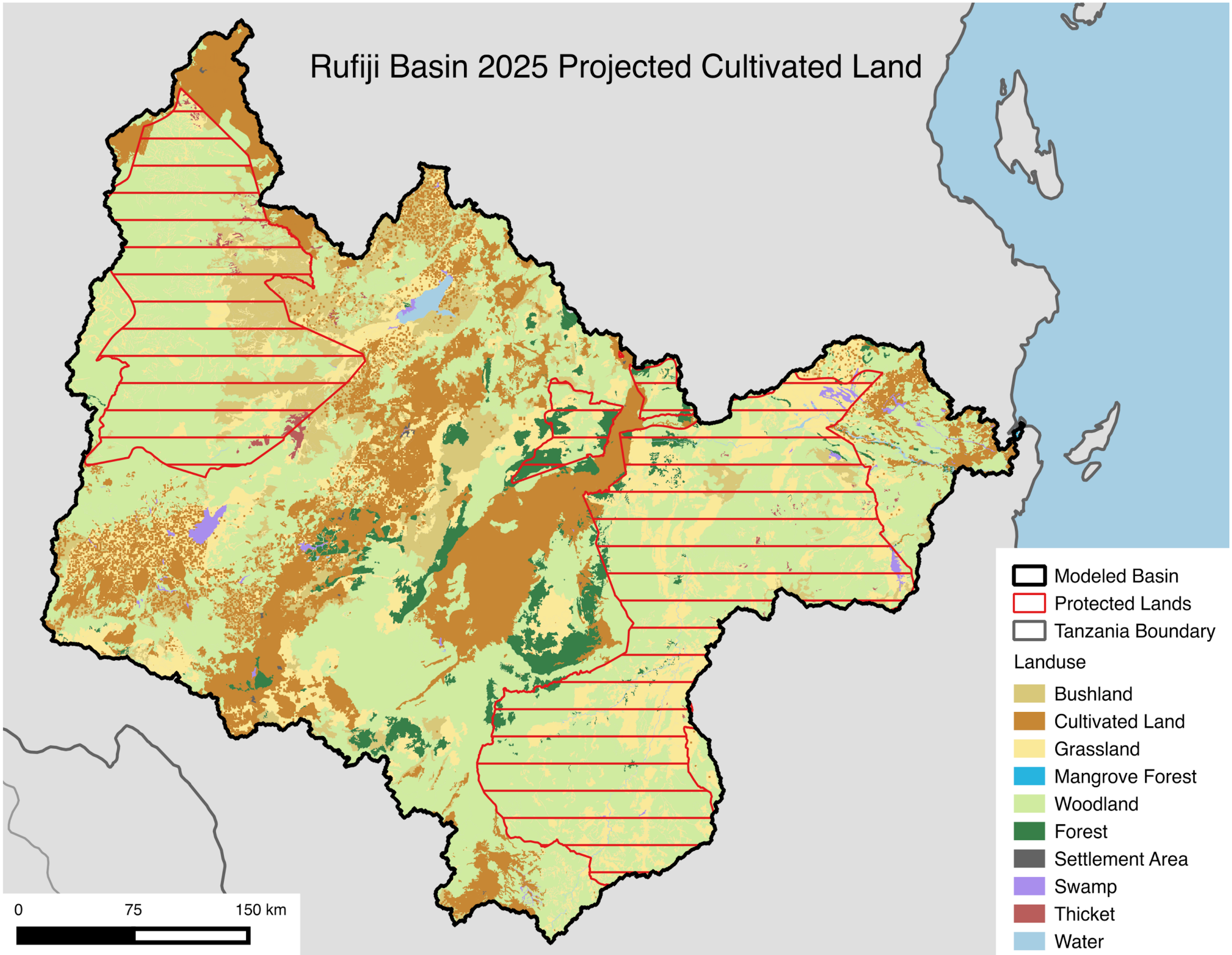
Period A: Historical - 1990 - 2010 (calibration)

Period B: 2000-2040 Delta method adjusted climate projection, plus land use and population change factors

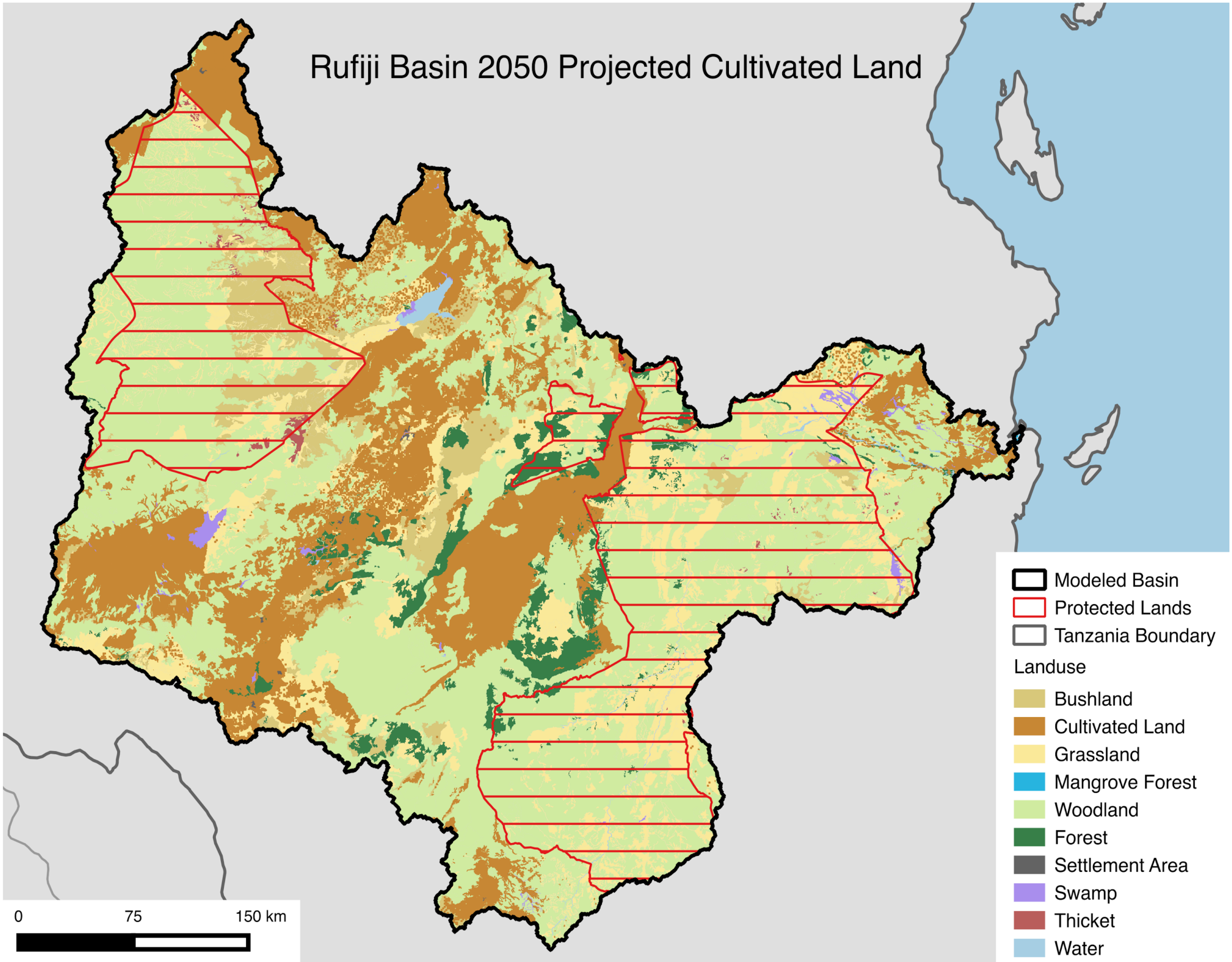
Period C: 2040 – 2060 Climate, plus land use and population change adjusted



1,602,722 hectares of cultivated land.



2,961,812 hectares of cultivated land.



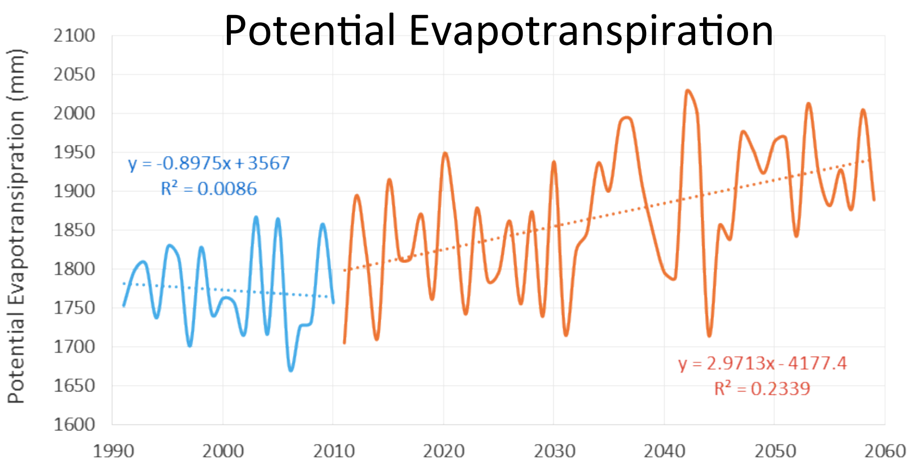
3,618,640 hectares of cultivated land

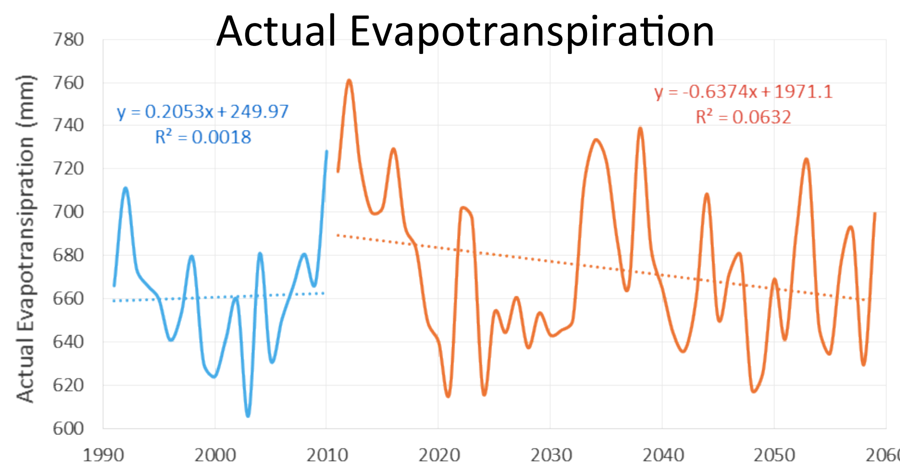
Projected Change in Land Area under Irrigated and non-Irrigated Crops

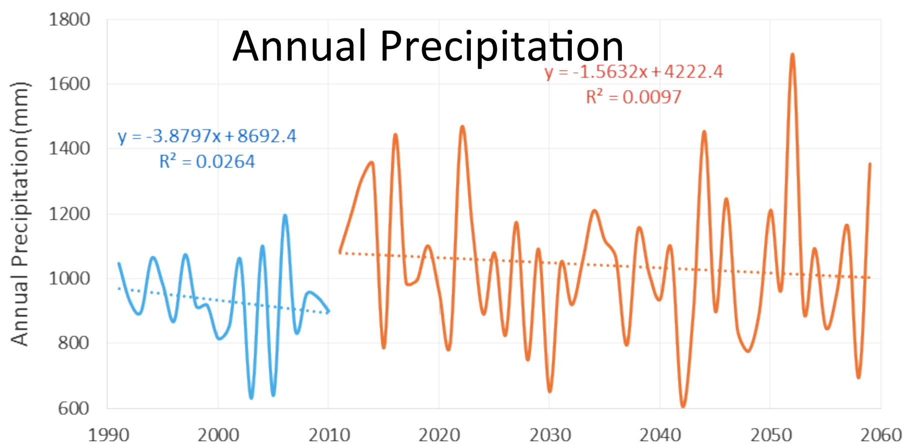
	Irrigated area (km^2)	Non-Irrigated Agriculture area (km^2)	% agricultural area irrigated
1990-2010	5430	6435	0.46
2010-2040	10339	14188	0.42
2041-2060	11835	19010	0.38

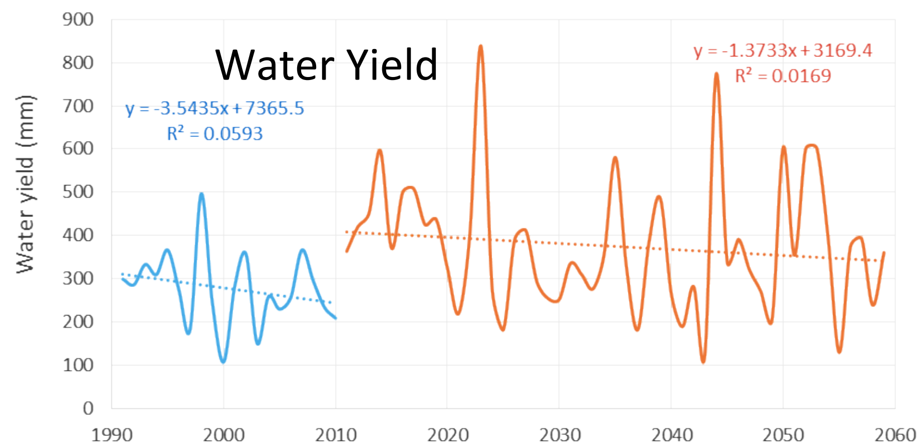
Expansion slows due to limited water

Climate Projection Effects on Water Yield Variables

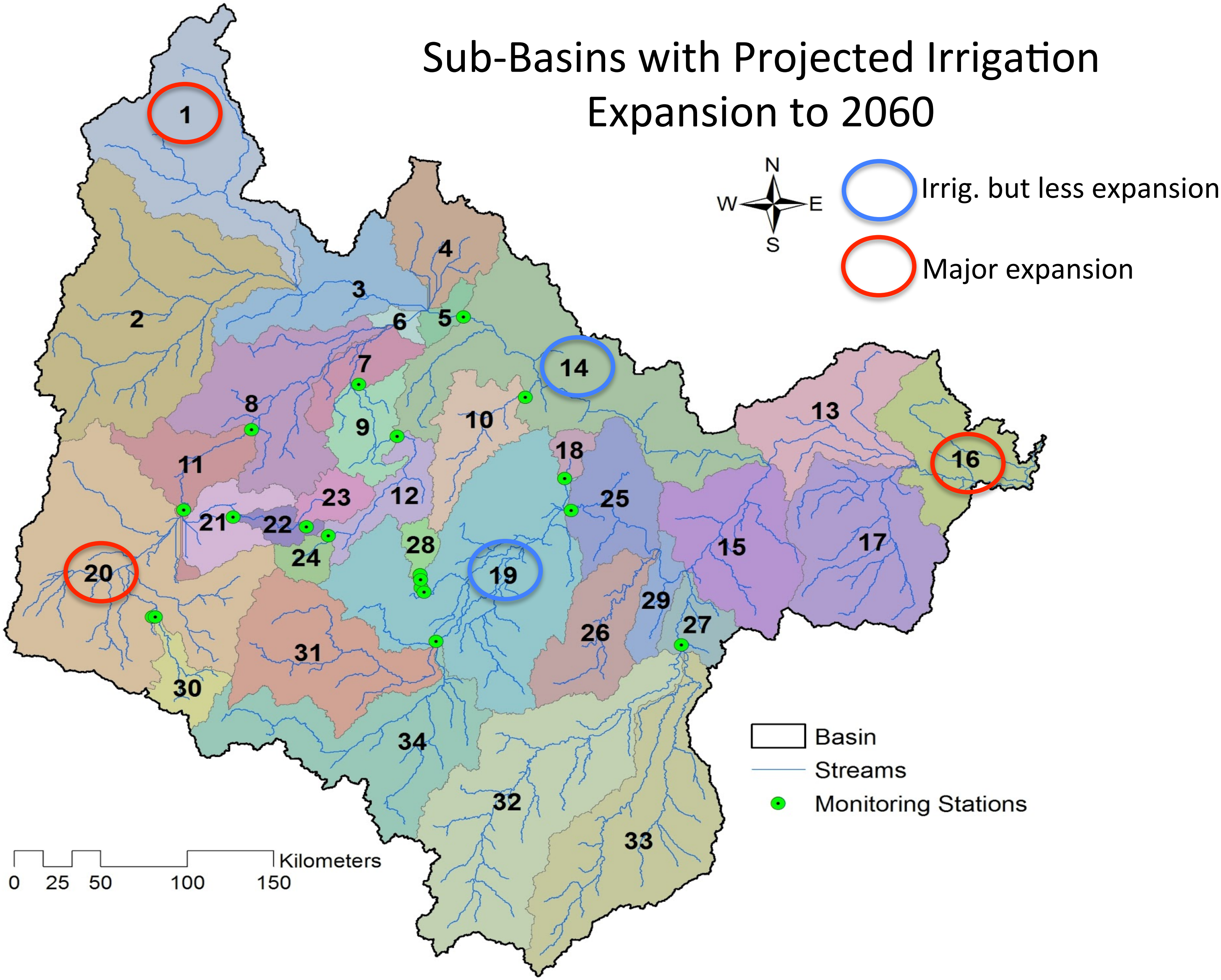








Sub-Basins with Projected Irrigation Expansion to 2060



Irrigation Technology Scenarios

Scenarios developed with four irrigation technology levels

Irrigation Tech. Level	*Canals*	*Water use managed*	*Type of weeding*	*Water returned*	*Fields leveled*	*Flooded vs. pivot*	*% water use efficiency*
A. Baseline	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%

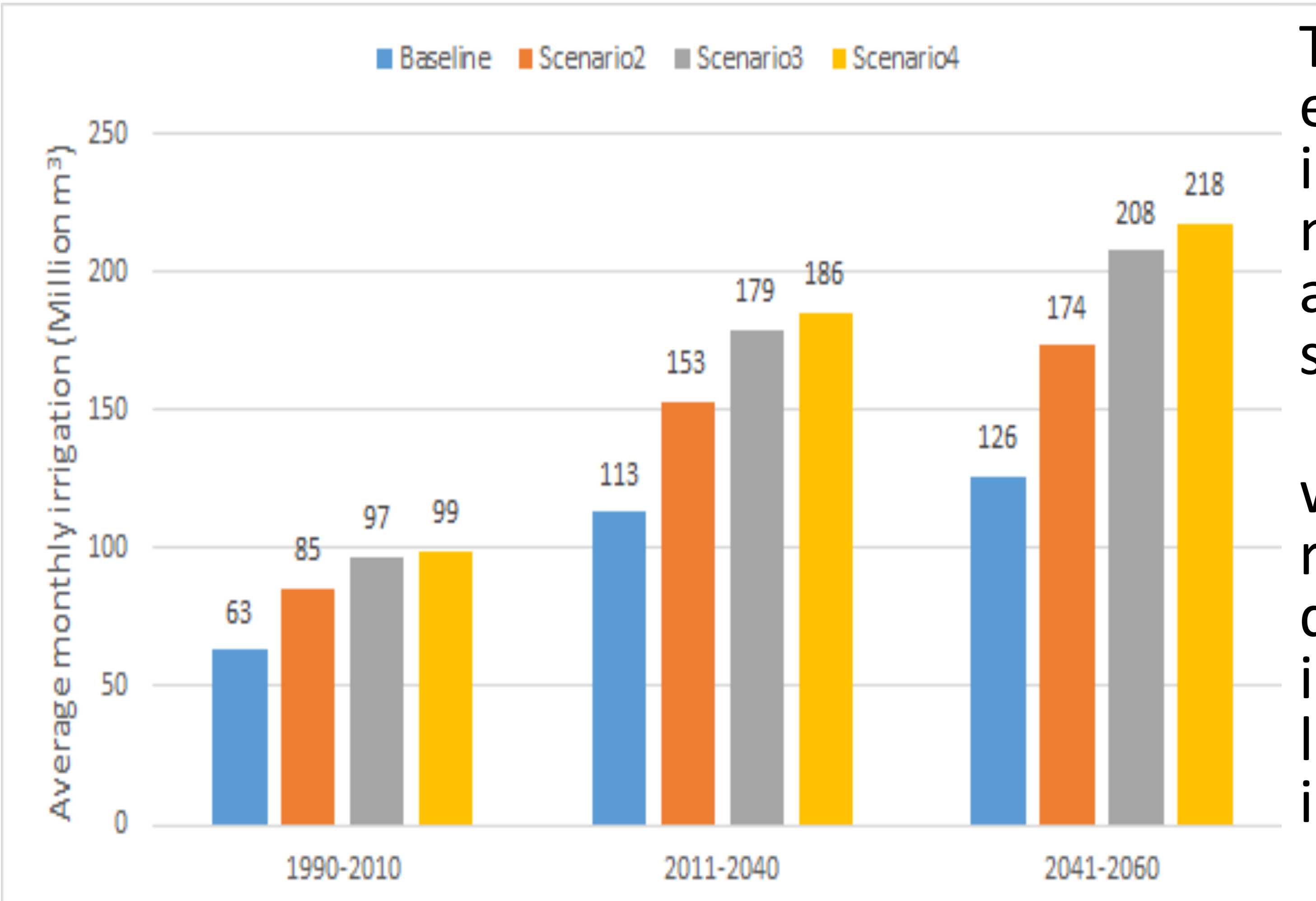
Under Current Technology

- Current conditions
  - Significant water withdrawals for irrigating crops occur following the rainy season into the dry season
  - Currently, irrigated crops regularly run out of water at this point
  - Continually increasing amount of cultivated land across the basin will require additional water supplies
- Future climate, based on results of the MPI model
  - Baseflow values may increase across the watershed (see second following slide)
  - However, periods of drought will cause stresses on all systems unless there is an improvement in water use efficiency.

Potential Effects of Technology Improvement

- Irrigation is the primary water use requirement; other water resources are minimal compared to irrigation.
- Infrastructure changes are required to increase irrigation efficiency
- Increasing irrigation efficiency will allow more cultivated areas to be supported based on increasing areas of farm land.
- *Increased efficiency doubles the amount of cropland that can be irrigated*

Change in Irrigation Water Volume



The more efficient the irrigation, the more cropped area can be served.

Irrigation water use will rise over time due to increases in land devoted to irrigated crops.

Impact of Climate Change on Rice and Maize?

Results of crop model informed by climate simulations

How does climate change affect crop growth?

1. Rising temperatures:
   a. Higher potential evapotranspiration and water demand
   b. Faster maturity and so lower yields
   c. Hot temperatures (>35°C) inhibit growth, reproduction.
2. Changing precipitation
   a. Declining rainfall causing water deficits
   b. Fewer, more intense storms cause higher runoff, less water available in soil, erosion
   c. Variable onset and ending of rainy seasons, possible shorter rainy seasons, and dry spells within rainy seasons, cause water stress.

Crop Modeling Methodology

- Climate data: Historical (TMA, CHIRPS, WorldClim), and up to mid-century (4 AR5 RCP 8.5 GCMs downscaled to 6 km)
- Process-based crop simulation modeling, CERES Maize and Rice models embedded in DSSAT v4.0.
- Crop model calibration for Rufiji Basin:
  - Soils from FAO soils map calibrated with soil profiles from WISE database (ISRIC).
  - Local crop varieties validated against observed data (Rice: Supa, TXD-85; Maize: Katumani, H-614).
  - Agronomic practices similar to farmer practices (surveys).
  - Climate models (GCMs) downscaled using local data.
- Scenarios of agricultural technologies:
  - Traditional and improved rice and maize cultivars
  - Low, moderate and high nitrogen fertilizer levels
  - Rainfed and irrigated.

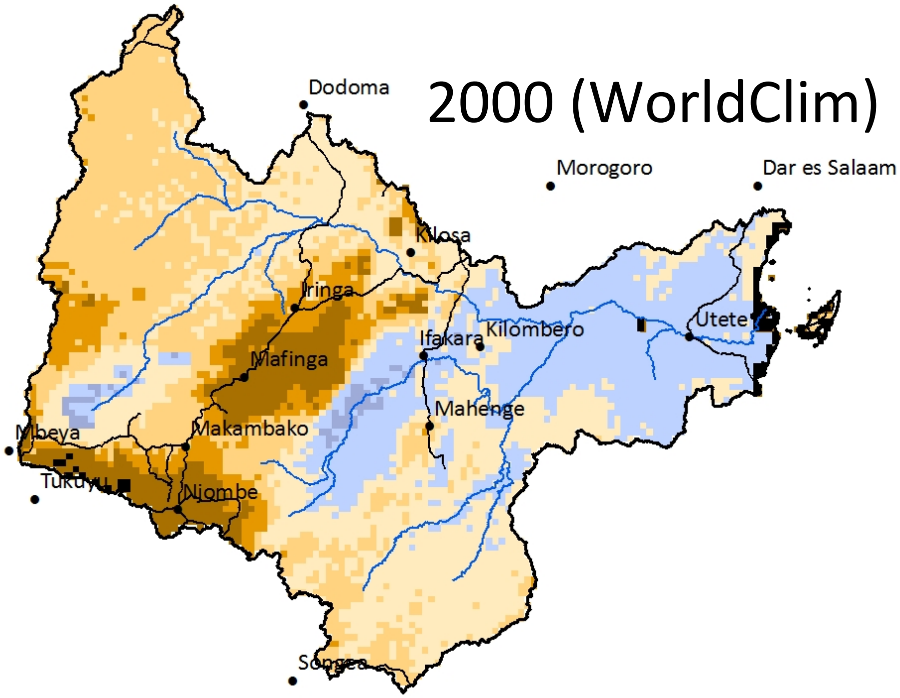
Caution: Simulated & Station Yields *versus* Farm Yields

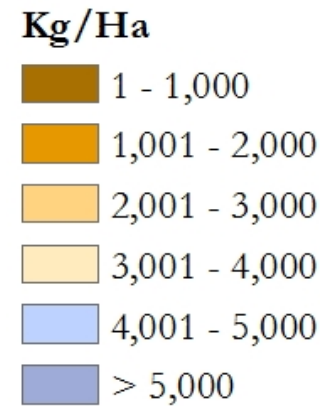
- Poor quality seeds, “recycled” hybrids
- Soil degraded
- Pests & diseases
- Weeds

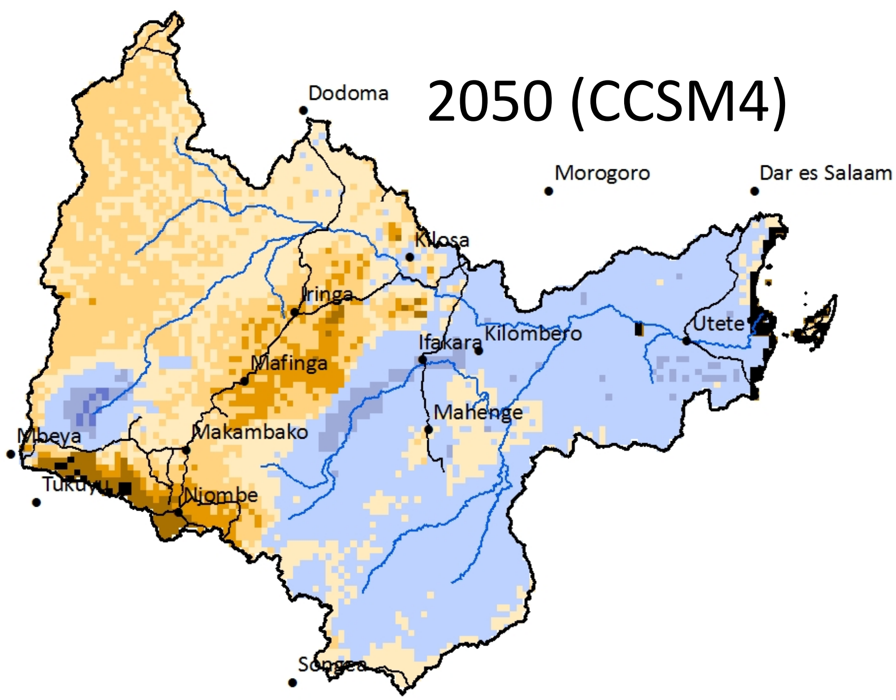
Rice Simulations

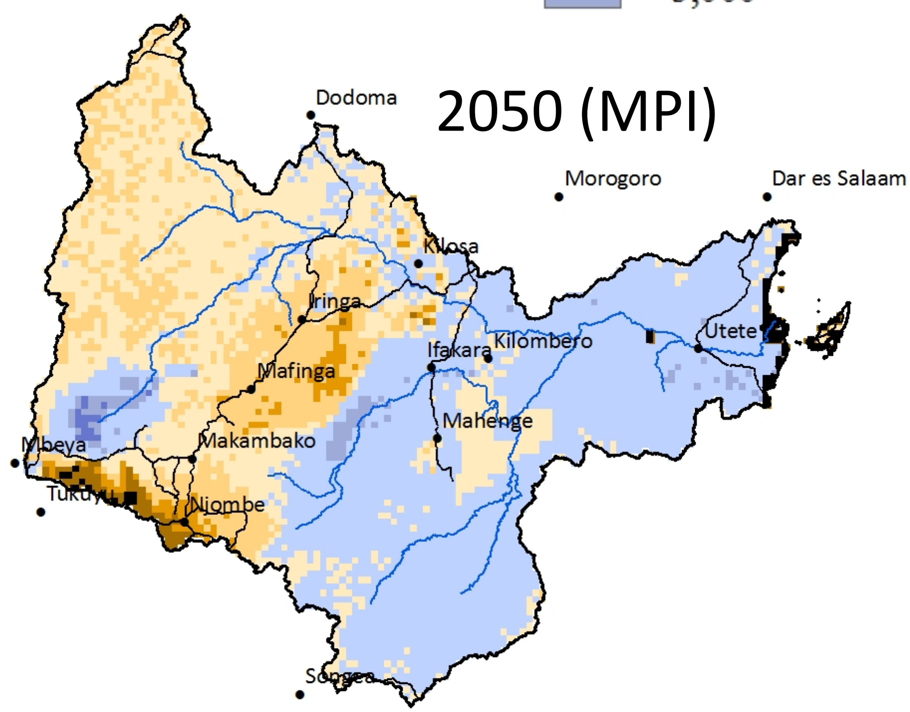
- Simulated rainfed rice grown during the rainy season (December transplanting) for current and 2050 climate conditions. Shown are results from IPCC AR5's MPI and CCSM of variety TXD-85 with 100 kg N (also modeled 2 other varieties, other N levels, other climate data not shown here)
- Also simulated irrigated rice, transplanted in June, using same climates and varieties.

Climate Effects: Rainfed Rice Yields. in 2000 and 2050



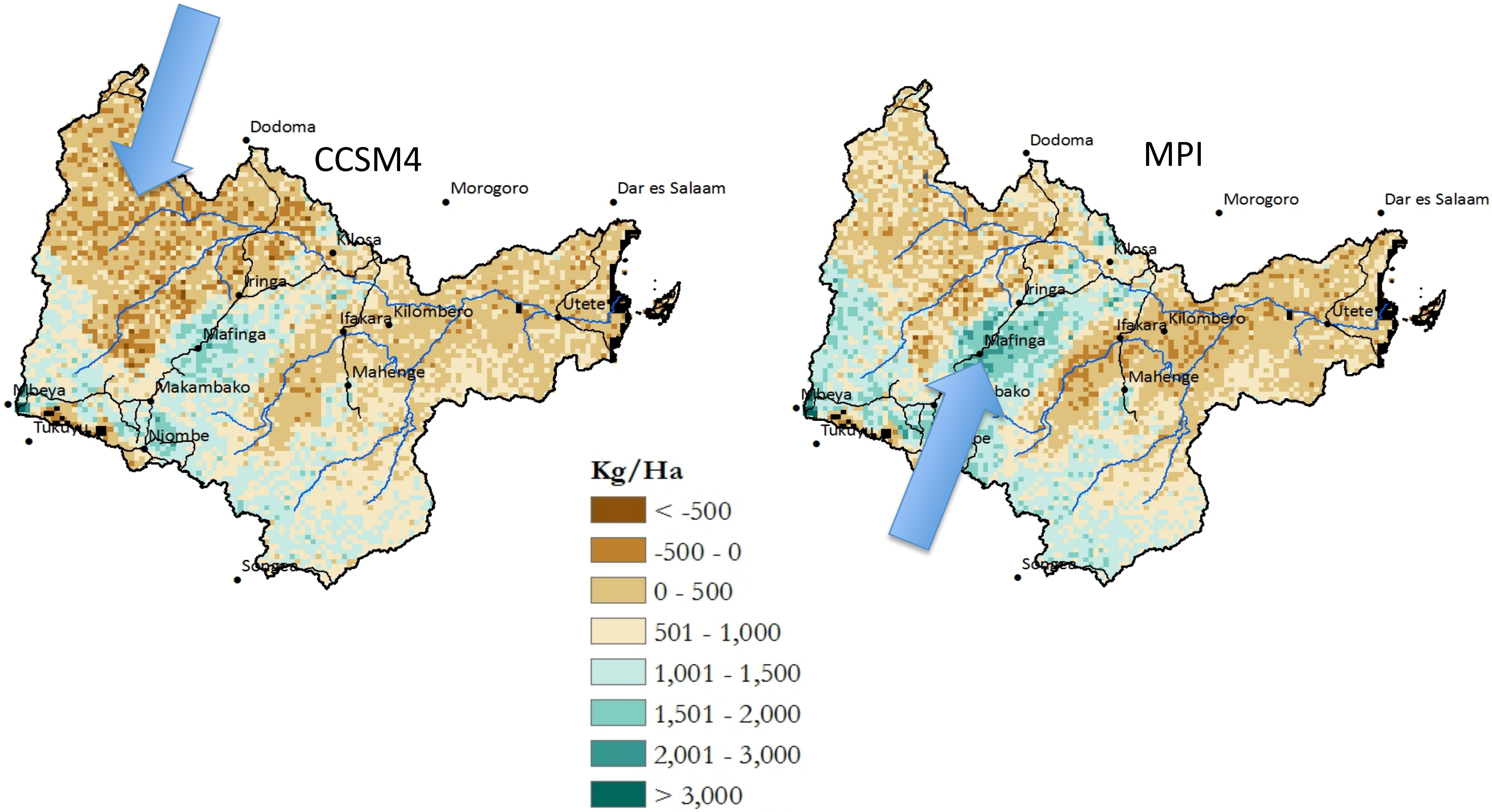




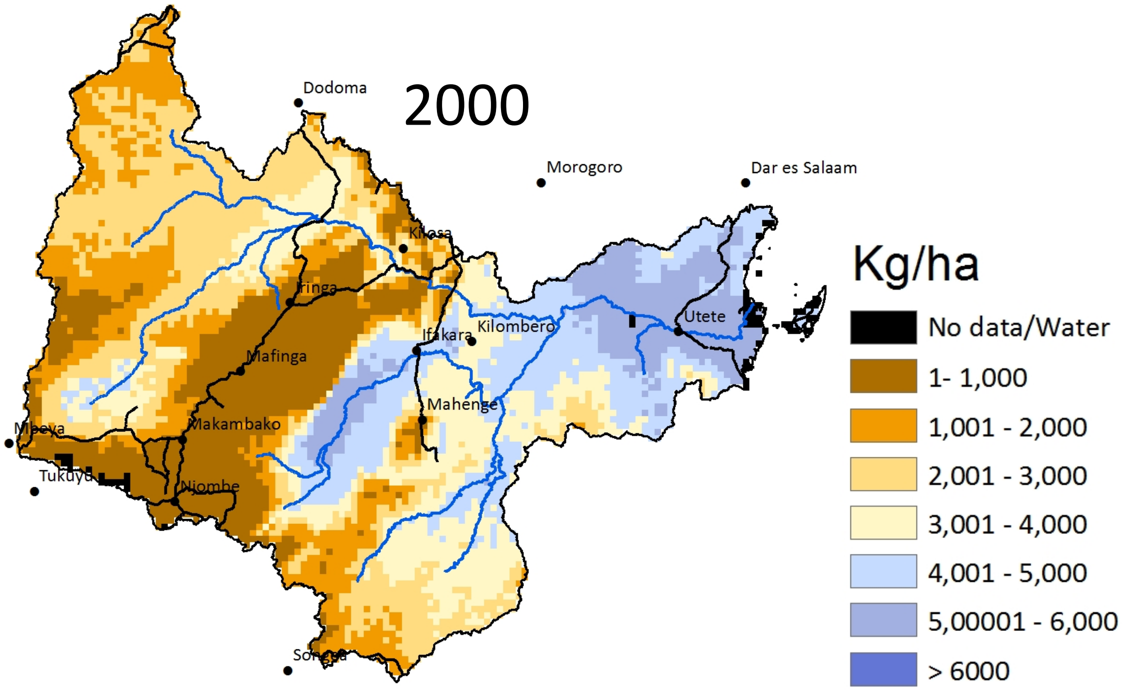


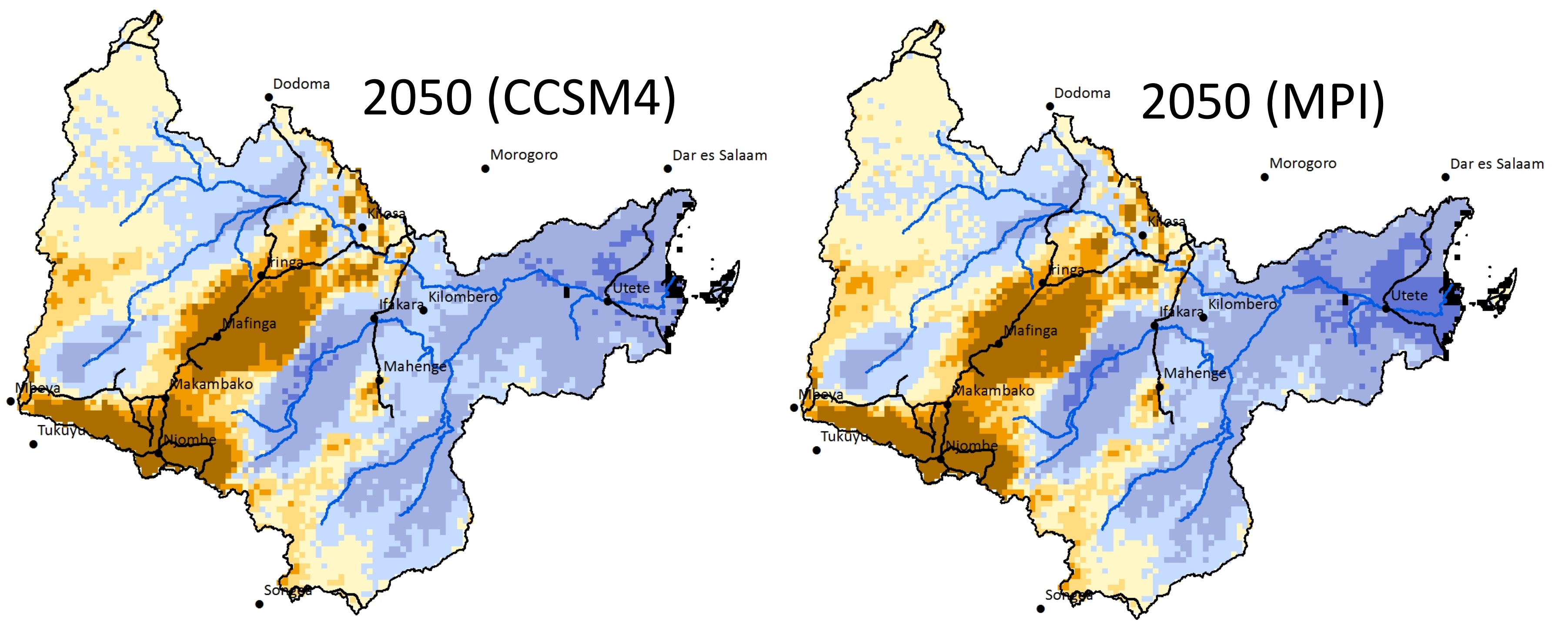
Change in Yield, from 2000 to 2050.

Rainfed Rice (Dec. planting)

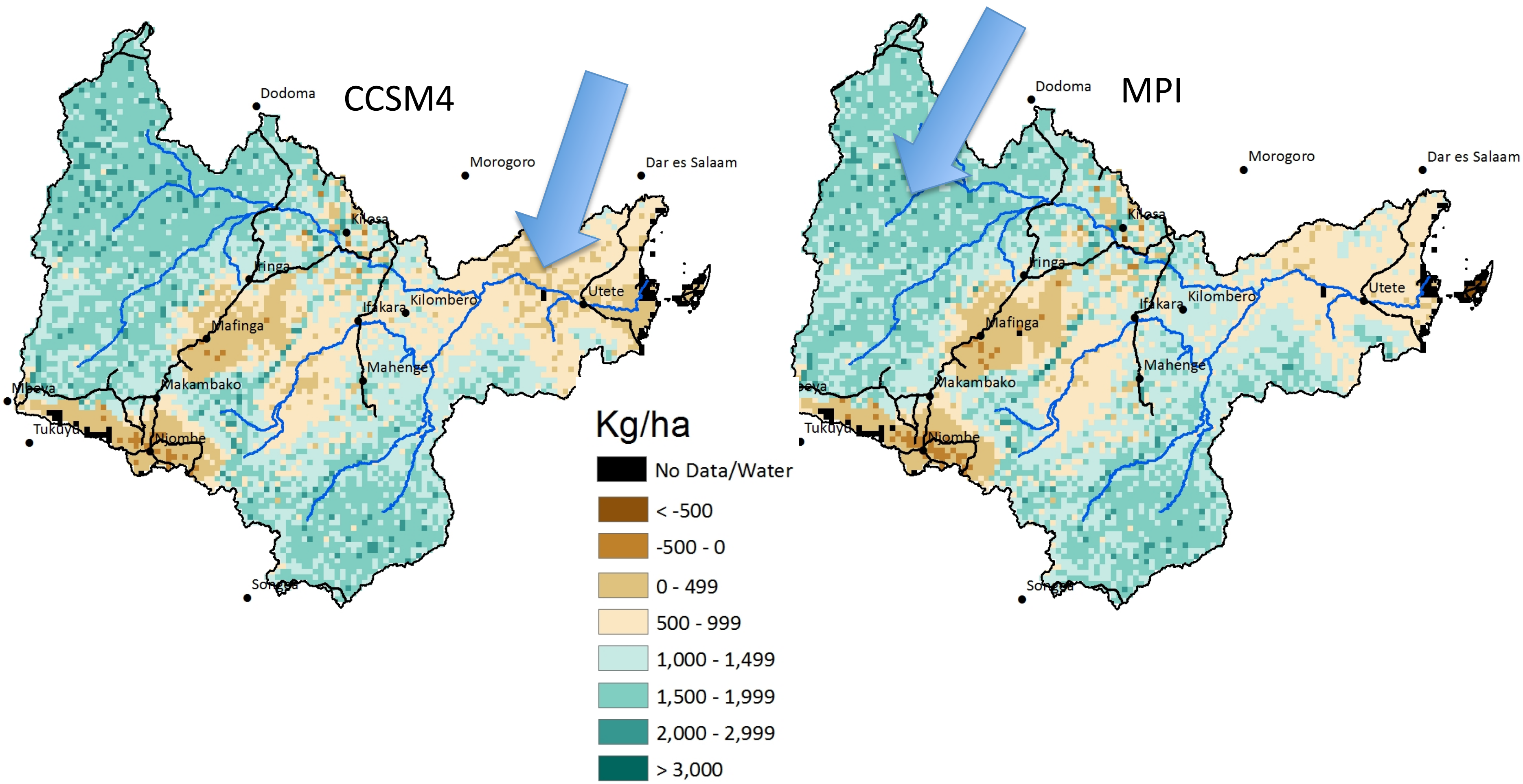


Climate Effects: Irrigated Rice Yields. June transplanting 2000 and 2050





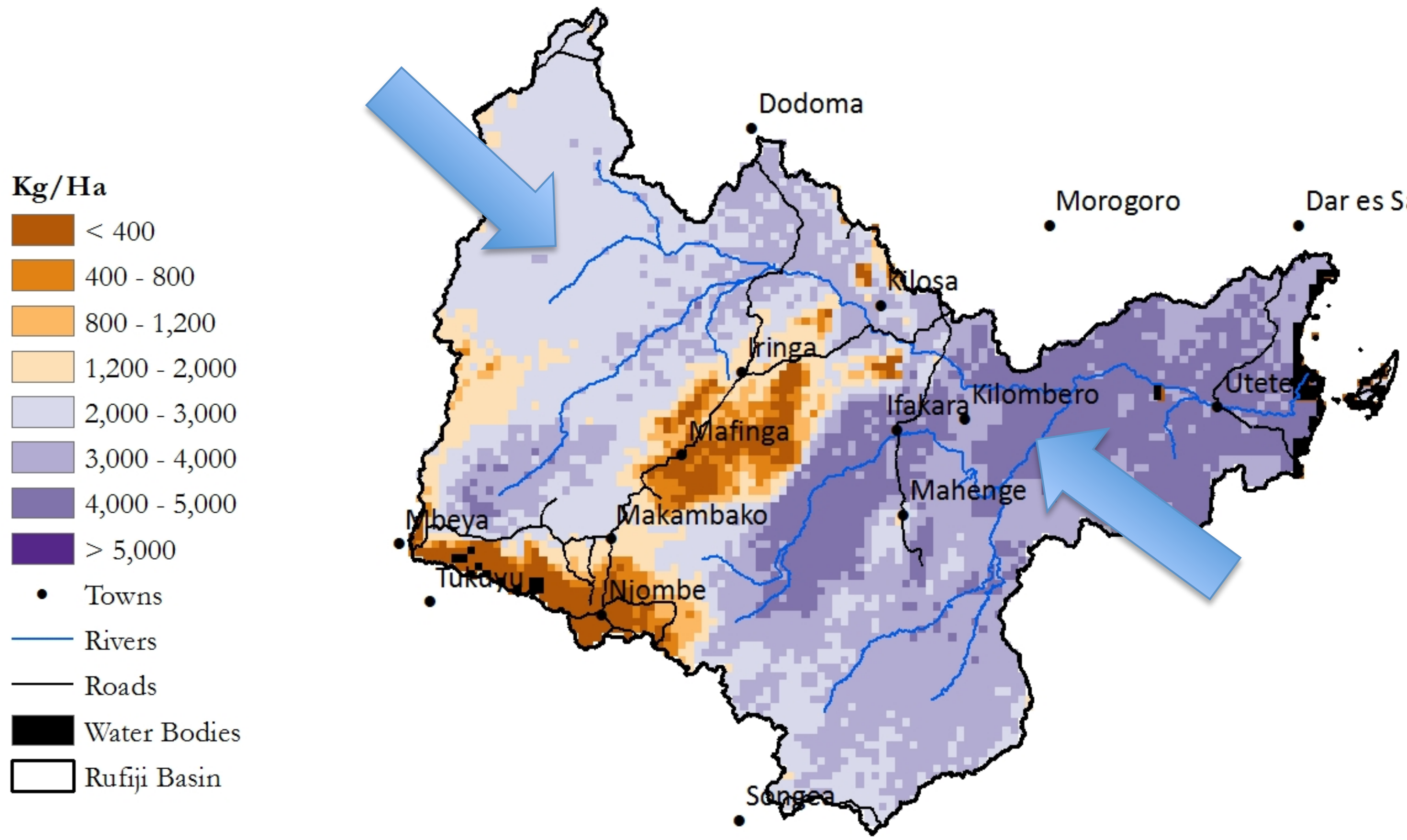
Change in Irrigated Rice Yield, 2000 to 2050 (June transplanting)



TXD85, irrigated, year 2000

Impact of Fertilizer on Rice: Additional Yield Obtained with Recommended Nitrogen

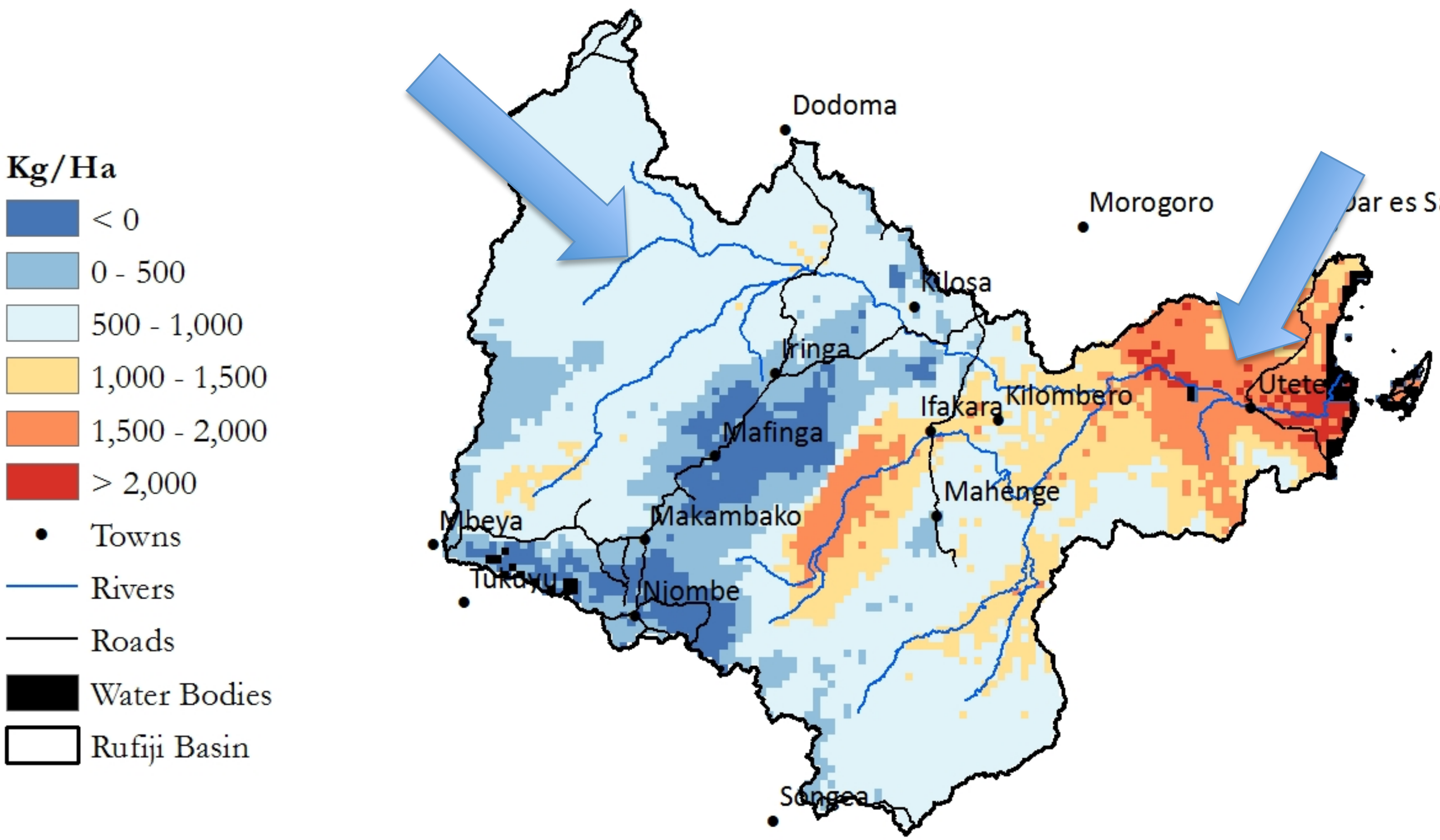
(100 versus 5 kg N)



TXD85, rainfed, year 2000

Impact of Varieties on Rice: Additional Yield Obtained with Improved Variety, Irrigated

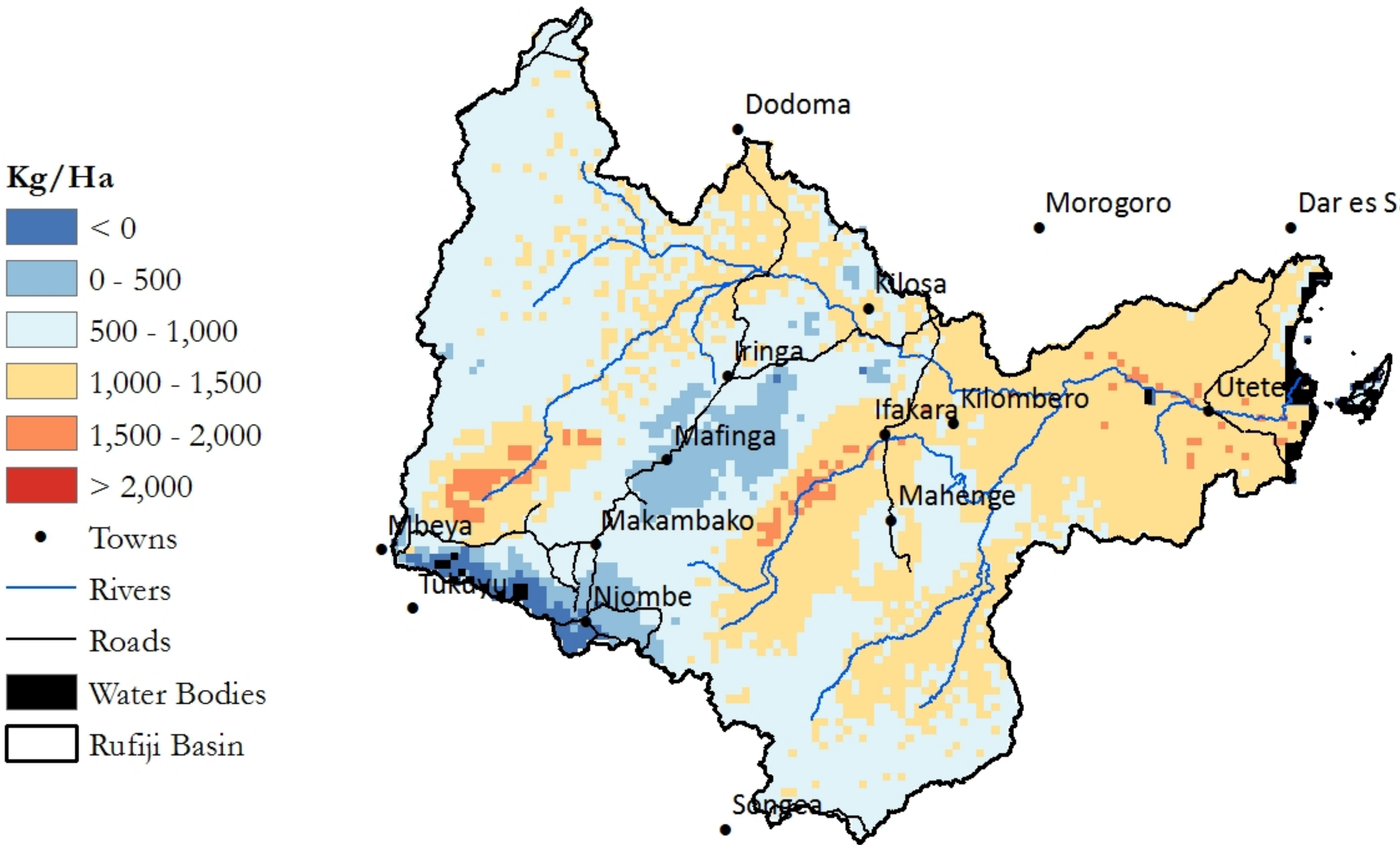
(TXD85 versus Supa; June transplanting)



TXD85, irrigated, year 2000

Impact of Varieties on Rice: Additional Yield Obtained with Improved Variety, Rainfed

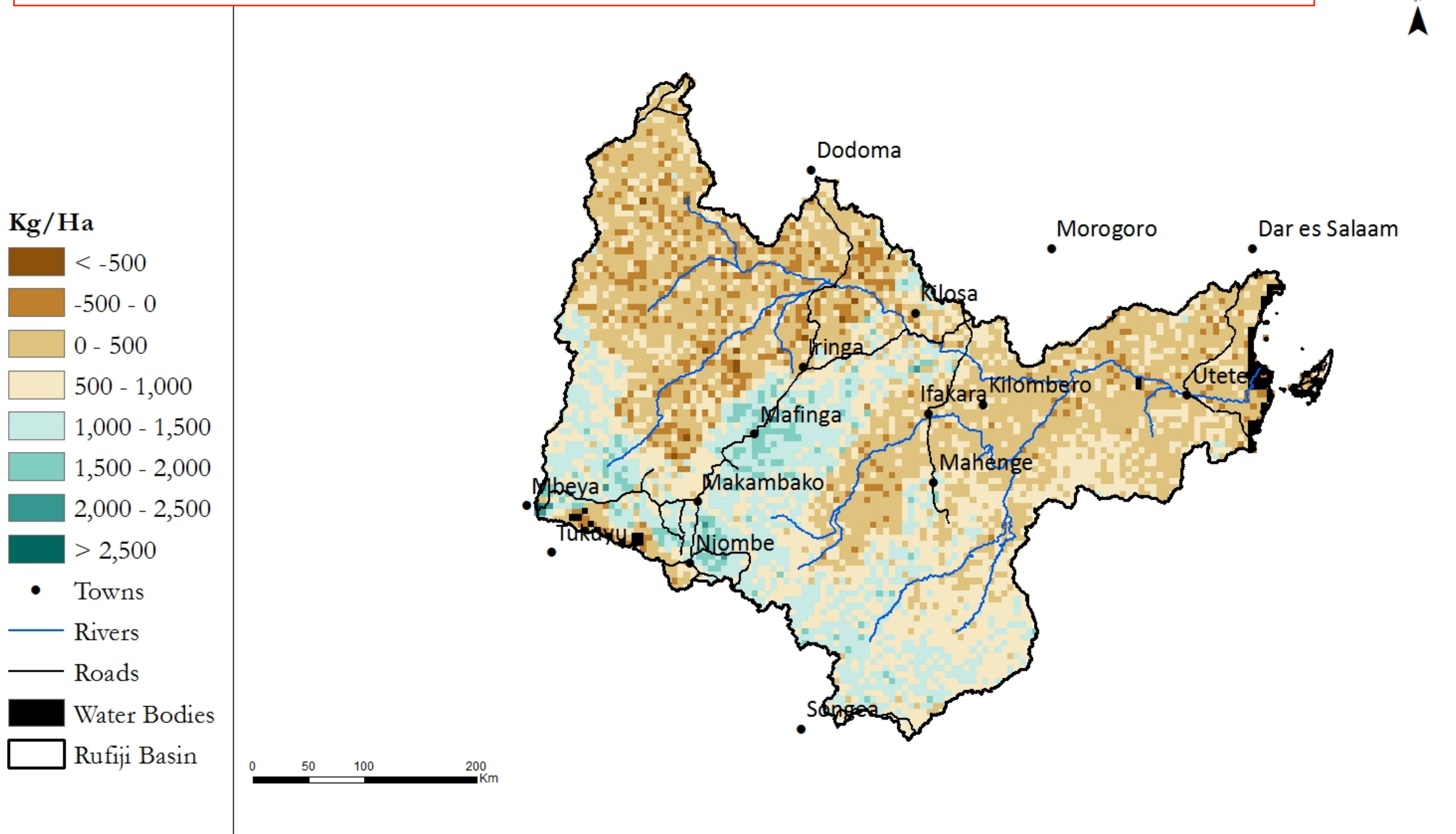
(TXD85 versus Supa, Dec. transplanting)



TXD85, rainfed, year 2000

Will these technologies help for adapting

Brown = Declining benefits of fertilizer in the future
Green = Rising impact of fertilizer in the future

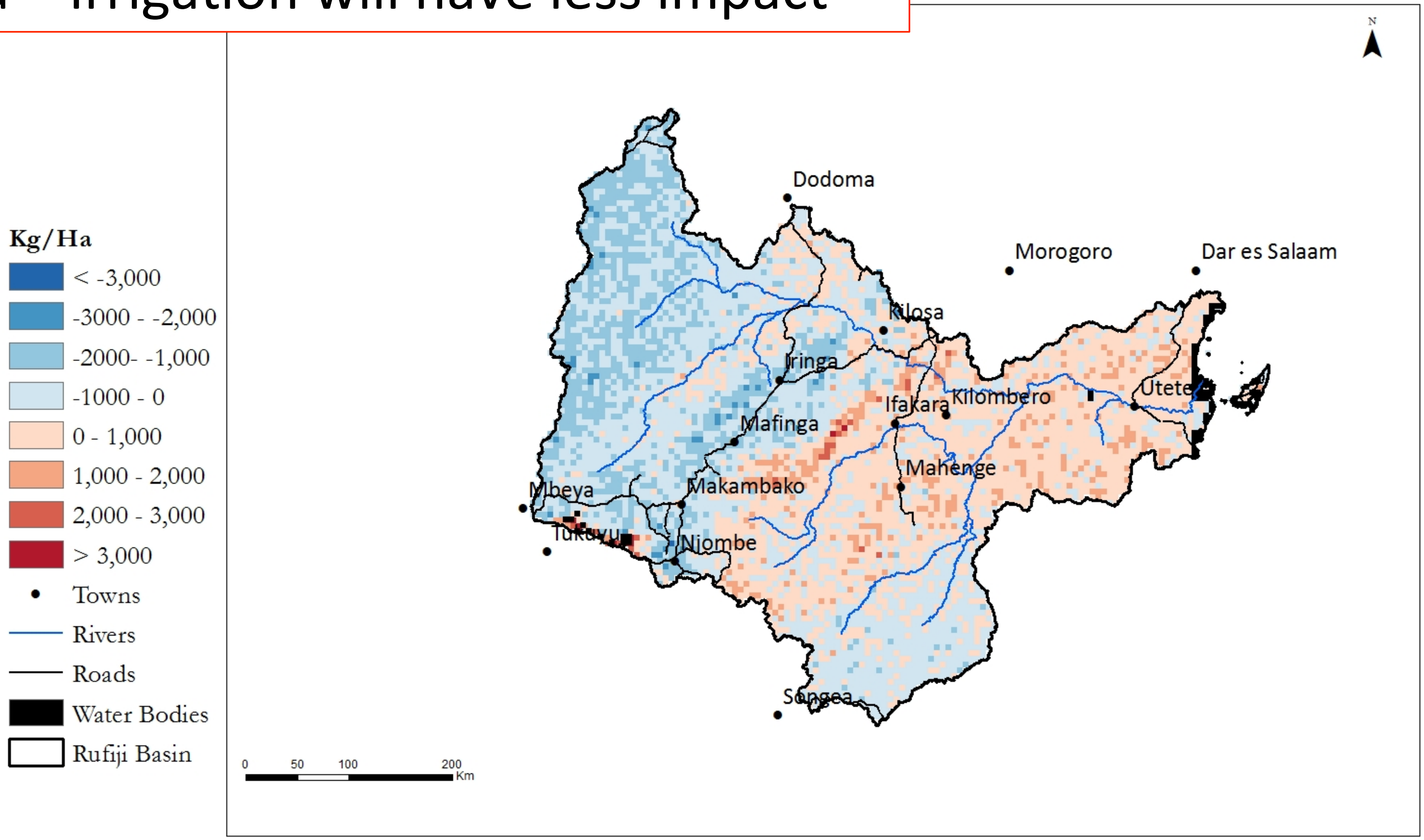


CCSM4 – WorldClim, Fert. Diff. TXD85, 100N, rainfed

Will these technologies help for adapting to climate change for maize?

Blue = Irrigation will have more impact
Red = Irrigation will have less impact

in the future?



Adaptation Implications for Rice

1. Rice yields greatly benefit from N applications, but the benefits are lower in the very warm or drier areas. Benefits will decline in future.
2. In the future, yields will improve in the Highlands, but the highest yields will remain in the lowlands.
3. However, rainfed rice yields are expected to decline in the future near the coast 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.
4. During the winter (June) planting, if the rice plants have sufficient irrigation and nutrients, yields will remain the same or even increase in the future in most areas.

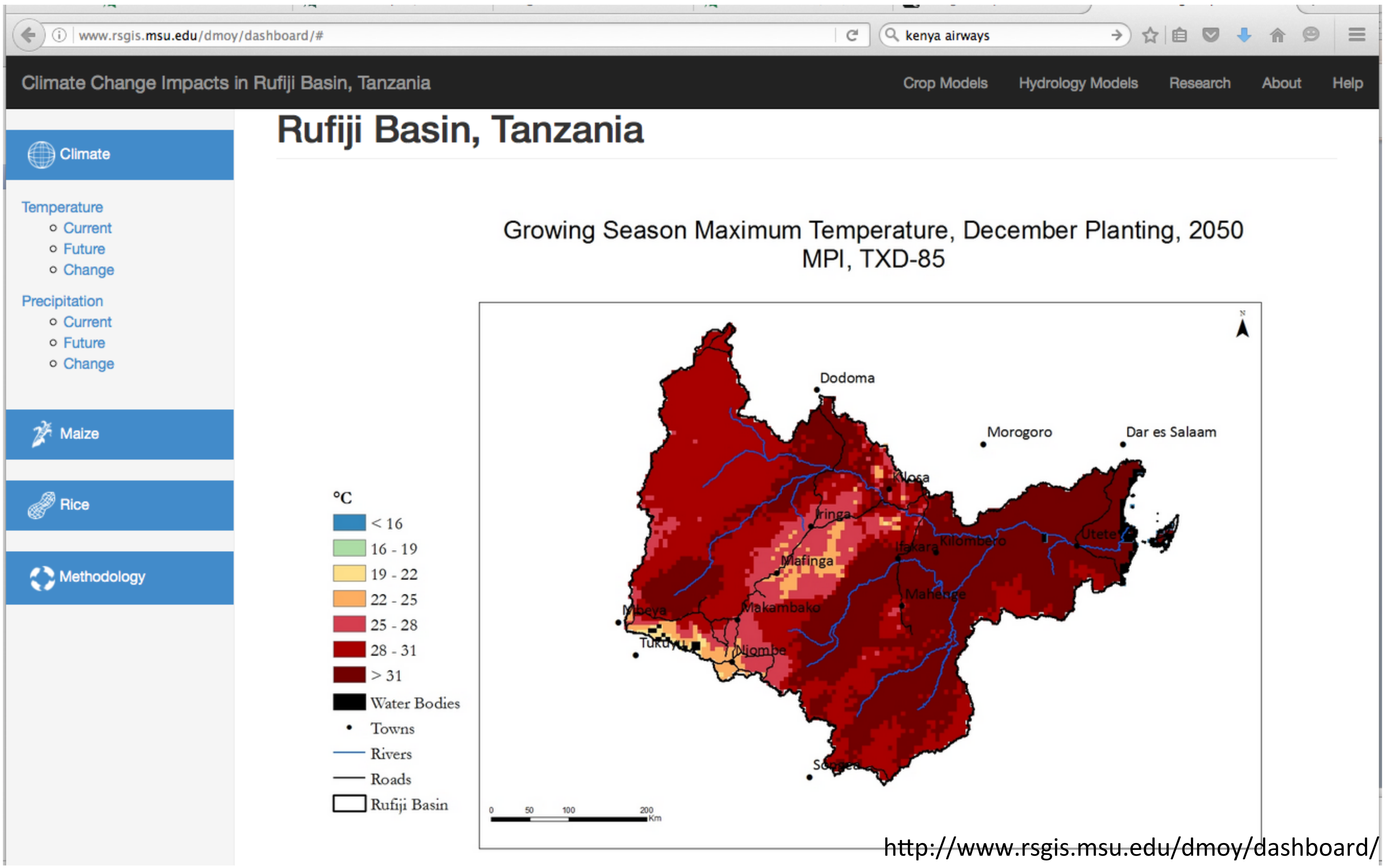
Adaptation Implications (2)

5. The beneficial effects of fertilizer and of high yielding varieties are expected to decline in the future for both rice and maize where environmental effects (heat, water stress) affect plants.
6. The beneficial effects of drought-tolerant (for maize especially) and heat tolerant (for both) varieties will be critical in the future
7. The biggest adaptation in the basin is, however, is more efficient irrigation.

Decision Support Tool

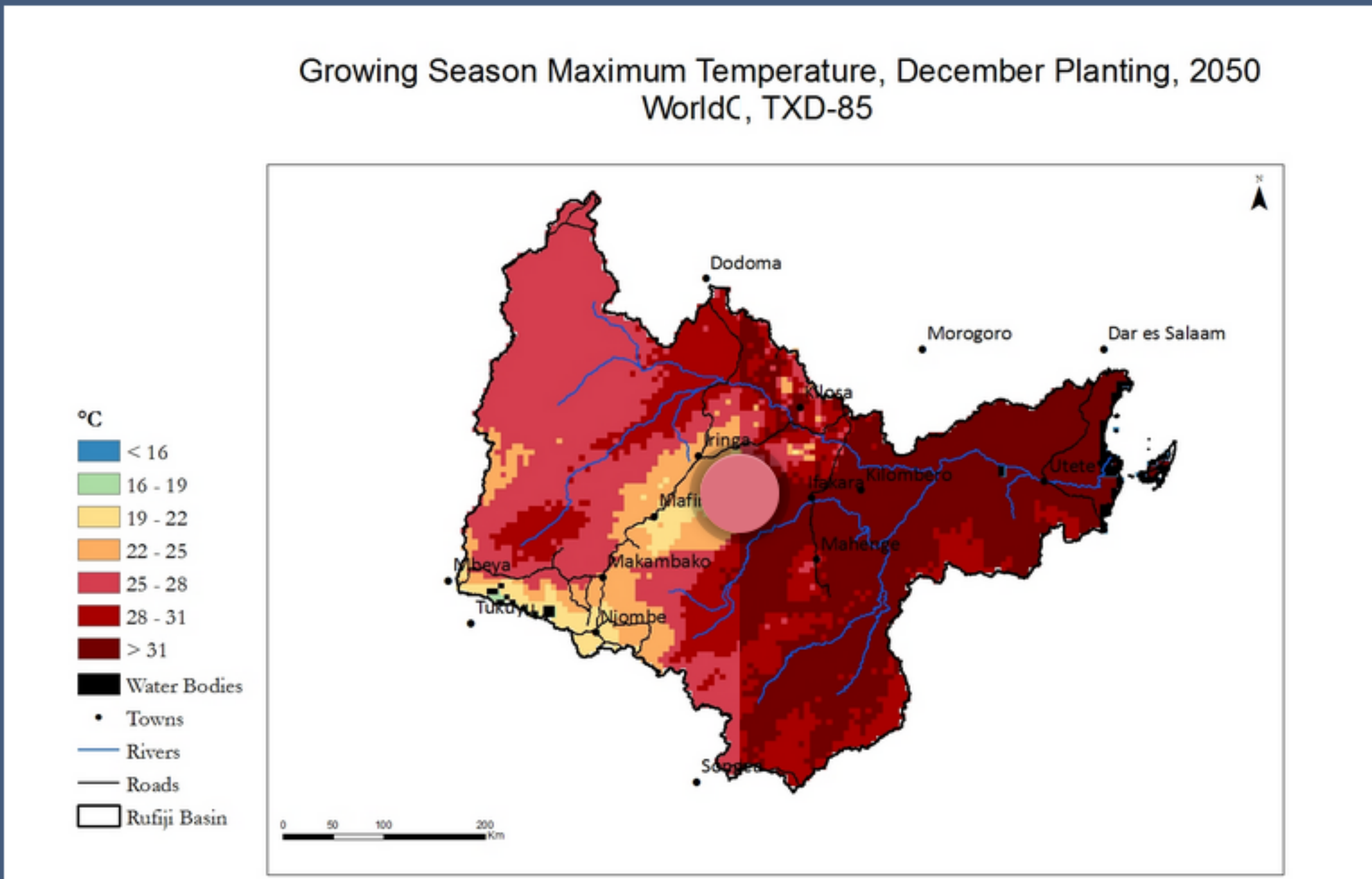
- On-line, interactive.
- User can select what technologies and time period (current, futures) to examine and see results in form of maps, graphs and text.
  - Hydrology section allows user to select technology and area irrigated in a sub-basin, and see effects on the level of crop production and water flows downstream.
  - Crop section allows user to examine effects of technologies now and in future.

Format, Climate & Crop Section



http://www.rsgis.msu.edu/dmoy/dashboard/

Image Comparison Slider



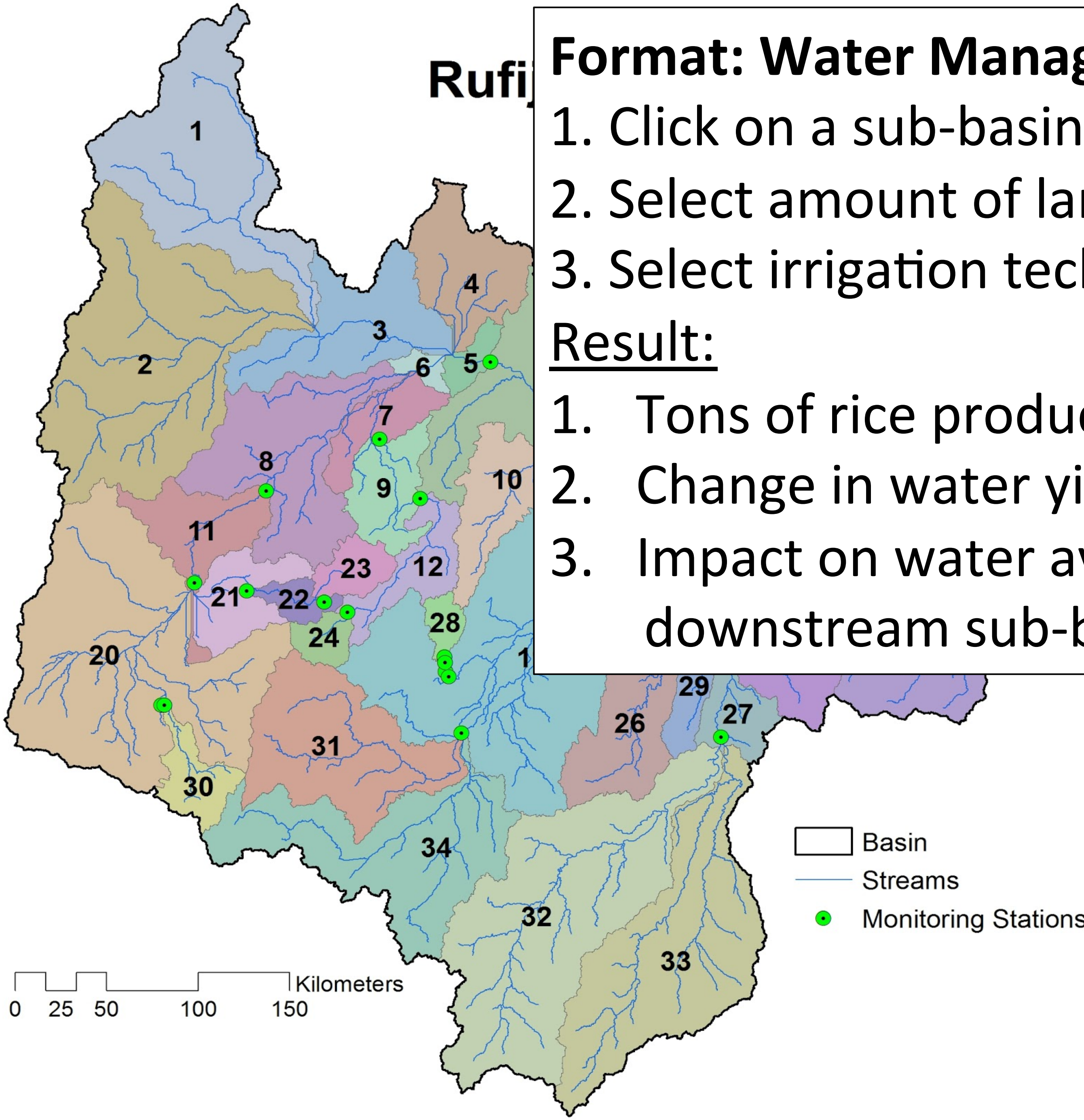
http://www.rsgis.msu.edu/dmoy/dashboard/image-comparison-slider/index2.html

Format: Water Management Section

1. Click on a sub-basin
2. Select amount of land irrigated
3. Select irrigation technology.

<u>Result:</u>

1. Tons of rice produced in sub-basin
2. Change in water yield in sub-basin
3. Impact on water availability on downstream sub-basins.



Next Steps

- Hydrological model: complete climate scenarios with additional GCMs
- Decision support tool populated with maps and data.
- National workshop, District plans approved by Districts, policy briefs and other outreach.