Presentation given the TransLinks workshop:

Modeling and Managing Watersheds

September 13-16, 2011

Kigali, Rwanda
Umubano Hotel, Boulevard de l'umuganda

This workshop was hosted by the Wildlife Conservation Society, the United States Forest Service (USFS) and the United States Agency for International Development (USAID)

This workshop was generously supported by the American people through the United States Department of Agriculture (USDA) Forest Service and the United States Agency for International Development (USAID), under the terms of the TransLinks Cooperative Agreement No.EPP-A-00-06-00014-00 to the Wildlife Conservation Society (WCS). TransLinks is a partnership of WCS, The Earth Institute, Enterprise Works/VITA, Forest Trends and the Land Tenure Center. The contents are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States government.

Modeling and Managing Watersheds Workshop: Results and Recommendations Rwanda

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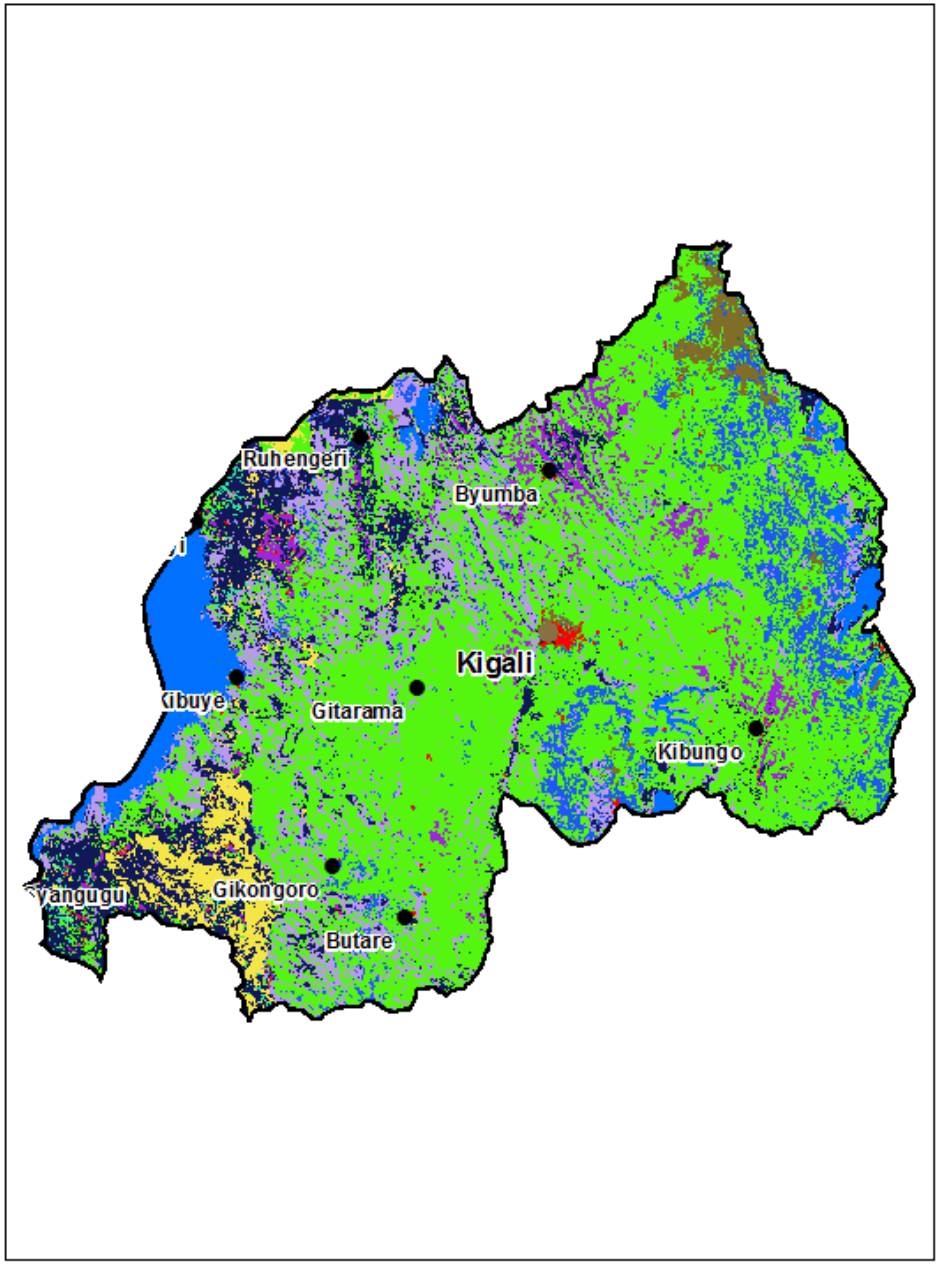
September 14, 2011; Kigali, Rwanda

Outline

- Study Location
- Physical Characteristics
- Environmental Issues
- Goal
- Results
- Summary and Recommendation



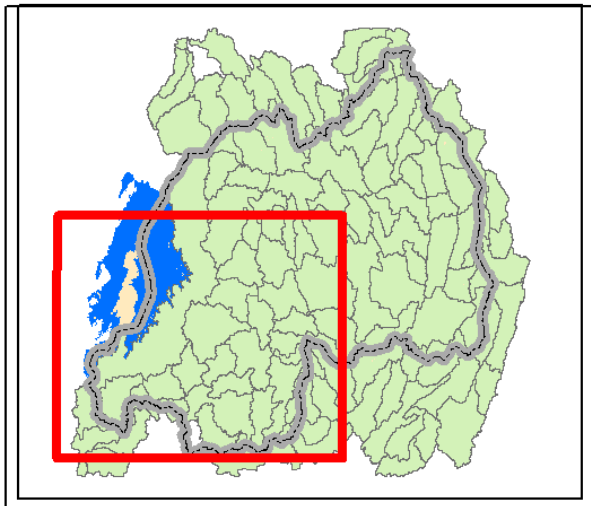
Rwanda

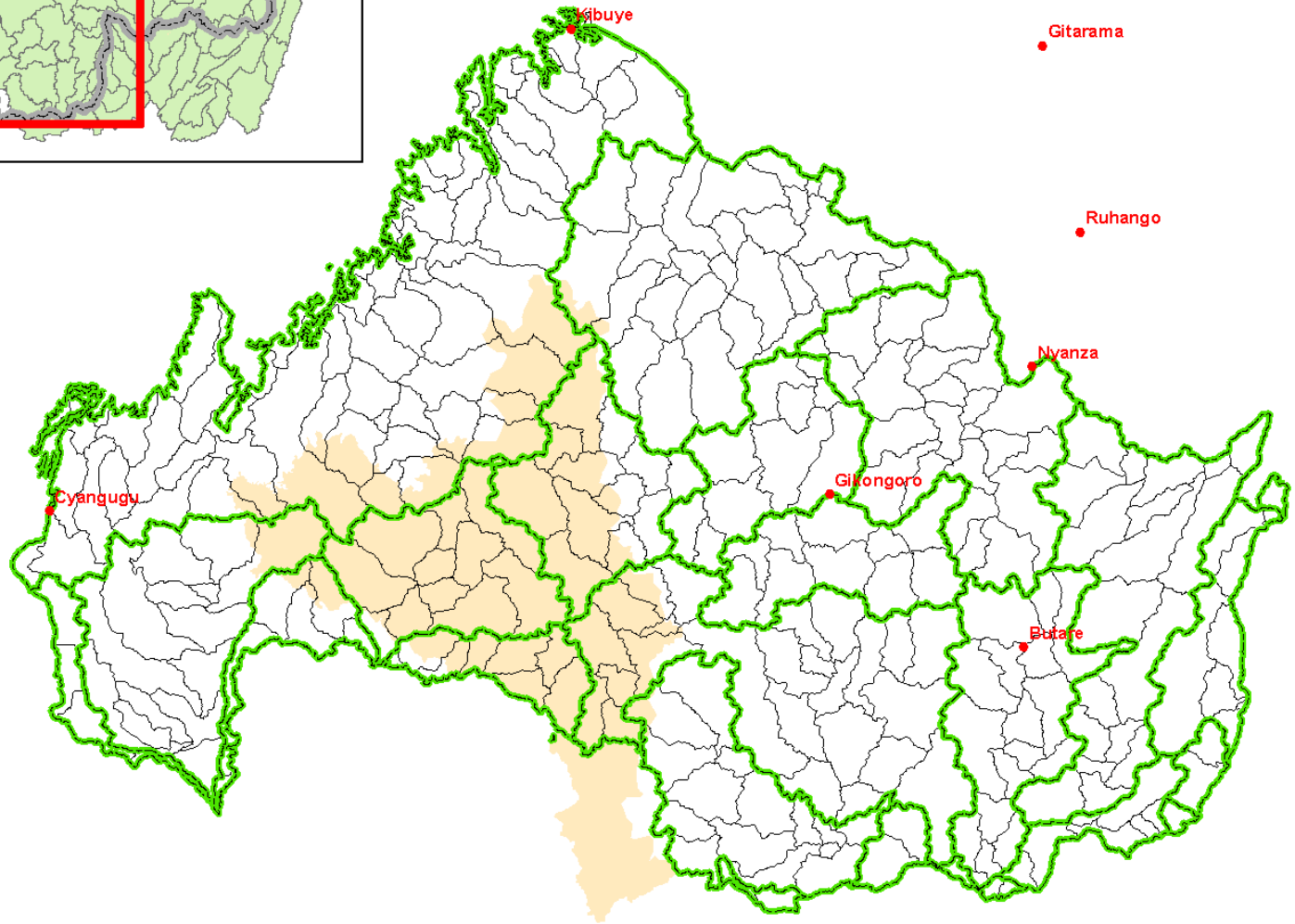
300 meter resolution
Land Cover
Globcover Dataset 2009

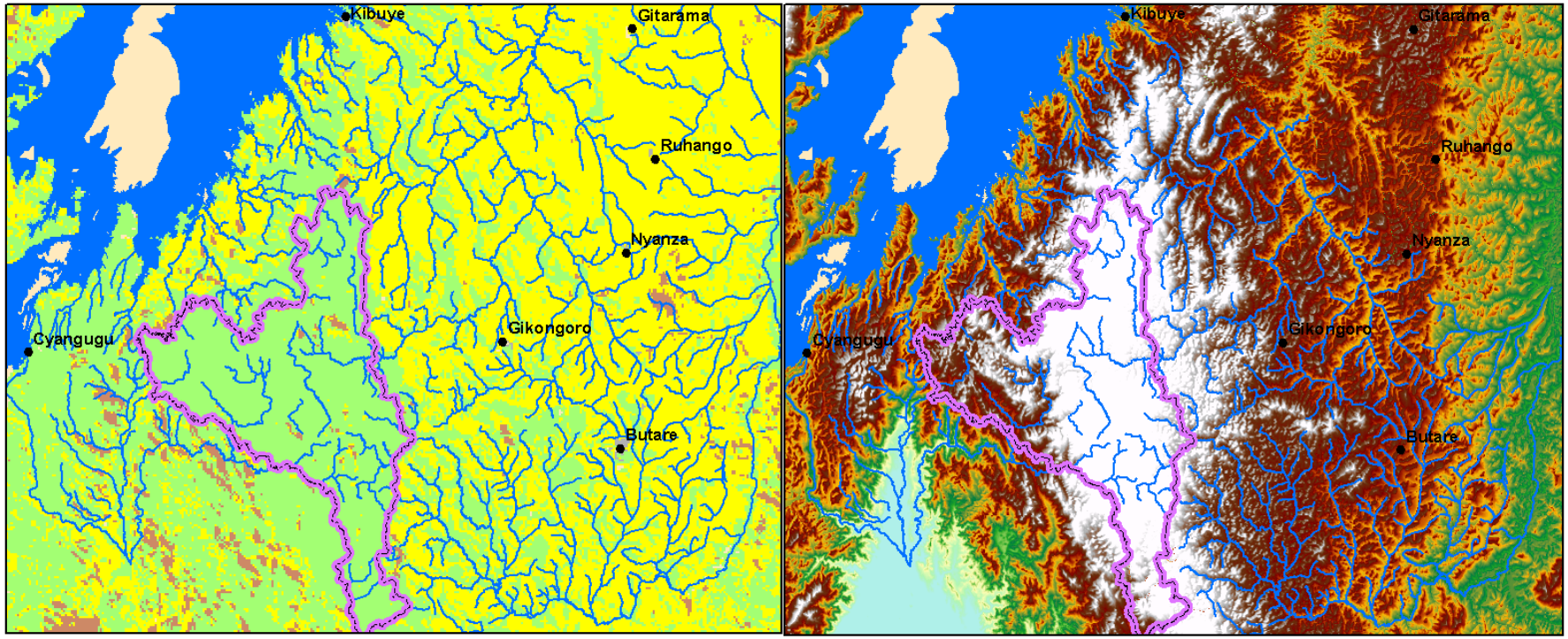
Land Cover Types

- Post-flooding or irrigated croplands
- Rainfed croplands
- Mosaic cropland (50-70%)
- Mosaic vegetation
- Closed to open (> 15%) broadleaved deciduous forest
- Closed (>40%) broadleaved deciduous forest
- Open (15 - 40 %) broadleaved deciduous forest
- Closed needleleaved evergreen forest
- Open needleleaved deciduous or evergreen forest
- Closed to open mixed broadleaved and needleleaved forest
- Mosaic forest or shrubland
- Mosaic grasland
- Closed to open shrubland
- Closed to open herbaceous vegetation
- Sparse Vegetation
- Closed to open flooded broadleaved forest
- Closed broadleaved forest permanently flooded
- Closed to open grassland or woody vegetation on waterlogged soil
- Artificial Surfaces and associated areas (Urban > 50%)
- Bare Areas
- Water bodies
- Permanent Snow

Study Location







Landuse

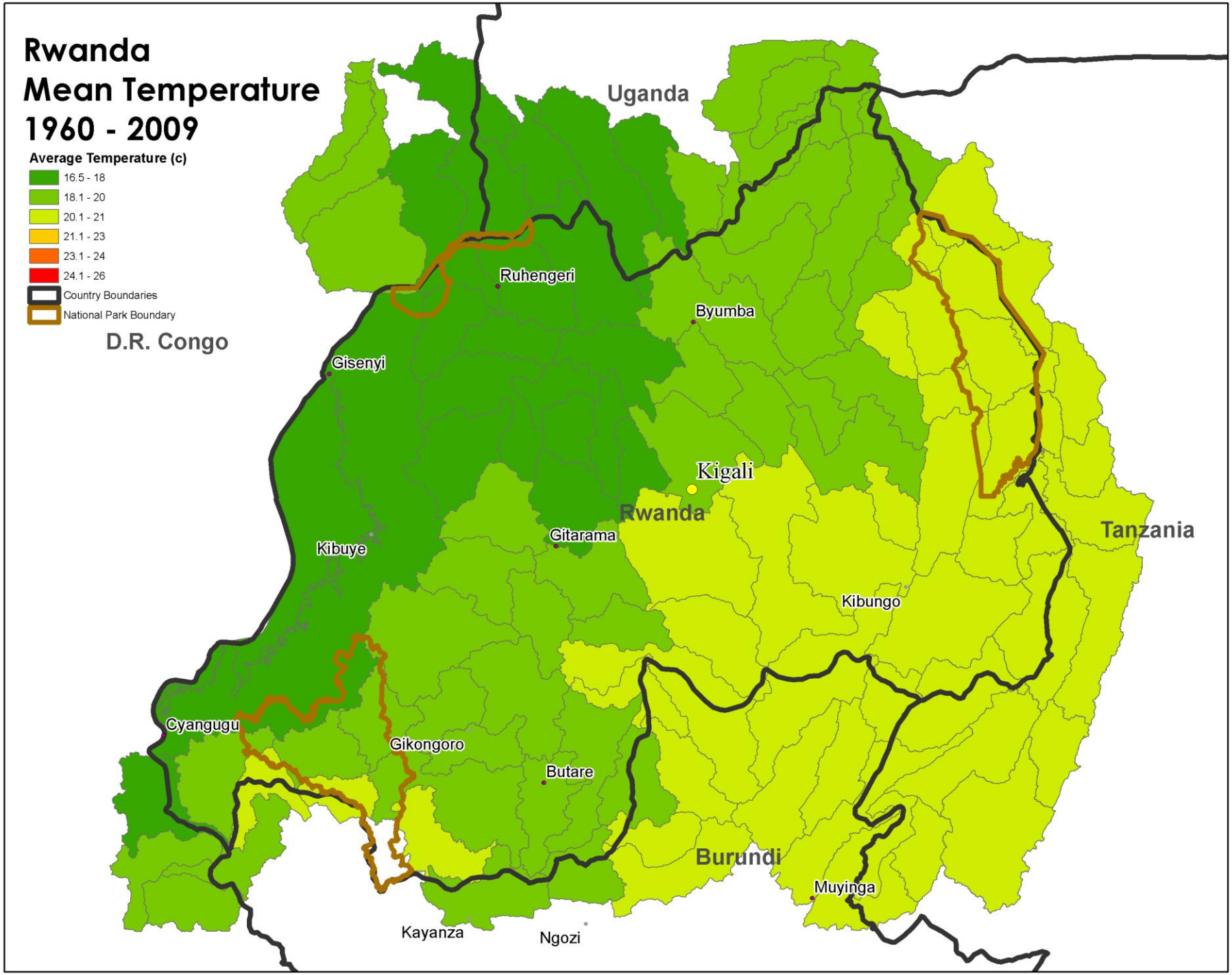
- Cropland
- Grassland
- Forest
- Shrubland, Savanna
- Sparse Vegetation
- Wetland, Water
- Urban

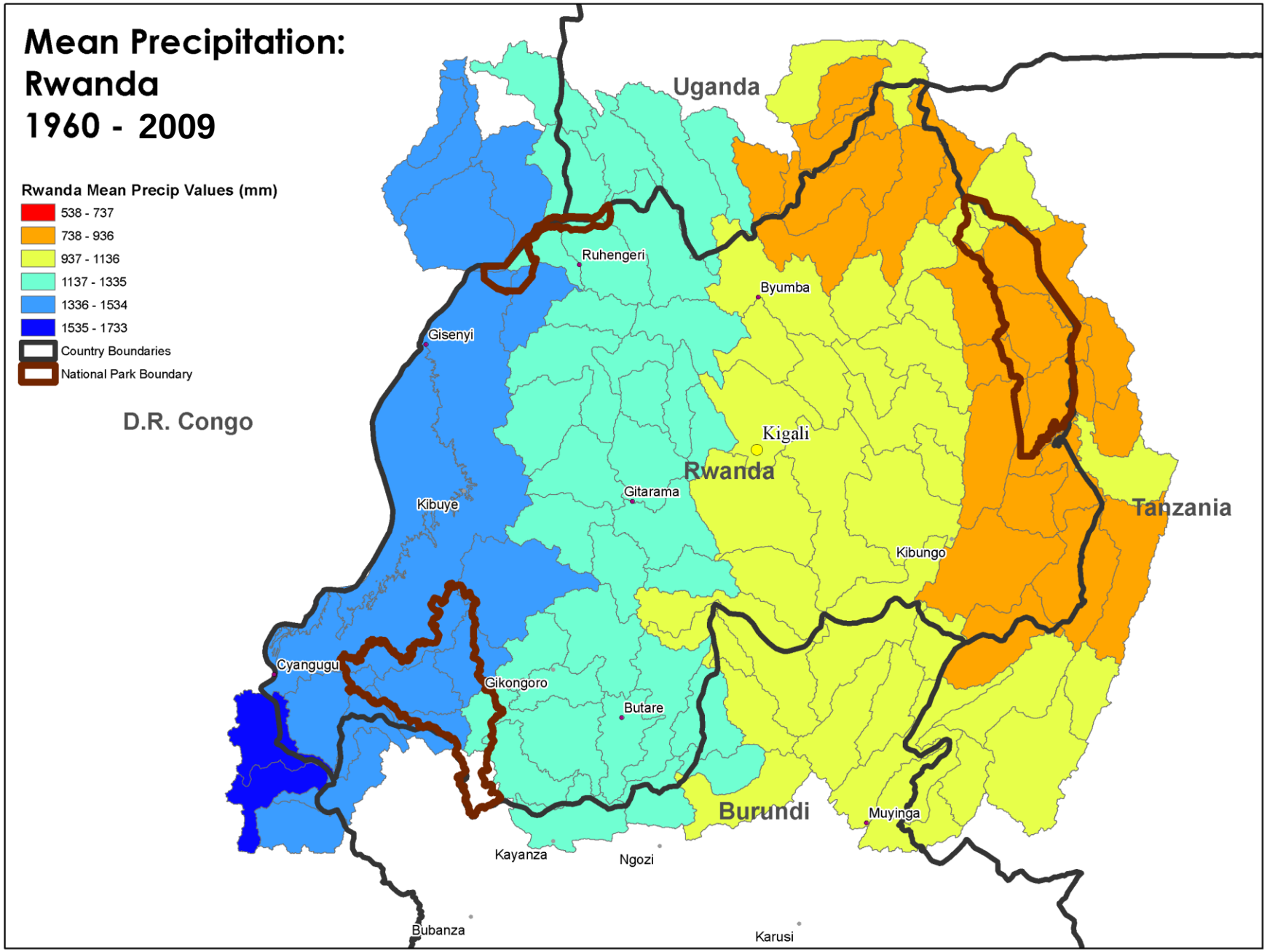
- Towns
- Nyungwe National Park
- Lake Kivu

Elevation (m)

High : 2924

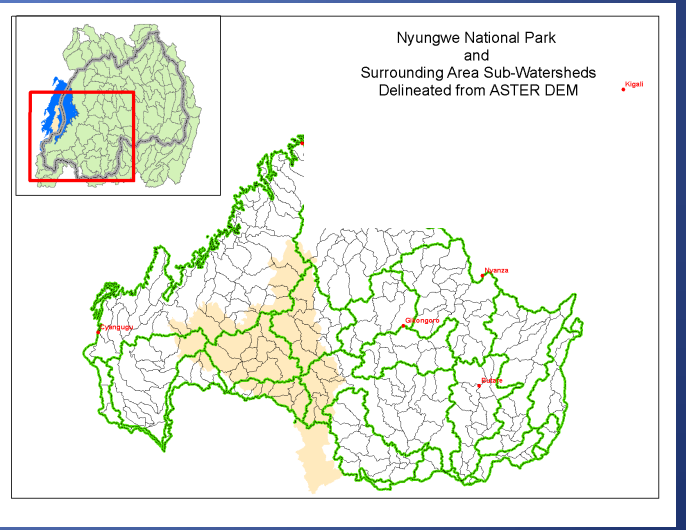
Low : 853


Rwanda
Mean Temperature
1960 - 2009
Average Temperature (c)
16.5 - 18
18.1 - 20
20.1 - 21
21.1 - 23
23.1 - 24
24.1 - 26
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Tanzania
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Burundi
Muyinga
Kayanza
Ngozi


Mean Precipitation:
Rwanda
1960 - 2009
Rwanda Mean Precip Values (mm)
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1733
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Tanzania
Burundi
Rwanda
Kigali
Ruhengeri
Byumba
Gisenyi
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Bubanza
Karusi

Environmental Issues

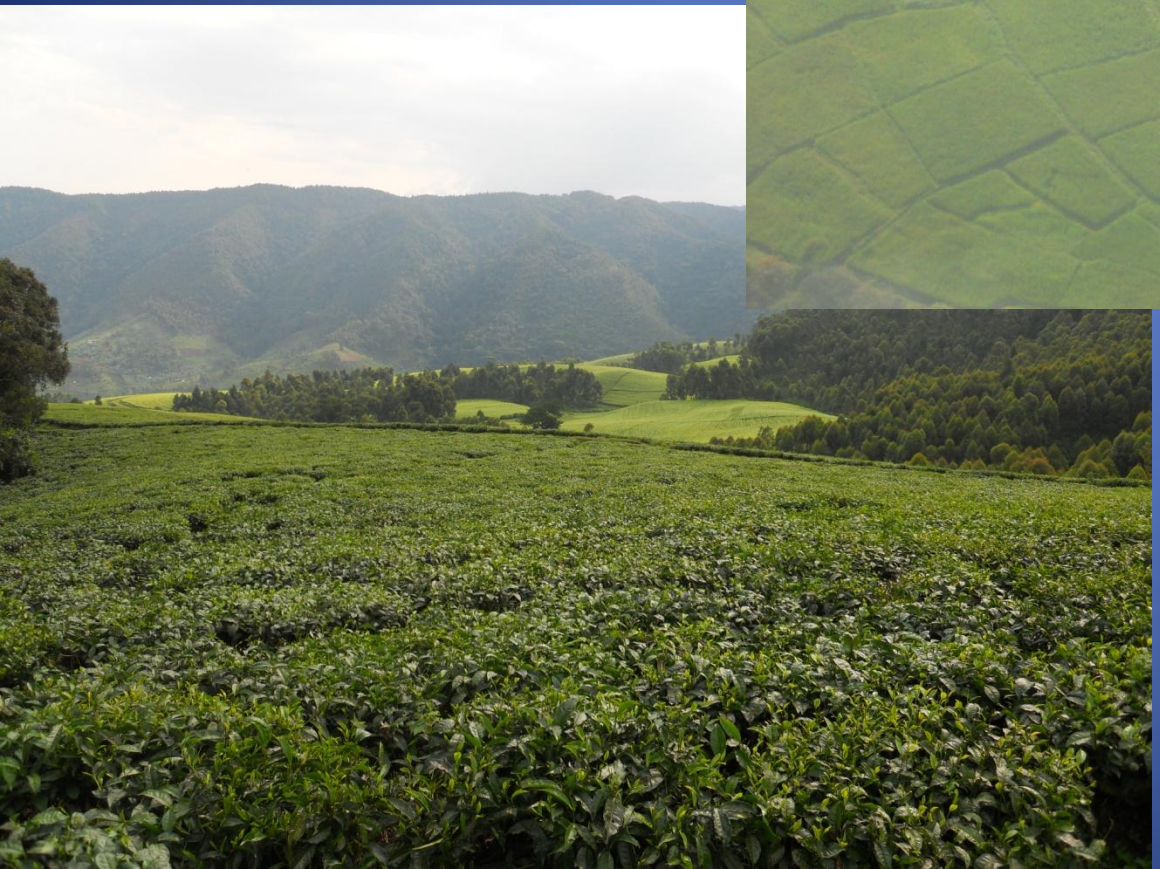
- Deforestation
  - Densely populated country (>350 /km^2)
  - Agriculture is a major land use
- Erosion, sedimentation
- Water supply for power generation, irrigation, tea plantations
- Wetland losses



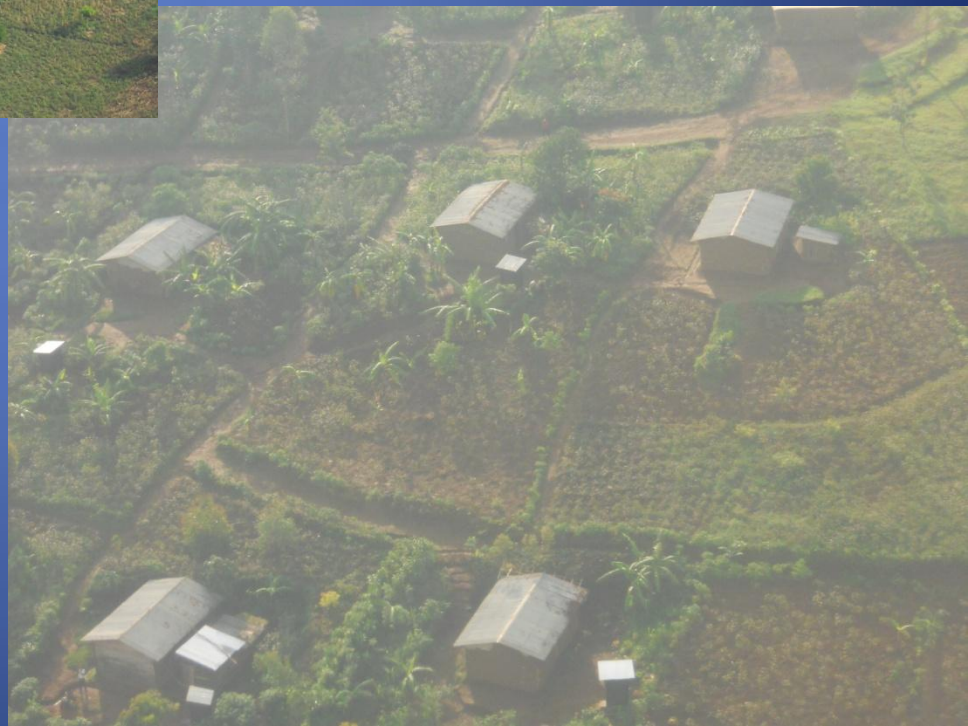
Rice Farming

Water Diversion for Irrigation

Tea Farming



Mixed Landuse



Erosion

Goal

- Model water quantity and sedimentation within Nyunwge and the area surrounding Nyungwe with current landcover conditions

- To simulate landuse and/or climate change within the modeling framework and quantify its impact on water quantity and sedimentation

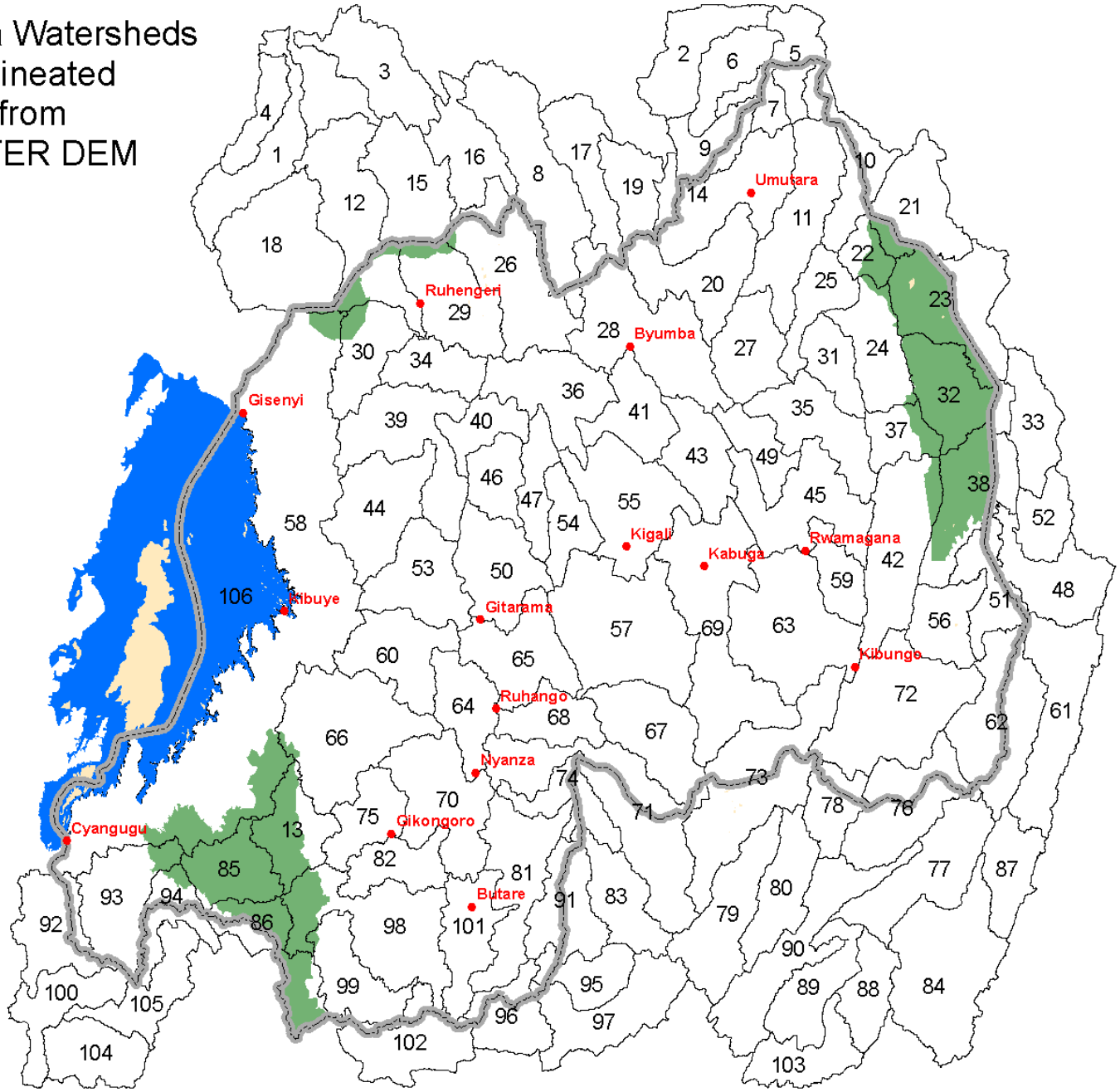
Result Scenario: Water Quantity

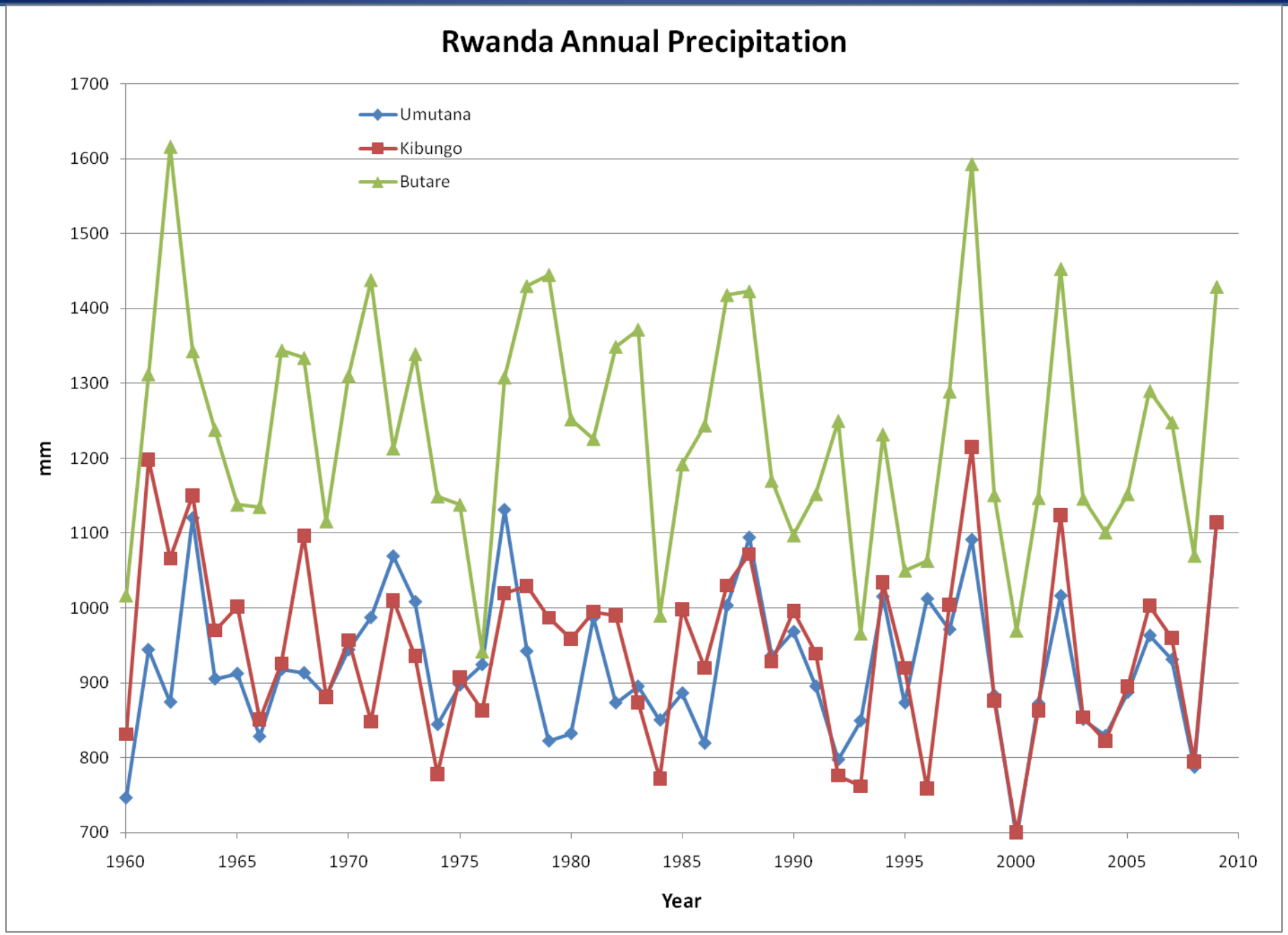
- Scenarios (4)
  - Baseline
    - 2009 landcover
    - Monthly precipitation and temperature from 1960-2009
  - Converting 20% of forest to cropland
  - 1 Degree temperature increase
  - 1 Degree temperature increase + 10% reduction in precipitation

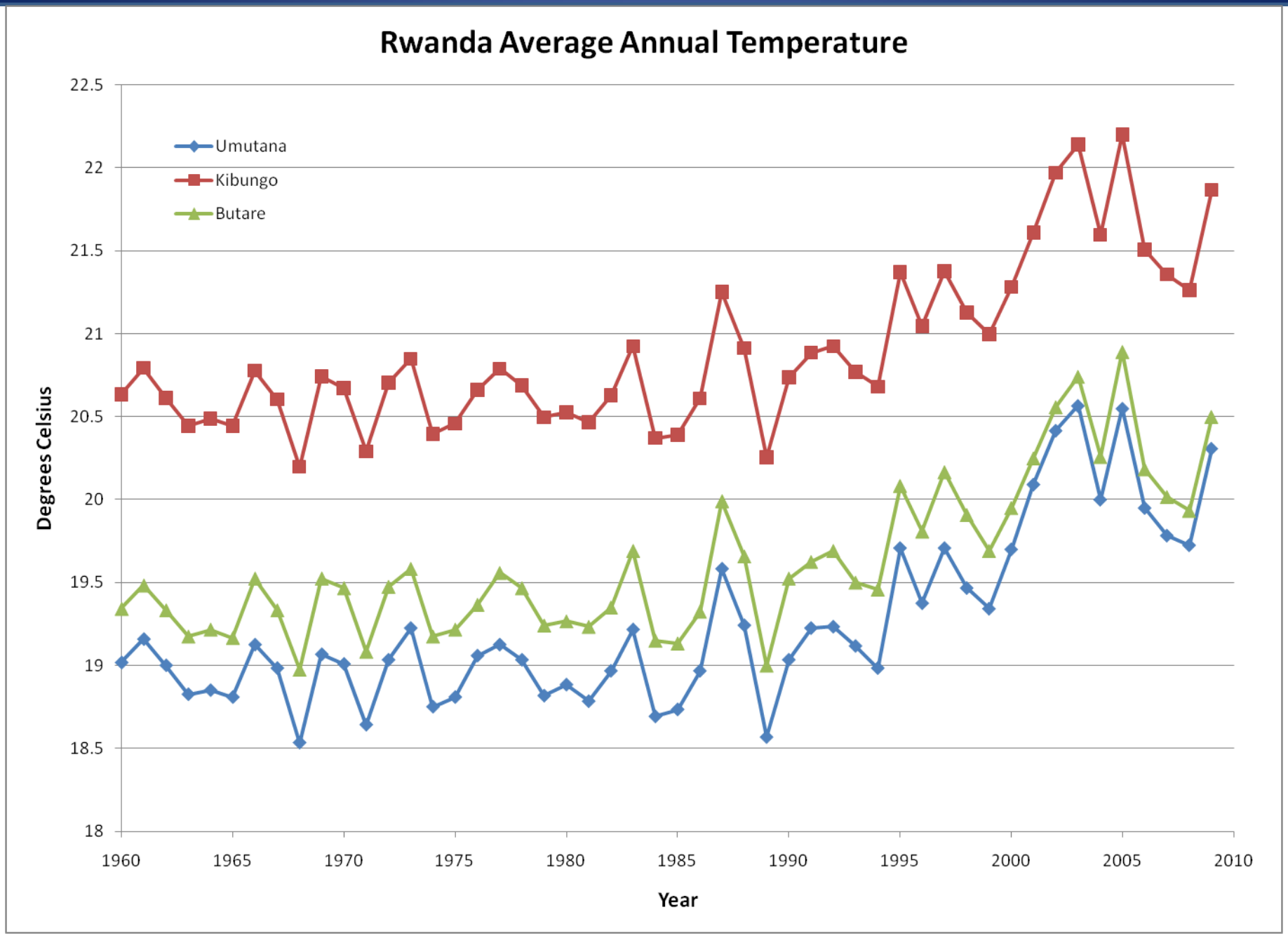
Input Databases

Data	Spatial Resolution	Temporal Resolution	Time Step	Source
Temperature and Precipitation	0.5° x 0.5°	1960-2009	Monthly	Climate Research Unit (CRU) Time-Series (TS) Dataset 3.1; The University of East Anglia
Leaf Area Index	1km x 1km	2000-2006	Monthly	Zhao et al.,2005; Numerical Terradynamic Simulation Group (NTSG) at the University of Montana Missoula MODIS Imagery, MOD15(FPAR/LAI),
Landcover	300m x 300m	2009	static	Globcover, European Space Agency (ESA), MERIS instrument

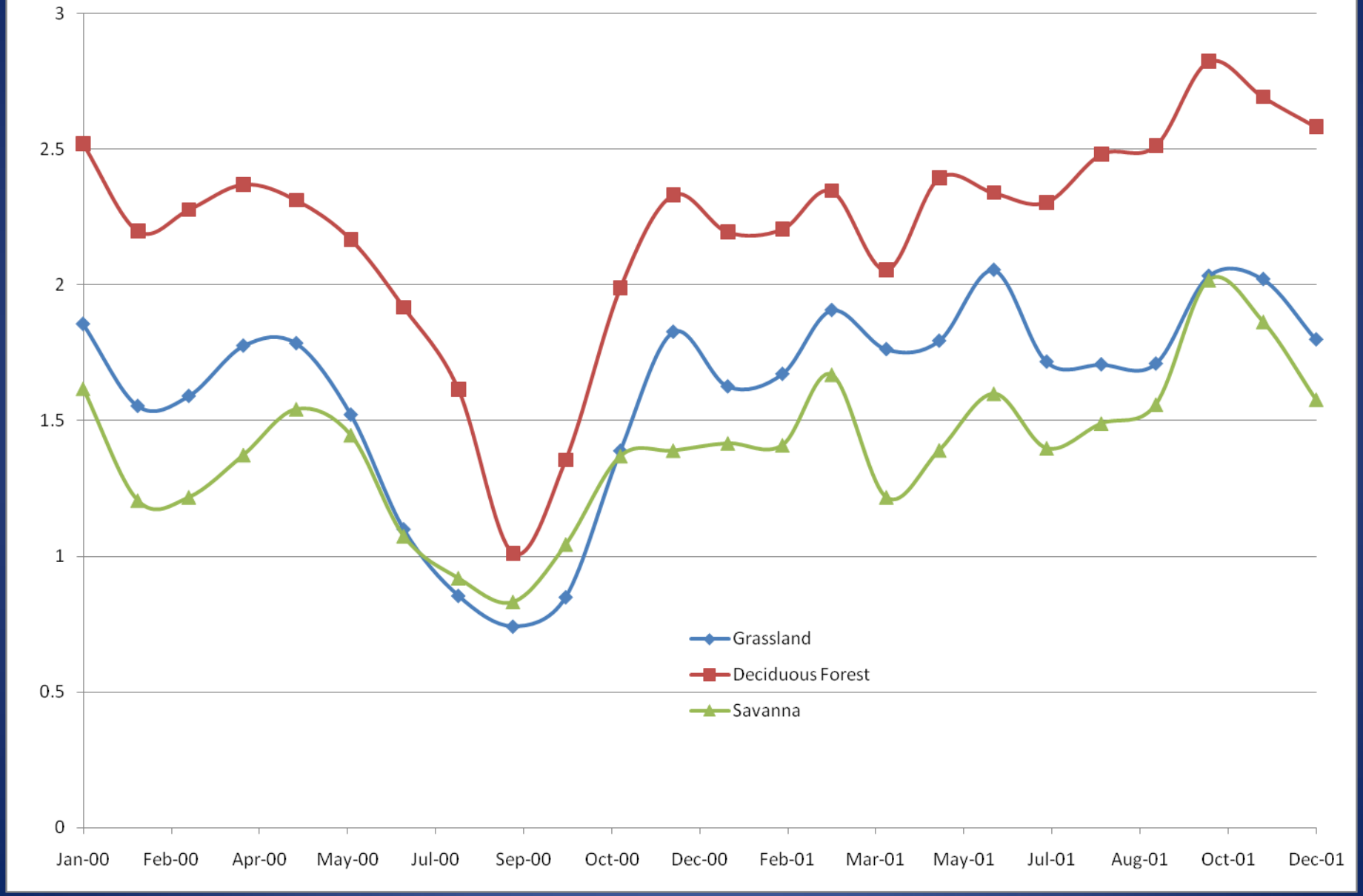
Rwanda Watersheds Delineated from ASTER DEM

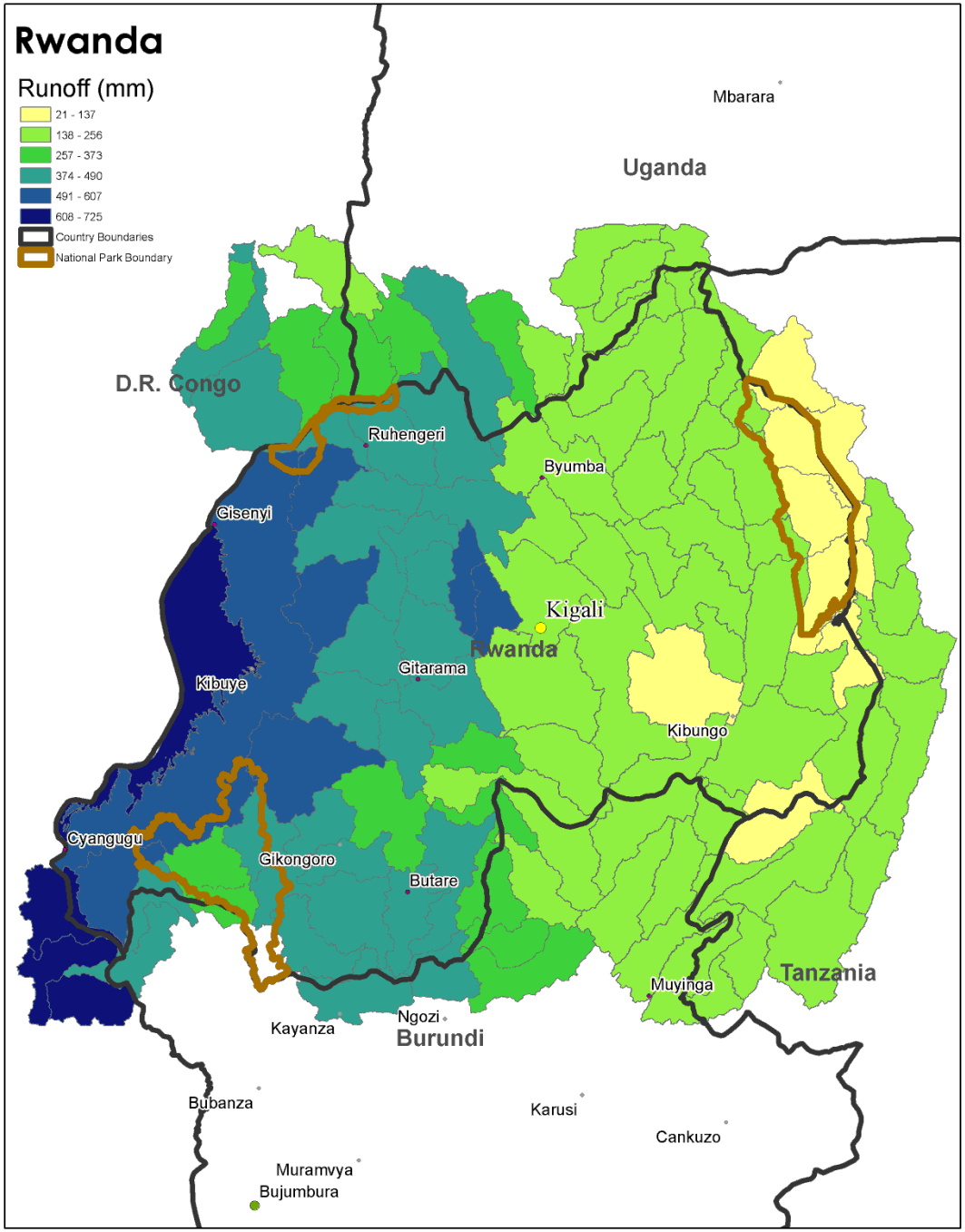



Rwanda Annual Precipitation
Umutana
Kibungo
Butare
mm
Year
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

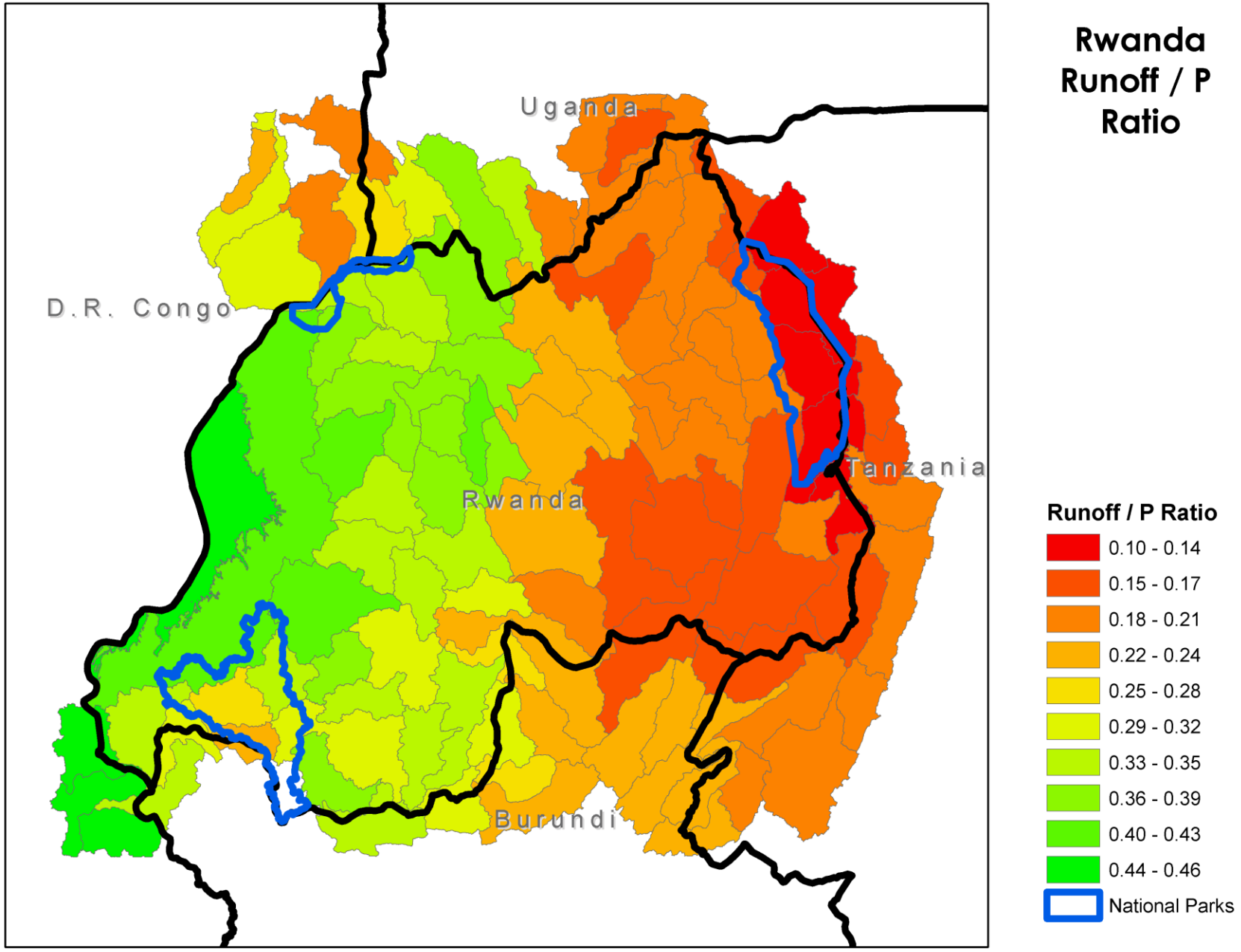

Rwanda Average Annual Temperature
Umutana
Kibungo
Butare
Degrees Celsius
Year
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

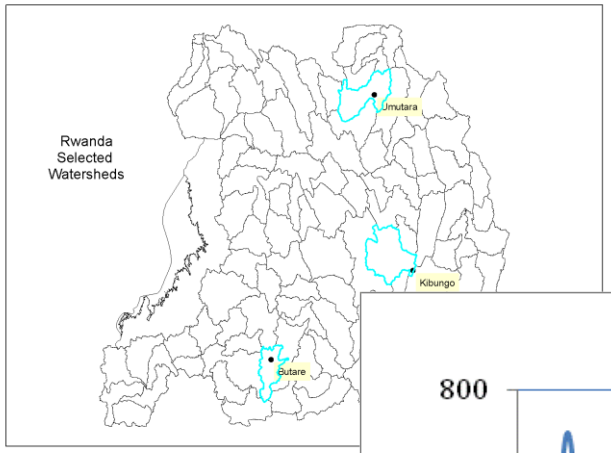
Mean Leaf Area Index by Landuse Butare Watershed




Rwanda
Runoff (mm)
21 - 137
138 - 256
257 - 373
374 - 490
491 - 607
608 - 725
Country Boundaries
National Park Boundary
Mbarara
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Tanzania
Muyinga
Ngozi
Kayanza
Burundi
Bubanza
Karusi
Cankuzo
Muramvya
Bujumbura

Rwanda Runoff / P Ratio





Model ed Runoff , Butare Watershed and Rwanda Mean

y = -2.5x + 5303
R² = 0.0875

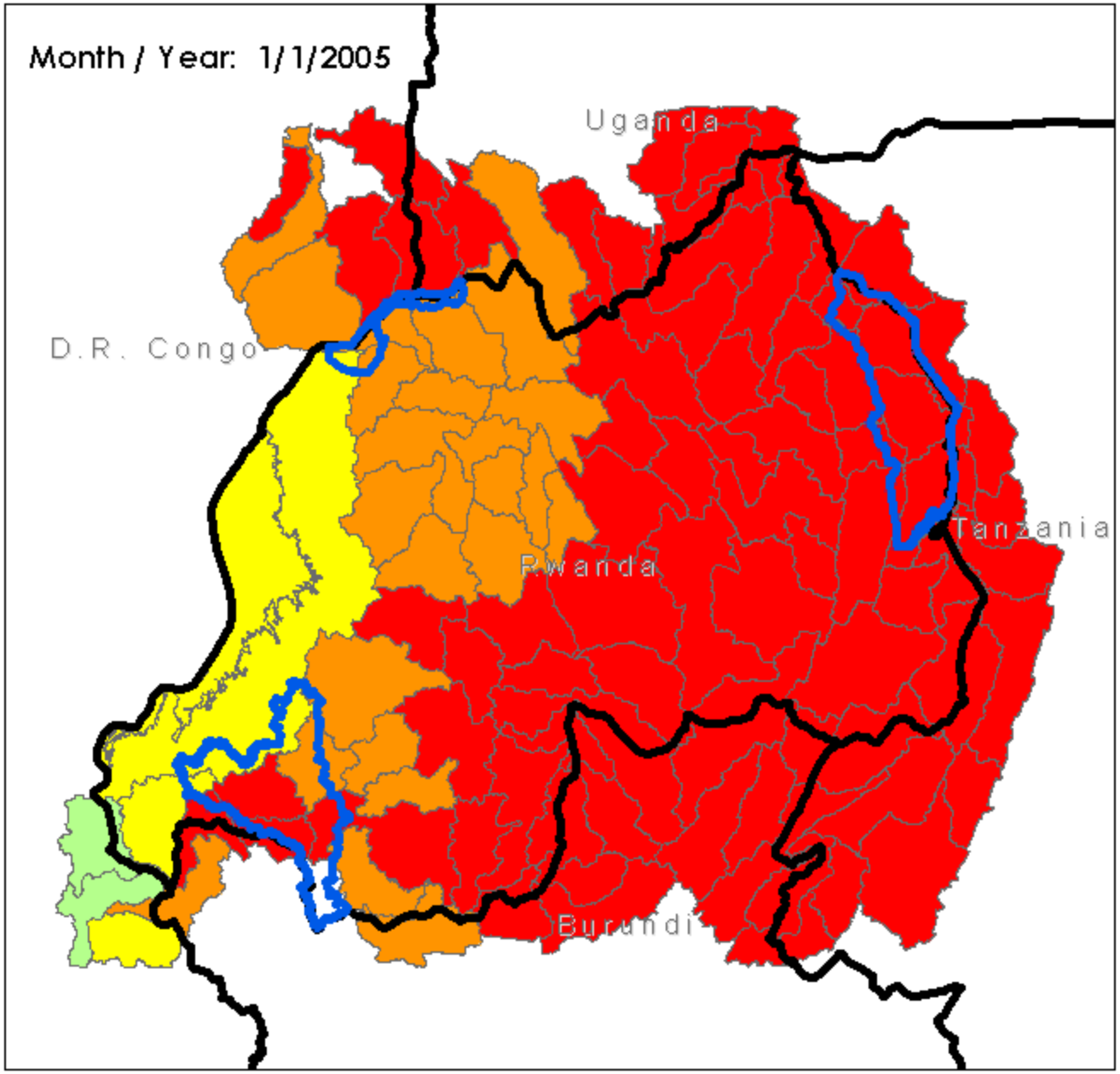
y = -2.3x + 4835.1
R² = 0.1608

P<0.05

Runoff (Butare)
Runoff (Rwanda)
Linear (Runoff (Butare))
Linear (Runoff (Rwanda))

Annual Runoff (mm/year)

Year



Rwanda Monthly Runoff

2005 - 2009

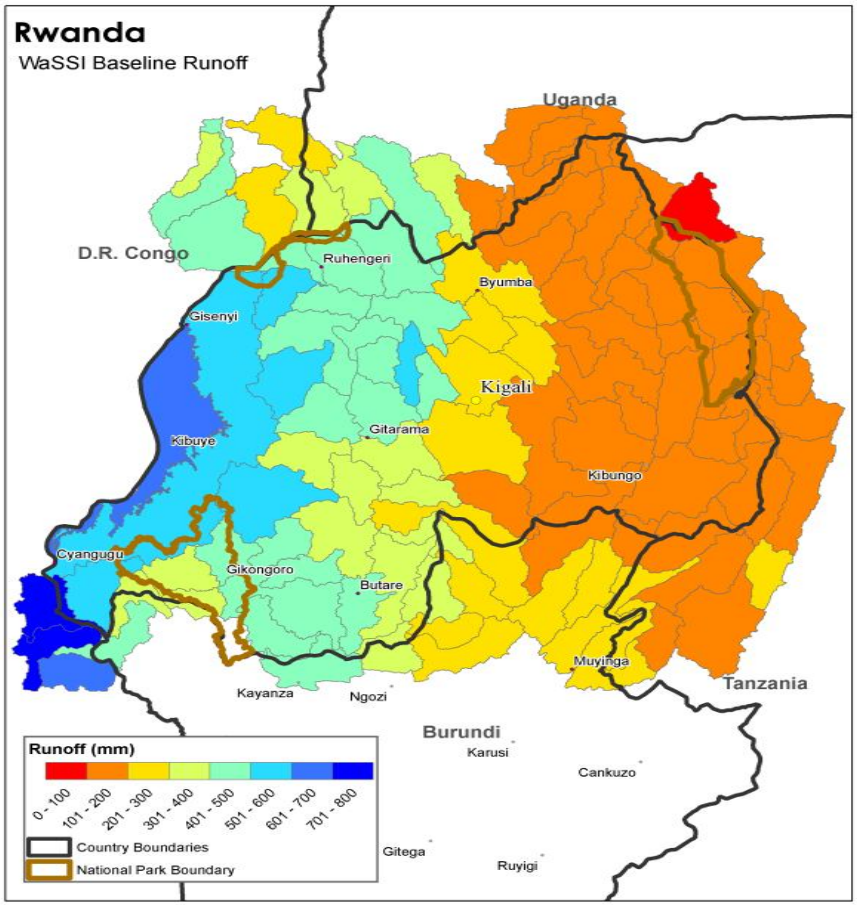
National Parks

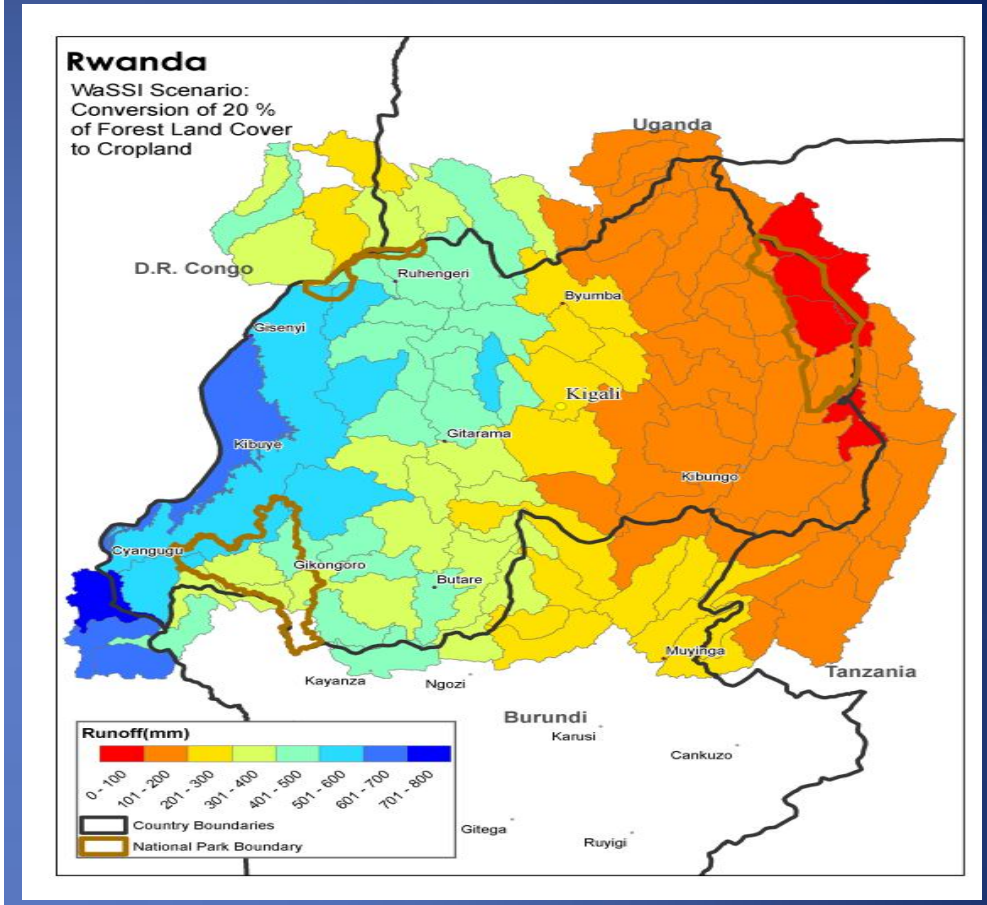
Runoff (mm)

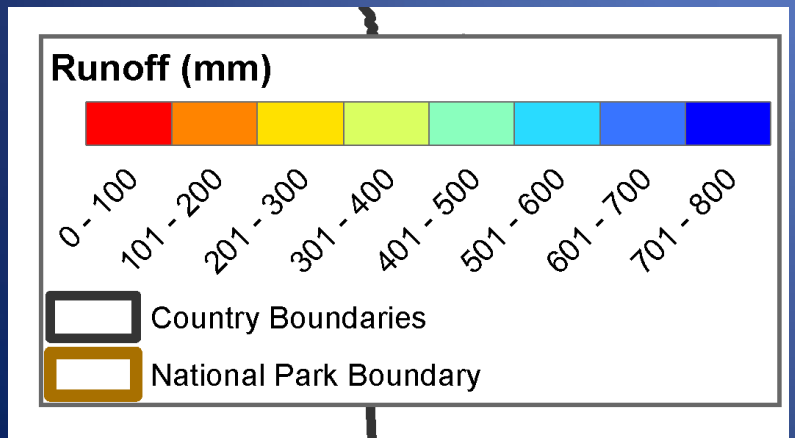
- 151 - 175
- 126 - 150
- 101 - 125
- 76 - 100
- 51 - 75
- 26 - 50
- 0 - 25

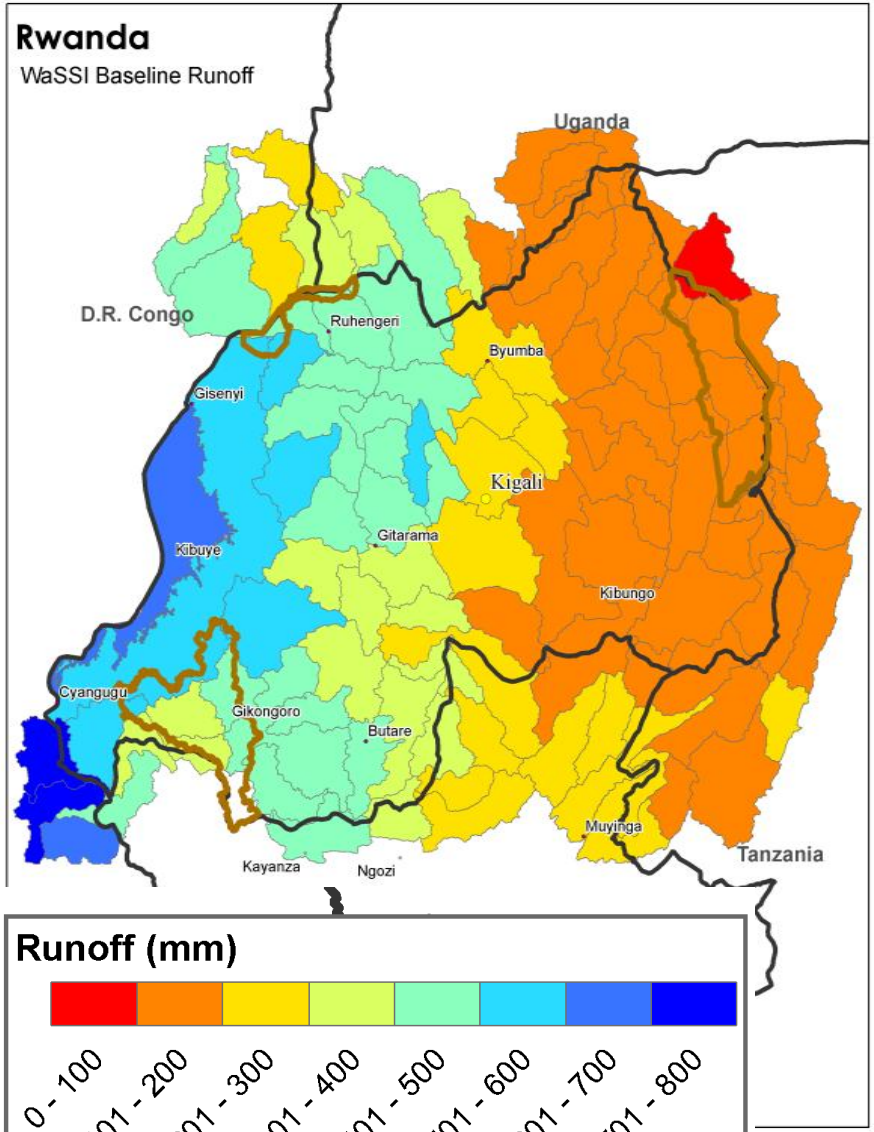
Result Scenario: Runoff

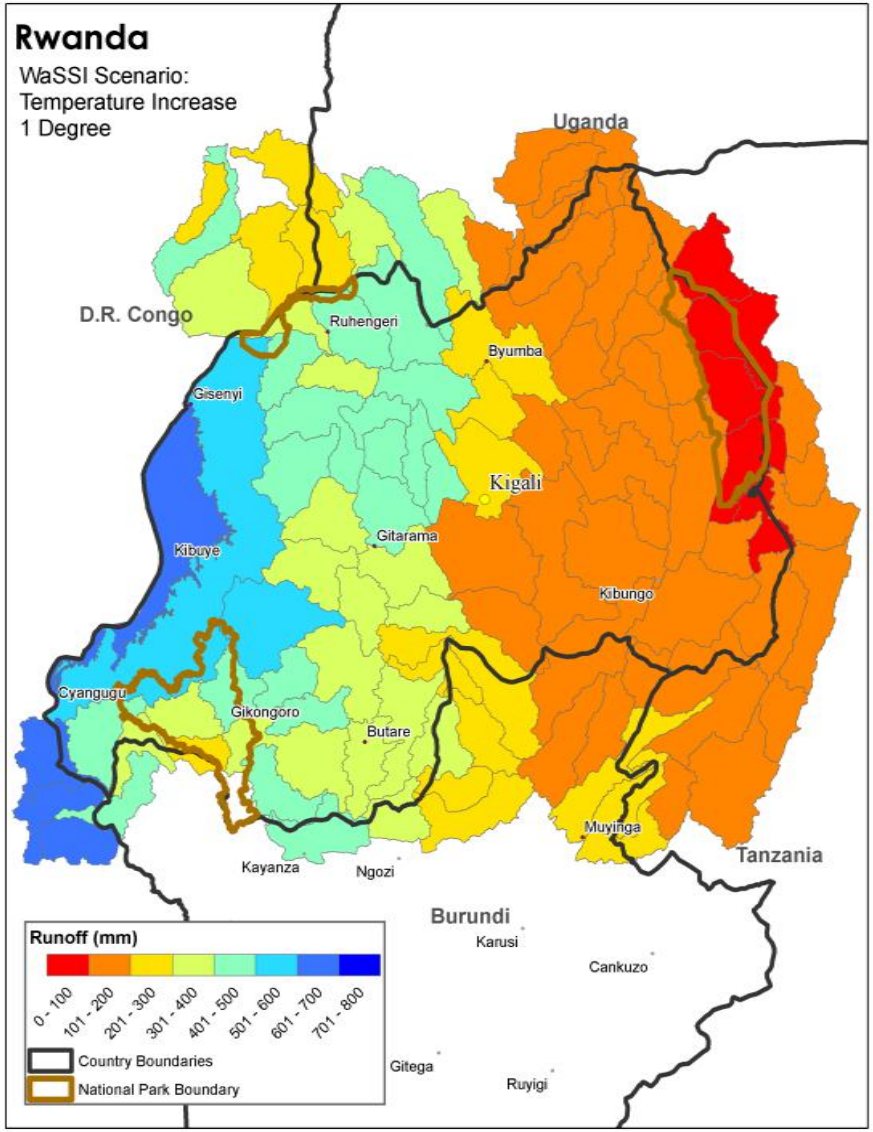
- Scenarios
  - Baseline
    - 2009 landcover
    - Monthly precipitation and temperature from 1960-2009
  - Climate Change (Temp increase 1 degree; Precip reduced 10%+ Temp increase 1 degree)
  - Deforestation
    - Simulate converting 20% forest to crop
      - LAI changed to 2.0 if cropland does not exist

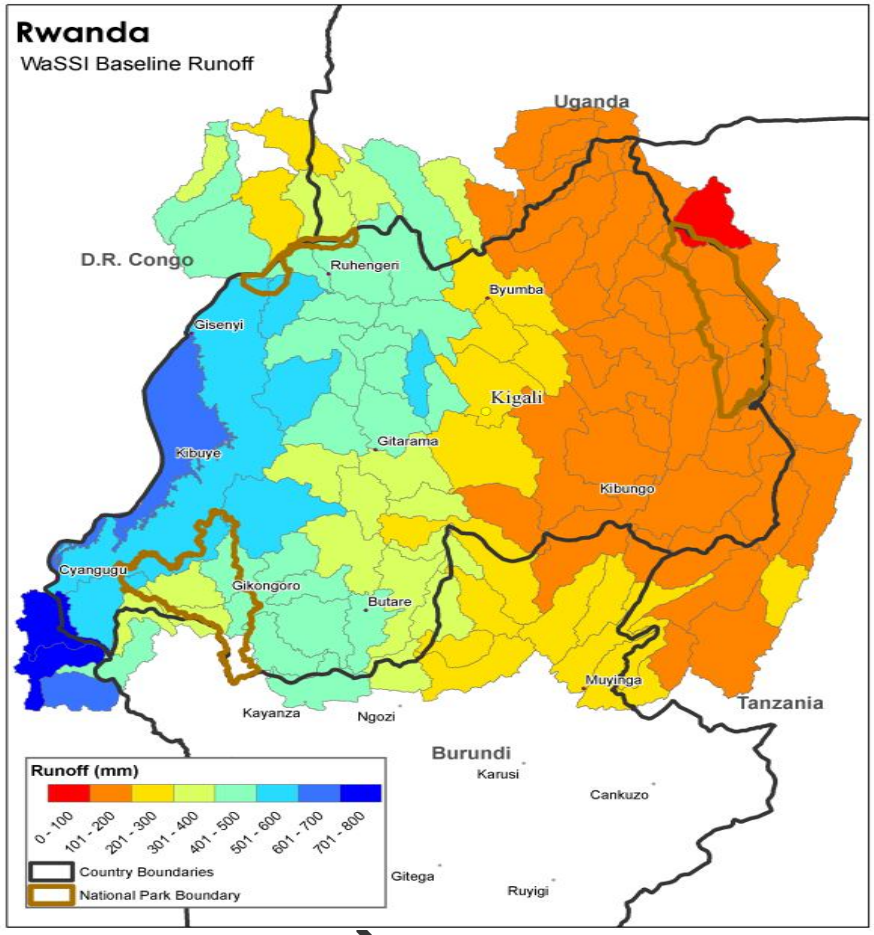

Rwanda
WaSSI Baseline Runoff
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Burundi
Karusi
Cankuzo
Gitega
Ruyigi
Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

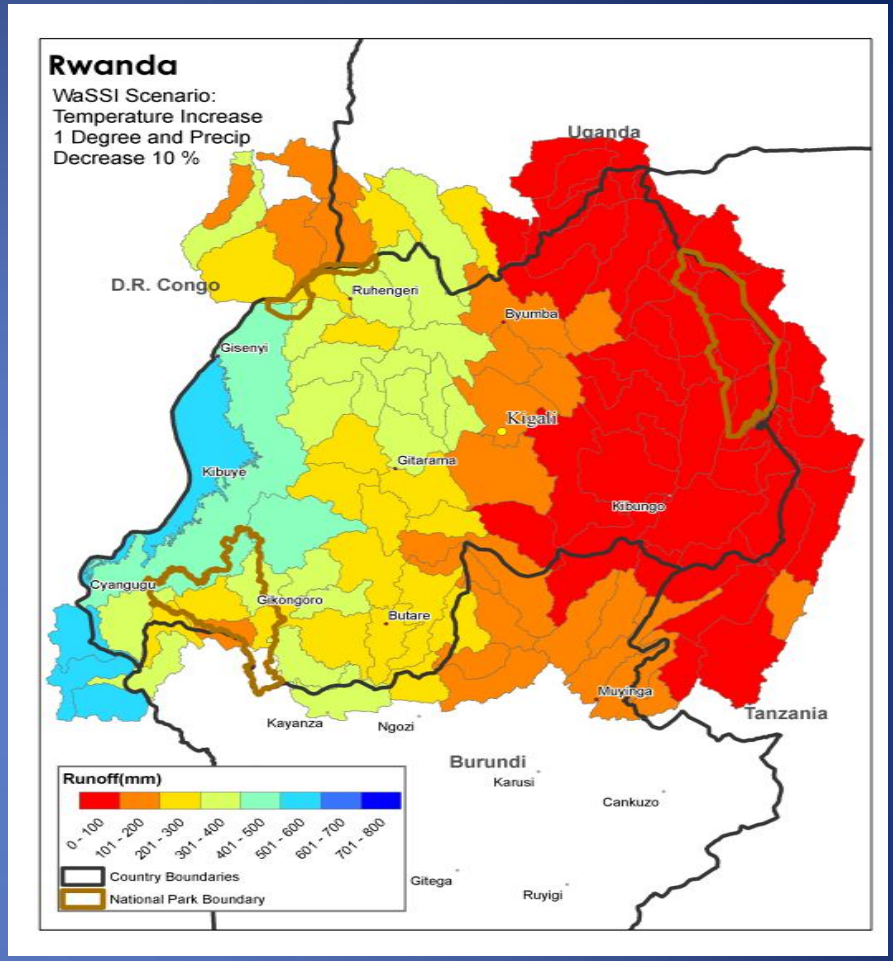

Rwanda
WaSSI Scenario:
Conversion of 20 %
of Forest Land Cover
to Cropland
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Burundi
Karusi
Cankuzo
Gitega
Ruyigi
Runoff(mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

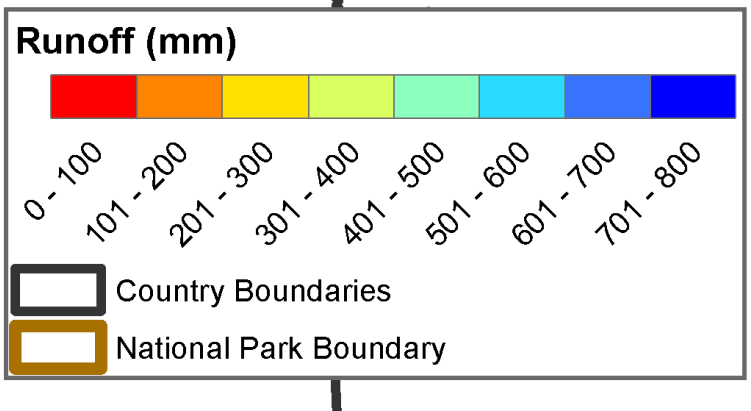

Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

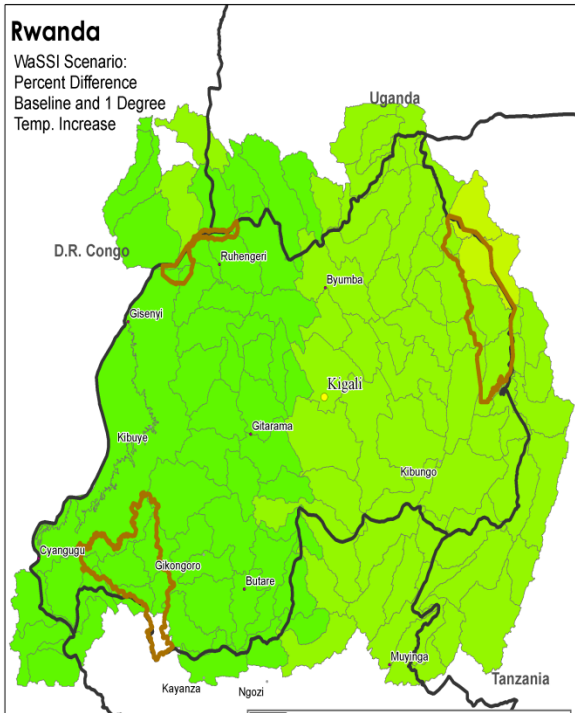

Rwanda
WaSSI Baseline Runoff
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

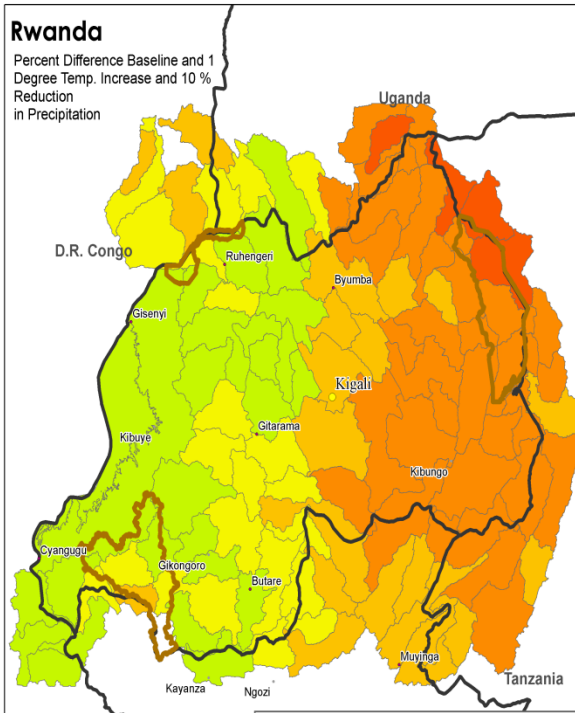

Rwanda
WaSSI Scenario:
Temperature Increase
1 Degree
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Burundi
Karusi
Cankuzo
Gitega
Ruyigi
Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

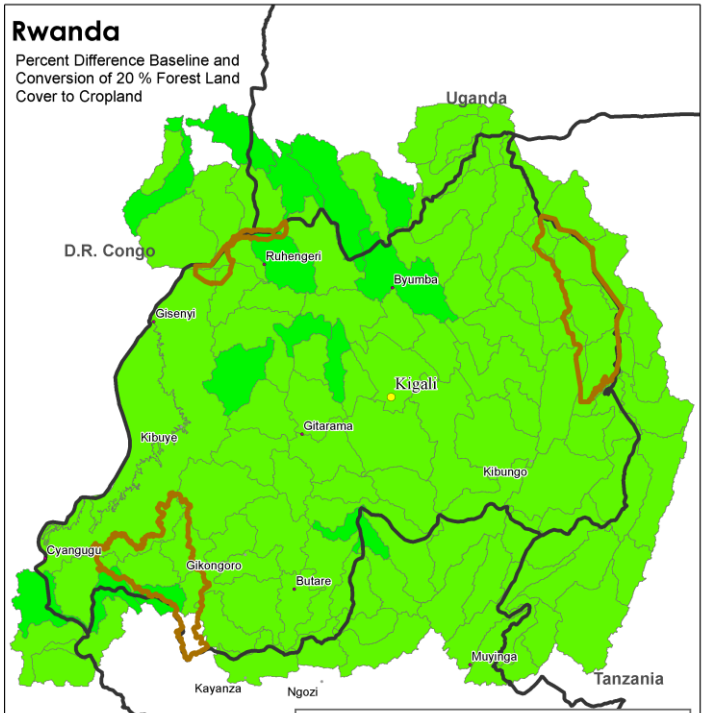

Rwanda
WaSSI Baseline Runoff
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Burundi
Karusi
Cankuzo
Gitega
Ruyigi
Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary

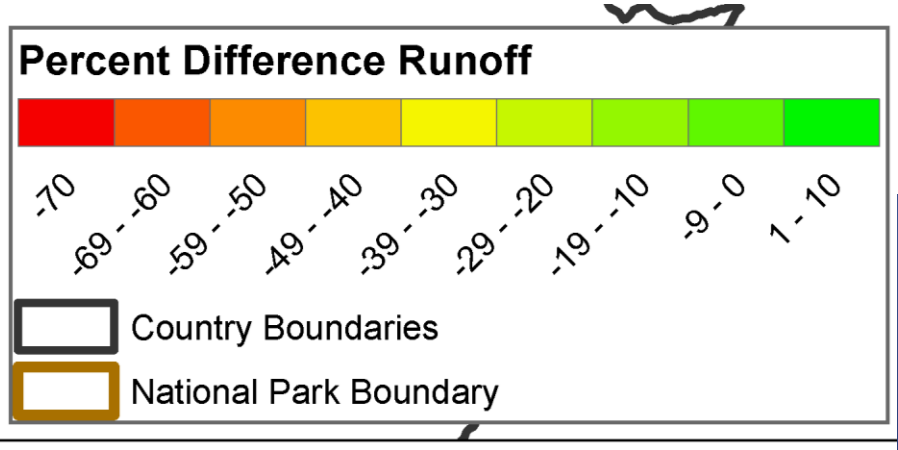

Rwanda
WaSSI Scenario:
Temperature Increase
1 Degree and Precip
Decrease 10 %
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania
Burundi
Karusi
Cankuzo
Gitega
Ruyigi
Runoff(mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary


Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Country Boundaries
National Park Boundary


Rwanda
WaSSI Scenario:
Percent Difference
Baseline and 1 Degree
Temp. Increase
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania

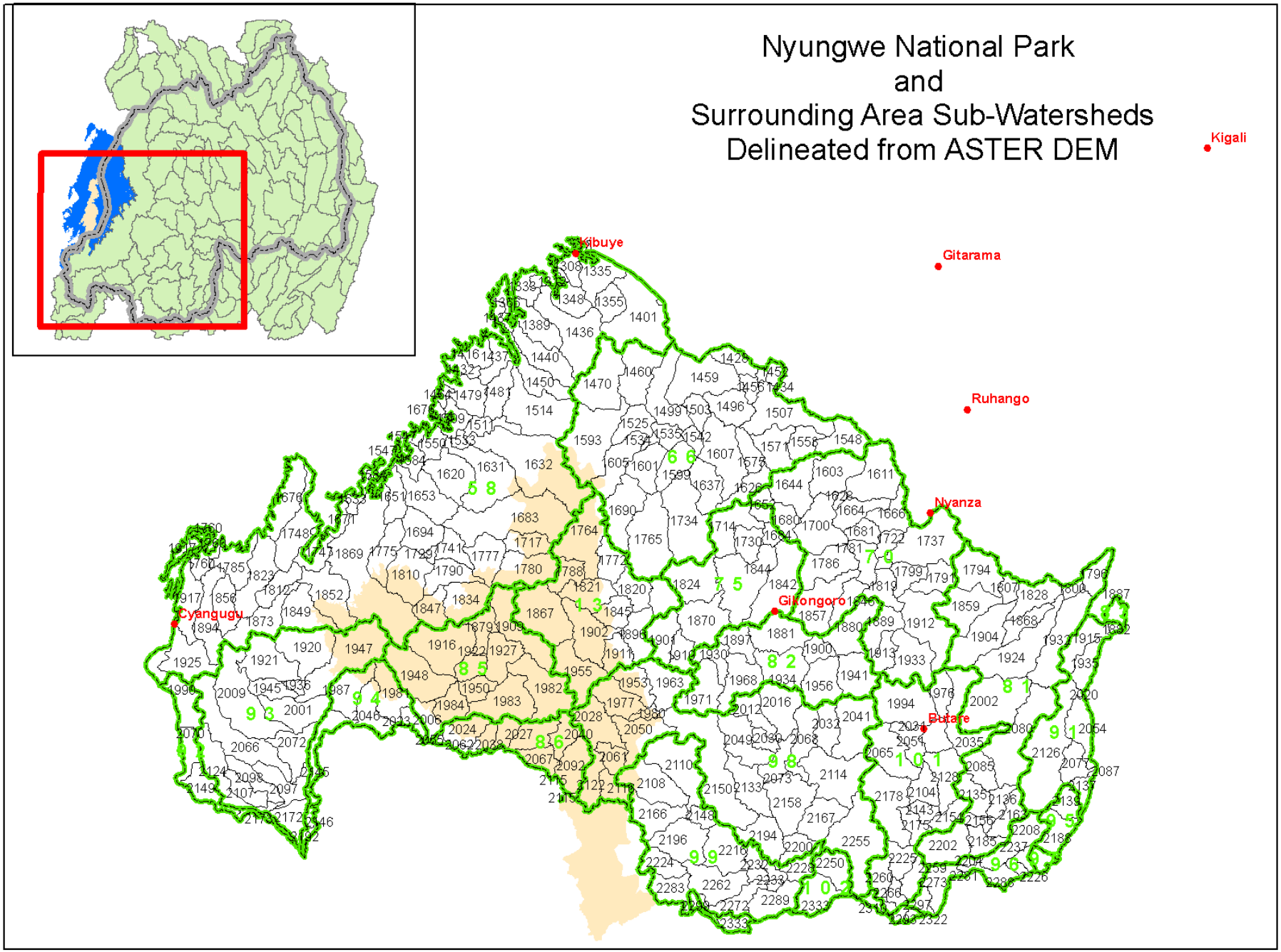

Rwanda
Percent Difference Baseline and 1
Degree Temp. Increase and 10 %
Reduction
in Precipitation
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania


Rwanda
Percent Difference Baseline and
Conversion of 20 % Forest Land
Cover to Cropland
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Tanzania


Percent Difference Runoff
-70
-69 - -60
-59 - -50
-49 - -40
-39 - -30
-29 - -20
-19 - -10
-9 - 0
1 - 10
Country Boundaries
National Park Boundary

Result Scenario: Sedimentation

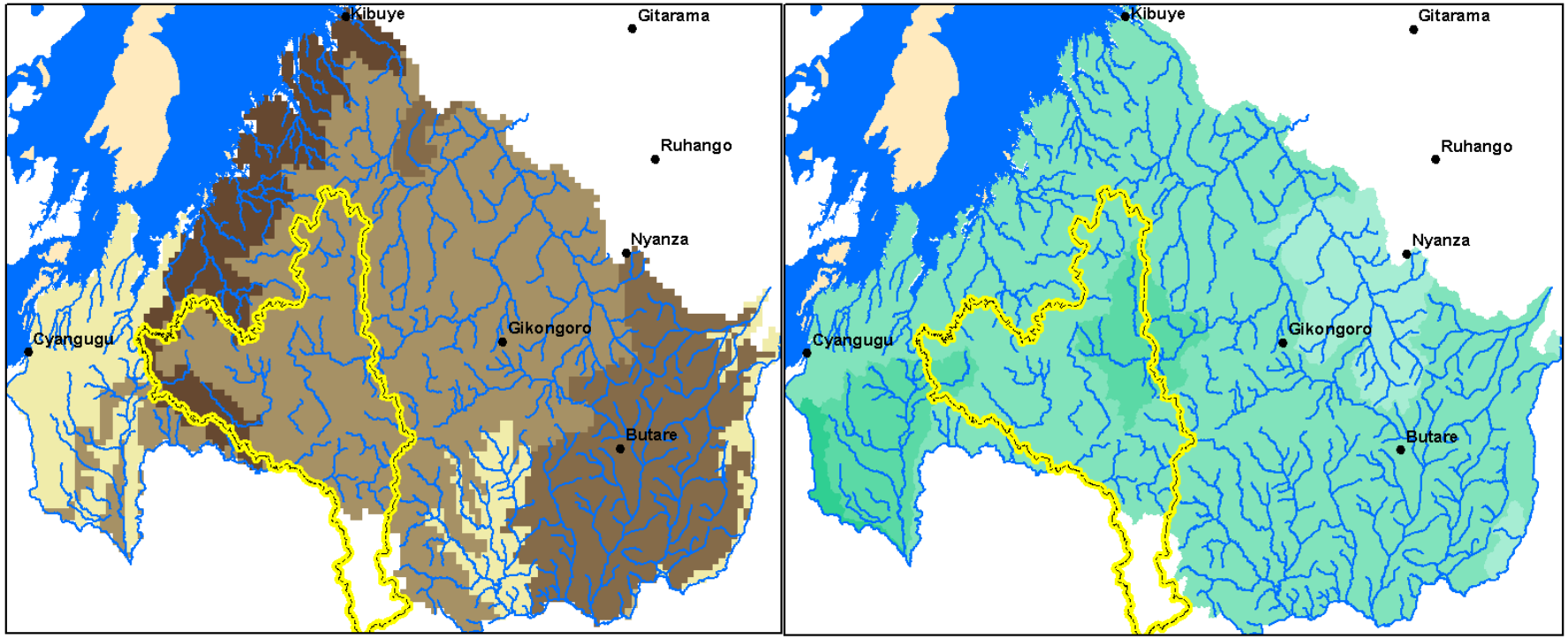
- Scenarios (2)
  - Baseline
    - 2009 landcover
    - Monthly precipitation and temperature from 1960-2009
  - Deforestation
    - Simulate converting one forest landcover class to crop
      - Open(15-40%) broadleaved deciduous forest/woodland (>5m)


Nyungwe National Park
and
Surrounding Area Sub-Watersheds
Delineated from ASTER DEM
Kigali
Kibuye
Gitarama
Ruhango
Nyanza
Gikongoro
Cyangugu
Butare

Universal Soil Loss Equation

$$A = R * K * LS * C * P$$

A: Average annual soil loss (Tons/ha*yr)
R : Rainfall and runoff erosivity
K: Soil erodibility
LS: Slope length-gradient factor
C: Crop and management Factor
P: Support practice factor



Soil Erodibility (K)

T*ha*h/ha*MJ*mm

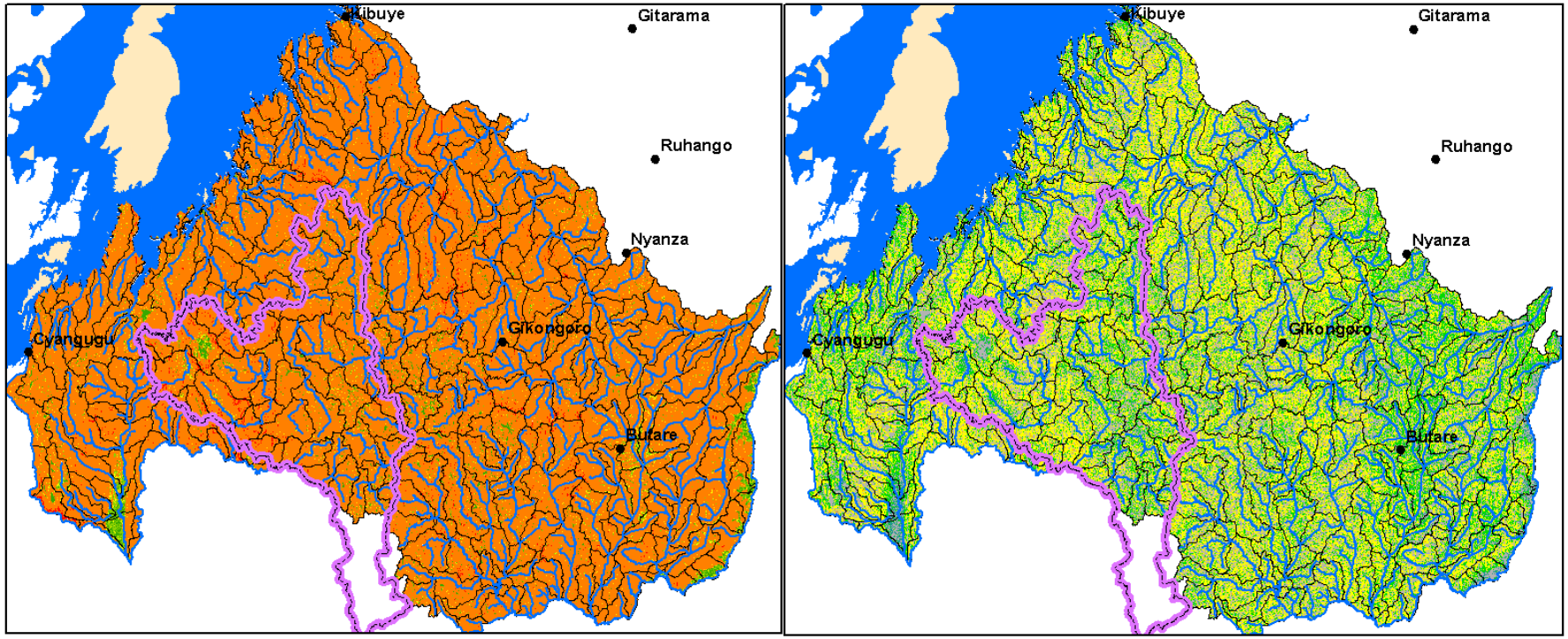
- 0 - 0.02
- 0.02 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.06

- Towns
- Nyungwe National Park
- Lake Kivu

Rainfall Erosivity (R)

MJ*mm/ha*h*yr

- 6,743 - 7,000
- 7,000 - 9,000
- 9,000 - 11,000
- 11,000 - 13,000
- 13,000 - 14,186



Slope

- 0% - 1.1%
- 1.2% - 3.5%
- 3.6% - 5%
- 5.1% - 75%
- 75.1% - 200%

- Towns
- Nyungwe National Park
- Lake Kivu

Slope Length (m)

- 0
- 0 - 1
- 1 - 10
- 10 - 100
- 100 - 1,000
- 1,000 - 1,525

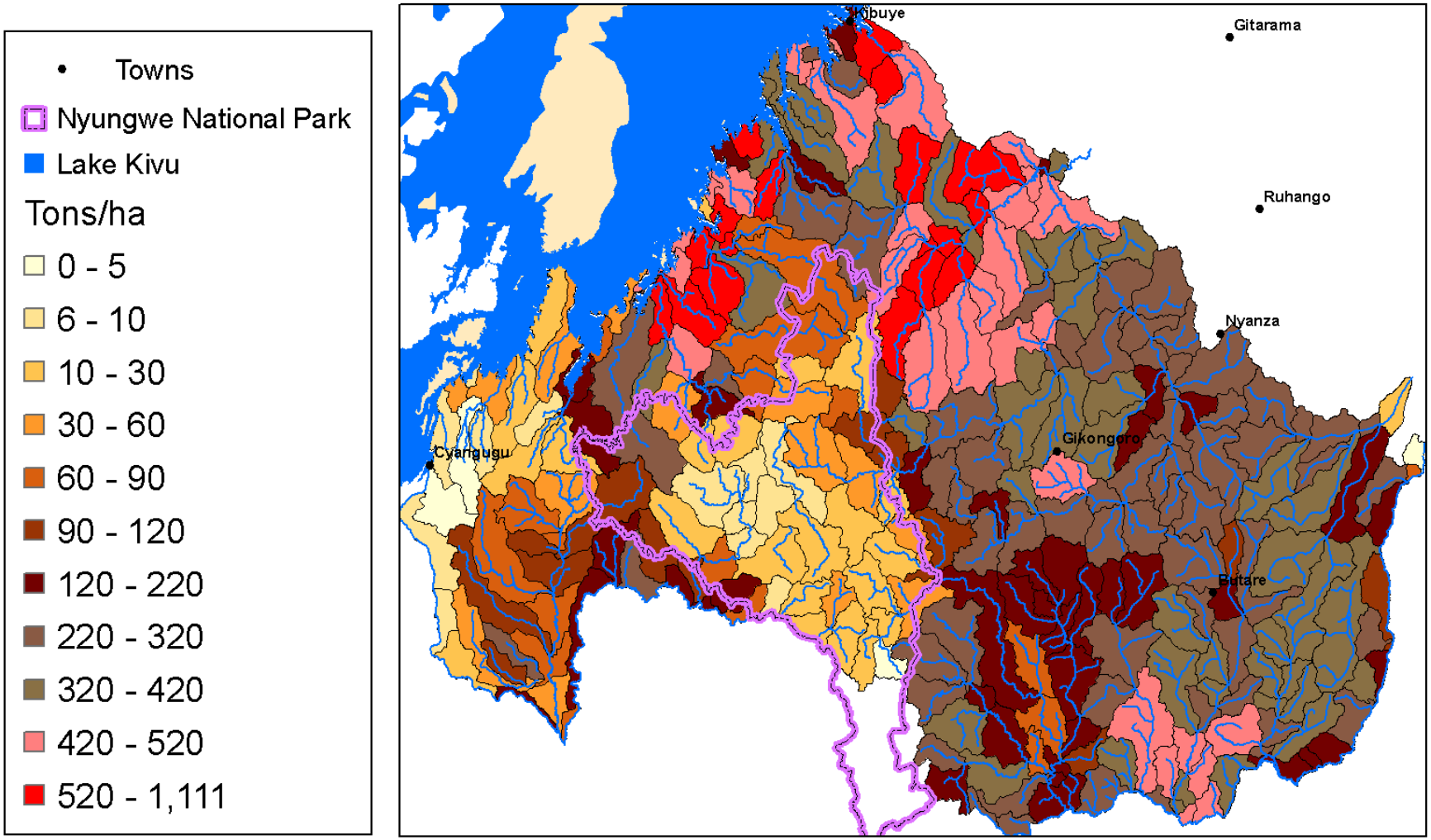
Cover and Management Factor(C) and Practice Factor (P)

lucode	LULC_desc	usle_c	usle_p
14	Rainfed croplands	0.07	0.5
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	0.07	0.5
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	0.1	1
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0.001	1
50	Closed (>40%) broadleaved deciduous forest (>5m)	0.001	1
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	0.001	1
70	Closed (>40%) needleleaved evergreen forest (>5m)	0.001	1
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	0.001	1
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	0.001	1
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	0.1	1
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	0.1	1
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	0.001	1
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	0.1	1
150	Sparse (<15%) vegetation	0	1
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	0	1
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	0	1
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0	1
190	Artificial surfaces and associated areas (Urban areas >50%)	0	1
200	Bare areas	0	1
210	Water bodies	0	1

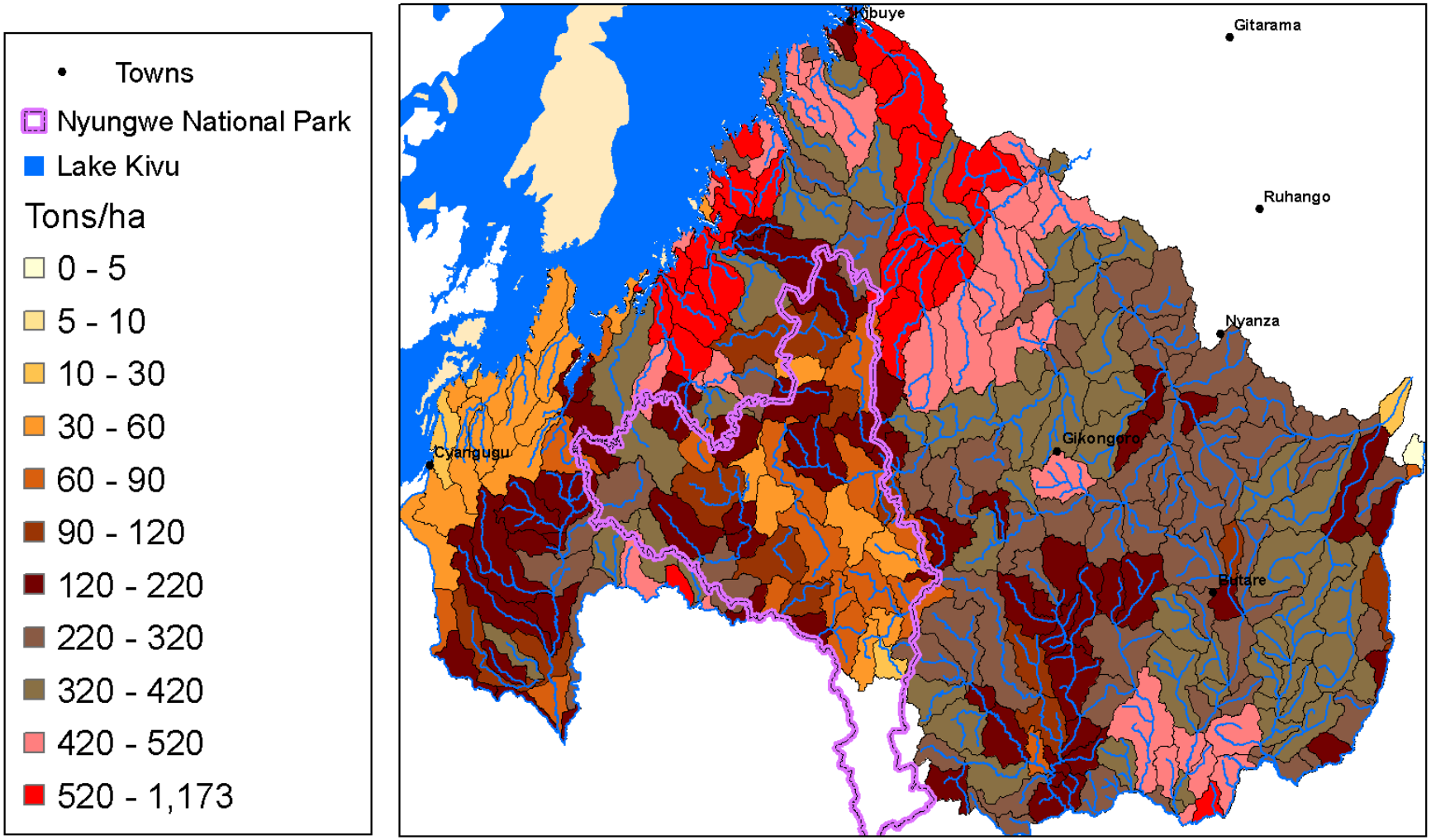
•Georgia Soil Water and Conservation Commission, 2000, Manuel for Erosion and Sediment Control in Georgia

•USLE Fact Sheet, Ontario Ministry of Agriculture Food and Rural Affairs

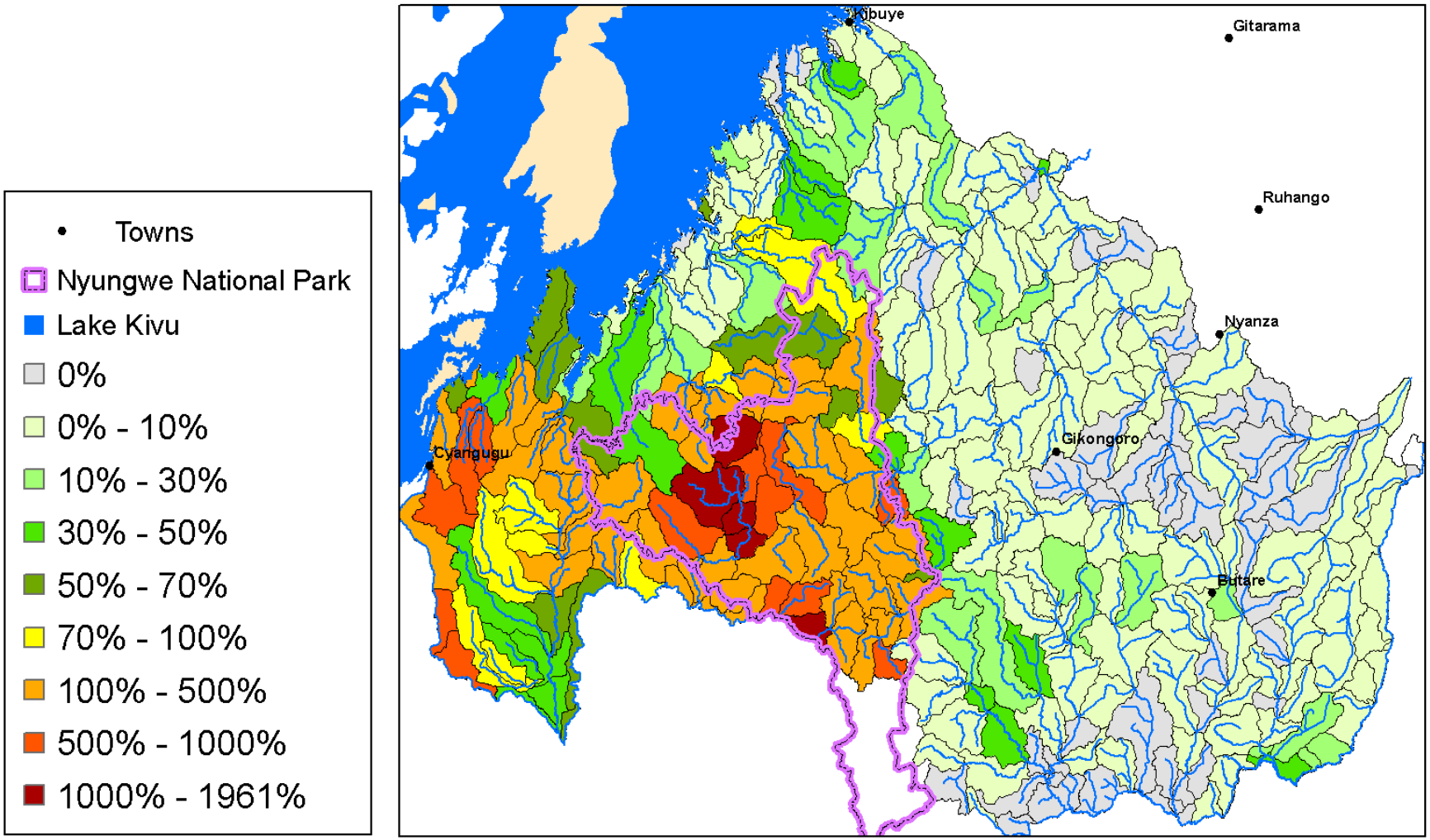
Universal Soil Loss Equation Mean Potential Soil Loss by Watershed: Baseline



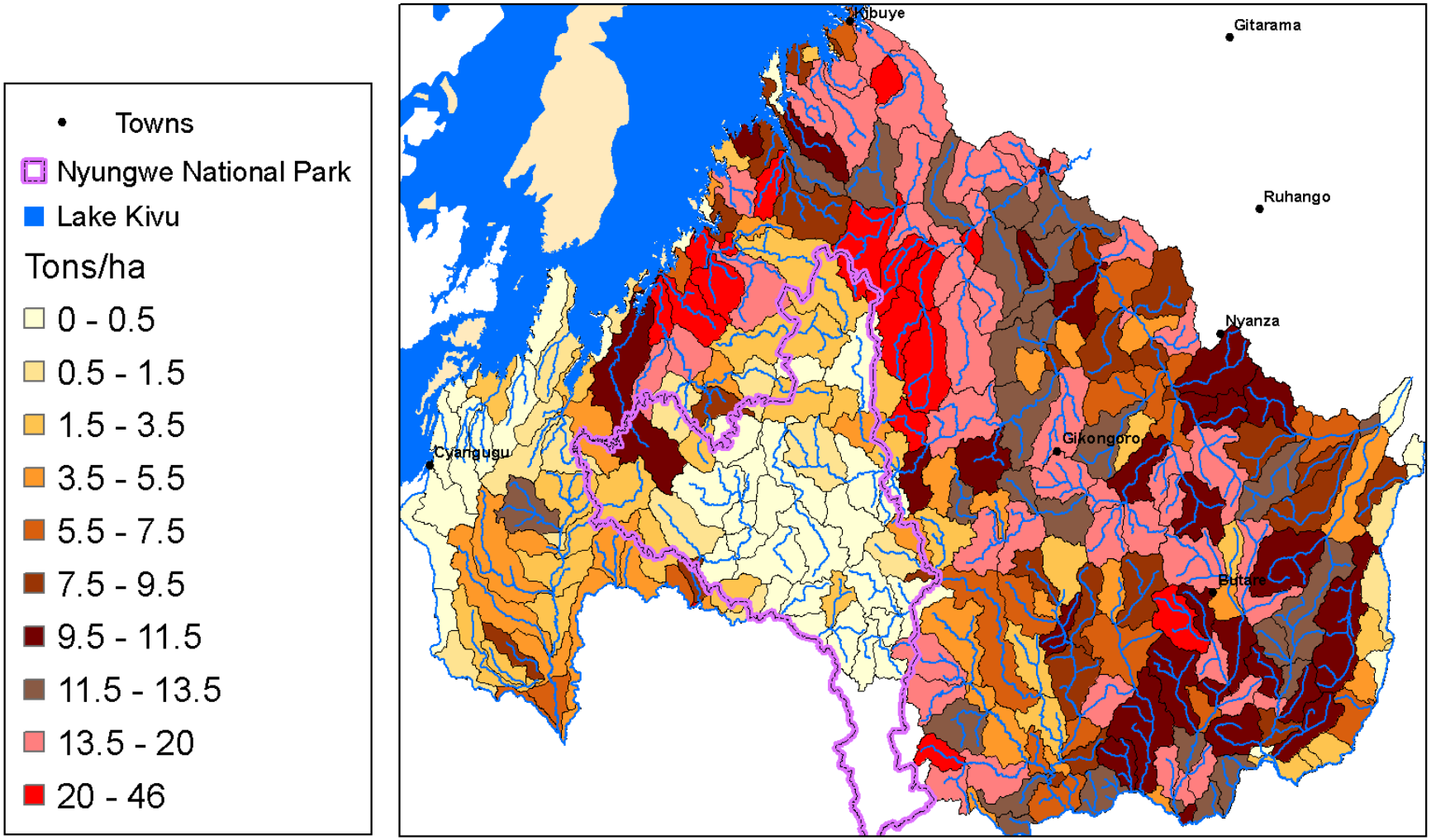
Universal Soil Loss Equation Mean
Potential Soil Loss by Watershed: Deforestation



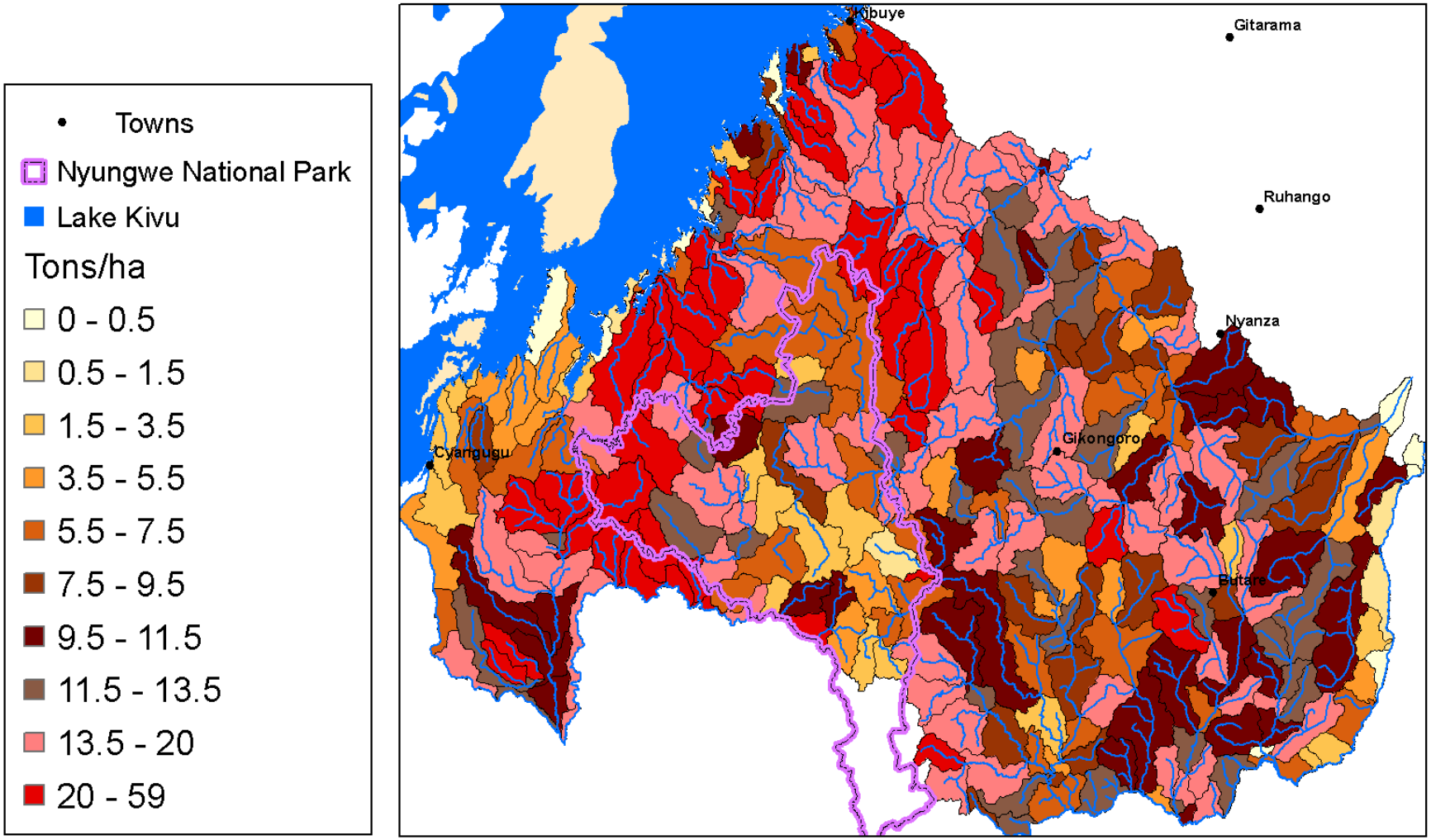
Universal Soil Loss Equation Potential Soil Loss by Watershed: Percent Difference



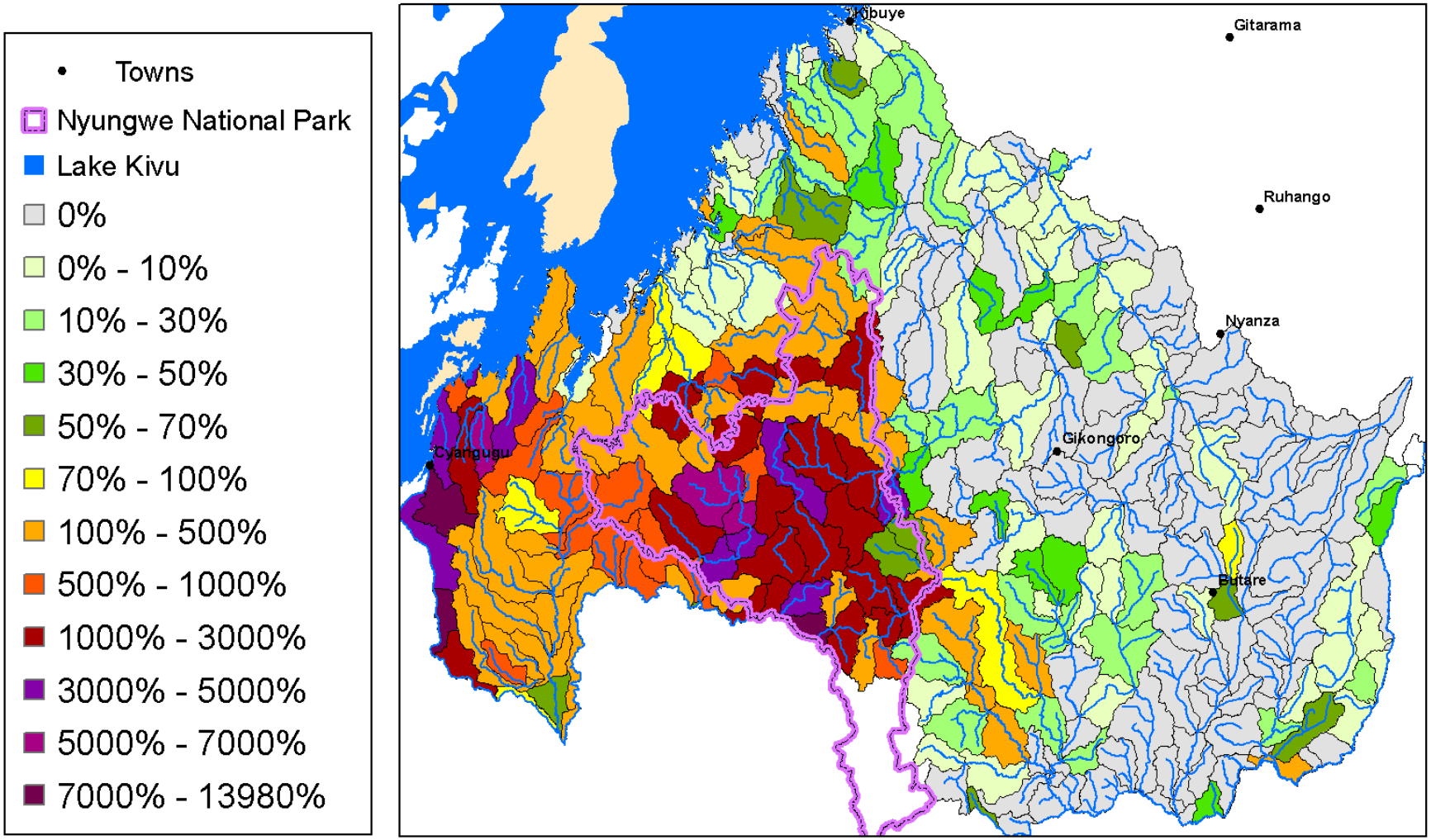
Mean Sediment Exported by Watershed: Baseline

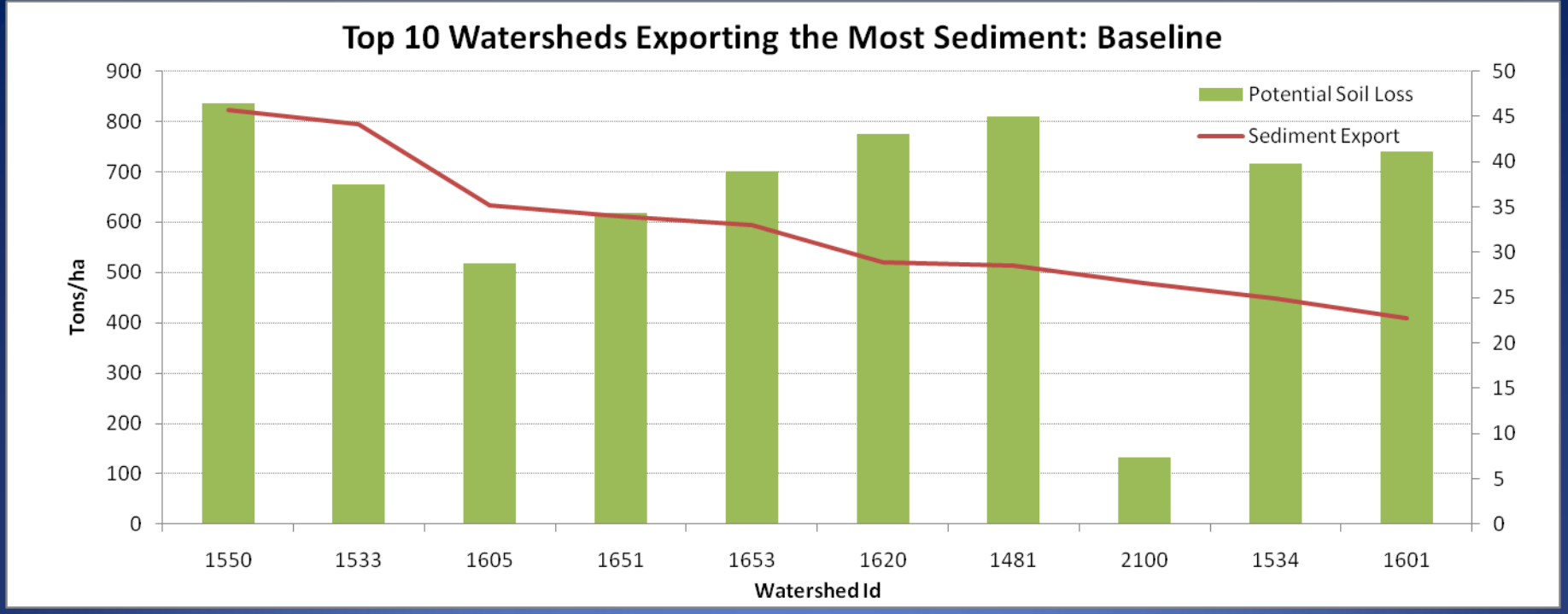


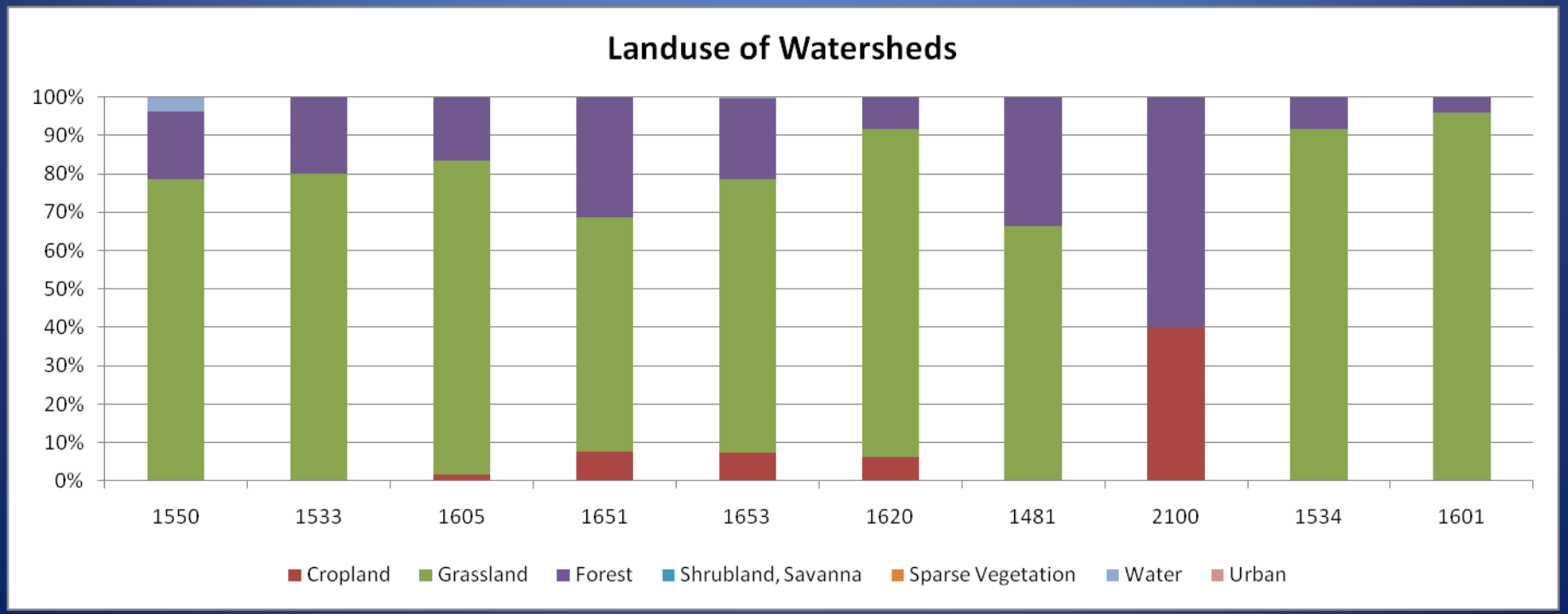
Mean Sediment Exported by Watershed: Deforestation

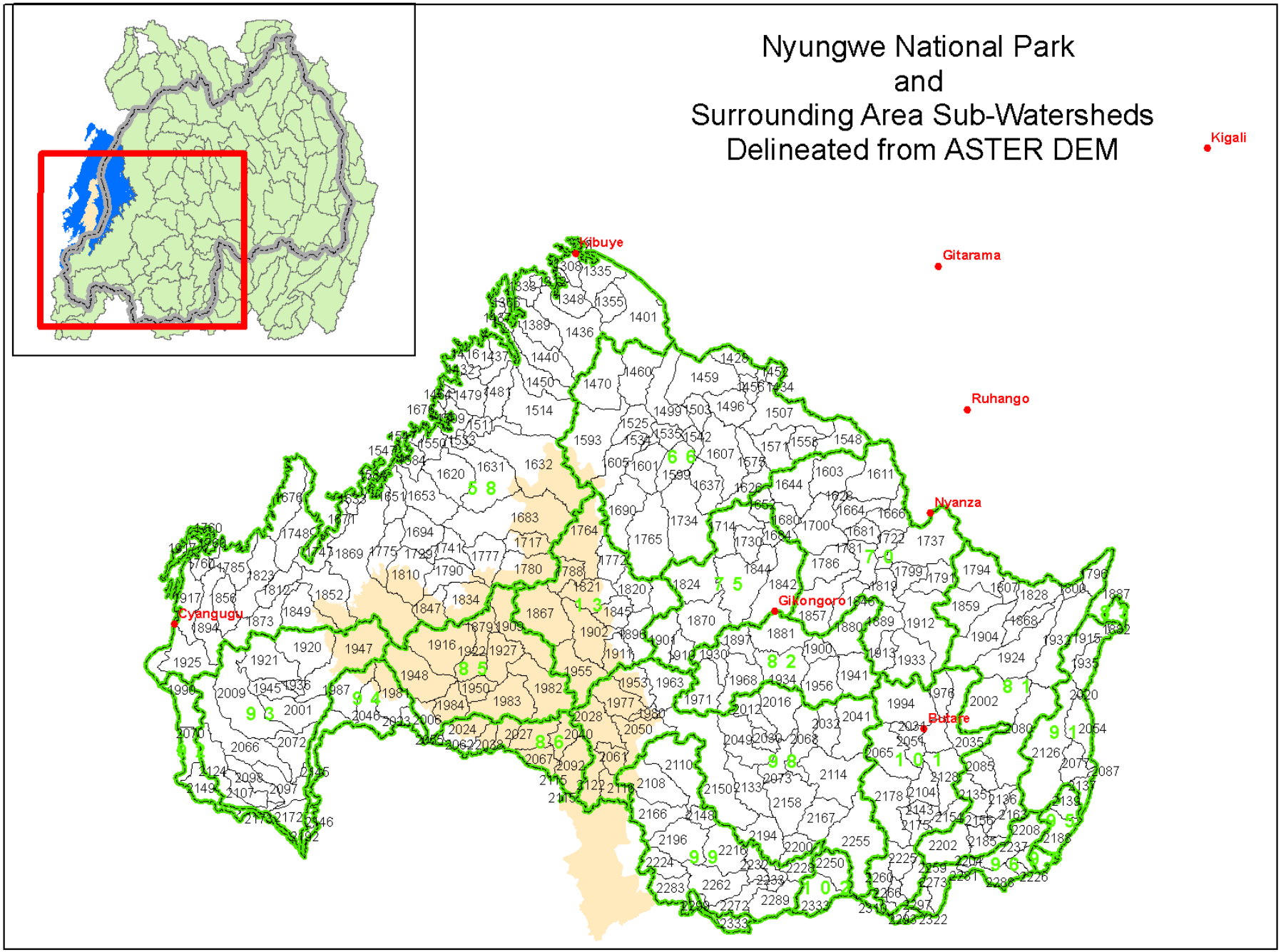


Sediment Exported by Watershed: Percent Difference

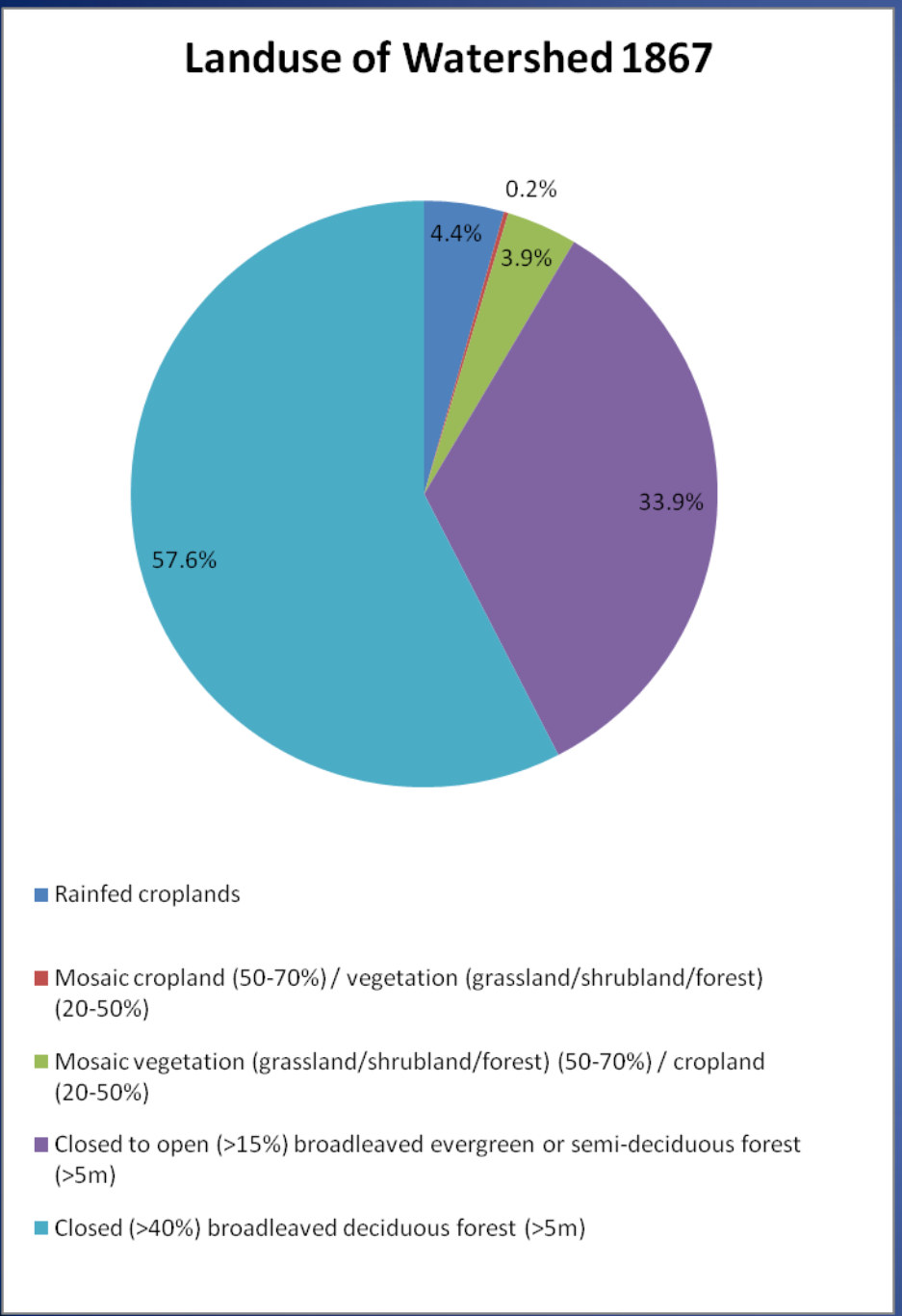



Top 10 Watersheds Exporting the Most Sediment: Baseline
Potential Soil Loss
Sediment Export
Tons/ha
900
800
700
600
500
400
300
200
100
0
50
45
40
35
30
25
20
15
10
5
0
1550
1533
1605
1651
1653
1620
1481
2100
1534
1601
Watershed Id

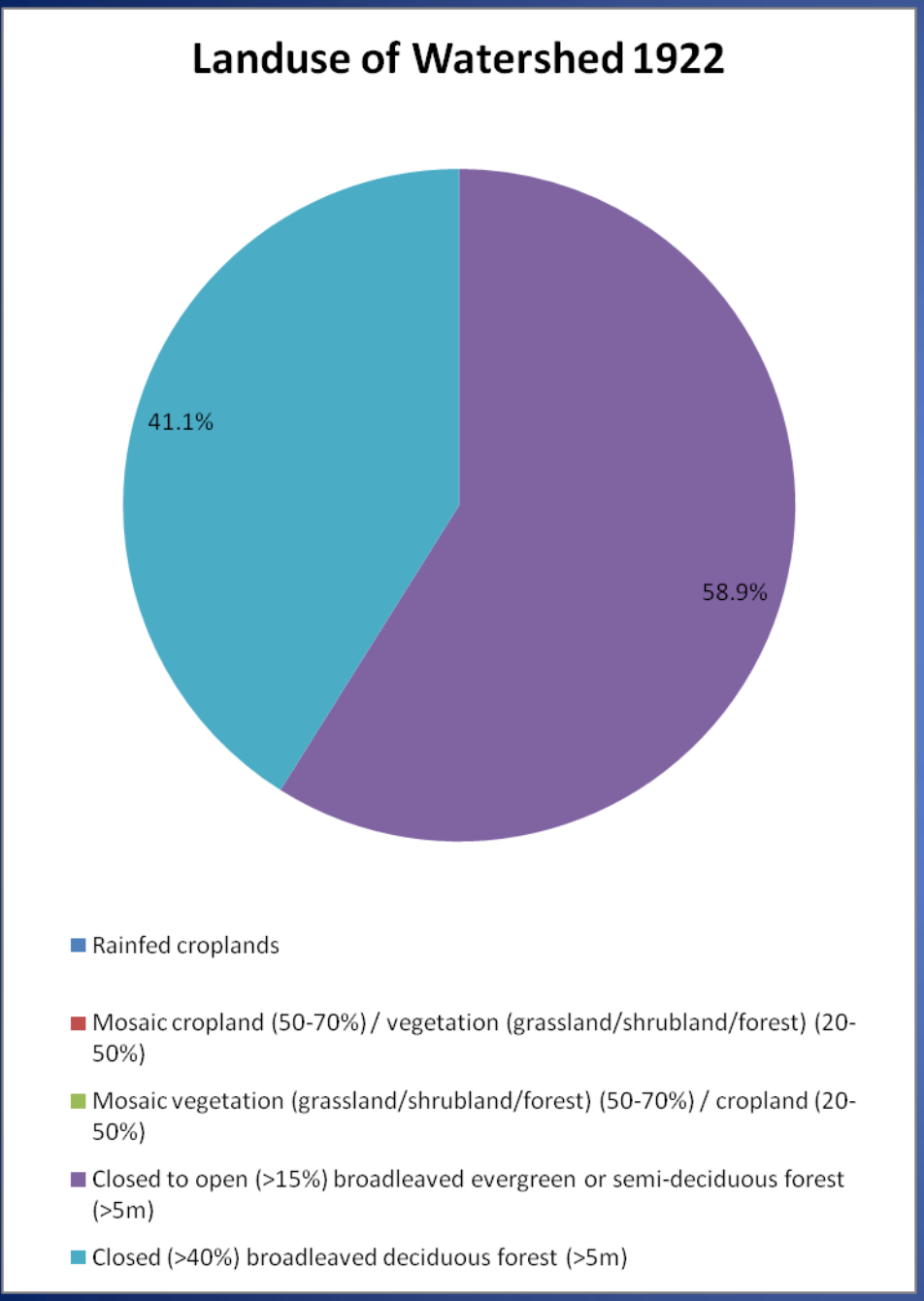

Landuse of Watersheds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1550
1533
1605
1651
1653
1620
1481
2100
1534
1601
Cropland
Grassland
Forest
Shrubland, Savanna
Sparse Vegetation
Water
Urban


Nyungwe National Park
and
Surrounding Area Sub-Watersheds
Delineated from ASTER DEM
Kigali
Kibuye
Gitarama
Ruhango
Nyanza
Gikongoro
Cyangugu
Butare

Deforestation Scenario within Nyungwe



	Baseline	Deforestation	Percent Difference
Watershed Id	1867	1867	
Mean Sediment Export (Tons/ha)	0.92	14.92	1521%
Mean Potenial Soil Loss (Tons/ha)	41.32	134.12	224%
Mean Slope (%)	90.66	90.66	
Mean Slope Length (m)	12.88	12.88	
Mean Soil Erodibility (MJ*mm)/ (ha*h*yr)	0.033	0.033	
Mean Rainfall Erosivity (T* ha*h) / (ha*MJ*mm)	11036	11036	
C Factor (deciduous forest)	0.001	0.07	
P Factor (deciduous forest)	1	0.5	



Deforestation Scenario within Nyungwe

	Baseline	Deforestation	Percent Difference
Watershed Id	1922	1922	
Mean Sediment Export (Tons/ha)	0.25	17.46	6884%
Mean Potenial Soil Loss (Tons/ha)	8.38	122.18	1357%
Mean Slope (%)	89.85	89.85	
Mean Slope Length (m)	23.61	23.61	
Mean Soil Erodibility (MJ*mm)/ (ha*h*yr)	0.033	0.033	
Mean Rainfall Erosivity (T* ha*h) / (ha*MJ*mm)	10635	10635	
C Factor (deciduous forest)	0.001	0.07	
P Factor (deciduous forest)	1	0.5	

Summary and Recommendation

- Our modeling suggests that, due to global climate warming, streamflow perhaps has decreased across Rwanda;
- The Nyungwe National Forest Park has relatively high water yield (30-40% of annual precip);
- The Nyungwe National Forest Park has low sediment yield, but deforestation can cause serious sedimentation problems due to high rainfall and steep slopes (as other watersheds dominated by croplands.
- Monitoring is needed to estimate water balance and sediment loading and improve WaSSI model and reduce uncertainty (evapotranspiration modeling and USLE parameterization).
- InVest and WaSSI models are useful tools to identify priority watersheds for conservation and management. Site specific data are most useful for model predictions.