Rainfall Estimation Raster Conversion Data Preparation for Hydrological Modeling with SWAT Mara Basin (Kenya / Tanzania)

Daniel Gann
GIS-RS Center, Florida International University, gannd@fiu.edu

Follow this and additional works at: https://digitalcommons.fiu.edu/gis

Part of the Life Sciences Commons

Recommended Citation

This work is brought to you for free and open access by the GIS Center at FIU Digital Commons. It has been accepted for inclusion in GIS Center by an authorized administrator of FIU Digital Commons. For more information, please contact dcc@fiu.edu.
Rainfall Estimation Raster Conversion
Data Preparation for
Hydrological Modeling with SWAT

Mara Basin (Kenya / Tanzania)

presented by Daniel Gann
GIS – RS Center
Florida International University
GLObal Water for Sustainability Program

- Consortium financed by (USAID).
  - launched in 2005
  - freshwater component of USAID's Global Program for Integrated Management of Coastal and Freshwater Systems (IMCAFS)
  - lead by Florida International University
  - FIU GIS-RS Center: Data preparation, Database Design, Web Portal including interactive Map Applications (ArcGis Server), Mapping and GIS Training of Collaborators
Mara Basin General Information

<table>
<thead>
<tr>
<th></th>
<th>Kenya</th>
<th>Tanzania</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mara Basin Area in sqkm</td>
<td>8,192.76</td>
<td>5,311.10</td>
<td>13,503.86</td>
</tr>
<tr>
<td>Mara River Length in km</td>
<td>119.02</td>
<td>223.51</td>
<td>342.53</td>
</tr>
<tr>
<td>Protected Area in sqkm</td>
<td>1,718.06</td>
<td>1,741.26</td>
<td>3,459.32</td>
</tr>
<tr>
<td>Wetland Area in sqkm</td>
<td>-</td>
<td>204.46</td>
<td>204.46</td>
</tr>
<tr>
<td>Wetland Width in km</td>
<td>-</td>
<td>12.90</td>
<td>12.90</td>
</tr>
<tr>
<td>Wetland Length in km</td>
<td>-</td>
<td>36.80</td>
<td>36.80</td>
</tr>
</tbody>
</table>
Challenges within the Basin

- **THREATS:**
  - loss of native forest cover
  - unsustainable agricultural expansion and intensification
  - water pollution
  - decreasing water supplies (competition for and conflicts over available water)

- **IMPACT:**
  - incomes
  - health
  - food security
  - natural resources
  - Ultimately on Masai Mara Reserve and Serengeti National Park and its stakeholders
Goals of GLOWS Mara

- understand the system hydrology and environmental flows
  - Establish the environmental flow requirements in MMNR & SNP
  - Develop a biodiversity action plan

- increase stakeholder participation in water management
  - Develop a community-based fisheries management plan
  - Facilitate development of Catchment Management Strategy in the Lake Victoria South Catchment Management

- explore new approaches to increase economic benefits
  - Assess value of water, current levels of use and demand, and move toward a mechanism for payment of water and environmental services
Crucial to accomplish Tasks

- How much water was and is available for use?
- How much enters the system and where does it go?
- How much will be available in future (change scenarios)?
  - Climate Change
  - Land Management Practices
  - Technology advances
Challenge to Hydrological Surface Runoff Models

General:

- Appropriate Accuracy and Precision of Data
  - Digital Elevation Models and Derivatives
  - Climate Data
  - Soils and Land Use
  - Land Management Practices

- Precipitation large spatial and temporal variability
  - Scale issues (point measures applied to areas HRU, watersheds …)
    for spatially explicit models not straight forward
  - Data Filtering (spatial and temporal - various Kernels)

Mara Specific

Data scarcity

- does not exist – no access – limited access – gaps – not very accurate -
  different formats and no standards
- EOD : Calibration of model in SWAT with rain gauge data delivers only limited
  satisfactory results exaggerating discharge of the Mara River for large parts of
  the basin
MAP Rain Gauge Voronoi Polygons

SWAT algorithm – Voronoi Polygons for Subbasins
Alternative / Complement

- Rain gauges
  - Advantages
    - accurate and precise measurements
  - Disadvantages
    - point measurements (PCP high spatial variability)
    - sparse observational network of rain gauge stations
    - sampling error when scaled to larger area

- Remotely Sensed Data
  - Advantages
    - cover large spatial extent at frequent sampling rate (METEOSAT)
  - Disadvantages
    - inferred estimates - high random error and bias introduced at different stages of data collection and estimation procedure
FEWS Rainfall Estimation (RFE) imagery automated (computer-generated) product which uses
- Meteosat infrared data (half-hour sampling rate)
- rain gauge reports from the global telecommunications system
- microwave satellite observations
- algorithm provides RFE in mm at an approximate horizontal resolution of 10 km
- distributed by the Famine Early Warning System (FEWS) is distributed as daily raster datasets at

Artificial Gauging Stations

- Centroids of Regions of Interest (Subwatershed)
- Zonal Statistics for Regions
- Regional daily Time Series
Prepare Data for SWAT Model

- **Structure for meteorological data Input to SWAT**
  - Stations Table (Artificial: Centroids of Subwatersheds)
    - Required Fields
  - PCP Tables
    - Required Fields

- **ArcGIS environment Batch Processing**
  - Python scripting to convert raster to time series tables
Corresponding Components

Gage Location Table:
Attribute Table of Region Centroids

ID: User Selected e.g HydroID
NAME: R_ID (e.g. HydroID)
XPR: POINT_X
YPR: POINT_Y

Precipitation Table:
Subset RFE_by.Region Table

DATE: Converted YYYYJ to mm/dd/yyyy

PCP: Zonal Statistic (User)

- Precipitation Gage Location Table (dBase)
  When measured precipitation data are to be used, a table is required to provide the locations of the rain gages. The precipitation gage location table is used to specify the location of rain gages.

  dBase Table Format: Preferred (5 fields)

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Format</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Integer</td>
<td>Gage identification number (not used by interface)</td>
</tr>
<tr>
<td>NAME</td>
<td>String max 8 chars</td>
<td>Corresponding table's name string</td>
</tr>
<tr>
<td>XPR</td>
<td>Floating point</td>
<td>X coordinate in the defined project</td>
</tr>
<tr>
<td>YPR</td>
<td>Floating point</td>
<td>Y coordinate in the defined projection</td>
</tr>
<tr>
<td>ELEVATION</td>
<td>Integer</td>
<td>Elevation of rain gage (m)</td>
</tr>
</tbody>
</table>

- Daily Precipitation Data Table (dBase or ASCII)
  The daily precipitation data table is used to store the daily precipitation for an individual rain gage. This table is required if the raingage option is chosen for rainfall in the weather data dialog box. There will be one precipitation data table for every location listed in the rain gage location table.
  The name of the precipitation data table is "name.dbf" or "name.txt" where name is the character string entered for NAME in the rain gage location table.
  This table may be formatted as a dBase table or as a comma delimited text table.

  dBase (.dbf) Table Format: (2 fields)

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Format</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE</td>
<td>Date (mm/dd/yyyy)</td>
<td>Day of precipitation</td>
</tr>
<tr>
<td>PCP</td>
<td>Floating points (f5.1)</td>
<td>Amount of precipitation (mm)</td>
</tr>
</tbody>
</table>
1. Script: RFE Stats by Region (SWAT)

PURPOSE:
Extract RFE statistics from daily rasters for user defined regions such as watersheds or sub-watersheds. Output is formatted to be compatible with input file format of ArcSWAT2005.

REQUIREMENTS:
Spatial Analyst Extension
Geodatabase RFE.mdb including template table used as output table schema.

Database has to hold the regions feature class (relation classes will be generated)

The raster files in the Raster Workspace are named in the following pattern: rain_YYYYj.bil (where YYYY is the 4 digit year and j stands for the julian day of that year).
The script loops through the raster datasets within a user-specified raster workspace.

Steps of the script are:

1. Create RFE_by_REGION Output Table.
2. Process all Raster files in Raster Workspace
   - Define Projection
   - Generate Zonal Statistics
   - Add Date and PCP fields and Update them from raster file name and statistics
   - Append table to RFE by Region table
   - Delete Intermediate Table
3. Create Relationship Class of Region Feature Class and Output Table
4. Create Centroids for Regions as "Precipitation Gauge Location Table"
   - Add SWAT required fields and XY Coordinates and Update them
5. Create Relationship Class of Centroid Feature Class and Output Table
6. Subset RFE_by_region table as "Daily Precipitation Data Table" in SWAT
Results (Script)
Analysis of RFE and Gauge Station

- **Raster Conversion**
  - Evaluation for 3 year period 2002 – 2004
    - 1096 Raster Datasets
    - Extract Single Cell Time Series (Script 2)
    - Extract Spatial Summary Statistics Time Series (Script 1)

- **Spatial Evaluation**
  - Station vs Grid Cell
  - SWAT Station vs RFE Zonal Statistics for SWS Centroid (Voronoi assigned)
  - Performance of SWAT

- **Temporal Evaluation Bias + RMSE**
  - Three year total ........ Daily
  - Optimization of temporal Signal (Kernel filtering)
2. Script: RFE Cell to Time Series

- PURPOSE: Evaluate RFE data and Gauge data
  - Convert Raster to Point Data for user selected Extent
## RESULTS

<table>
<thead>
<tr>
<th>TIME</th>
<th>STATION</th>
<th>STATISTIC</th>
<th>GRID</th>
<th>CENTROID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>G_140</td>
<td>R_304</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G_223</td>
<td>R_305</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G_460</td>
<td>R_306</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_307</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_308</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_309</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_311</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R_312</td>
</tr>
<tr>
<td>2002</td>
<td>S_9035228</td>
<td>Difference</td>
<td>-6</td>
<td>-110</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>273</td>
<td>556</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>751</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>502</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>503</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>676</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>658</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>941</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>653</td>
</tr>
<tr>
<td>2003</td>
<td>S_9035228</td>
<td>Difference</td>
<td>297</td>
<td>429</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>596</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>326</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>271</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>372</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>353</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>728</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>504</td>
</tr>
<tr>
<td>2004</td>
<td>S_9035228</td>
<td>Difference</td>
<td>-90</td>
<td>-253</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>52</td>
<td>331</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>508</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>335</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>229</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>402</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>468</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>875</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>555</td>
</tr>
<tr>
<td>2004</td>
<td>S_9035228</td>
<td>Difference</td>
<td>201</td>
<td>-121</td>
</tr>
<tr>
<td></td>
<td>S_9035302</td>
<td>Mean</td>
<td>0.19</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std</td>
<td>6.60</td>
<td>6.37</td>
</tr>
<tr>
<td>3 YEARS</td>
<td>S_9035302</td>
<td>Difference</td>
<td>397</td>
<td>1316</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>0.36</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std</td>
<td>8.89</td>
<td>8.37</td>
</tr>
<tr>
<td></td>
<td>S_9135021</td>
<td>Difference</td>
<td>160</td>
<td>8.41</td>
</tr>
<tr>
<td></td>
<td>S_9135021</td>
<td>Mean</td>
<td>0.15</td>
<td>8.11</td>
</tr>
<tr>
<td></td>
<td>S_9135021</td>
<td>Std</td>
<td>6.73</td>
<td>8.75</td>
</tr>
</tbody>
</table>
Conclusion

- Discrepancy to actual discharge data is due to overestimated precipitation amounts in the south-eastern arid region of the basin caused by a gap in rain gauges in close proximity, therefore discharge estimates of a major tributary to the Mara River were increased.

- Regional Means of RFE Raster Data conversion for SWAT input is automated and takes very little analyst time – only cheap CPU processing time.
Future Work

- Evaluate new datasets
  - Spatial and temporal Filtering
  - Performance of Calibration and Validation process in SWAT (12 year data)

- Streamline Data Preparation for ArcSWAT
  - Extract Elevations from DEM for Region Centroids
  - Conversion Tools for all feature classes of IWRM Database to ArcSWAT Database

- Evaluate Data and Method for TRMM World Data
  - GLOWS Wakel, India; Pastaza, Peru
  - CCS Dominican Republic, Puerto Rico, Jamaica, Cuba

- ArcGIS Server – service provides access to tool