Utilizing Remote Sensing and Climate Predicted Precipitation Patterns to Drive Water Resource Infrastructure Investment Decisions: Marwa, Tanzania

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Introduction

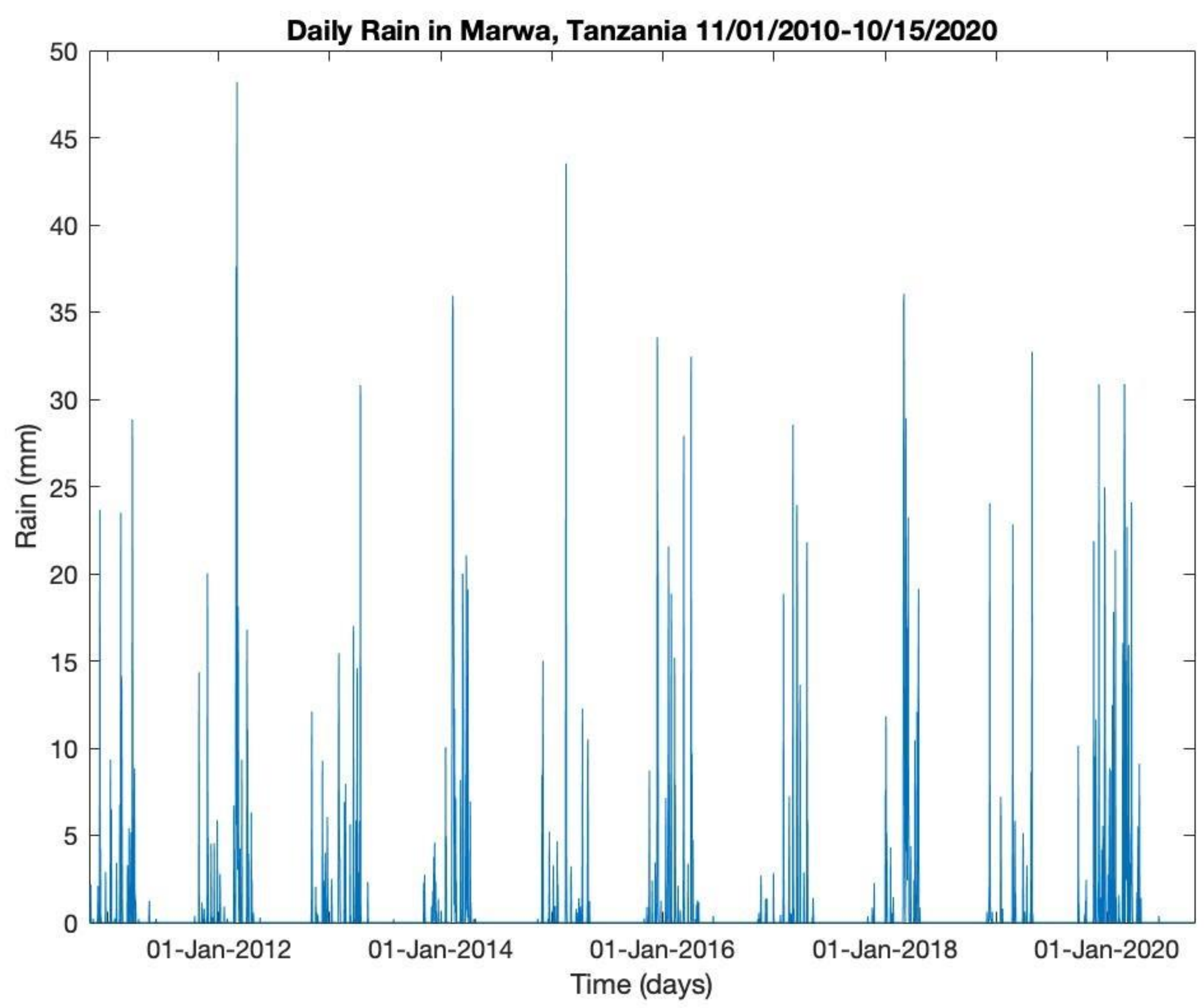
Near the village of Marwa, Tanzania, cattle graze on vegetation along the shoreline of the Pangani River resulting in significant erosion thereby increasing flooding and spreading water-borne illnesses to the villagers' primary freshwater source. The community, which has an estimated population of 2,500, has requested for an alternate location for the cattle to graze and water. The development of reservoirs upslope of the village that capture the surface runoff generated from the rangeland has been identified as a potential solution to be evaluated. An additional benefit of capturing this runoff upslope is the reduction in periodic flooding to the village itself.

PERSIANN Precipitation Modelling

Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) is a satellite-based precipitation retrieval algorithm, providing near-real time precipitation products (Ashouri et al., 2015). It uses an adaptive neural network algorithm to combine information from various satellites. Within PERSIANN, the Center for Hydrometeorology and Remote Sensing (CHRS) i-Rain system provides access to real-time global high-resolution (~4km) satellite precipitation products from the PERSIANN-CCS (Cloud Classification System), which has been developed by a research team at the University of California, Irvine (UCI). Daily rain data was retrieved from this system from November 1, 2010 through October 15, 2020 using the coordinates of Marwa, Tanzania. This data was plotted (see plot below) to gain an understanding of rain patterns for this region.

Annual precipitation in the region is characterized by distinct wet and dry seasons. Over the last 10 years, the maximum annual rainfall was 404.07 mm (2018) and the minimum 180.51 mm (2017). Examining the hydrologic year (Jul 1 - Jun 30) to capture the seasonality of the rainfall, we find a maximum seasonal rainfall of 539 mm and a minimum of 142 mm. This seasonality makes the need for water infrastructure more pressing.

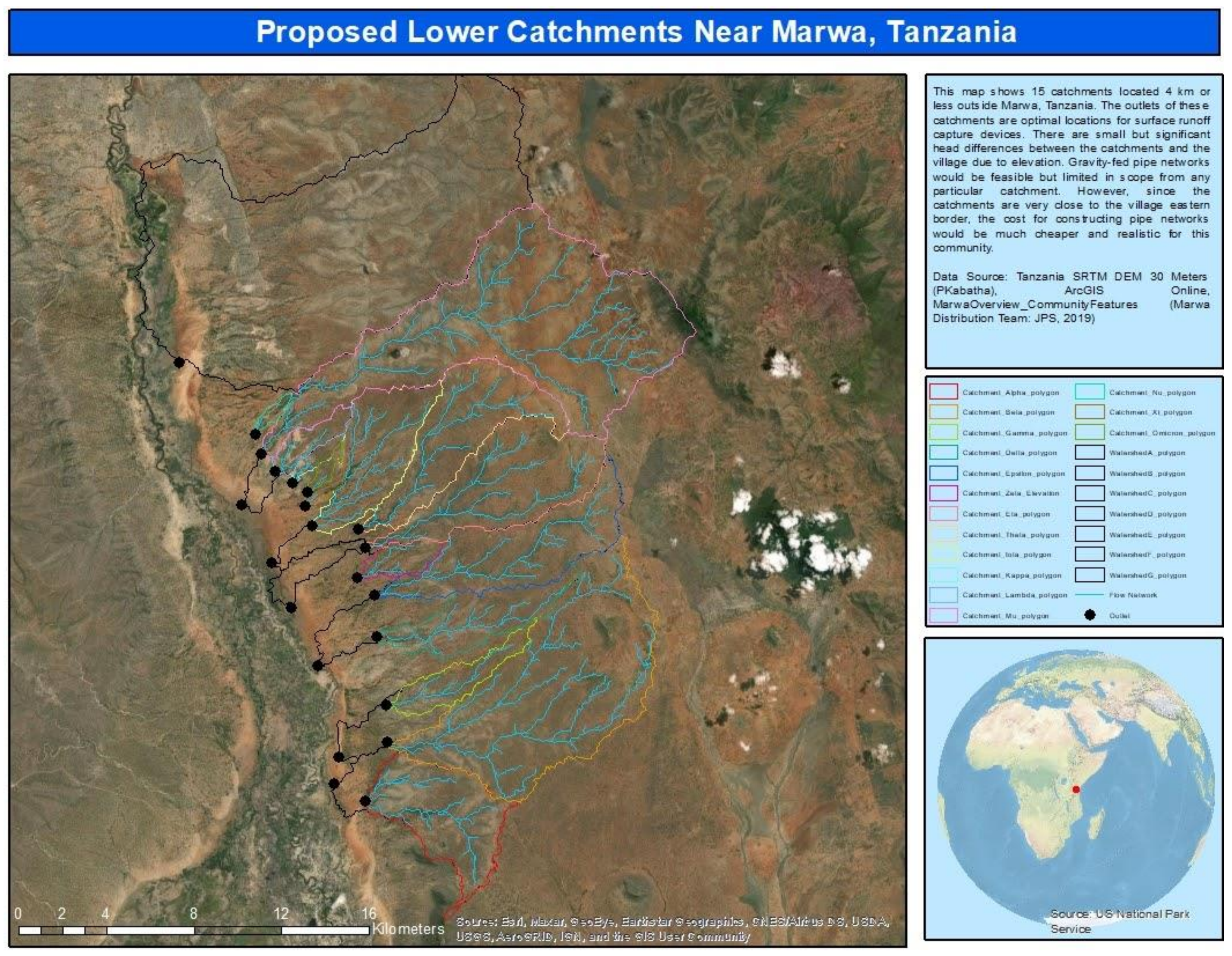
Being so close to the equator, temperatures in the region are very stable all year round. From an agricultural perspective, the limiting resource for the region is availability of water during the dry periods.



Watershed Delineation

ArcMap software was used to delineate the watersheds in this study. First, a 30-meter Digital Elevation Map (DEM) was downloaded from ArcGIS Online that provided elevation measurements for all of Tanzania (Kabatha, 2018). The "World Topographic Map" from Esri provided the basemap to visualize the topography of the region (Esri, 2020). The research team at the Ohio State University provided the coordinates of the village. Using the spatial analyst hydrology toolbox, stream order and stream network layers of Marwa and the surrounding area were generated.

The research team at the Ohio State University provided a community features map that identified the locations of settlements and agricultural fields within the village (Marwa, 2019). Using this map, outlets were chosen that were 4 km or less uphill from the village. Altogether, 15 of these lower catchments were delineated (see map below). Although these catchments generate small but sufficient head differences with the village, their nearness to the village makes the cost for constructing gravity-fed pipe networks relatively inexpensive and realistic for this community.



Reservoir Bucket Modeling

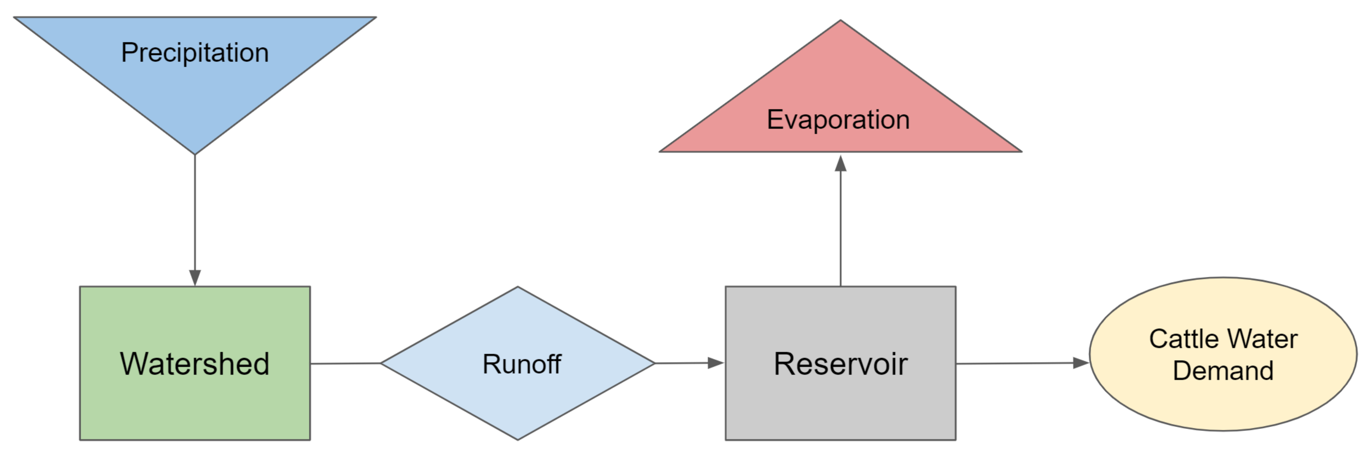
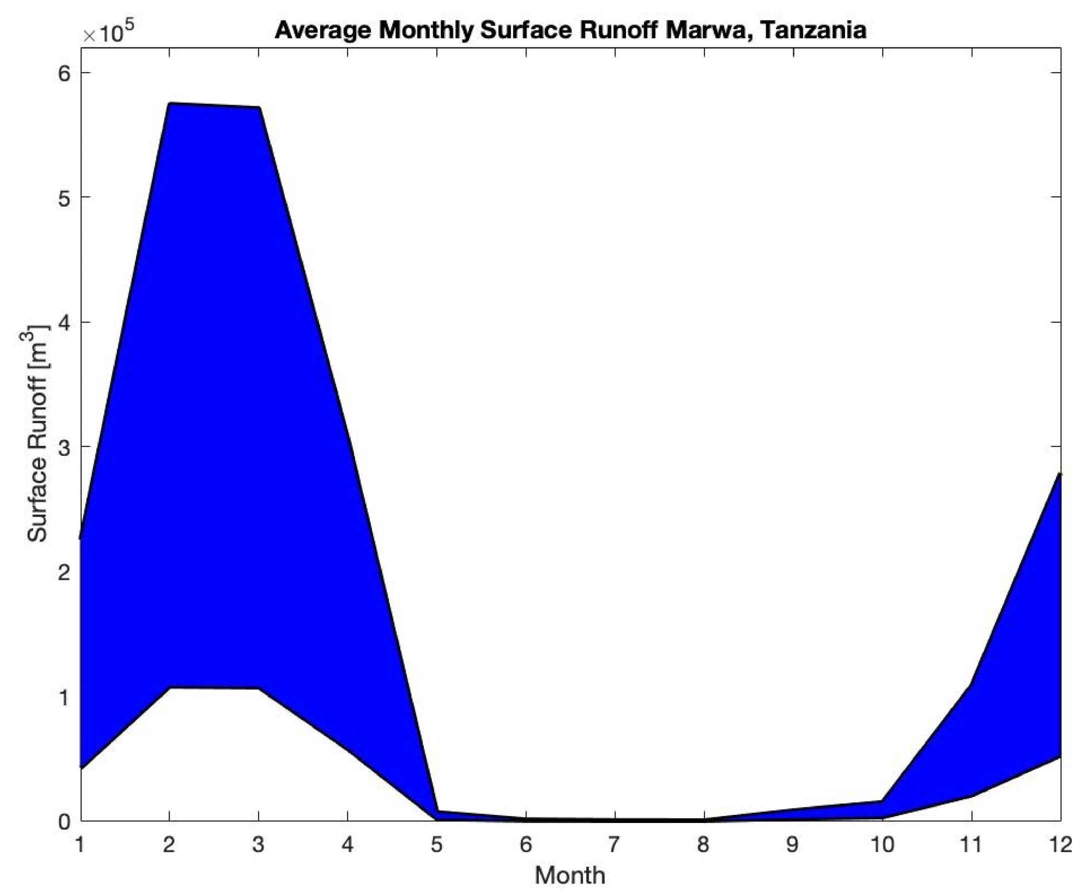
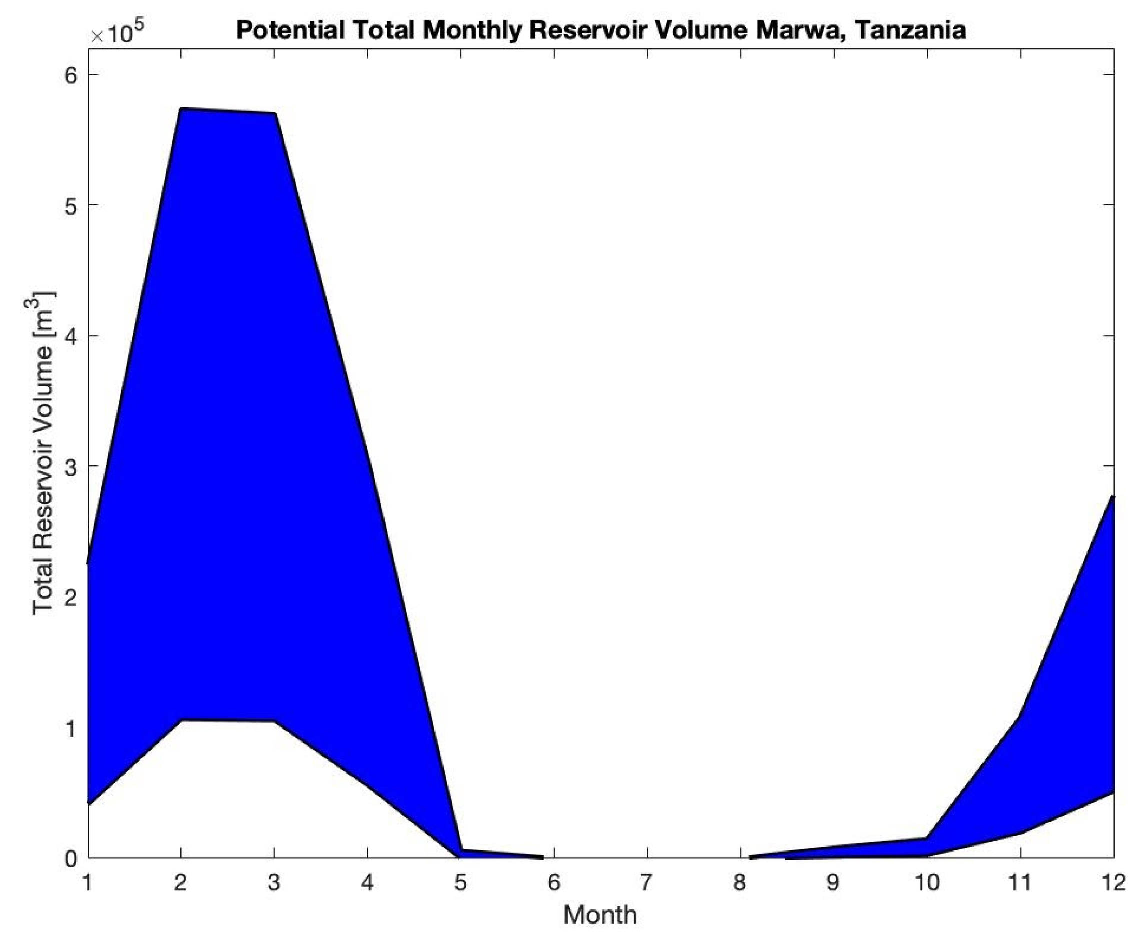


Figure 1. Flow Diagram of Reservoir Bucket Model

The reservoir bucket model centers around the flow diagram of water inflows and outflows to the watershed(s) and subsequently the reservoir. Precipitation accumulates in the watershed(s) and naturally flows downhill to the reservoir as surface runoff. The reservoir then loses water to both evaporation and cattle usage reliant on cattle water demand. With an understanding of this rudimentary flow diagram, a reservoir bucket model was created using a programming platform, MATLAB. This yielded several useful plots to determine how much surface runoff would be collected by the upslope reservoirs.



The envelope in this graph above depicts the surface runoff generated from the smallest available watershed to the largest. A runoff coefficient of 5% was assumed to account for potentially dry soil characteristics (Mul et al. 2006). There is a considerably large volume of water available through surface runoff alone in the particular wet seasons. However, in the dry seasons, the monthly runoff accumulation is quite minimal due to low and infrequent rainfall events.



Subtracting the potential monthly evaporation ("Monthly Global Evaporation" 2020) out of the reservoir from the potential monthly surface runoff into the reservoir, the potential total monthly reservoir volume creates another envelope (shown above) which clearly denotes that at either location downhill from the smallest or largest watershed, the reservoir at its current assumed capacity will have more than enough volume to capture any potential total inflowing water.

Conclusion

Overall, optimal locations were determined for the upslope reservoirs. Using surface runoff estimations, soil data, and the delineated watersheds, potential threats to the structure were examined and possible solutions were recommended. This research project proves that remotely sensed data alone can provide sufficient insights toward environmental decision-making. In addition, it provides a methodology for planning robust water infrastructure that can be tested against projected changes to precipitation patterns. Altogether, these methods will undoubtedly save time and resources for engineers and help suffering communities receive long-lasting aid promptly and inexpensively.

References and Acknowledgements

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