A Deterministic Approach to Flood Modeling in Northern Ghana using GIS and Web Development

Leonard Shaw, MSAG 2019
Readers: Nathan Zimmerman, Charles Dana Tomlin PhD.

Abstract

Flooding of the White Volta River is a recent and ongoing humanitarian crisis in Northern Ghana In September 2018, flooding resulted in 34 people dead and an estimated 100,000 people displaced (Davies 2019). An official International Federation of Red Cross and Red Crescent Societies (IFRC) emergency response was carried out to provide shelter, food, and water to 31,903 people who lost their homes and livelihoods from the flooding (IFRC 2019). 11,959 hectares of farmland were inundated, introducing major food insecurity to the region.

The causes of flooding have been linked to two environmental factors: high precipitation levels in Northern Ghana and emergency releases from the upstream Bagre Dam located in Burkina Faso. These two factors can be modeled and visualized using a deterministic approach combining geographical information systems (GIS) and web development. A fully-functional web application was developed to calculate and map both inflow to Bagre Dam and rainfall density in Ghana. The application can potentially serve as a technological foundation for future collaboration with organizations such as CloudtoStreet, SONABEL, governmental bodies in Ghana and Burkina Faso, and others.

Methods

$$RC(m) - RC(m-1) = Q_{in}(m) - Q_{out}(m) - E_S(m),$$

where

$RC(m)$	is reservoir volume at the end of month m, in million cubic meters;
$Q_{in}(m)$	is inflow for month m, in million cubic meters;
$Q_{out}(m)$	is outflow for month m, in million cubic meters; and
$E_S(m)$	is net evaporation (evaporation minus precipitation) for month m, in million cubic meters.

Figure 1: A simple water balance for reservoir modeling (Vining and Vecchia 2007)

Emergency releases from Bagre Dam can be modeled based on the reservoir model water balance (Figure 1). Total volume is provided by the full capacity of the Bagre Dam reservoir of 7,000,000 cubic meters and evaporation can be assumed as negligible in the short time range of an emergency release. This leaves inflow and outflow of the reservoir as the determining factors for potential emergency releases.

Bagre Dam Watershed Delineation

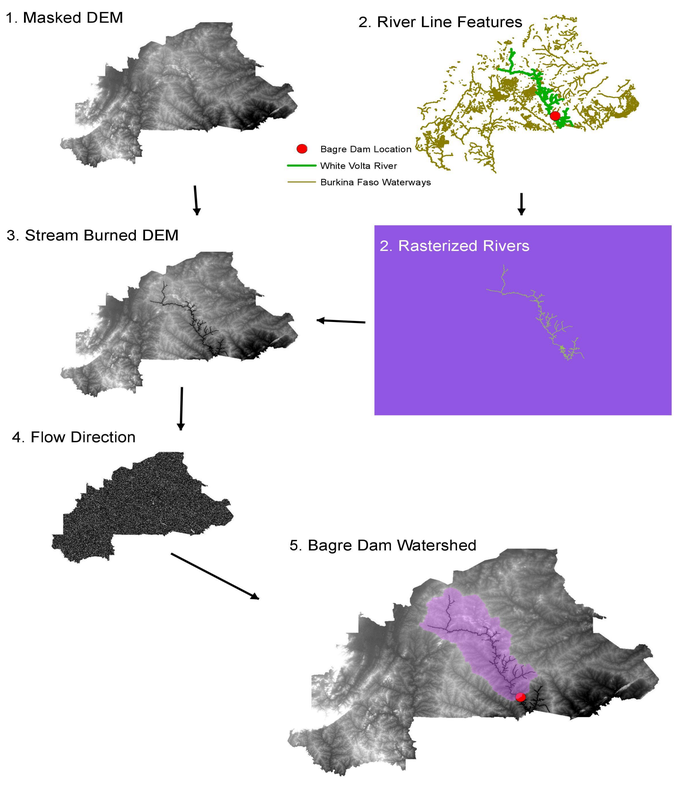

Figure 2: ArcMap Spatial Analyst Workflow for Bagre Dam Watershed Delineation. The arrows sequentially connect each of the maps, which show the outputs of the respectively described geoprocessing tools.

Inflow to the Bagre Dam Reservoir is estimated by calculating rainfall levels in the Bagre Dam Watershed. The watershed is delineated by using the Hydrology toolset in ArcGIS (Figure 2). The White Volta river is extracted from a waterways dataset from the Humanitarian Data Exchange using recursive selection. The river is then burned into a digital elevation map of Burkina Faso.

Backend Development

Real-time rainfall values are collected for Burkina Faso and Ghana by scheduling application programming interface (API) calls in a backend Flask server built for the web application. Calls are made to the OpenWeatherMap API using unique city IDs for 120 cities in the two countries. City weather data is appended to JSONs that are routed to the application frontend.

Frontend Development

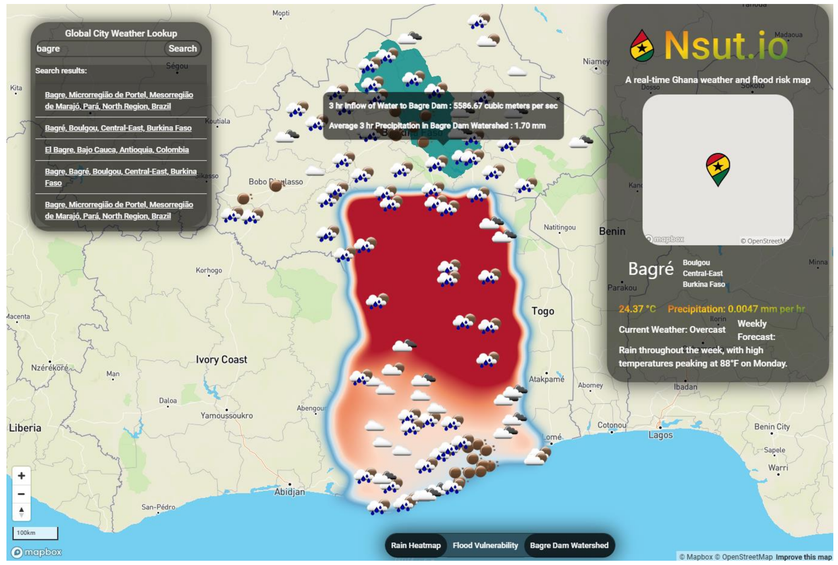

Figure 3: Frontend UI showing interpolated rainfall levels, inflow to Bagre Dam, and the global weather geocoding service.

The frontend UI displays GeoJSONs showing the real-time weather data, a grid of surface soil clay percentage representing flood vulnerability, and Bagre Dam watershed with inflow estimations. The frontend was also designed with a global weather geocoder to allow additional engagement with the web application from users. The website was named Nsut.io after the Akan/Twi word for raindrop and can be viewed at http://leoshaw.pythonanywhere.com/.

Conclusion

The web application developed serves as a technological proof-of-concept for modeling and visualizing factors for flooding in Northern Ghana. In the future, Nsut.io and the underlying GIS work can be scaled to address flooding disasters across the world.

References

- Aon. "Global Catastrophe Recap." March 2019. http://thoughtleadership.aonbenfield.com/Documents/20190409-analytics-if-mar-global-recap.pdf.
- Davies, Richard. "Ghana – Dozens Killed by Flooding in Northern Regions." Floodlist. September 21, 2018. Accessed August 2, 2019. http://floodlist.com/africa/ghana-floods-northern-regions-september-2018.
- Denchak, Melissa. "Flooding and Climate Change: Everything You Need to Know." NRDC. August 01, 2019. Accessed August 02, 2019. https://www.nrdc.org/stories/flooding-and-climate-change-everything-you-need-know.
- "Emergency Plan of Action Final Report Ghana: Floods in Upper East Region." *International Federation of Red Cross and Red Crescent Societies*MDRGH015 (July 4, 2019). https://reliefweb.int/sites/reliefweb.int/files/resources/MDRGH015dfr.pdf.
- Guha-Sapir, Debarati, Philippe Hoyois, Pasacline Wallemacq, and Regina Below. "Annual Disaster Statistical Review 2016: The Numbers and Trends." *Centre for Research on the Epidemiology of Disasters*. Accessed October 31, 2017. https://reliefweb.int/sites/reliefweb.int/files/resources/adsr_2016.pdf.
- Guha-Sapir, Debarati, Philippe Hoyois, Pasacline Wallemacq, and Regina Below. "Annual Disaster Statistical Review 2016: The Numbers and Trends." *Centre for Research on the Epidemiology of Disasters*. Accessed October 31, 2017. https://reliefweb.int/sites/reliefweb.int/files/resources/adsr_2016.pdf.
- Lindsay, John. (2015). The practice of DEM stream burning revisited. Earth Surface Processes and Landforms. 2016. 658–668. 10.1002/esp.3888.
- "More Spillage Expected From Bagre Dam." Bolgatanga. Accessed August 02, 2019. https://web.archive.org/web/20150527145934/http://www.northernghana.com/news/i/?n=1926.
- "NADMO Issues Flood Alert Ahead of Bagre Dam Spillage." General News 2018-08-21. August 21, 2018. Accessed August 02, 2019. https://www.ghanaweb.com/GhanaHomePage/NewsArchive/NADMO-issues-flood-alert-ahead-of-Bagre-dam-spillage-678442.
- Ramsar. "Burkina Faso Barrage De Bagre." *Fiche Descriptive Ramsar*, October 7, 2009. https://rsis.ramsar.org/RISapp/files/RISrep/BF1874RIS_1703_fr.pdf
- Vining, Kevin C., and Aldo V. Vecchia. "Water-balance Simulations of Runoff and Reservoir Storage for the Upper Helmand Watershed and Kajakai Reservoir, Central Afghanistan." *Scientific Investigations Report*, 2007. doi:10.3133/sir20075148.