Dynamics of Migration: Population Growth, Food Security, and Water Resource Management in the Nile River Basin

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Abstract: The purpose of our study is to examine the interactive relationships among water resources, food production, and population on migratory patterns within the Nile River Basin. Insofar as the population of the African continent is projected to reach two billion persons by 2050, 70% of whom are subsistence farmers, changes in water resources could result in widespread human displacement. Historical data are drawn on the World Bank to provide reference modes of these key state variables. Our model depicts an overshoot and collapse behavior of the population of the Nile River Basin, which is driven by the structure of the relationship between population and resources. Results from our study provide a plausible venue through which to re-examine African Union strategies for informing continental early warning systems.

Problem Articulation: Global human displacement is viewed as a systemic outcome of interactions among population growth, distribution and constraints of resources, and changes in agricultural cycles reflective of shifts in temperature and precipitation. This project will identify locations in Africa at greatest risk of human displacement and examine strategies intended to mitigate challenges with migration. The proposed solution—to reduce displacement among rural subsistence farmers—seeks to strengthen Africa's surveillance systems, create a forum through which results improve the continent's capacity to sustainably address, monitor, and manage human displacement, and explore the leadership role of the US in addressing this global challenge.

One might call the confluence of population and climate change in Africa a "perfect storm," whereby the intersection of population growth, an abundance of rural subsistence farmers, and environmental changes create the potential for massive human displacement. Population on the African continent is projected to reach two billion persons by 2050, nearly doubling its current level of 1.2 billion (AU 2016a). Seventy percent of this population across the continent (~1.4 billion persons by 2050) consists of subsistence farmers who rely on predictable agricultural produce from the land during each growing season. With 90% of these farmers earning less than $3 per day and 50% earning less than one dollar a day, subsistence farmers depend on predictable growing seasons to survive from year to year. But climatologists report that the African continent is likely to be severely impacted by volatility in precipitation and monotonic increases in temperature throughout the 21st Century. If only seven percent of these rural inhabitants become displaced over the next three decades, 100 million people could be wandering in search of greener pastures. The result of such migration patterns produces an unparalleled global security threat. What are needed are models capable of forecasting locations in Africa where such outcomes are most likely to occur. Results of these models can then be used within forums to inform and potentially mitigate outcomes before the onset of a widespread crisis.

Dynamic Hypothesis: Migration in the Nile River Basin is a function of three stocks: population, food, and water resources. As population growth pushes population levels beyond water resource capacity, the population base will exceed the food production levels necessary to sustain it. While we expect that the volatility of rain cycles in the Nile River Basin, which are expected to continue to fluctuate, will subsequently spur a migration through a series of causal relationships and reinforcing and balancing feedback mechanisms, our analysis in this paper has held precipitation and temperature at constant levels. As development of our model progresses, we will vary climate conditions in the model's inputs. Although climate change alone cannot lead to human migration, we rely on the assumption that the interactions between our state variables will lead to second and third order effects that will subsequently induce widespread migratory patterns that are larger than throughout history.

Causal Loop Diagram

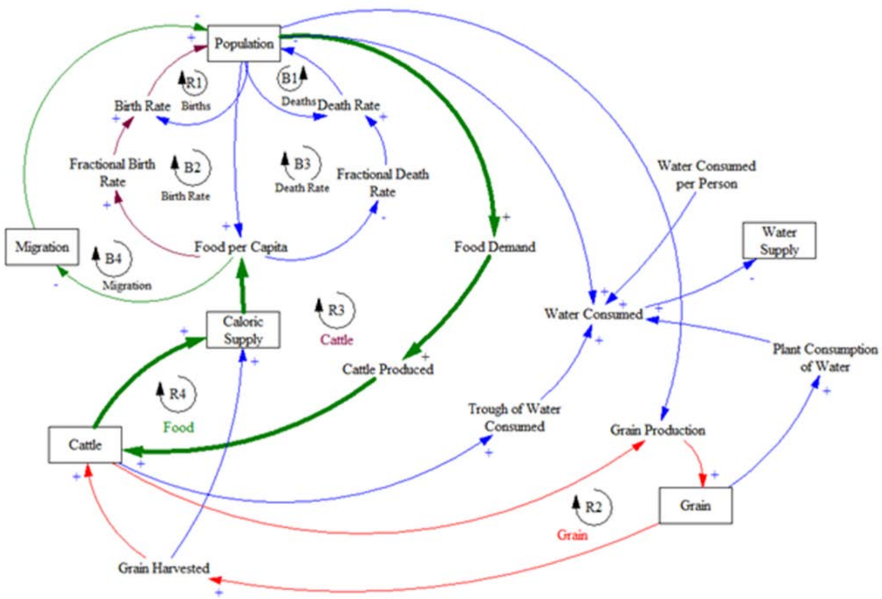

Figure 1: Casual Loop Diagram

The casual loop diagram is shown in Figure 1. As displayed by the population loop consisting of sub loops R1 and B1-3, the dominant behavior shown by this relationship is overshoot and collapse. The initial growth of the population (overshoot) is due to the fractional birth rate being greater than the fractional death rate. This explains why the reinforcing loop is so dominant in describing the consistent growth of the population. However, as shown by our final reference mode, the population subsequently collapses. This is due to the balancing loops throughout the rest of the model.

With an overall higher demand for food and a lower capacity of arable land, the rate of soil degradation will be accelerated by the over farming of what land is still available. This will lead to an overall change in the dynamics of the population. A population will be forced to learn new skills in harvesting new crops, and the international and domestic markets will adjust, or fail to adjust to a new supply of crops. As shown in the reinforcing loops "Grain" and "Cattle," both loops are dependent on the available water supply and demand from the population. As water is readily available, the grain and cattle supply will grow and the population demand will grow as more nutritive properties are added to the existing diet. However, if the inverse occurs because a population depletes the existing water supply, the supply of grain and cattle will also decrease- leading to a subsequent decline in availability and overall food supply.

As overall temperatures increases, the oscillation and volatility of climate patterns and precipitation also increases. This oscillation is induced by an increased delay in rain cycles that ultimately lead to longer periods of drought and longer periods of rainfall. In an area where the primary driver of economics is agriculture, the effects of sustained drought and flooding can be severe. As the water supply, comprised of ground water and surface water either decreases or increases, the current food supply produced in a particular region will be forced to either adapt or be replaced by a less susceptible crop. This will increase or decrease the water consumption and water per capita.

Initial Assumptions and Considerations: For the purpose of the model, we made necessary assumptions to aide in our model development. We assumed that water is used by cattle, people, grain, and runoff. Assumptions were made regarding the daily caloric diet of people, the calories available per cow, and the slaughter rate were constants within the model. Other general assumptions regarding grain were that grain will oscillate due to weather patterns as well as the ability of grain to grow without a population present.

Model: Our model merged together a Nile River Basin Streamflow Model (Keith, Ford, Horton, 2017) and the Sahel model (MIT). The Sahel model incorporated similar types of feedback loops that related population growth with cattle supply. The biggest alteration from this model was incorporating human water consumption as this model simplified the internal complexities of the region into five main stocks: population, cattle, ground water, water storage, and grass. We used the Nile River Basin Streamflow model to account for rainfall patterns within the region. In our completed model, we also factored in grain as a part of the human diet.

Sensitivity Analysis: Sensitivity analysis was conducted by varying exogenous variables. Those variables were human diet consumption, water consumed per hectare of crops, water extraction, and crop capacity. The initial values of each variable were altered by a percentage and analyzed according to their effect on population. When varying human diet consumption, the sensitivity analysis revealed that the less reliant the population is on cattle, the more stable the population is. Water consumed per hectare of crops, proved to be more sensitive than the other exogenous variables. Similarly though, the policy design heavily depends on the education of the region on this underlying issue. A new irrigation policy would be necessary to decrease the amount of water wasted through current poor irrigation systems. Ideally this would lead to increasing water usage efficiency in the NRB. New technologies would need to be introduced similarly through an education program that stresses the importance of water within the region.

Model Validation: Our model was validated based off of visual analysis. The output of our model strongly resembles that of our historical reference mode implying that our model is not only representative of historical data, but also able to predict future events accurately. Once we produce substantial data from our model, we will run a correlation analysis in order to validate our model beyond a behavioral aspect.

Preliminary Results: Behavior from the model produces a distribution reflective of overshoot and collapse (Figure 2), which is consistent with our reference mode. As population, cattle, and grain grow to a level that their combined usage of water overshoots sustainability. With water being a limited resource, the population, cattle, and grain begin a rapid decline.

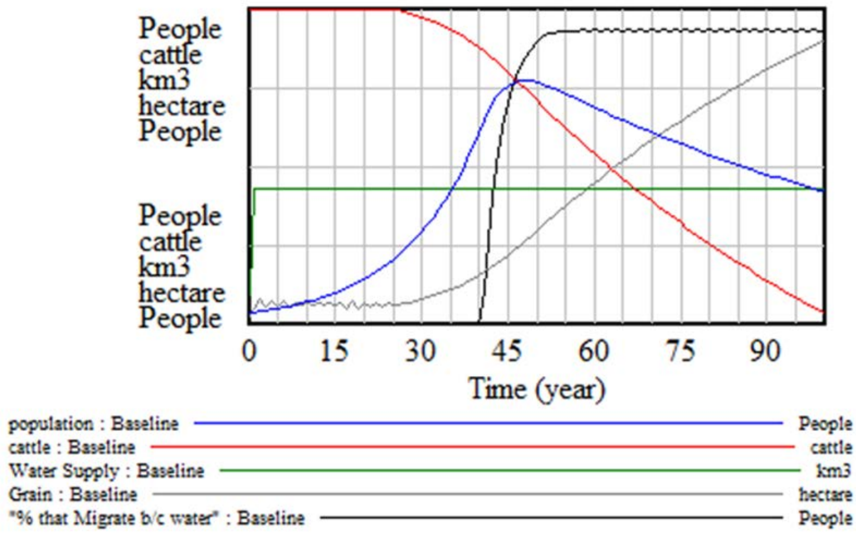

Figure 2: Base Case Model Behavior

Discussion and Conclusion: Migration in the Nile River Basin is a function of three stocks population food and water resources. Our model is able to simulate the behavior of the relationship between the variables and produce outputs that are reflective of historical data. While our model produces behavior that is similar to that of historical data, we still have a few disparities between what our model produces and what historical data has reflected. One difference is that oscillation of the grain stock. Currently we are working through adjusting our model to create a smooth function as opposed to an oscillation. This is occurring due to an incongruence between our primary variables: population and water.

Our next step is to further critique the model, structure our data more intuitively, and analyze and address the effects of changing variable inputs. Once the model is further solidified we will enhance the effects of climate change on the inputs. This will focus on the effects of climate change on rainfall and temperature change on crop growth. We anticipate the climate change will enhance the collapse depicted by the current model by subtracting from the already limited water supply. We hope to have a model that is robustly applicable and able to be transferred to a vast number of regions. Therefore, our solidification of the model and data organization is imperative to meet this goal.