Mapping Populations at Greater Risk of Malaria Due to Hydroelectric Dams in Ethiopia: A Case Study of the Gilgel Gibe III Hydroelectric Dam

Abigail Smith, Department of Geography, University of North Alabama

Introduction

- Malaria is a parasitic infection that is spread by female mosquitos of the *Anopheles* genus.
- It is acutely prevalent in Sub-Saharan Africa where—90% of all malaria deaths occur—killing approximately 400,000 people each year (Centers for Disease Control and Prevention 2018)
- Ethiopia has historically been impacted by malaria.
- In 2018, the World Health Organization estimates that there were 2.7 million cases and 5.4 thousands deaths attributed to malaria in Ethiopia.
- Two malaria parasites are most common in Ethiopia:
  - *Plasmodium falciparum* (the most abundant and deadly type in Sub-Saharan Africa)
  - *Plasmodium vivax*
- Malaria transmission is highly dependent upon environmental conditions
- Since 2000, many programs have been put into place to combat malaria with a common goal of lessening to global malaria burden.
- These programs have made significant strides in reducing malaria cases and death throughout the world (Otten et al. 2009). However, despite all the progress that has been made to combat malaria, anthropogenic environmental alterations are changing the landscape of malaria prevalence.
- Ethiopia, as well as other countries in Sub-Saharan Africa, has been increasing its hydroelectric infrastructure and is planning new hydroelectric projects
- Ethiopia currently has nine hydroelectric dams with twelve more large hydroelectric projects planned.
- Scholarly literature has found a statistically significant relationship between distance to reservoirs, the result of large hydroelectric dams and malaria risk (Lautze et al. 2007, Yewhalew et al. 2009)

Background

- Remote sensing offers health researchers an alternative technique for studying the geography of disease.
- Remote sensing enables researchers to acquire information about a location without physical making contact or conducting laborious amounts of field work.
- Previous scientific research has studied the relationship between malaria prevalence and climatic/environmental variables (Ebhuoma and Gebresalasie 2016).
- Multiple variables have been found to contribute to malaria prevalence. These include:
  - Land Surface Temperature, Slope, Elevation, Landuse/Landcover type, healthy vegetation, and stagnant water bodies (Ebhuoma and Gebresalasie 2016).
- Risk Assessment mapping using remote sensing data has been used to located areas and populations at varied levels of risk (Minale and Alemu 2018).

Study Area

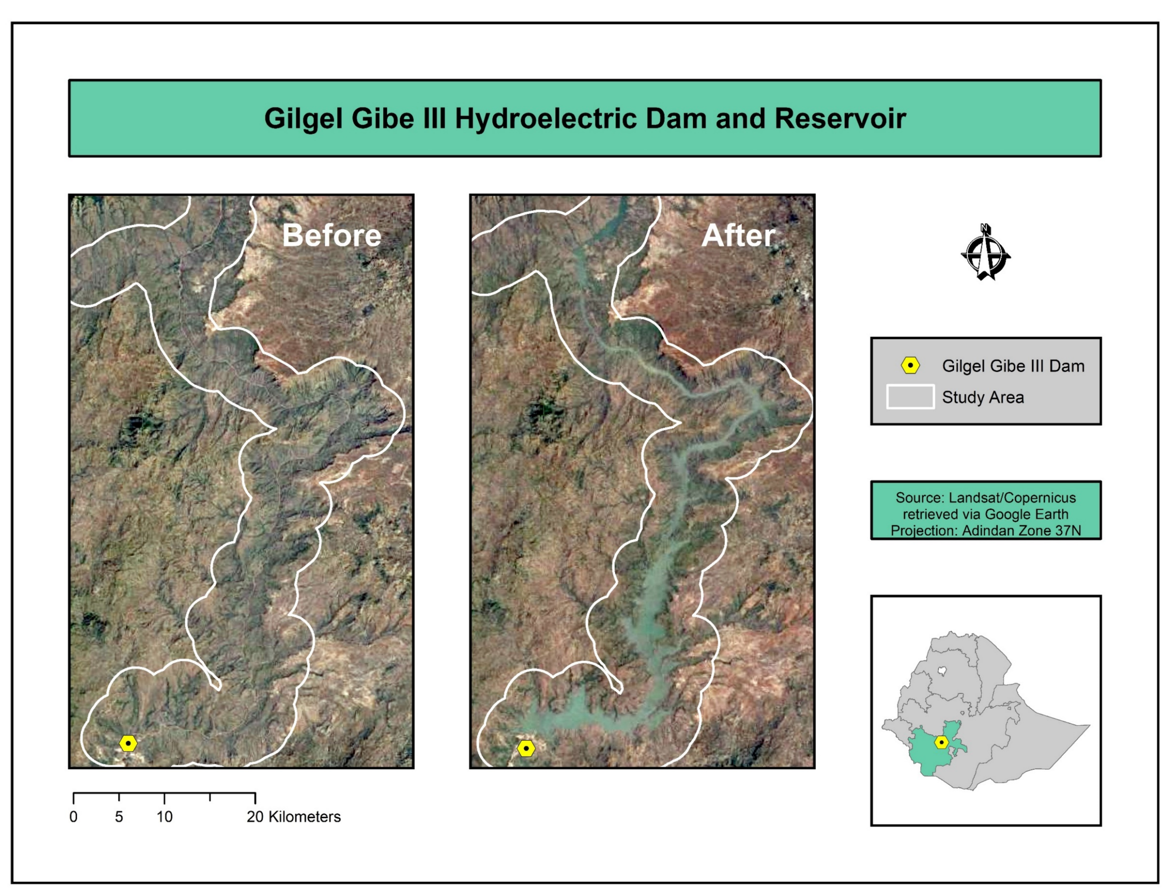

Figure 1: Shows how much the Gilgel Gibe III Hydroelectric Dam has changed the landscape of the Lower Omo River Valley featured.

- The Gilgel Gibe III Hydroelectric Dam is located in the Southern Nations, Nationalities, and Peoples' Region in southwestern Ethiopia, on the Omo River.
- According to the Federal Ministry of Health in Ethiopia, this region contains almost 50% of Ethiopia's malaria cases.
- It is 250 meters tall and generates 1,870 Mega Watts of energy and At capacity, the Gilgel Gibe III's reservoir can hold 14,700 million m^3 of water (Poindexter, 2015). Construction began on the dam in 2006 and it began generating power in 2015.

Acknowledgements

I thank the University of North Alabama Department of Geography and College of Arts and Sciences for helping fund this research and conference travel. I also thank my thesis advisor, Dr. Sunhui Sim who has aided in the development of this research.

Presented at UNA Scholars Week, Florence, Alabama., April 22-24, 2019.

Research Objectives

1. Utilize remote sensing techniques to locate mosquito breeding habitats
2. Quantify how the Gilgel Gibe III Hydroelectric Dam has changed mosquito breeding habitats
3. Identify populations at greater risk of malaria due to the Gilgel Gibe III Hydroelectric Dam

Methods

- Create a model in ArcGIS 10.6 ModelBuilder that identifies mosquito breeding habitats using remotely sensed data.
  - Evaluate the Study Area both before and after the Gilgel Gibe III Hydroelectric Dam was built
- Calculate the total number of pixels identified at each risk level and compare.
- Identify the estimated population living within the entire Study Area (Technique 1) and compare it populations living near areas of high risk pixel concentrations (Technique 2).

Data

Model Input Variables		
Specific Input	Source	Purpose
Band 4 Band 5 Band 10	Landsat 8 (USGS) • Before (12/11/14) • After (12/3/17)	To calculate Land Surface Temperature (LST)
Band 3 Band 6	Landsat 8 (USGS)	To calculate Modified Normalized Difference Water Index (MNDWI)
DEM	STRM (USGS)	To calculate slope and elevation
Shapefile of the Gilgel Gibe III Reservoir	Manually created using Sentinel 2 (USGS)	To extract input variables to the study areas
Population Data		
Used to investigate Research Objective 3	Landscan (Oak Ridge National Laboratory) • 2017	To quantify populations at greater risk of malaria

Table 1: Describes the data used in this study.

Weighted Overlay Criteria, Rating, and Weights

Criteria	Low Risk (1)	Low/Medium Risk (2)	Medium Risk (3)	Medium/High Risk (4)	High Risk (5)	Assigned Weight
Slope	> 20.1		15.1 - 20	7.1 - 15	< 7	7%
LST (Celsius)	< 16°, > 40°		16° – 24°, 28° - 40°		24° - 28°	41%
Elevation (Meters)	> 2500		1500 – 2500		< 1500	11%
MNDWI	< 0.1		0.2 - 1		0.1 – 0.2	41%

Table 2: Describes the criteria, rating, and weights used to determine mosquito breeding suitability. Variables and scale values were determined based on expert opinion and scholarly literature. Weights were assigned based on Expert Opinion and an Analytical Hierarchical Process calculator.

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Results: Mosquito Breeding Habitats

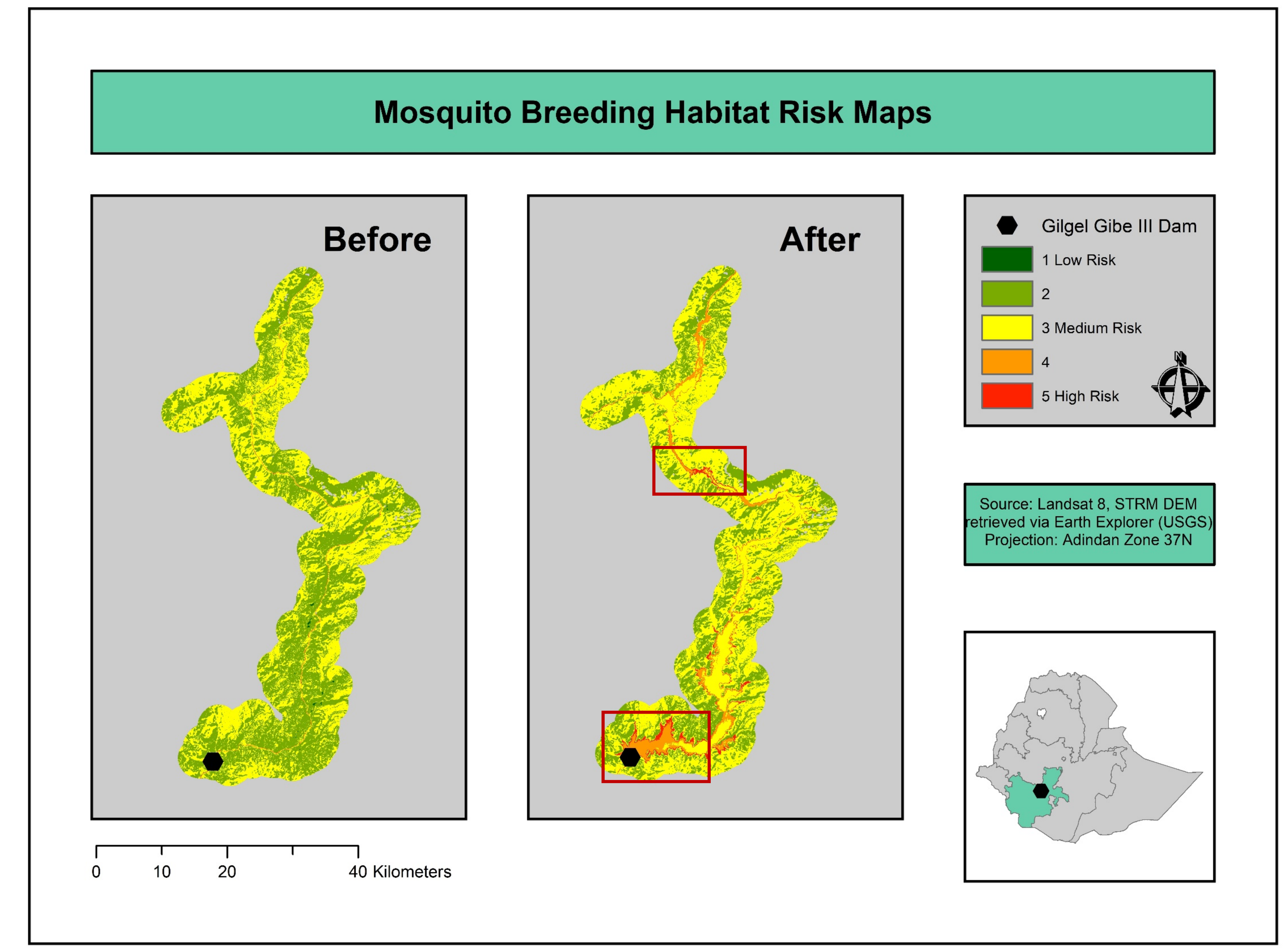

Figure 2: Features the results of the model from Figure 2.

Pixel Classification	Before (# of Pixels)	After (# of Pixels)
5 High Risk	3,424	26,204
4 Medium/High Risk	4,325	59,212
3 Medium Risk	507,837	648,735
2 Low/Medium Risk	588,992	371,416
1 Low Risk	1,004	15

Table 3: Shows the number of pixels classified in each risk category

- **22,780** more pixels are classified as being High Risk for mosquito breeding habitats **after** the Gilgel Gibe III Hydroelectric Dam was completed.
- **Before** the dam was completed, only **0.31%** of the Study Area is classified as High Risk.
- **After** the dam was completed, **2.37%** of the Study Area is classified as High Risk.
- The High Risk areas occur along the edges of the Omo River with two main concentrations.
  - One occurs close to the dam and the other occurs approximately midway in the reservoir, as denoted by the red boxes in the After map.

Results: Populations at Greater Risk of Malaria

- Technique 1 identifies all populations living within 3 km of the Gilgel Gibe III Hydroelectric Dam as being a greater risk.
  - **29,418** more people than Technique 2
- Technique 2 only considers populations living within 3 km of the two areas of High Risk pixel concentration in the After map in Figure 2.

	Estimated Populations at Greater Risk
Technique 1	**51,987**
Technique 2	**22,569**

Table 4: Shows the estimated people living in the associated areas.

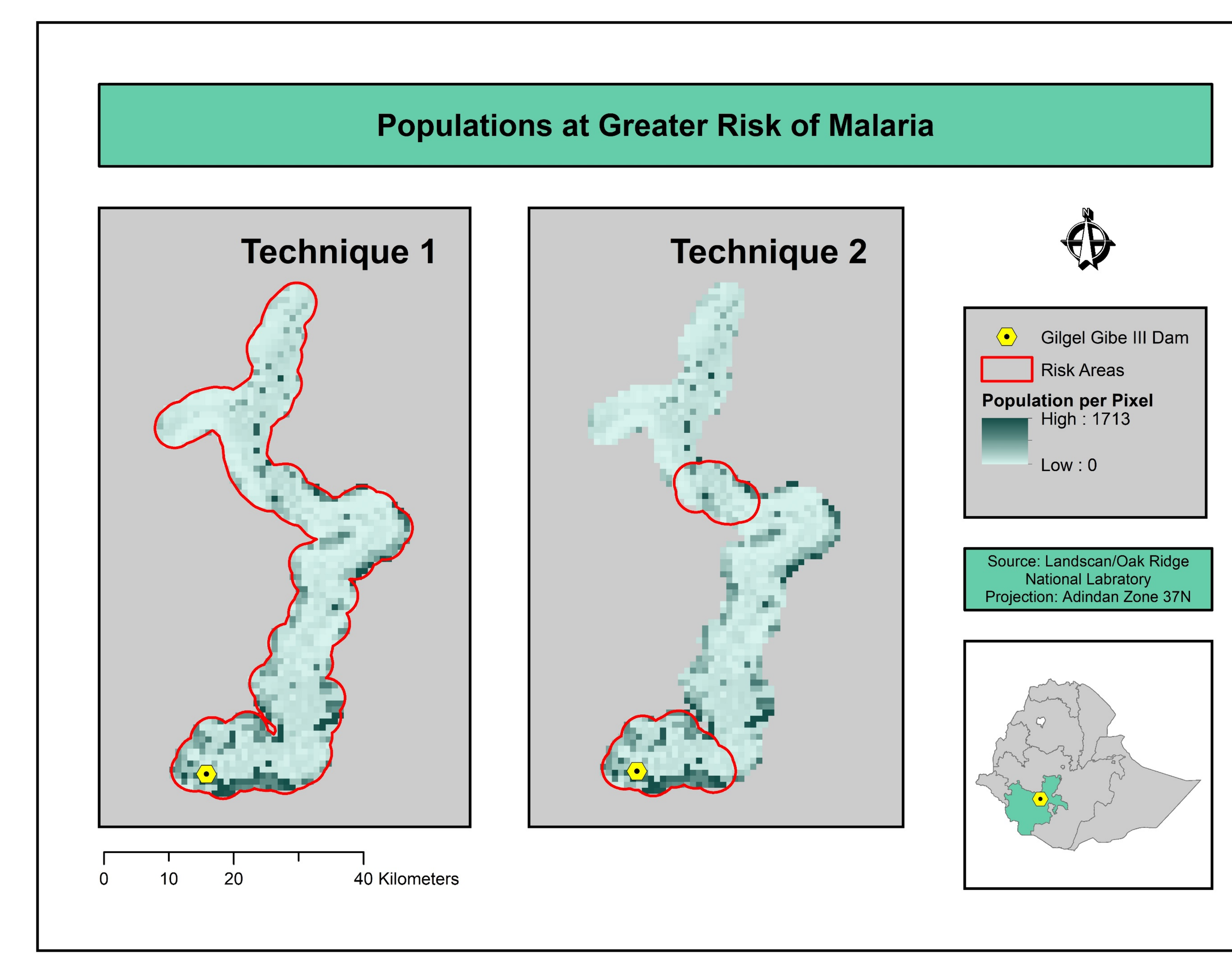

Figure 3: Features the population groups identified by each technique.

Conclusion

- This study suggests that mosquito breeding habitats are not equally distributed throughout the Gilgel Gibe III Reservoir. This causes certain populations to be at a greater risk of malaria than others. In countries with limited economic capital and resources, the populations are at the greatest risk of malaria should be identified and prioritized.
- The model presented in this research can be applied to other study areas as long as researchers obtain all of the necessary input data listed in Table 1. All of remote sensing data used in this study is free to download or is able to be created with minimal input.