Social factor modification of malaria-weather relationship in Kanungu, UG

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Abstract

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Background: There is growing concern in the international community regarding the influence of climate change and season on rates of malaria and other diseases. In this study we examine the role of social demographics in modifying the relationship between weather variability and malaria in Kanungu (Southwest Uganda). *Methods:* Hospital admissions data from Bwindi Community Hospital were combined with meteorological satellite data from 2011 to 2014. Descriptive statistics were used to describe the distribution of malaria admissions to the hospital by age, sex and ethnicity. I used negative binomial regression and stratified models to determine association between rates of malaria and meteorological variables temperature and season, as well as the interactive role of demographic variables age, sex and ethnicity. Results: During the hottest quartile of temperature, admissions for malaria were highest among the ethnic Batwa IRR 2.35 (95% CI: 0.88, 6.25) and the age group of 6-12 year olds IRR 2.04 (95% CI: 1.24, 3.37). Discussion: Results indicate that social demographic variables modify the relationship between weather variability and malaria. This may suggest that promoting local level policy could be necessary to implement adaptation strategies that will optimize equitable health outcomes among uniquely diverse populations in a changing climate.

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Keywords

Malaria, climate change, weather, sociodemographic modifiers

Study Aims and Objectives

Study Aim: Asses the role of effect modification of age, sex, and ethnicity –primary modifier of interest- on the relationship between weather variability and malaria in Kanungu District Uganda from 2011 to 2014 using Bwindi Community Hospital data.

Study Objectives:

1. Implement effect modification analysis using an interaction model analysis and a stratification method
2. Assess the implications of results for public health policy in the changing climate scenario

1 Introduction/ Background

Climate change poses a threat to human health worldwide with regards to human displacement and disease transmission (Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. Engelbrecht, J. Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, 2018; Tanser, Sharp, & le Sueur, 2003; Uganda- Government, 2015; USAID, 2018). While there have been many studies on the implications climate change and temperature variability for malaria transmission (Beck-Johnson et al., 2017; Caminade et al., 2014; Okuneye & Gumel, 2017) many of these studies focus mainly on the direct relationship between climate weather and malaria and do not address matters of social equity. This study aims to address this gap in knowledge through evaluation of the role of social demographic factors — age, sex and ethnicity — in modifying the relationship between weather variability and malaria in Kanungu District Uganda from 2011 to 2014 using Bwindi Community Hospital Data. More specifically I will implement effect modification analysis using an interaction model analysis and stratification methods in order to assess the implications of results for public health policy under a changing climate.

Malaria continues to pose a threat to human health worldwide. Approximately 92% of all malaria cases in 2017 occurred in the WHO's African Region. Five of these countries, primarily in Sub-Saharan Africa, accounted for half of the malaria cases worldwide (WHO, 2018). Uganda accounted for 4% of all cases of malaria in 2017, and is among the countries with the lowest feasibility of Plasmodium falciparum malaria elimination (Donnelly et al., 2016). This is largely due to the presence of highly competent mosquito vectors, poverty, lack of infrastructure, and overburdened health systems (Donnelly et al., 2016; WHO, 2018). Climate change threatens progress made towards malaria elimination in many areas of the world. The Intergovernmental Panel on Climate Change (IPCC)'s climate scenarios suggest with medium to high confidence that climate change could alter the geographic range of the *Anopheles* vector, creating the potential for longer transmission seasons and increasing the number of people at risk, acknowledging that this projection is subject to regionally variability patterns (Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. Engelbrecht, J. Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, 2018)

Among the most vulnerable to the effects of climate change are global Indigenous populations who already face disproportionate burdens of health and social inequality (MacVicar, Berrang-Ford, Harper, Steele, et al., 2017b). Sub-Saharan African Indigenous populations in particular have poorer health outcomes than non-Indigenous populations living in the same geographic areas. They frequently live in more impoverished circumstances, face discrimination, and experience loss of traditional lands, marginalization, and limited access to healthcare services (Berrang-Ford et al., 2012; Donnelly et al., 2016). Malaria has additionally been identified locally as a climate sensitive health priority by the study community in this thesis (Berrang-Ford et al., 2012; Labbé et al., 2016).

In recent years, a number of countries have moved to establish nation-wide policies regarding climate change adaptation activities, including in Uganda (Nyasimi, Radeny, A.O.Mungai, & Kamini, 2015; Uganda-Government, 2015; USAID, 2018). However it is important not only to look at national contributions to climate and health adaptation activities, but also to address these at more localized scales to inform resource distribution (Bishop-Williams et al., 2018). The districts of Uganda vary greatly in their geography, demographic makeup, primary health concerns, and in the way they experience climate change impacts. These will be important factors in determining the most effective course of adaptive action within specific communities. This study could have implications for implementation of locally specific policy and early warning systems based on the needs of unique climate experience and the needs of their particular population.

2 Methods

2.1 Population & Study Area

This study was conducted in Kanungu District, which is located in southwestern Uganda, near Bwindi Impenetrable National Park (Figure 1). Over the last 50 years, this region of eastern Africa, including Uganda, Kenya, South Sudan and Ethiopia, have experienced an increase in seasonal mean temperature (Niang et al., 2014; USAID, 2012). Furthermore climate scenarios indicate that warming trends are likely to continue, projecting an increase in the mean temperature of less than 2.0C by 2030, and an increase in regional drying (Niang et al., 2014). According to Bishop et al. 'Short term meteorological findings in the Southwestern Uganda area increased 0.6C over the course of this four year study period, reflecting concerning global warming trends in 121 models, which predict an increase from 1 to 7C by 2100' (Bishop-Williams et al., 2018).

The region is primarily inhabited by Bakiga and Batwa ethnic populations, both of which face relatively high health burdens when compared to the national average. Both Bakiga and Batwa populations are highly vulnerable to health impacts of a warming climate, and have identified malaria, food insecurity, and gastro-intestinal illnesses as climate-sensitive health concerns (MacVicar, Berrang-Ford, Harper, Huang, et al., June 2017a; Berrang-Ford et al., 2012). The Indigenous Batwa population faces particularly high rates of malaria when compared to the Bakiga, 9.4% vs 4.5% respectively (MacVicar, Berrang-Ford, Harper, Steele, et al., 2017b). This difference in malaria rates is paralleled by a range of health and socio-economic disparities between the two populations (Table 1) including reduced life expectancy (Donnelly et al., 2016; MacVicar, Berrang-Ford, Harper, Steele, et al., 2017b; Patterson et al., 2017). The Batwa have a life expectancy of 28 years when compared with the Ugandan national average of 53 years (Donnelly et al., 2016). The Batwa were removed from their ancestral lands with the creation of the Bwindi Impenetrable Park in 1991, where they were traditionally hunter- gatherers; eviction from the park forced them into settlement in agrarian communities outside the park boundaries (Berrang-Ford et al., 2012). There are currently approx. 6,700 Batwa individuals living in southwestern Uganda (Kulkarni et al., 2017), 900 of which live within Kanungu District. There are no notable ecological or geographic differences in the areas where the Batwa or Bakiga live that would increase risk of malaria in either population.

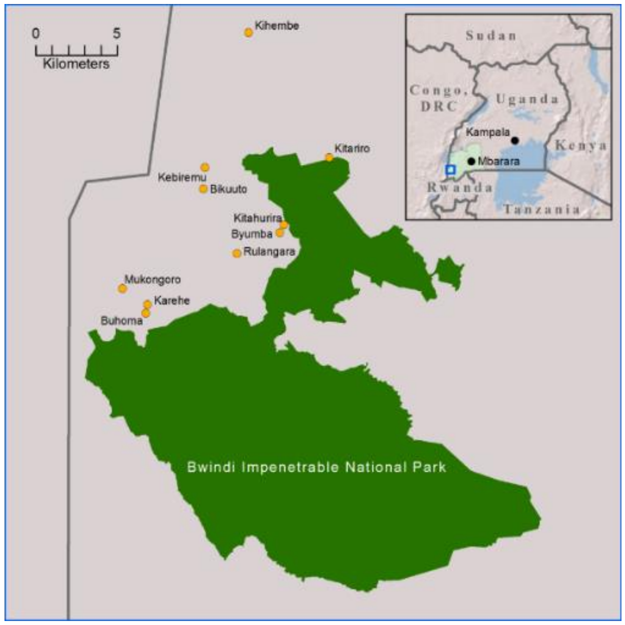


Figure 1: Map of the study area and location of Batwa settlements (Source: www.ihacc.ca)

Table 1: Socio-economic and health differences between Batwa and Bakiga populations as described (MacVicar et al. 2017a)

Health and Socio-econ measure	Batwa (proportion of the population)	Bakiga (proportion of the population)
Malaria prevalence among adult *	6.45	4.46
Moderate acute malnutrition among adult women**	45.86	0.42
Household mosquito net use (did not have nets)	70.99	53.56
Access to handwashing facilities (did not have access to handwashing)	73.85	56.40
Access to soap (did not have access to soap)***	73.85	56.40
*Prevalence of positive malaria antigen detection test in July 2013 and April 2014- survey of all Batwa adults, sample of Bakiga adults ** Classified as moderately malnourished according to the Uganda Ministry of Health Integrated Management of Acute Malnutrition Guidelines)** *** Only asked of people that had access to hand washing facility, for example for the Batwa, 32 or 94% of the households that had access to handwashing had access to soap		

The Bwindi Community Hospital (BCH) was founded in 2003 as a clinic to primarily serve the Batwa population (Bwindi Community Hospital, n.d.). Since the founding of BCH, it has expanded into a large facility which includes six in-patient wards, including a pediatric, adult, maternity, and immunodeficiency wards, as well as an out-patient ward, and several satellite clinics for remote settlements (Bishop-Williams et al., 2018; MacVicar, Berrang-Ford, Harper, Steele, et al., 2017b). BCH operates on a fee-for service model; donations help to subsidize an insurance scheme for residents who qualify (Bishop-Williams et al., 2018; Labbé et al., 2016). All Batwa residents are covered under this insurance plan (Bwindi Community Hospital, n.d.).

Kanungu is a rural area of rolling hills located at an elevation of 1,310m above sea level (Kilama et al., 2014). There are four species of malaria parasite that affect humans in Uganda, the most virulent being *Plasmodium falciparum* (Breman, 2001; Yeka et al., 2012). *Plasmodium Falciparum* is the primary endemic malaria parasite found in the Kanungu region and is most often carried by the *Anopheles gambiae* mosquito species (Okello PE, 2006).

2.2 Outcome: Malaria and population data

Electronic records of patients with a malaria diagnosis from 1-Jan-11 through 21-Dec-14 were obtained through partnership with Bwindi community hospital (BCH). Malaria diagnosis was defined as any case with a positive rapid diagnostic test (RDT) or blood slide in conjunction with symptoms. Individual inpatient records from the hospital were merged with insurance coverage data based on patient ID to provide additional data on sex, age and ethnicity (Bishop-Williams et al., 2018). Data were de-identified prior to analysis to ensure the confidentiality of patients. In total, there were data for 39,287 admissions (all diagnoses) at BCH and 6,602 cases of malaria were reported at BCH during the years 2011-2014. Of these, 18,846 (48 %) of the admissions and 3,440 (52%) of malaria cases could be matched on sex, age, and ethnicity, and were retained for this study; cases with incomplete information on age, sex and ethnicity were excluded. Approximately 51% of data were missing information on Ethnicity, which is the primary effect modifier of interest. Excluded cases were found to have a similar demographic distribution to the final sample used in the analysis according to initial testing (Table 2).

Table 2: Descriptive statistics of variables from the original (full dataset) including variables with missing demographic information

Demographics						
	All admissions (% total)		% demographic recorded	Malaria admissions (% total malaria)		% demographic recorded
Female	14,260	(36.30)	54.28%	2,602	(39.41)	51.07%
Male	12,011	(30.57)	45.72%	2,493	(37.76)	48.93%
Blank Sex	13,016	(33.13)		1,507	(22.83)	
Total Sex Reported	26,271	(66.87)		5,095	(77.17)	
Age 0	8,496	(21.63)	21.89%	1,648	(24.96)	25.48%
Age 1	4,816	(12.26)	12.41%	1,535	(23.25)	23.74%
Age 2	4,269	(10.87)	11.00%	824	(12.48)	12.74%
Age 3	16,739	(42.61)	43.12%	2,160	(32.72)	33.40%
Age 4	4,500	(11.45)	11.59%	300	(4.54)	4.64%
Blank Age	467	(1.19)		135	(2.04)	
Total Age Reported	38,820	(98.81)		6,467	(97.96)	
Batwa	245	(0.62)	1.26%	56	(0.85)	1.56%
Bakiga	19,158	(48.76)	98.74%	3,541	(53.64)	98.44%
Blank Eth	19,884	(50.61)		3,005	(45.52)	
Total Eth Reported	19,403	(49.39)		3,597	(54.48)	
Season (Wet)	22,886	(58.25)	58.25%	3,760	(56.95)	56.95%
Season (Dry)	16,401	(41.75)	41.75%	2,842	(43.05)	43.05%
Blank Season	-	(0.00)		-	(0.00)	
Total Season	39,287			6,602		
Grand total	**39,287**			**6,602**		

2.3 Exposure: Meteorological data

Meteorological data were estimated from the European Centre for Medium Range Weather Forecasts Re-analysis (ERA)-Interim Climate Database, which combined data from multiple sources. The ERA-Interim climate databases have spatial resolution of 0.75° by 0.75°. Daily values for total precipitation (i.e. rainfall (mm)) as well as maximum, minimum, and average temperature (°C) were obtained for all dates matching the extracted medical records (i.e. 1 January, 2011 to 31 December, 2014) (Bishop-Williams et al., 2018). Meteorological data were merged with BCH data based on date of admission; lags were then created to account for the time between mosquito/parasite development, point of infection, and finally the day of admission.

In this study, I focused on how non-meteorological variables acted to modify the effect of temperature on malaria incidence. As such, my models did not aim to maximize precision in the specification of the temperature-malaria relationship, but rather assess the extent to which this generalized relationship is sensitive to effect modification. Lags were created for both ambient temperature and precipitation out to six months prior to admission date under the *a priori* assumption that a biologically plausible time lag for malaria would not extend past four months, and would not be less than one month (Githeko & Ndegwa, 2001; Huang, Zhou, Zhang, Wang, & Tang, 2011; Nanvyat et al., 2018; Okello PE, 2006; Sewe et al., 2015). A combined 12 and 13-week lag — the time between admission date and temperature preceding that date by 77-91 days — in mean weekly temperature was identified as having the most significant and strongest association with malaria rates and was thus chosen for further analysis (Table 3). I converted the variable (temperature) into a binary variable reflecting the highest quartile (versus the lowest 3 quartiles combined) of mean weekly temperature 12 and 13 weeks prior to admission. A binary variable for season was created based on date of admission, rainy seasons were defined as March-June and September-November, and dry seasons were defined as December-February and July-August (McSweeney et al., 2010). Season was retained in our models to account for the dependent nature of temperature and precipitation in the mosquito- weather relationship.

Table 3: Temperature lags by week

Lag by Week	IRR	P-Value	95% CI

10	1.02	0.63	(0.94, 1.11)
11	.99	0.82	(0.91, 1.08)
12	1.09	0.04	(1.00, 1.19)
13	1.12	0.01	(1.03, 1.22)
14	1.06	0.15	(0.98, 1.16)
15	1.07	0.09	(0.98, 1.18)

2.4 Effect Modifiers: Sociodemographic data

Weekly malaria counts were stratified based on age, sex and ethnicity. Age was categorized into: <5 years, 6-12 years, 13-18 years, 19-55 years, and > 55 years of age. Ethnicity was divided into the two main ethnic groups: the Indigenous Batwa, and all other ethnic groups, primarily consisting of ethnic Bakiga.

2.5 Conceptual Approach

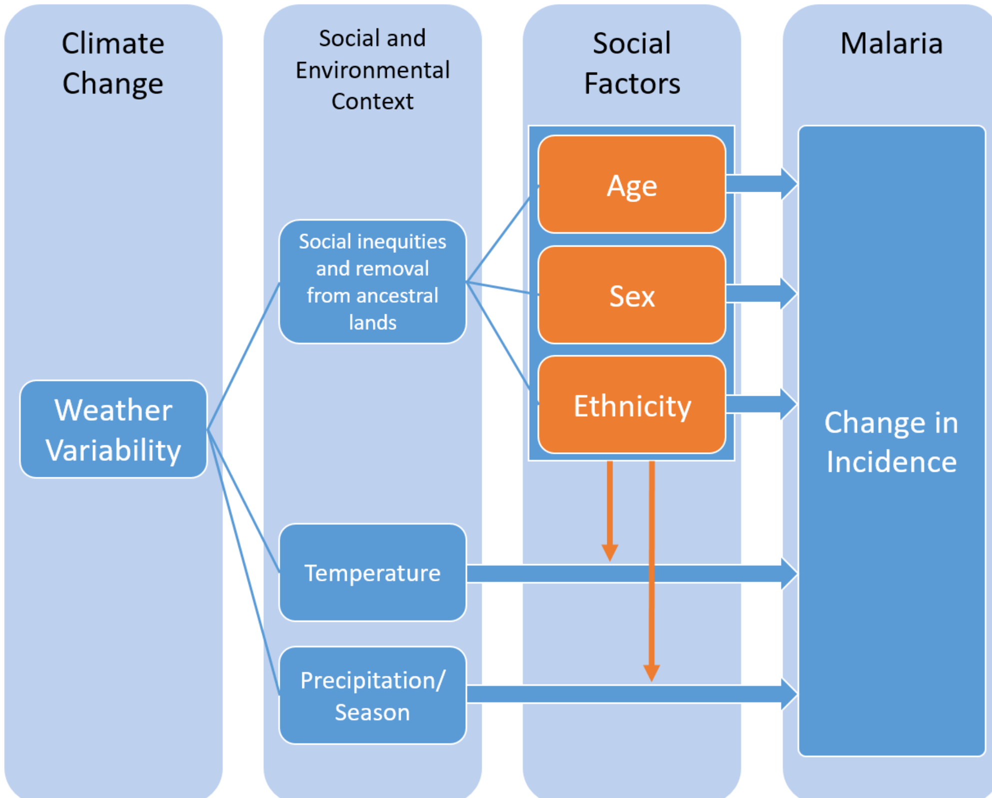
Effect modification occurs when a variable differentially modifies the observed effect of a risk factor on disease status. In this study I examine the way in which age, sex and ethnicity change the effect of meteorological variable, temperature, on malaria incidence. This can be achieved through two methods; both use negative binomial multivariable regression models. I compared both methods to a base model which did not include interaction variables or evaluate the way in which demographic strata modified the relationship between temperature and malaria.

The first method was an interaction model, results are achieved by fitting a single model with all effect modification and confounding variables of interest and then using STATA post estimation codes (margins, or in this case lincom) to achieve results by strata. The benefit of using this method is that it takes all interaction and confounding between all variables in the model into account when results are produced.

This also means that results can be more difficult to interpret. Results for this method are interpreted as strata1/strata0 and were run for both hot and cool temperatures.

The second method uses stratified models, where results are achieved by fitting models for each level of strata; for each temperature category (hot vs cool quartiles). Due to the very small (n) for the Batwa population, using this additional method helped to both verify and more fully understand the complex interaction results. Stratified models allow us to understand the direct relationship between the effect modifiers of interest, with the weather-malaria relationship making them more easily interpretable. However, stratified models do not incorporate the interaction that may occur between the strata and confounders in the model. Results for this method are interpreted as strata1 hot/strata1 cool, and are useful for then calculating easily interpretable ratio of ratios to compare IRRs between demographic variables.

Conceptual Model:



2.6 Data analysis

I used a negative binomial multivariable regression model with total weekly malaria cases for BCH as our dependent (outcome) variable. For our population at risk (offset) variable, I used the weekly total admissions to BCH for any diagnosis. Year was controlled for in all models as a confounding variable. Season was retained in all final models to account for potential seasonal modification/interaction of temperature effects. Because BCH is in a rural setting the data collection and entry is variable over time, therefore, I controlled for year as a confounding variable in all of our statistical analyses to minimize the potential for reporting bias over time. A summary of variables used in the models is provided in Table 4.

Table 4: Variables used in regression analysis

Variable (Units)	Description
Dependent (outcome) variable	
Weekly malaria cases	Total case count per 7-day period, stratified by ethnicity, sex, and age (n=20 strata)
Independent (predictor) variable	
Mean weekly temperature (˚C)	Binary: lower (cooler) quartiles 1-3 (ref); top (hottest) quartile
Effect modification variables *(modelled with interaction terms with the independent variable)*	
Ethnicity	Binary: Bakiga and other (ref); Batwa
Sex	Binary: male (ref); female
Age	Categorical: <5yrs (ref); 6-12yrs; 13-18yrs; 19-55yrs; >55yrs
Control variables	
Season	Binary: dry (ref); wet *Modelled with an interaction term with the independent variable*
Year	Categorical: 2011 (ref), 2012, 2013, 2014
Offset variable	
Population at risk (PAR)	Weekly total number of patients at BCH in all wards

Base Model: I first ran model with no interactions that included sociodemographic and meteorological exposures. The model with no interactions was:

$$ln(weekly\ malaria\ counts) = +\beta_1(mean\ weekly\ T°L12 - 13) + \beta_2(sex) + \beta_3(age) + \beta_4(ethnicity) + \beta_5(season) + \beta_6\ Year$$

Interaction Model: I incorporated interactions to evaluate effect modification among variables for the study period (2011-2014). I included interaction terms between the binary weekly mean temperature variable (top quartile) and age, sex, ethnicity, and season. The associations between the interaction terms and the outcome is an indicator of effect modification (interaction) of the temperature-malaria relationship by age, sex, and/or ethnicity.

To illustrate the size, direction and confidence interval of interactions, I evaluated linear combinations of estimates for season, sex, age, and ethnicity. I included all control and interaction variables in a single model to account for confounding between variables.

The final model equation used for analyses was the following:

$ln(weekly\ malaria\ counts) = \beta_0 + \beta_1(mean\ weekly\ T°L12 - 13) + \beta_2(sex) + \beta_3(age) + \beta_4(ethnicity) + \beta_5(season) + \beta_6(mean\ weekly\ T°L12 - 13 * season) + \beta_7(mean\ weekly\ T°L12 - 13 * sex) + \beta_8(mean\ weekly\ T°L12 - 13 * age) + \beta_9(mean\ weekly\ T°L12 - 13 * ethnicity) + \beta_{10}(mean\ weekly\ T°L12 - 13 * Year)$ + *ln(population at risk)*

Stratified Models: Additionally, I ran models stratified by effect modifiers age, sex, ethnicity, and season to enhance our understanding of the relationships between effect modifiers and the outcome of interest in a more direct way. Stratified models also contained all control and interaction variables to minimize the effect of confounders in the analysis. All analyses were conducted in STATA v.15.1 (Stata Corp., USA), effect modification results were displayed using guidance from (Knol & VanderWeele, 2012).

2.7 Ethics

Primary data collection for this data set was approved by ethics boards at McGill University and the University of Guelph. For the purposes of this research personal identifiers were removed before analysis. This research project received ethics approval May 2018 by the University of Washington IRB (Zipline) as 'Human Research, Not Engaged', ID: STUDY00004668.

3 Results

3.1 Descriptive Statistics

The study period ranged from 1 January 2011 to 31 December 2014. Out of the population with ethnicity recorded during that time, I found that 56.7 percent of malaria cases in the sample occurred during the wet season from March-June or September-November. Sex was fairly evenly distributed, with 53 percent of malaria cases being female, making up 56 percent of the total admissions data. A majority (37%) of the total admission sample fell into the age category of 19-55 year olds and 36 percent of 6-12 year olds admitted to BCH had a malaria infection during the study period. Finally, only 238 (1%) of the sample was recorded as being Batwa; 23% of the Batwa population had a malaria infection during the study period, while 18% percent of the Bakiga population experienced a malaria episode**.**

Table 5: Descriptive statistics of variables included in final models

Demographics				
	All admissions	**% of admissions**	**Malaria admissions**	**% of malaria admissions**
Sex=F	10,565	56.10%	1,826	53.10%
Sex=M	8,281	43.90%	1,614	46.90%
Age (0) 0-5 yrs	5,687	30.20%	1,143	33.20%
Age (1) 6-12 yrs	2,514	13.30%	896	26.00%
Age (2) 13-18 yrs	1,950	10.30%	414	12.00%
Age (3) 19-55 yrs	6,957	36.90%	895	26.00%
Age (4) 55+ yrs	1,738	9.20%	92	2.70%
Ethnicity (Bakiga)	18,608	98.70%	3,386	98.40%
Ethnicity (Batwa)	238	1.30%	54	1.60%
Season (Wet)	10957	58.14%	1948	56.63%
Season (Dry)	7889	41.86%	1492	43.37%
Total Number*	**18,846**		**3,440**	

Dropped **	20,441		3,162
Meteorological (average of daily)			
Temperature (Celsius)	**Mean**	**Min**	**Max**
2011	18.91	13.13	27.51
2012	19.07	12.22	28.67
2013	19.54	12.96	28.98
2014	19.55	13.32	29.19
Rainfall (mm)	**Average Daily**	**Yearly Total**	
2011	3.55	1296	
2012	3.55	1300	
2013	3.22	1174	
2014	3.07	1197	

*Data were collected for years 2011-2014, 4 observations were excluded due to implausible dates

** Values dropped from original dataset due to incomplete demographic information

3.2 Baseline model (without interaction/effect modification)

Weekly temperatures in the highest quartile 29.30̊ C- 29.42̊ C (with a lag of 12-13 weeks) were associated with an increase in malaria incidence rates 1.36 (1.07, 1.72) times higher than weeks in the three cooler quartiles of weekly mean temperature. Malaria incidence among the Indigenous Batwa was 0.016 (0.012, 0.020) times the incidence of the non-Indigenous Bakiga, and this difference was significant. The incidence rate of malaria for females was 1.13 (1.05, 1.22) times higher than for males, and also significant. Children <5yrs had the highest incidence rate of malaria, followed by young children 6-12yrs, with lowest rates among youths aged 13-18yrs. Malaria incidence was significantly higher (IRR: 1.16, 95% CI 1.02-1.31) during the dry season compared to the wet season in this model.

Table 6: Baseline model results

	Baseline Model IRR (95% CI)
Temperature Q1-3	*Reference*
Temperature Q4	1.36 (1.07, 1.72)
Bakiga	*Reference*

Batwa	0.016 (0.012 ,0.020)
Male Female	*Reference* 1.13 (1.05, 1.22)
Age 0-5 Age 6-12 Age 13-18 Age 19-55 Age 55+	*Reference* 0.82 (0.72, 0.94) 0.35 (0.31, 0.40) 0.74 (0.66, 0.83) 0.08 (0.06, 0.10)
Season (Wet) Season (Dry)	*Reference* 1.16 (1.02, 1.31)

3.3 Evidence of effect modification of the temperature-malaria relationship

Interaction Model: My analysis revealed that the effect of temperature on malaria differed by age, sex, and ethnicity. Women experienced a higher incidence of malaria compared to men, with this difference substantially higher during hotter weeks (top quartile of mean temperature) compared to cooler weeks. During weeks in the combined cooler 3 quartiles of temperature, malaria rates between men and women were similar (IRR 1.02, 95% CI: 0.79-1.31). During the hottest weeks, however, the rate of malaria incidence among women was significantly higher, 1.51 (1.09, 2.09) times the rate among men. Increases in malaria incidence were higher in the wet season than the dry season and higher in the highest temperature quartile with a 12-13 week lag than the cooler quartiles of the dry season IRR 0.51 (95% CI: 0.28, 0.93) vs IRR 0.34 (95% CI: 0.18, 0.65) respectively. Age categories ranged from the lowest incidence rate ratio (IRR) of 1.03 for 13-18 year olds to the highest being among 6-12 year olds with an IRR of 2.04. The incidence of malaria among the Batwa was greater than the Bakiga regardless of temperature and was more than double that in the Bakiga during the hottest temperature quartile (IRR 2.35, 95% CI 0.88-6.25). Though still elevated among Batwa during cooler weeks, the difference between Batwa and Bakiga rates was lower (IRR 1.49, 95% CI 0.71-3.55). All of these differences, however, have wide and overlapping confidence intervals owing to a small Batwa sample size, which severely limits statistical power to detect significant differences for these effect size differences.

Table 7: *Comparison between baseline model and interaction models*

	Temperature *(IRR, 95%CI)*		
	Quartile 1-3(Cool)	Quartile 4(Hot)	IRR Hot/IRR Cool *Ratio of Ratios (ROR)*
Overall (Baseline)	*Reference*	1.36 (1.07, 1.72)	*Reference*
Bakiga	*Reference*	*	
Batwa	1.58 (0.71, 3.55)	2.35 (0.88, 6.25)	1.49
Male	*Reference*	*	
Female	1.02 (0.79, 1.31)	1.51 (1.09, 2.09)	1.48
Age 0-5	*Reference*	*	
Age 6-12	1.38 (0.93, 2.04)	2.04 (1.24, 3.37)	1.47
Age 13-18	0.69 (0.49, 0.97)	1.03 (0.72, 1.46)	1.49
Age 19-55	0.89 (0.59, 1.33)	1.31 (0.98, 1.77)	1.47
Age 55+	0.76 (0.35, 1.65)	1.13 (0.57,2.24)	1.48
Season (Wet)	*Reference*	*	
Season (Dry)	0.34 (0.18, 0.65)	0.51 (0.28, 0.93)	1.5
*Due to small sample size there was not enough data to produce an IRR for these categories using an interaction analysis			

Interpretation for Ethnicity: The Batwa are 2.35 times more likely to experience malaria infection than Bakiga during the hot season. The ratio of ratios for Batwa vs Bakiga in the hot quartile over the cool quartiles is 1.49

Stratified Model: I found that results were consistent between the interaction results and the results of our stratified model method. The Batwa population was found to have a higher IRR than Bakiga 2.75 (95% CI 0.90, 8.44) versus 1.51 (95% CI 1.16, 1.96) respectively with a ratio of ratios of 1.82, indicating that in both models the Batwa were more likely to experience malaria infection than the Bakiga. As in the interaction models we found that 6-12 year olds, and females to experience higher rates of malaria infection, while there was an overall increase in malaria during the wet season during times of high (4^{th} quartile) temperatures.

Table 8- *Stratification model results*

	Temperature *(IRR, 95%CI)*	
	Quartile 4(Hot)	IRR Strata1(+)/IRR Strata0
Overall (Baseline)	1.36 (1.07, 1.72)	-

Bakiga	1.51 (1.16, 1.96)	*Strata 0*
Batwa	2.75 (0.90, 8.44)	1.82
Male	1.46 (1.07, 2.00)	*Strata 0*
Female	1.58 (1.20, 2.08)	1.08
Age 0-5	1.44 (1.04, 1.98)	*Strata 0*
Age 6-12	1.92 (1.32, 2.78)	1.33
Age 13-18	1.04 (0.71, 1.53)	0.72
Age 19-55	1.37 (1.02, 1.83)	0.95
Age 55+	1.20 (0.61, 2.36)	0.83
Season (Wet)	1.54 (1.19, 1.99)	*Strata 0*
Season (Dry)	0.61 (0.34, 1.10)	0.39

Interpretation for Ethnicity: The Batwa are 2.75 times more likely to experience a malaria infection in the hot quartile than in the cool quartiles. The ratio of ratios (ROR) for Batwa vs. Bakiga in the hot season only is 1.82.

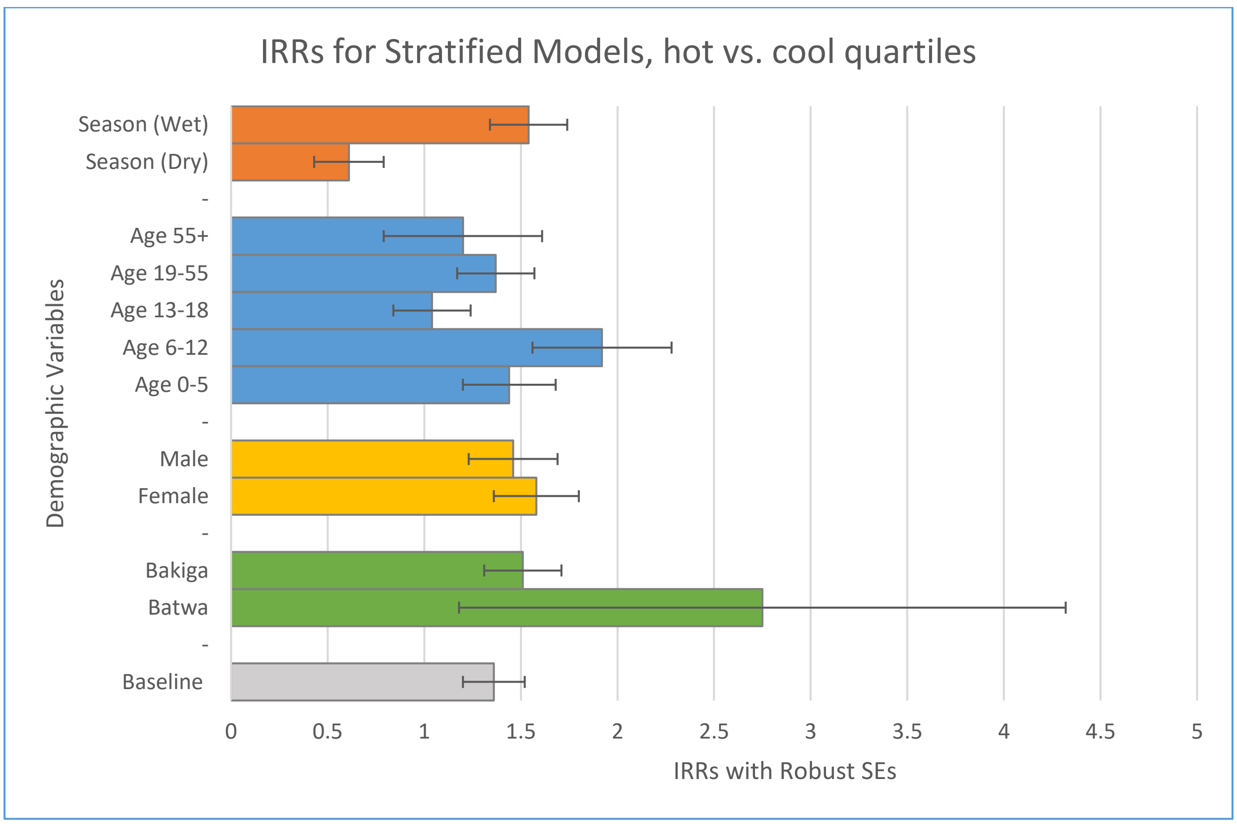


Figure 2: Incidence rates by demographic category for stratified models

4 Discussion

This study aimed to investigate whether social factors such as age, sex, and ethnicity modify the relationship between weather variability and malaria incidence. My analysis suggests that social factors, most do modify the relationship between meteorological factors and malaria infection, more specifically findings indicate that the association between weather variability and malaria incidence stronger among young individuals and members of the Batwa Ethnicity.

One interesting finding that we observed in this study is the inconsistency between the IRR results for Batwa found in the base model when compared to both the interaction and stratification models. The base model results show that Batwa have lower rates of malaria than the Bakiga, however in the effect modification models the relationship switched, indicating that Batwa have higher incidence of malaria than their non-indigenous counterparts. Furthermore our descriptive statistics show that 18.2% of all Bakiga admissions to BCH were for malaria, while 22.7% of all Batwa admissions were for malaria. The base model results are also inconsistent with community survey research conducted by (Donnelly et al., 2016) that found the actual burden of malaria to be much higher among the Batwa than Bakiga. This inconsistent finding in the study could be due to several factors: [1] that the Batwa have lower levels of disease, but that burden of disease is much more sensitive to heat. Or [2] because we are working with hospital data, we are finding reporting bias in our sample, and that the Batwa are less likely to seek hospital services for malaria than the Bakiga, and therefore be less likely to make it into our case counts. This finding supports the need for caution when analyzing hospital level data for illnesses determined to be climate/weather sensitive, without considering the role of meteorological factors. Because my analysis took interaction with temperature into account we were able to get a more complete picture of the comparative incidence between the populations.

In addition to interesting ethnicity modification findings, the age results changed between my baseline and effect modification model. The baseline results indicated that the highest incidence of malaria was among 0-5 year olds, which is consistent with the literature; however in our effect modification results we found that 6-12 year olds had a higher rate of malaria in the highest temperature quartile (WHO, 2018). This could possibly be explained by findings of the Indigenous Health Adaptation to Climate Change (IHACC) community survey, which found that 0-5 year olds were more likely to sleep under a mosquito net at night than any other age group, and that use declined in the 6-12 year old group (Clark et al., 2016). This could serve as an explanation for higher rates of malaria in 6-12 year olds associated with the temperature-malaria relationship.

The results from this study cannot be directly used to make conclusions about climate change and malaria due to the short study period, however these results are important in the context of climate change, because of its potential impact on weather variability. Results show that the association between weather variability and malaria is stronger among certain social strata in the Kanungu region, it suggests that certain demographic strata are at higher risk of malaria infection depending on meteorological conditions, which is important context in climate change adaptation planning.

Uganda has several national level calls for stronger climate policy including: The Lake Victoria Basin Report 2018, Uganda's National Adaptation Program of Action (NAPA) 2007, The Uganda National Climate Change Policy 2015, and a National Policy for Disaster Preparedness and Management 2010. Most of these policies have broad goals that address national level concerns such as water, agriculture, economic, and preparedness adaptation. My findings suggest that local level policy may be beneficial in addressing some of the more 'micro' level concerns that districts will face, such as differential risk of malaria infection among certain subsets of the population. An example that illustrates the use of local policy to reduce the incidence of mosquito borne disease comes from Indonesia. In Indonesia, there is no national level early warning system for disease outbreaks, however the Ministry of Health advises local governors when to prepare for outbreaks. Local government then carries out health campaigns, prompting the local population to clear breeding sites and increase their use of mosquito nets (Ebi, Lewis, & Corvalan, 2006b). Policies like this can be easily adapted to help populations at higher risk of contracting malaria during high census seasons prepare for the local malaria season.

In Uganda's more remote districts, like Kanungu, results suggest that while the entire population is more susceptible to malaria compared to the national average, some, like the Batwa and young individuals, experience higher rates of malaria during high temperature, wet seasons and may need additional planning and resource allocation, such as assistance with the removal of mosquito breeding sites around the home, or distribution of mosquito bed nets, to achieve more equitable adaptation activity needs. Currently Uganda has policy surrounding the distribution of mosquito nets to pregnant women and children under the age of 5 (Clark et al., 2016), local policy could expand to include the Batwa population in their high priority prevention efforts. In community surveys the Batwa have been reported to have less mosquito nets, as well as lower net use/ownership retention when compared to their counterparts, the Bakiga (Clark et al., 2016).

Greater investment in local adaptation policy should be considered as part of an integrated, harmonized multi-level/ multi-sector framework to addressing climate change policy, like that which is called for in Lake Victoria Basin Report (USAID, 2018). Furthermore the Lancet Climate Commission also recommends a multi-level policy adaptation approach through fostering collaboration between multiple levels of governmental and health organizations in order to ensure that "health and climate considerations are thoroughly integrated in government-wide strategies", and warns against a siloed approach to protecting human health (Watts et al., 2015).

As part of comprehensive policy recommendations the USAID report on Planning for Resilience in East Africa through Policy, Adaptation, Research and Economic Development (PREPARED report) recommends "incorporating systems that strengthen and institutionalize surveillance, early warning, and communication systems on climate-sensitive diseases"(USAID, 2012). This policy recommendation should be adopted at multiple levels of government and health systems. Early warning systems partner well with education strategies and resource distribution to aid populations in preparedness and can be easily tailored to target populations in a local setting.

5 Limitations

There was a significant reporting bias found in the data by year and admission ward due to the nature of the location and quality of data collection. I was able to control for most of the confounding of those two variables, however it is possible that there is some residual confounding present in the results. Additionally, these data were obtained from a local hospital operating on a fee-for-service basis, though they have programs to create more financially accessible services for patients living in poverty, it is possible that inability to pay for services may have unintentionally excluded some individuals from our analysis. Data also represent a short period of time (four years) which is not indicative of the relationship between malaria and climate change, results should be interpreted with caution in this context, and are more suitable to speaking to a relationship with temperature. The Batwa population is very small, therefore the (N) is not ideal for robust statistical analysis. Regardless of this less than ideal sample size this population is an important one to study in the context of weather variability and climate change due to their susceptibility to climate-sensitive illnesses (Berrang-Ford et al., 2012; Labbé et al., 2016). Additionally, four data points were excluded due to implausible dates.

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