Check for updates

RESEARCH ARTICLE

REVISED Impact of 1.5 °C and 2 °C global warming scenarios on malaria transmission in East Africa [version 3; peer review: 2 approved]

Obed Matundura Ogega [1,2], Moses Alobo [1]

[1]Programmes, The African Academy of Sciences, Nairobi, Kenya
[2]School of Environmental Studies, Kenyatta University, Nairobi, Kenya

v3 **First published:** 03 Jun 2020, **3**:22
https://doi.org/10.12688/aasopenres.13074.1
Second version: 23 Oct 2020, **3**:22
https://doi.org/10.12688/aasopenres.13074.2
Latest published: 15 Mar 2021, **3**:22
https://doi.org/10.12688/aasopenres.13074.3

Abstract

Background: Malaria remains a global challenge with approximately 228 million cases and 405,000 malaria-related deaths reported in 2018 alone; 93% of which were in sub-Saharan Africa. Aware of the critical role than environmental factors play in malaria transmission, this study aimed at assessing the relationship between precipitation, temperature, and clinical malaria cases in East Africa and how the relationship may change under 1.5 °C and 2.0 °C global warming levels (hereinafter GWL1.5 and GWL2.0, respectively).
Methods: A correlation analysis was done to establish the current relationship between annual precipitation, mean temperature, and clinical malaria cases. Differences between annual precipitation and mean temperature value projections for periods 2008-2037 and 2023-2052 (corresponding to GWL1.5 and GWL2.0, respectively), relative to the control period (1977-2005), were computed to determine how malaria transmission may change under the two global warming scenarios.
Results: A predominantly positive/negative correlation between clinical malaria cases and temperature/precipitation was observed. Relative to the control period, no major significant changes in precipitation were shown in both warming scenarios. However, an increase in temperature of between 0.5 °C and 1.5 °C and 1.0 °C to 2.0 °C under GWL1.5 and GWL2.0, respectively, was recorded. Hence, more areas in East Africa are likely to be exposed to temperature thresholds favourable for increased malaria vector abundance and, hence, potentially intensify malaria transmission in the region.
Conclusions: GWL1.5 and GWL2.0 scenarios are likely to intensify malaria transmission in East Africa. Ongoing interventions should, therefore, be intensified to sustain the gains made towards malaria elimination in East Africa in a warming climate.

Open Peer Review

Reviewer Status ✔ ✔

	Invited Reviewers 1	Invited Reviewers 2
version 3 (revision) 15 Mar 2021	✔ report	
version 2 (revision) 23 Oct 2020	? report	✔ report
version 1 03 Jun 2020	? report	? report

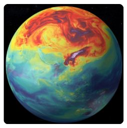
1. **Masilin Gudoshava**, National University of Science and Technology, Bulawayo, Zimbabwe

2. **Ramesh C. Dhiman**, ICMR-National Institute of Malaria Research, New Delhi, India

Any reports and responses or comments on the article can be found at the end of the article.

Keywords

SR1.5, CORDEX, malaria, RCP 8.5, global warming, mosquito vectors



This article is included in the Climate collection.

Corresponding author: Obed Matundura Ogega (obed.matundura@gmail.com)

Author roles: Ogega OM: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Alobo M**: Conceptualization, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: The author(s) declared that no grants were involved in supporting this work.

How to cite this article: Ogega OM and Alobo M. **Impact of 1.5 ºC and 2 ºC global warming scenarios on malaria transmission in East Africa [version 3; peer review: 2 approved]** AAS Open Research 2021, **3**:22 https://doi.org/10.12688/aasopenres.13074.3

First published: 03 Jun 2020, **3**:22 https://doi.org/10.12688/aasopenres.13074.1

REVISED **Amendments from Version 2**

This version has minor revisions in the Introduction (paragraph 1) and the Methodology (paragraph 3 of the Data Analysis sub-section) sections for coherence.

Any further responses from the reviewers can be found at the end of the article

Introduction

Malaria is an illness caused by *Plasmodium* parasites that are spread to humans through bites of infected female *Anopheles* mosquitoes, commonly referred to as "malaria vectors". Of the five parasite species that cause malaria in humans, *P. falciparum and P. vivax* pose the highest threat (WHO, 2020). According to the World Health Organization (WHO), an estimated 228 million malaria cases and 405,000 malaria-related deaths were reported in 2018, globally. About 93% of the malaria cases and 94% of the malaria-related deaths occurred in sub-Saharan Africa. Uganda, for instance, tops East Africa with the highest number of malaria cases; accounting for 5% of global totals in 2018.

Malaria transmission is affected by, among other things, climatic factors such as temperature, rainfall, and humidity that influence the abundance and survival of mosquitoes (Caminade *et al.*, 2012; Metelmann *et al*., 2019; Nsoesie *et al*., 2016). While efforts are underway towards elimination, malaria remains a big challenge in East Africa (Bashir *et al*., 2019; Nkumama *et al*., 2017; WHO, 2020). In a special report on global warming of 1.5 °C (hereinafter SR1.5), the Intergovernmental Panel on Climate Change (IPCC; Hoegh-Guldberg *et al*., 2018) highlighted sector-specific risks posed by a global temperature rise of 1.5 °C and beyond. The SR1.5 identifies a knowledge gap in the impacts of global and regional climate change at 1.5 °C on, *inter alia*, public health and infectious diseases, particularly for developing nations. Some work has been done towards understanding the potential impact of global warming in East Africa (e.g. Gudoshava *et al*., 2020; Osima *et al*., 2018). However, no conclusive literature exists on the potential impacts of 1.5 °C and 2 °C global warming levels (hereinafter GWL1.5 and GWL2.0) on health, among other sectors, in East Africa. This study, therefore, aimed at assessing the relationship between precipitation, temperature, and clinical malaria cases in East Africa and how the relationship may change under the GWL1.5 and GWL2.0 scenarios.

Methodology

Study area

The study focuses on the East Africa sub-region (marked EA on Figure 1) of the COordinated regional Downscaling Experiment (CORDEX) Africa domain (Kim *et al*., 2014). A slight extension of the CORDEX-EA sub-region was done to cover five countries part of the East African Community (EAC) namely Kenya, Uganda, Tanzania, Rwanda, and Burundi (Figure 1).

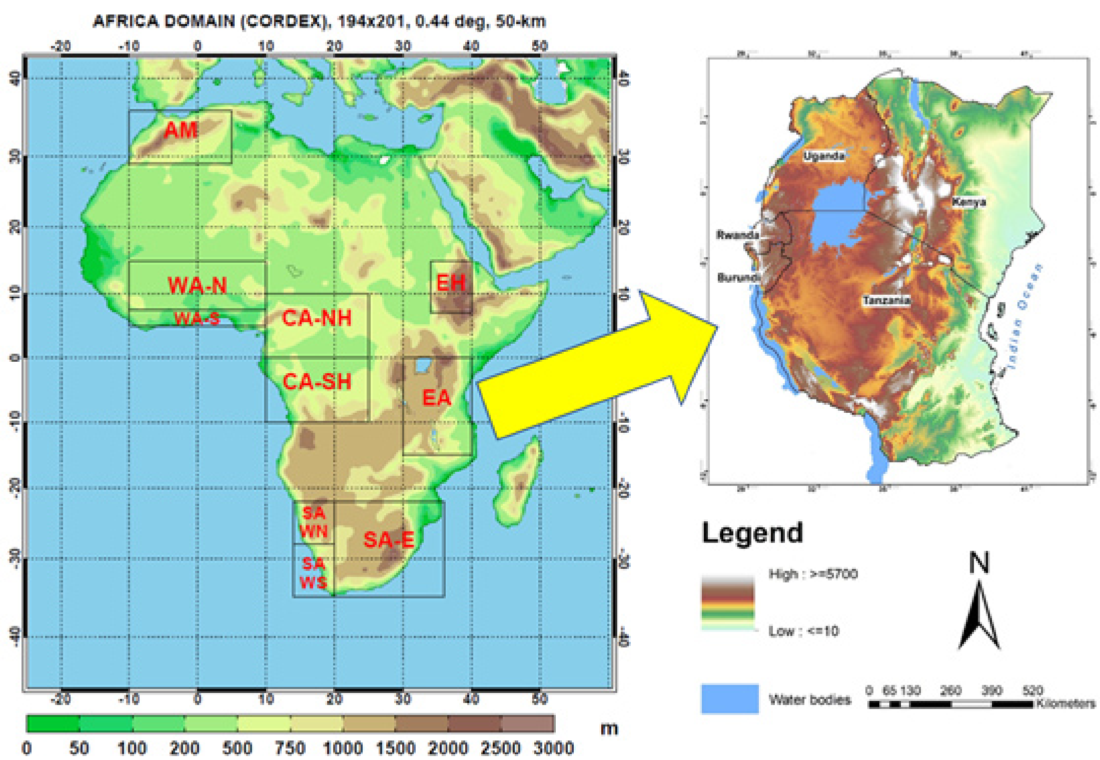


Figure 1. Map of the study domain. Figure is reproduced from Ogega *et al.* (2020) under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Climate model data
Daily precipitation data (in its native form) from two regional climate models (RCMs) participating in CORDEX-Africa were used. Specifically, the study used four RCM realizations (Table 1) driven by general circulation models (GCMs) from the 5th phase of the Coupled Model Intercomparison Project (CMIP5, Meehl *et al.*, 2014), under the representative concentration pathway (RCP) 8.5 (Moss *et al.*, 2010). Here, we chose the RCP 8.5 due to its more realistic representation of global warming scenario considering todays' global greenhouse gas emission trajectory (Taylor *et al.*, 2012). Additionally, the RCP 8.5 has been widely used in Africa and beyond (e.g. Gudoshava *et al.*, 2020; Ogega *et al.*, 2020; Yan *et al.*, 2019). The four CORDEX-Africa RCM runs have been identified to be among the best in simulating precipitation characteristics over East Africa (Ogega *et al.*, 2020). The RCMs are described in detail in Nikulin *et al.* (2012).

Observational climate data
The daily Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version 2.0 was used as observational precipitation data. CHIRPS data, which have been validated for East Africa (Dinku *et al.*, 2018), incorporate satellite imagery (at 0.05° resolution) with *in-situ* station data resulting in a gridded rainfall time series available from 1981 to near-present (Funk *et al.*, 2015). For mean temperature, the Climatic Research Unit time-series (CRU) dataset were used. CRU data are computed on high-resolution (0.5 by 0.5 degree) grids based on a database of monthly mean temperatures from at least 4,000 weather stations from around the world (Harris *et al.*, 2020).

Clinical malaria cases data
Data on clinical malaria cases for East Africa were obtained from the Malaria Atlas Project (Hay & Snow, 2006; Weiss *et al.*, 2019). The Malaria Atlas Project (MAP) obtains, curates, and shares a variety of malariometric data including malaria cases reported by surveillance systems, nationally representative cross-sectional surveys of parasite rate, and satellite imagery capturing global environmental conditions that influence malaria transmission. The dataset has been validated (e.g. Nakakana *et al.*, 2020) and used widely across the world (e.g. Battle *et al.*, 2019; Bhatt *et al.*, 2015; Weiss *et al.*, 2019).

Data analysis
Precipitation and temperature have been identified as the most important climatic factors for malaria vectors (e.g. Arab *et al.*, 2014; Mohammadkhani *et al.*, 2016). In the current study, a review of literature was done to identify precipitation and temperature thresholds within which malaria vectors thrive. The search was done in Scopus and Google Scholar using the following terms: temperature threshold for *Anopheles* mosquitos, precipitation threshold for *Anopheles* mosquitos, and malaria transmission in East Africa. Results of the review were used to analyse historical (2000–2017, due to limited availability of data on clinical malaria cases from MAP) trends in temperature, precipitation, and clinical malaria cases in East Africa. Specifically, standardized anomalies, which remove influences of location and distribution from the data (as in Dabernig *et al.*, 2016), were computed to determine the year-to-year variability of incidences. Linearly de-trended precipitation and temperature data were used for correlation analysis with reference to the reported clinical malaria cases in the study domain.

A detailed analysis done by Nikulin *et al.* (2018) identified years 2022 and 2037 as mid-years for 30-year periods when GWL1.5 and GWL2.0 were likely to be experienced in Africa, respectively, using an ensemble mean of a subset of GCMs driving the CORDEX-Africa RCM realizations. Our study adapted periods 2008–2037 and 2023–2052 to correspond to GWL1.5 and GWL2.0, respectively. With reference to 1977–2005 as the control period (CTL), we assessed changes in precipitation and temperature by calculating differences between climatological values in GWL1.5 and GWL2.0 and the CTL. A comparison of precipitation and temperature values in the current (CTL), GWL1.5 and GWL2.0 (relative to established thresholds within which malaria vectors thrive) was used to determine the potential impact of 1.5 °C and 2.0 °C GWLs on malaria transmission in East Africa.

Statistical computations and data visualization
Processing (conversion to common calendar, units, grid, and resolution) and statistical computations (e.g. means, anomalies, standard deviation, summations, and data detrending) of climate (precipitation and temperature) data in NetCDF format was done using the Climate Data Operators (CDO), version 1.9.8 – a

Table 1. CORDEX-Africa RCM runs used in the current study, downloaded in April 2020 from the Deutsches Klimarechenzentrum (DKRZ[1]), for the period 1977–2005 (historical) and 2008–2052 (RCP 8.5).

Institute	RCM	Herein-after	Ensemble	Driving Model
Max Planck Institute (MPI), Germany	REMO2009	REMO2009	r1i1p1	MPI-M-MPI-ESM-LR
Sveriges Meteorologiska och Hydrologiska Institut (SMHI), Sweden	SMHI Rossby Center Regional Atmospheric Model (RCA4)	RCA4	r1i1p1	MPI-M-MPI-ESM-LR
				CNRM-CERFACS-CNRM-CM5
			r2i1p1	MPI-M-MPI-ESM-LR

The terms in the table can be used to search for the required data files

[1]http://bit.ly/2RoIist

command line suite for manipulating and analysing climate data. A description of CDO operators is available from the CDO user guide. Additional computations were done using the R Project for Statistical Computing (R, version 3.6.3). Specifically, the *fields, graphics, and ncdf4* R packages were used to process and compute future changes in precipitation and temperature under the 95% confidence level. Data detrending and correlation analysis were done in R using the *pracma* package and the *cor.test* function, respectively. Spatial data visualization was done using the Grid Analysis and Display System (GrADS, version 2.2.1.oga.1). Line plots were done in R using the *ggplot2* (*version 3.3.0*) package.

Due to resolution differences between model and observations data, the data were processed in their native grids before bi-linearly interpolating them to the RCM grid to facilitate comparison (as in Diaconescu *et al*., 2015). Here, final products (after all the statistical computations) for both observational and model data were remapped into the same grid to facilitate comparison. Remapping was done using the '*remapbil*' function in the CDO software.

Results and discussion

An overview of the relationship between temperature, precipitation, and malaria vectors

An. gambiae s.s., An. funestus, and *An. arabiensis* have been identified as the top three potent malaria vectors in sub-Saharan Africa (Wiebe *et al*., 2017) and, in particular, East Africa (e.g. Dida *et al*., 2018; Karungu *et al*., 2019). Among other climatic factors that influence malaria transmission is temperature – which has been shown to be a useful predictor of incidence (e.g. Pascual *et al*., 2006). Any climate-induced changes in temperature are likely to disproportionately affect malaria control interventions across the world (e.g. Ryan *et al*., 2020; Siraj *et al*., 2014). A study by (Charlwood, 2017) established that *An. funestus* seemed to be adversely affected by temperatures above 28 °C. Additionally, the wing size of *An. funestus* is said to be highly correlated with temperature and elevation (Spearman test, $p<0.001$) and minimally affected by rainfall and wind speed (Ayala *et al*., 2011). Christiansen-Jucht *et al*. (2014) inferred that temperature during larval development and adult maintenance influences the survival of *An. gambiae* s.s. Their study established that temperatures beyond 27 °C significantly influenced the survival of adult *An. gambiae* s.s. by increasing their mortality.

In areas where malaria transmission by *An. funestus* is high, transmissions by *An. gambiae* s.s. and *An. arabiensis* seemed to be higher/lower with precipitation/temperature (Kelly-Hope *et al*., 2009). Further, a temperature-dependent and stage-structured delayed differential equation developed by Beck-Johnson *et al*. (2013) showed that mosquito population abundance is strongly influenced by the dynamics of juvenile mosquito stages which are temperature-dependent. Their model places a peak in abundance of mosquitoes old enough to transmit malaria at around 25 °C. Generally, studies have shown that significant malaria transmission in Africa occurs in areas with temperature ranging from 18 °C to 28 °C, with 25 °C as the optimum temperature (e.g. Craig *et al*., 1999; Mordecai *et al*., 2013). Hence, our study adopted the 18 °C – 28 °C as the temperature range within which significant malaria transmission occurs.

While no distinct annual precipitation thresholds have been established for malaria transmission, precipitation plays a vital role in both mosquito abundance and spatial and temporal malaria transmission. It does so by providing good aquatic environments to host malaria vectors. Indeed, heavy and extreme precipitation events have been associated with higher malaria cases in East Africa (e.g. Brown *et al*., 1998; Hashizume *et al*., 2009; Kilian *et al*., 1999). For instance, a study by (Gilioli & Mariani (2011) established that a 10 percent increase in precipitation can result in about 6 percent increase in mosquito population in Kenya. Therefore, we assessed the climatology for mean annual precipitation and how it may change under GWL1.5 and GWL2.0. The changes in precipitation patterns will give an indication of the intensity and extent of malaria transmission under the two warming scenarios.

Trends in temperature, precipitation, and clinical malaria cases in East Africa

Despite heavy investments (Head *et al*., 2017) made to combat and eliminate malaria in the study domain, clinical malaria cases showed some correlation with precipitation and temperature. Siaya and Kigali (b and d, respectively, in Figure 2) are good examples where clinical malaria cases corresponded to trends in climate variables, especially the mean temperature.

Pearson correlation coefficients (PCCs) for five administrative areas recording the highest number of clinical malaria cases per country (Table 2) showed a positive relationship between temperature and clinical cases, in 22 out of 25 areas under consideration. Burundi recorded the highest positive PCCs (up-to 0.6) between temperature and clinical cases while Uganda recorded the highest negative PCCs (up-to -0.4). Most areas (16 out of 25) recorded a negative correlation between precipitation and clinical malaria cases, with the highest negative correlation being -0.4. The rest showed a marginal positive correlation with the highest being 0.3.

Given that precipitation regimes over the study domain are well-defined (e.g. Nicholson, 2017; Schreck & Semazzi, 2004), the observed negative correlation between precipitation and clinical malaria cases could be as a result of deliberate intensification efforts to combat malaria during the rainy seasons. For instance, an analysis of confirmed malaria cases in Uganda between 2013 and 2016 concluded that the declining cases of Malaria incidence in Uganda was as a result of effective vector-control measures and case management (Ssempiira *et al*., 2018). The study showed that a 100% increase in the use of insecticide-treated mosquito nets was associated with a malaria incidence decline of up-to 44% in children below five years of age. In Burundi, where a high correlation between malaria cases and precipitation was recorded, malaria is still a major public health problem responsible for about 25% of all outpatient visits (USAID, 2016). The relatively high malaria burden could be attributed to, among other factors, limited vector and case control interventions (e.g. Protopopoff *et al*., 2007; USAID, 2016). Nonetheless, areas that

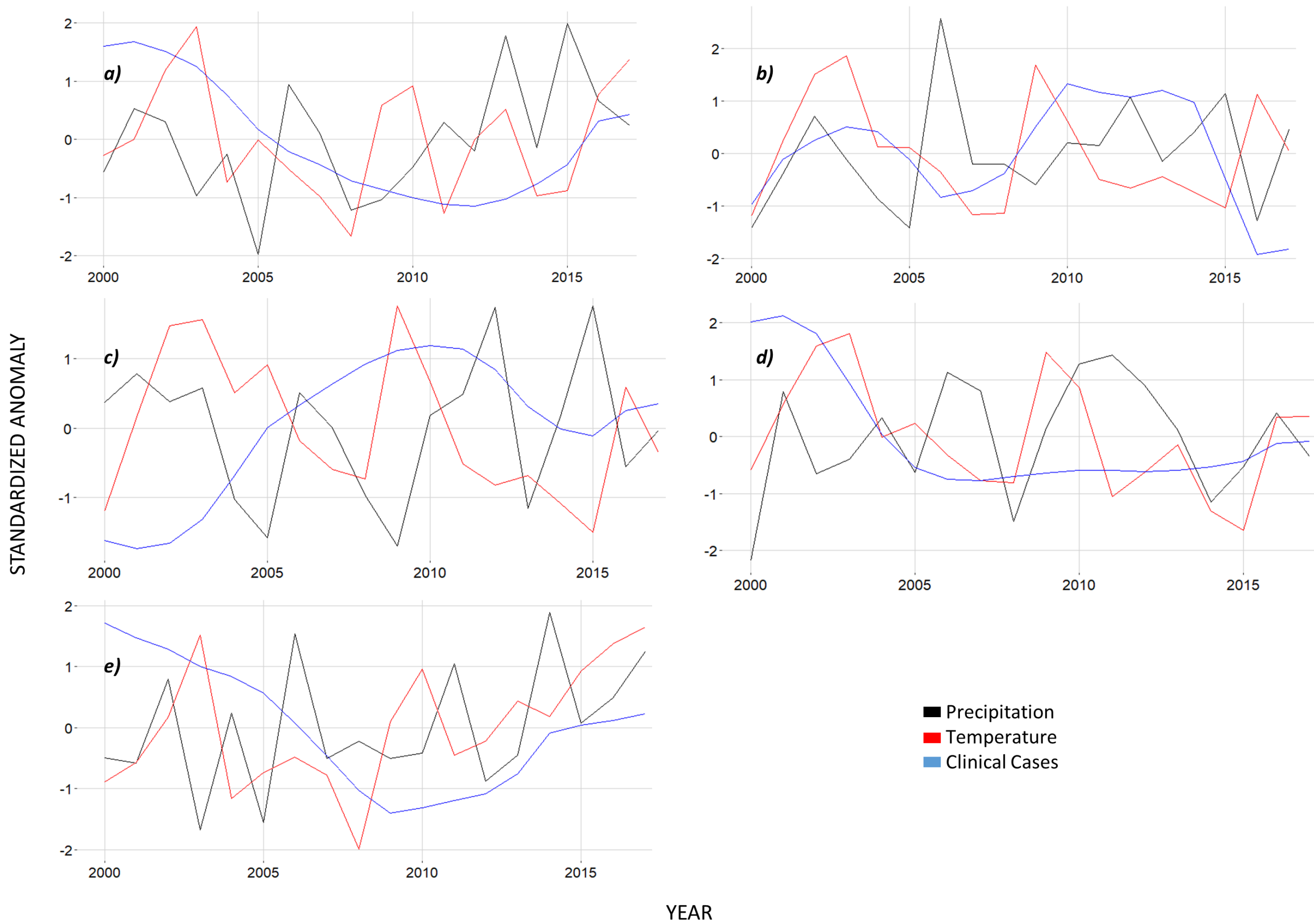


Figure 2. Year-to-year anomalies (standardized) for annual precipitation (black), mean temperature (red), and clinical malaria cases (blue) for Gitega, Burundi (**a**), Siaya, Kenya (**b**), Jinja, Uganda (**c**), Kigali, Rwanda (**d**), and Morogoro, Tanzania (**e**), for the period 2000–2017, using CHIRPS data.

Table 2. Pearson correlation coefficients for de-trended precipitation (pr) and mean temperature (tmp) values relative to clinical malaria cases. Values marked with * are significant at 95% significance interval.

	Kenya					**Rwanda**				
	Busia	**Kisumu**	**Siaya**	**Kakamega**	**Bungoma**	**Kigali**	**North**	**South**	**East**	**West**
pr	-0.01	0.1	0.14	0.19	-0.13	-0.31	-0.3	-0.1	-0.2	-0.1
tmp	0.19	0.23	0.07	0.23	0.4	0.2	0.3	0.4	0.4	0.23
	Tanzania					**Burundi**				
	Geita	**Kagera**	**Mwanza**	**Mbeya**	**Morogoro**	**Gitega**	**Kirundo**	**Muyinga**	**Ngozi**	**Ruyigi**
pr	0.03	-0.35	-0.18	0.29	0.24	0.24	-0.09	-0.13	0.07	0.07
tmp	0	0.55*	0.25	0.4	0.44	0.5*	0.5*	0.6*	0.5*	0.36
	Uganda									
	Iganga	**Jinja**	**Kaabong**	**Kamuli**	**Wakiso**					
pr	-0.21	-0.33	-0.35	-0.23	-0.21					
tmp	-0.11	0.1	-0.39	-0.03	0.3					

record a positive correlation between rainfall and malaria cases (9 out of 25) imply that more interventions are needed to minimize malaria transmission in the region. The interventions will contribute to the sustenance of gains made and enhance the march towards malaria elimination in East Africa.

Future changes in precipitation and temperature under 1.5 °C and 2.0 °C GWLs

Most of the study domain (except northern Kenya) recorded an annual precipitation exceeding 400 mm (Figure 3). Many areas such as the L. Victoria region, most of Tanzania and Uganda, and coastal Kenya showed receipt of annual precipitation exceeding 800 mm. Under 1.5 °C and 2.0 °C GWLs, no significant changes in annual precipitation (at 95% confidence interval) were recorded over the study domain.

While a global warming of up-to 2.0 °C may not necessarily significantly change East Africa's mean annual precipitation, the region already receives enough precipitation for malaria vector abundance and malaria transmission. Besides, projections show a possibility of increased precipitation intensity and occurrence of extreme events (e.g. Ogega *et al.*, 2020; Weber *et al.*, 2018). More intense and extreme rainfall events in future could enhance the provision of aquatic environments to facilitate more malaria vector abundance and malaria transmission.

In terms of temperature, all areas in the study domain recorded temperatures within the suitability threshold (18–28 °C) for malaria transmission (Figure 3, bottom row). A few areas such as the Mount Kenya region (around 0.5° S, 36° E) recorded mean annual temperatures below 18° C implying a low likelihood of malaria transmission. Under GWL1.5, temperature changes ranging from 0.5 to 1.5 °C were recorded. This implies a potential increase in the region's geographical extent for malaria transmission. This is particularly true for many areas in Burundi, Rwanda, and central Kenya (Central and Nairobi

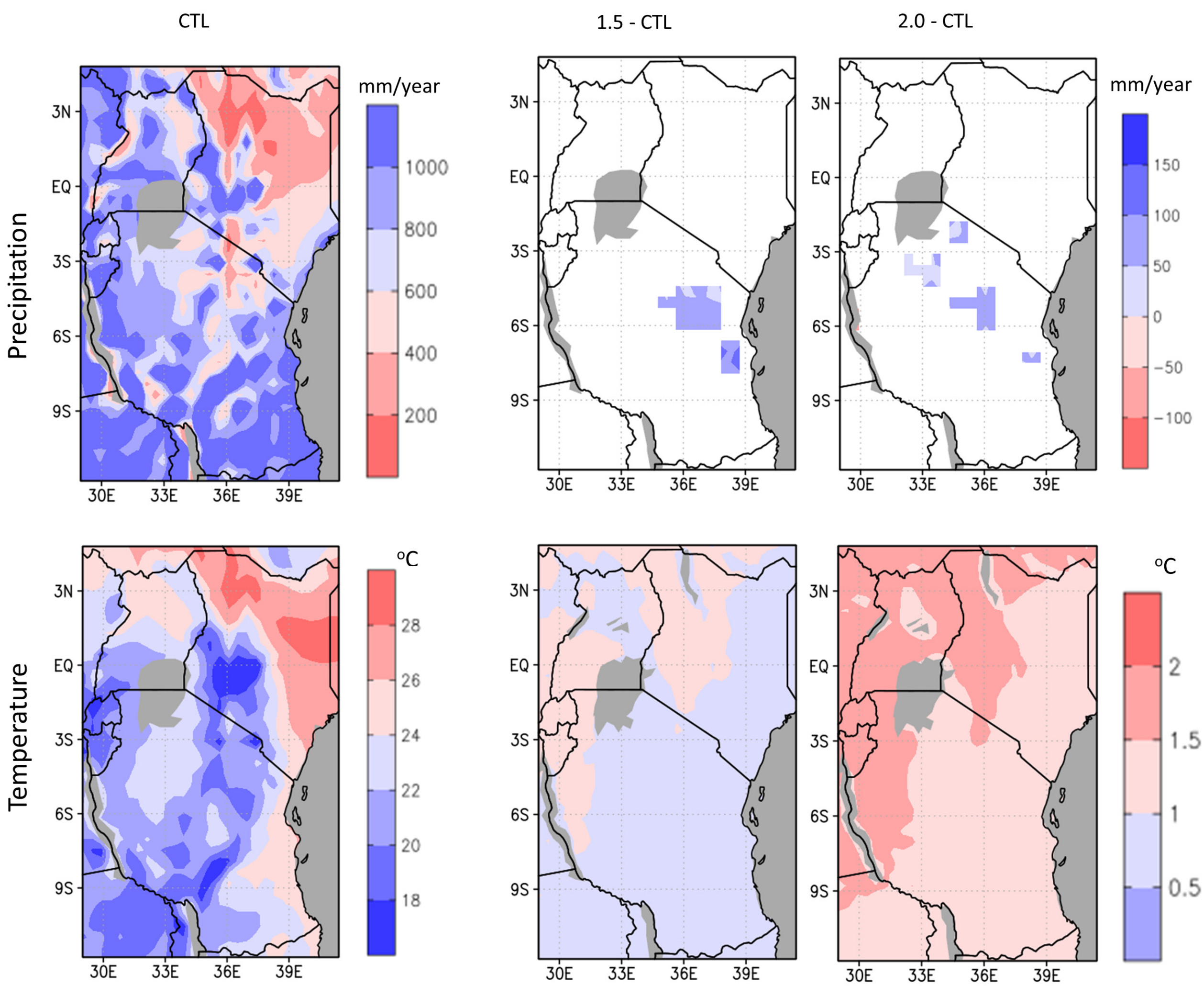


Figure 3. Climatology and future changes (at 95% confidence interval) in precipitation (top row) and temperature (bottom row) under GWL1.5 and GWL2.0 scenarios, relative to the control period (1977–2005). Water bodies are shown in grey.

provinces) where clinical malaria cases are currently relatively low. A mean temperature increase of between 1–2 °C is expected over the study domain under the GWL2.0. The temperature increase is likely to affect many parts of western Kenya and Tanzania, most of Rwanda, Burundi, and Uganda hence potentially increasing the areas with suitable conditions for malaria transmission. Our results are consistent with findings from similar studies done over the study domain (e.g. Gudoshava *et al.*, 2020; Ogega *et al.*, 2020; Osima *et al.*, 2018).

Global warming is likely to increase the seasons and geographical extents for malaria transmission resulting in more cases and newer malaria hotspots (e.g. Ebi *et al*., 2018; Himeidan & Kweka, 2012; Karungu *et al*., 2019; Peterson, 2009). An analysis of climate projections shows changes in the geographical and seasonal suitability for malaria transmission for East Africa (e.g. Ryan *et al.*, 2020). More investment may be required to facilitate adequate planning and action to minimize the effects of possible future outbreaks. Adequate planning and prioritization of interventions in East Africa is, often, hampered by limitations in data availability (e.g. Deutsch-Feldman *et al.*, 2020; Valle & Lima, 2014). Therefore, more research is needed to enhance the understanding of various factors affecting malaria transmission to inform interventions.

While big investments have been made towards eliminating malaria in East Africa, sustaining the gains made so far remains a big challenge (Bashir *et al*., 2019; Nkumama *et al*., 2017). The current study establishes that, despite the ongoing interventions in East Africa, climatic factors still influence the number of clinical malaria cases. Unless adequate mitigative and adaptive measures are taken, a warming globe is likely to make it difficult to sustain gains made, and slow down the match, towards malaria elimination in East Africa.

Conclusions

Global warming scenarios of 1.5 °C and 2 °C are likely to increase malaria transmission seasons and geographical extents of malaria transmission in East Africa. Unless interventions are sufficiently intensified, sustaining the gains made towards malaria elimination is likely to be more difficult in a warming climate. Hence, the global community should intensify its collective efforts towards minimizing global warming. Meanwhile, more investment should be made to sustain the gains made and hasten the match towards malaria elimination in East Africa. More research (considering other variables such as altitude, humidity, and vulnerability of communities) is also required to enhance the understanding of spatial and temporal impacts of global warming on malaria transmission in East Africa. Specifically, disease modelling is required to project the new exposed population which will inform future malaria eradication efforts.

Data availability

Source data

CORDEX-Africa RCM simulations (files listed in Table 1) were downloaded free of charge from the Deutsches Klimarechenzentrum (DKRZ) accessible at http://bit.ly/2RoIist. To download the data, one needs to create a user account after which data can be downloaded freely for non-commercial use. Gridded mean surface air temperature data (CRU TS v. 4.04) were obtained from the Climatic Research Unit, University of East Anglia and accessed free of charge at https://crudata.uea.ac.uk/cru/data/hrg/. Gridded daily precipitation data (CHIRPS Daily v. 2.0) were obtained from the Climate Hazards Center, University of California, Santa Barbra. The data were freely downloaded from https://bit.ly/3buFCj8. Data on clinical malaria cases for Uganda, Kenya, Burundi, Rwanda, and Tanzania were downloaded (in .csv format) free of charge from the Malaria Atlas Project accessible at https://malariaatlas.org/data-directory/.

Acknowledgements

Both authors are employees of the African Academy of Sciences.

The authors wish to thank colleagues at the African Academy of Sciences (AAS) for their insights that helped shape this paper. Contribution of various modelling groups participating in CORDEX as outlined in Table 1 (as well CHIRPS, CRU, and MAP data) are acknowledged for making the data publicly available. Further, the lead author thanks his Ph.D research supervisors and collaborators (Prof. James Kung'u, Dr. James Koske, Dr. Benjamin Gyampoh, and Dr. Malcolm M. Mistry) for their guidance and support towards the realization of this publication. Statements made and errors, if any, are those of the authors and not the institutions they represent.

References

Arab A, Jackson MC, Kongoli C: **Modelling the effects of weather and climate on malaria distributions in West Africa.** *Malar J.* 2014; **13**: 126.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Ayala D, Caro-Riaño H, Dujardin JP, *et al.*: **Chromosomal and environmental determinants of morphometric variation in natural populations of the malaria vector *Anopheles funestus* in Cameroon.** *Infect Genet Evol.* 2011; **11**(5): 940–947.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Bashir IM, Nyakoe N, Van Der Sande M: **Targeting remaining pockets of malaria transmission in Kenya to hasten progress towards national elimination goals: An assessment of prevalence and risk factors in children from the Lake endemic region.** *Malar J.* 2019; **18**(1): 233.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Battle KE, Lucas TCD, Nguyen M, *et al.*: **Mapping the global endemicity and clinical burden of *Plasmodium vivax*, 2000-17: a spatial and temporal modelling study.** *Lancet.* 2019; **394**(10195): 332–343.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Beck-Johnson LM, Nelson WA, Paaijmans KP, *et al.*: **The Effect of Temperature on *Anopheles* Mosquito Population Dynamics and the Potential for Malaria Transmission.** *PLoS One.* 2013; **8**(11): e79276.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Bhatt S, Weiss DJ, Cameron E, *et al.*: **The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015.** *Nature.* 2015; **526**(7572): 207–211.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Brown V, Issak MA, Rossi M, *et al.*: **Epidemic of malaria in north-eastern**

Kenya. *Lancet.* 1998; **352**(9137): 1356–1357.
PubMed Abstract | Publisher Full Text

Caminade C, Medlock JM, Ducheyne E, *et al.*: **Suitability of European climate for the Asian tiger mosquito *Aedes albopictus* : recent trends and future scenarios.** *J R Soc Interface.* 2012; **9**(75): 2708–2717.
PubMed Abstract | Publisher Full Text | Free Full Text

Charlwood JD: **Some like it hot: a differential response to changing temperatures by the malaria vectors *Anopheles funestus* and *An. gambiae* s.l.** *PeerJ.* 2017; **5**: e3099.
PubMed Abstract | Publisher Full Text | Free Full Text

Christiansen-Jucht C, Parham PE, Saddler A, *et al.*: **Temperature during larval development and adult maintenance influences the survival of *Anopheles gambiae* s.s.** *Parasit Vectors.* 2014; **7**: 489.
PubMed Abstract | Publisher Full Text | Free Full Text

Craig MH, Snow RW, le Sueur D: **A climate-based distribution model of malaria transmission in sub-Saharan Africa.** *Parasitol Today.* 1999; **15**(3): 105–111.
PubMed Abstract | Publisher Full Text

Dabernig M, Mayr GJ, Messner JW, *et al.*: **Spatial ensemble post-processing with standardized anomalies.** *Q J Roy Meteor Soc.* 2016; **143**(703): 909–916.
Publisher Full Text

Deutsch-Feldman M, Brazeau NF, Parr JB, *et al.*: **Spatial and epidemiological drivers of *Plasmodium falciparum* malaria among adults in the Democratic Republic of the Congo.** *BMJ Glob Health.* 2020; **5**(6): e002316.
PubMed Abstract | Publisher Full Text | Free Full Text

Diaconescu EP, Gachon P, Laprise R: **On the Remapping Procedure of Daily Precipitation Statistics and Indices Used in Regional Climate Model Evaluation.** *J Hydrome.* 2015; **16**(6): 2301–2310.
Publisher Full Text

Dida GO, Anyona DN, Abuom PO, *et al.*: **Spatial distribution and habitat characterization of mosquito species during the dry season along the Mara River and its tributaries, in Kenya and Tanzania.** *Infect Dis Poverty.* 2018; **7**(1): 2.
PubMed Abstract | Publisher Full Text | Free Full Text

Dinku T, Funk C, Peterson P, *et al.*: **Validation of the CHIRPS satellite rainfall estimates over eastern Africa.** *Q J Roy Meteor Soc.* 2018; **144**(S1): 292–312.
Publisher Full Text

Ebi KL, Hasegawa T, Hayes K, *et al.*: **Health risks of warming of 1.5 °c, 2 °c, and higher, above pre-industrial temperatures.** *Environ Res Lett.* 2018; **13**(6).
Publisher Full Text

Funk C, Peterson P, Landsfeld M, *et al.*: **The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes.** *Sci Data.* 2015; **2**: 150066.
PubMed Abstract | Publisher Full Text | Free Full Text

Gilioli G, Mariani L: **Sensitivity of *Anopheles gambiae* population dynamics to meteo-hydrological variability: a mechanistic approach.** *Malar J.* 2011; **10**(1): 294.
PubMed Abstract | Publisher Full Text | Free Full Text

Gudoshava M, Misiani HO, Segele ZT, *et al.*: **Projected effects of 1.5 °C and 2 °C global warming levels on the intra-seasonal rainfall characteristics over the Greater Horn of Africa.** *Environ Res Lett.* 2020; **15**(3): 034037.
Publisher Full Text

Harris I, Osborn TJ, Jones P, *et al.*: **Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset.** *Sci Data.* 2020; **7**(1): 109.
PubMed Abstract | Publisher Full Text | Free Full Text

Hashizume M, Terao T, Minakawa N: **The Indian Ocean Dipole and malaria risk in the highlands of western Kenya.** *Proc Natl Acad Sci U S A.* 2009; **106**(6): 1857–1862.
PubMed Abstract | Publisher Full Text | Free Full Text

Hay SI, Snow RW: **The Malaria Atlas Project: Developing Global Maps of Malaria Risk.** *PLoS Med.* 2006; **3**(12): e473.
PubMed Abstract | Publisher Full Text | Free Full Text

Head MG, Goss S, Gelister Y, *et al.*: **Global funding trends for malaria research in sub-Saharan Africa: a systematic analysis.** *Lancet Glob Health.* 2017; **5**(8): e772–e781.
PubMed Abstract | Publisher Full Text | Free Full Text

Himeidan YE, Kweka EJ: **Malaria in East African highlands during the past 30 years: Impact of environmental changes.** *Front Physiol.* 2012; **3**: 315.
PubMed Abstract | Publisher Full Text | Free Full Text

Hoegh-Guldberg O, Jacob D, Taylor M, *et al.*: **Impacts of 1.5°C Global Warming on Natural and Human Systems**. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* [Masson-Delmotte, V., Zhai, P., Pörtner, H. -O., *et al.* (eds.)]. In Press. 2018.
Reference Source

Karungu S, Atoni E, Ogalo J, *et al.*: **Mosquitoes of etiological concern in Kenya and possible control strategies.** *Insects.* 2019; **10**(6): 173.
PubMed Abstract | Publisher Full Text | Free Full Text

Kelly-Hope LA, Hemingway J, McKenzie FE: **Environmental factors associated with the malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya.** *Malar J.* 2009; **8**(1): 268.
PubMed Abstract | Publisher Full Text | Free Full Text

Kilian AH, Langi P, Talisuna A, *et al.*: **Rainfall pattern, El Niño and malaria in Uganda.** *Trans R Soc Trop Med Hyg.* 1999; **93**(1): 22–23.
PubMed Abstract | Publisher Full Text

Kim J, Waliser DE, Mattmann CA, *et al.*: **Evaluation of the CORDEX-Africa multi-RCM hindcast: systematic model errors.** *Clim Dyn.* 2014; **42**(5–6): 1189–1202.
Publisher Full Text

Meehl GA, Moss R, Taylor KE, *et al.*: **Climate Model Intercomparisons: Preparing for the Next Phase.** *Eos, Transactions American Geophysical Union.* 2014; **95**(9): 77–78.
Publisher Full Text

Metelmann S, Caminade C, Jones AE, *et al.*: **The UK's suitability for *Aedes albopictus* in current and future climates.** *J R Soc Interface.* 2019; **16**(152): 20180761.
PubMed Abstract | Publisher Full Text | Free Full Text

Mohammadkhani M, Khanjani N, Bakhtiari B, *et al.*: **The relation between climatic factors and malaria incidence in Kerman, South East of Iran.** *Parasite Epidemiol Control.* 2016; **1**(3): 205–210.
PubMed Abstract | Publisher Full Text | Free Full Text

Moss RH, Edmonds JA, Hibbard KA, *et al.*: **The next generation of scenarios for climate change research and assessment.** *Nature.* 2010; **463**(7282): 747–756.
PubMed Abstract | Publisher Full Text

Mordecai EA, Paaijmans KP, Johnson LR, *et al.*: **Optimal temperature for malaria transmission is dramatically lower than previously predicted.** *Ecol Lett.* 2013; **16**(1): 22–30.
PubMed Abstract | Publisher Full Text

Nakakana UN, Mohammed IA, Onankpa BO, *et al.*: **A validation of the Malaria Atlas Project maps and development of a new map of malaria transmission in Sokoto, Nigeria: a cross-sectional study using geographic information systems.** *Malar J.* 2020; **19**(1): 149.
PubMed Abstract | Publisher Full Text | Free Full Text

Nicholson SE: **Climate and climatic variability of rainfall over eastern Africa.** *Rev Geophys.* 2017; **55**(3): 590–635.
Publisher Full Text

Nikulin G, Jones C, Giorgi F, *et al.*: **Precipitation Climatology in an Ensemble of CORDEX-Africa Regional Climate Simulations.** *J Clim.* 2012; **25**(18): 6057–6078.
Publisher Full Text

Nikulin G, Lennard C, Dosio A, *et al.*: **The effects of 1.5 and 2 degrees of global warming on Africa in the CORDEX ensemble.** *Environ Res Lett.* 2018; **13**(6): 065003.
Publisher Full Text

Nkumama IN, O'Meara WP, Osier FHA: **Changes in Malaria Epidemiology in Africa and New Challenges for Elimination.** *Trends Parasitol.* 2017; **33**(2): 128–140.
PubMed Abstract |Publisher Full Text | Free Full Text

Nsoesie EO, Kraemer MUG, Golding N, *et al.*: **Global distribution and environmental suitability for chikungunya virus, 1952 to 2015.** *Euro Surveill.* 2016; **21**(20): 1–12.
PubMed Abstract | Publisher Full Text | Free Full Text

Ogega OM, Koske J, Kung'u JB, *et al.*: **Heavy precipitation events over East Africa in a changing climate: results from CORDEX RCMs.** *Clim Dyn.* 2020; 55: 993–1009.
Publisher Full Text

Osima S, Kondowe AL, Indasi VS, *et al.*: **Projected climate over the Greater Horn of Africa under 1.5 °c and 2 °c global warming.** *Environ Res Lett.* 2018; **13**(6): 065004.
Publisher Full Text

Pascual M, Ahumada JA, Chaves LF, *et al.*: **Malaria resurgence in the East African highlands: temperature trends revisited.** *Proc Natl Acad Sci U S A.* 2006; **103**(15): 5829–5834.
PubMed Abstract | Publisher Full Text | Free Full Text

Peterson AT: **Shifting suitability for malaria vectors across Africa with warming climates.** *BMC Infect Dis.* 2009; **9**: 59.
PubMed Abstract | Publisher Full Text | Free Full Text

Protopopoff N, Van Herp M, Maes P, *et al.*: **Vector control in a malaria epidemic occurring within a complex emergency situation in Burundi: a case study.** *Malar J.* 2007; **6**(1): 93.
PubMed Abstract | Publisher Full Text | Free Full Text

Ryan SJ, Lippi CA, Zermoglio F: **Shifting transmission risk for malaria in Africa with climate change: a framework for planning and intervention.** *Malar J.* 2020; **19**(1): 170.
PubMed Abstract | Publisher Full Text | Free Full Text

Schreck CJ, Semazzi FHM: **Variability of the recent climate of eastern Africa.** *Int J Climatol.* 2004; **24**(6): 681–701.
Publisher Full Text

Siraj AS, Santos-Vega M, Bouma MJ, *et al.*: **Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia.** *Science.* 2014; **343**(6175): 1154–1158.
PubMed Abstract | Publisher Full Text

Ssempiira J, Kissa J, Nambuusi B, *et al.*: **The effect of case management and vector-control interventions on space-time patterns of malaria incidence in Uganda.** *Malar J.* 2018; **17**(1): 162.
PubMed Abstract | Publisher Full Text | Free Full Text

Taylor KE, Stouffer RJ, Meehl GA: **An Overview of CMIP5 and the Experiment Design.** *Bull Am Meteorol Soc.* 2012; **93**(4): 485–498.
Publisher Full Text

USAID: **Burundi Malaria Operational Plan FY 2016**. 2016.
Reference Source

Valle D, Lima JMT: **Large-scale drivers of malaria and priority areas for prevention and control in the Brazilian Amazon region using a novel multi-pathogen geospatial model.** *Malar J.* 2014; **13**(1): 443.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Weiss DJ, Lucas TCD, Nguyen M, *et al.*: **Mapping the global prevalence, incidence, and mortality of *Plasmodium falciparum*, 2000-17: a spatial and temporal modelling study.** *Lancet.* 2019; **394**(10195): 322–331.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Weber T, Haensler A, Rechid D, *et al.*: **Analyzing Regional Climate Change in Africa in a 1.5, 2, and 3°C Global Warming World.** *Earths Future.* 2018; **6**(4): 643–655.
Publisher Full Text

Wiebe A, Longbottom J, Gleave K, *et al.*: **Geographical distributions of African malaria vector sibling species and evidence for insecticide resistance.** *Malar J.* 2017; **16**(1): 85.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

World Health Organization (WHO): **Malaria**. 2020.
Reference Source

Yan Y, Lu R, Li C: **Relationship between the Future Projections of Sahel Rainfall and the Simulation Biases of Present South Asian and Western North Pacific Rainfall in Summer.** *J Clim.* 2019; **32**(4): 1327–1343.
Publisher Full Text

Open Peer Review

Current Peer Review Status: ✔ ✔

Version 3

Reviewer Report 26 March 2021

https://doi.org/10.21956/aasopenres.14304.r28476

✔ **Masilin Gudoshava**
National University of Science and Technology, Bulawayo, Zimbabwe

The authors have revised and addressed all the questions raised. The manuscript is in acceptable form to be indexed.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 14 December 2020

https://doi.org/10.21956/aasopenres.14263.r28098

✔ **Ramesh C. Dhiman**
ICMR-National Institute of Malaria Research, New Delhi, Delhi, India

The authors have revised the paper in light of the suggestions of the reviewers and it is acceptable for indexing.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology and vector control of vector borne diseases. Climate change impacts on VBDs. Early warning of outbreaks of malaria and dengue using climate and satellite data.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 12 November 2020

https://doi.org/10.21956/aasopenres.14263.r28097

?

Masilin Gudoshava
National University of Science and Technology, Bulawayo, Zimbabwe

Introduction section: Uganda, for instance, tops East Africa “hereinafter East Africa” seems redundant in this case, since its just a repetition.

The authors only use 4 realizations of the RCMS however one of the justification of use of RCP8.5, is that the scenario provides the largest number of ensemble members, I would suggest that they drop this justification as it doesn’t seem to fit with the design of the analysis.

I am still finding it hard to understand how the authors calculated/identified the mid year for the different global warming levels using the 2 GCMs. Is this calculation from Nikulin *et al.*, 2018 using all the GCMs? A brief explanation on how this is done will be helpful.

A recommendation is drawn about Malaria cases and precipitation however these values are not statistically significant. I suggest that the authors mostly focus on the temperature which has statistical significant correlations. (“record a positive correlation between rainfall and malaria cases (9 out of 25) imply that more interventions are needed to minimize malaria transmission in the region.”)

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: climate science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 26 Dec 2020

Obed Matundura Ogega, The African Academy of Sciences, Nairobi, Kenya

Comment: Introduction section: Uganda, for instance, tops East Africa "hereinafter East Africa" seems redundant in this case, since its just a repetition.
Response: *Now revised to exclude "hereinafter East Africa"*

Comment: The authors only use 4 realizations of the RCMS however one of the justification of use of RCP8.5, is that the scenario provides the largest number of ensemble members, I would suggest that they drop this justification as it doesn't seem to fit with the design of the analysis.
Response: *now revised to exclude "provides the largest set of ensemble members than other RCPs and"*

Comment: I am still finding it hard to understand how the authors calculated/identified the mid year for the different global warming levels using the 2 GCMs. Is this calculation from Nikulin et al., 2018 using all the GCMs? A brief explanation on how this is done will be helpful.
Response: *This part has now been revised for coherence in paragraph 3 of the Data Analysis section.*

Comment: A recommendation is drawn about Malaria cases and precipitation however these values are not statistically significant. I suggest that the authors mostly focus on the temperature which has statistical significant correlations. ("record a positive correlation between rainfall and malaria cases (9 out of 25) imply that more interventions are needed to minimize malaria transmission in the region.")
Response: *this is well-noted. As we focus on temperature, we also want the region to keep monitoring the contribution of precipitation on malaria transmission. While our results show minimal effect of precipitation on malaria cases, the region needs to hasten the interventions to avoid reversing the gains made towards malaria elimination – hence the recommendation.*

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 23 September 2020

https://doi.org/10.21956/aasopenres.14170.r27822

? **Ramesh C. Dhiman**

ICMR-National Institute of Malaria Research, New Delhi, Delhi, India

- The study has used 20-25^{o}C as thresholds of temperature within which maximum suitability for survival of Anopheles mosquitoes is achieved. What is the basis of selecting this range? This requires clarification. Further, instead of selecting the range for survival of mosquitoes, the threshold for transmission of malaria (sporogony) would have been ideal as the present communication deals with future scenario of malaria and not the anopheles vector. Mosquitoes are known to survive even at lower than 13^{o}C temperature also (IPCC, 2001). The temperature between 18-32^{o}C is considered suitable for transmission of malaria (Craig *et al.*, 1999[1]). Further Mordecai *et al.* (2013[2]) found that the upper threshold is 28^{o}C, bit lower than 32^{o}C.

- In the study, the threshold of rainfall has been taken of Aedes mosquitoes. Anopheles and Aedes mosquitoes are quite different in their ecology, biology and climatic requirements. Therefore, using the thresholds of rainfall meant for Aedes, does not seem appropriate for Anopheles.

- The authors are advised to consult Craig *et al.* (1999[1]) on a climate-based distribution model of malaria in SS Africa where 80 mm rainfall has been considered as the threshold of rainfall causing outbreaks of malaria.

- Using only RCP 8.5 of climate model does not seem appropriate; RCP 4.5 being moderate, would have been ideal.

- Relevance of Fig 2 is not clear.

- Fig 3: Analysis with annual precipitation data is not desirable for a climate-sensitive disease like malaria. The significance of depicting water bodies is not clear.

- Page 6, last paragraph: ‘In terms of temperature, all areas in the study domain record temperatures within suitability threshold (13-30^{o}C) for malaria vectors’ is not appropriate as at lower than 18^{o}C temperature, transmission is not possible as the mosquitoes would require 56 days to complete sporogony (Craig *et al.*, 1999[1]).

- The authors have undertaken painstaking efforts in analyzing the projected scenario of malaria in view of projected rise in temperature. The objective of the study is also very pertinent. But owing to methodological issues stated above, reanalysis of data is required.

References

1. Craig M, Snow R, le Sueur D: A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Africa. *Parasitology Today*. 1999; **15** (3): 105-111 Publisher Full Text
2. Mordecai EA, Paaijmans KP, Johnson LR, Balzer C, et al.: Optimal temperature for malaria transmission is dramatically lower than previously predicted.*Ecol Lett*. 2013; **16** (1): 22-30 PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?
No

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology and vector control of vector borne diseases. Climate change impacts on VBDs. Early warning of outbreaks of malaria and dengue using climate and satellite data.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 17 Oct 2020

Obed Matundura Ogega, The African Academy of Sciences, Nairobi, Kenya

The authors are very grateful for the Reviewers' comments. The comments and suggestions have been very useful during the revision process and have been incorporated into the revised manuscript. We believe the quality of the revised manuscript has been improved significantly. The specific actions in response to the reviewers' comments are outlined as follows.

Reviewer #2:

Comment: The study has used 20-250 C as thresholds of temperature within which maximum suitability for survival of Anopheles mosquitoes is achieved. What is the basis of selecting this range? This requires clarification. Further, instead of selecting the range for survival of mosquitoes, the threshold for transmission of malaria (sporogony) would have been ideal as the present communication deals with future scenario of malaria and not the anopheles vector. Mosquitoes are known to survive even at lower than 130 C temperature also (IPCC, 2001). The temperature between 18-320C is considered suitable for transmission of malaria (Craig et al., 19991). Further Mordecai et al. (20132) found that the upper threshold is 280 C, bit lower than 320 C.

Response: This is well-noted. The 20-25 ^{O}C is the range within which the mosquito abundance increases to maximum. However, we have revised our manuscript to focus on malaria transmission and not mosquito survival (see lines 143 – 146).

Comment: In the study, the threshold of rainfall has been taken of Aedes mosquitoes. Anopheles and Aedes mosquitoes are quite different in their ecology, biology and climatic requirements. Therefore, using the thresholds of rainfall meant for Aedes, does not seem appropriate for Anopheles.

Response: We have revised the section on rainfall to focus on malaria transmission rather than Aedes mosquitoes (see lines 136-146).

Comment: The authors are advised to consult Craig et al. (19991) on a climate-based distribution model of malaria in SS Africa where 80 mm rainfall has been considered as the threshold of rainfall causing outbreaks of malaria.

Response: This has been revised. We now discuss precipitation patterns in general without referring to specific thresholds (e.g. lines 136-143).

Comment: Using only RCP 8.5 of climate model does not seem appropriate; RCP 4.5 being moderate, would have been ideal.

Response: Considering the current global greenhouse emission scenarios, RCP 8.5 gives a more realistic representation of global warming scenario compared to the RCP 4.5. Additionally, more simulations are available for RCP 8.5 compared to RCP 4.5. This explanation has now been given in lines 40-44.

Comment: Relevance of Fig 2 is not clear.

Response: Fig. 2 has been discarded and its details included in the narrative (see lines 127-131).

Comment: Fig 3: Analysis with annual precipitation data is not desirable for a climate-sensitive disease like malaria. The significance of depicting water bodies is not clear.

Response: Fig. 3 has been revised to exclude the spatial plots. We computed and compared year-to-year standardized anomalies for precipitation, temperature, and clinical malaria cases to show a general relationship in trend behaviour for the three variables. Standardized anomalies free data from location and distribution influences hence giving a more realistic trend. While malaria prevention efforts are designed to counter the potential effect of weather and climate in malaria transmission, we wanted to show if any discernible relationships still exist between climatic factors (malaria and temperature) and annual clinical cases. We showed major water bodies (Lake Victoria and Indian Ocean) in grey to focus the analysis only on land.

Comment: Page 6, last paragraph: 'In terms of temperature, all areas in the study domain record temperatures within suitability threshold (13-300C) for malaria vectors' is not appropriate as at lower than 18 0C temperature, transmission is not possible as the mosquitoes would require 56 days to complete sporogony (Craig et al., 19991).

Response: The manuscript has been revised accordingly (e.g. lines 137-141).

Comment: The authors have undertaken painstaking efforts in analyzing the projected scenario of malaria in view of projected rise in temperature. The objective of the study is also very pertinent. But owing to methodological issues stated above, reanalysis of data is required.

Response: We appreciate your comments and have made the suggested revisions to make the current version of the manuscript more plausible.

Comment: Additional references
1. Craig M, Snow R, le Sueur D: A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Africa. Parasitology Today. 1999; 15 (3): 105-111 Publisher Full Text
2. Mordecai EA, Paaijmans KP, Johnson LR, Balzer C, et al.: Optimal temperature for malaria transmission is dramatically lower than previously predicted.Ecol Lett. 2013; 16 (1): 22-30 PubMed Abstract | Publisher Full Text

Response: We are grateful for these suggestions – which have now been used to enrich the manuscript.

Competing Interests: No competing interests were disclosed.

Reviewer Report 10 August 2020

https://doi.org/10.21956/aasopenres.14170.r27675

? **Masilin Gudoshava**
National University of Science and Technology, Bulawayo, Zimbabwe

- In the introduction section paragraph 2, the authors discuss that there have been some studies done towards understanding the impact of climate over the region at the different GWL and state that there are no conclusive literature on the impact. Did this statement mean to say no conclusive literature on impacts in sectors such as health, agriculture water etc?

- Methods Climate Modelling paragraph 1: A statement explaining why the authors only chose RCP85 scenario is required in this case as the different scenarios can have differing impacts.

- Table 1 indicates that data was downloaded from 2071-2100 however this is not the same time period that was analyzed. This is a typo that needs to be corrected.

- In paragraph 2 of the data analysis section the authors state that 2022 and 2037 have been identified as mid-years for 30-year windows when GWL1.5 and GWL2.0, respectively, are likely to be first experienced. However different GCMs hit these levels at different times, is it the assumption in this manuscript that both these GCMs will reach the GWL at the same time? I would suggest that the authors rework on this and use the GWL for the different GCMS.

- The malaria temperature survival has two different threshold values (13-30 ^{o} C) in one section and in another section it is written as 15-30 ^{o} C. Double check this.

- Trends in temperature, precipitation, and clinical malaria cases in E. Africa paragraph graph two: an explanation on why malaria clinical cases and temperature are negatively correlated over Uganda is needed here, since in all the other countries the correlation is positive.

- Trends in temperature, precipitation, and clinical malaria cases in E. Africa paragraph three: could the negative correlations be caused by the washing away of the eggs due to high rainfall rather than intensification of efforts to combat malaria?

- Figure 3: The line plots do not show any obvious relationships between the malaria clinical cases and the temperature/rainfall - could this be because people are taking preventive measures? Is it possible to obtain the actual vector data and do the analysis using this rather than the clinical cases?

- Figure 4: The caption seems incorrect, I would not expect rainfall of up to 700mm/day in any season over East Africa, also in the write-up it is written mm/year.

- A discussion on the large scale drivers and malaria cases could be helpful in explaining any likely changes in the future of the reported clinical cases.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: climate science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 17 Oct 2020

Obed Matundura Ogega, The African Academy of Sciences, Nairobi, Kenya

The authors are very grateful for the Reviewers' comments. The comments and suggestions have been very useful during the revision process and have been incorporated into the revised manuscript. We believe the quality of the revised manuscript has been improved significantly. The specific actions in response to the reviewers' comments are outlined as follows.

Reviewer #1:
Comment: In the introduction section paragraph 2, the authors discuss that there have been some studies done towards understanding the impact of climate over the region at the different GWL and state that there are no conclusive literature on the impact. Did this statement mean to say no conclusive literature on impacts in sectors such as health, agriculture water etc.?

Response: Indeed, we meant to say impacts on the health sector. This has been corrected (see line 22).

Comment: Methods Climate Modelling paragraph 1: A statement explaining why the authors only chose RCP85 scenario is required in this case as the different scenarios can have differing impacts.

Response: An explanation has now been given in lines 40-44.

Comment: Table 1 indicates that data was downloaded from 2071-2100 however this is not the same time period that was analyzed. This is a typo that needs to be corrected.

Response: Now revised to show 2008-2052 (see line 51).

Comment: In paragraph 2 of the data analysis section the authors state that 2022 and 2037 have been identified as mid-years for 30-year windows when GWL1.5 and GWL2.0, respectively, are likely to be first experienced. However different GCMs hit these levels at different times, is it the assumption in this manuscript that both these GCMs will reach the

GWL at the same time? I would suggest that the authors rework on this and use the GWL for the different GCMS.

Response: It is indeed true that different GCMs hit the said levels at different times. Years 2022 and 2037 represent values for an ensemble mean of the subset of GCM simulations used in CORDEX. Our analysis used an ensemble mean of these CORDEX GCM simulations. The section has been revised for coherence (see lines 86-97).

Comment: The malaria temperature survival has two different threshold values (13-30 o C) in one section and in another section it is written as 15-30 o C. Double check this.
Response: This has been revised (in both cases) to 18 – 28 ^{o}C (see e.g. lines 132-134).

Comment: Trends in temperature, precipitation, and clinical malaria cases in E. Africa paragraph graph two: an explanation on why malaria clinical cases and temperature are negatively correlated over Uganda is needed here, since in all the other countries the correlation is positive.

Response: We have provided more information in lines 172-184.

Comment: Trends in temperature, precipitation, and clinical malaria cases in E. Africa paragraph three: could the negative correlations be caused by the washing away of the eggs due to high rainfall rather than intensification of efforts to combat malaria?

Response: Egg flushing can indeed be a possibility. However, no major rainfall changes have been recorded during the period under study. Rainfall has mostly remained within the normal range (as shown in Figure 2). As detailed in lines 172-184 of the revised manuscript, the relatively low/high correlation between malaria cases and climatic factors in Uganda/Burundi result from case and vector control investment.

Comment: Figure 3: The line plots do not show any obvious relationships between the malaria clinical cases and the temperature/rainfall - could this be because people are taking preventive measures? Is it possible to obtain the actual vector data and do the analysis using this rather than the clinical cases?

Response: Please refer to our response in 7 above. The use of actual vector data is out of the scope of the current study. We have recommended a further study (see lines 231-235) where such data can be obtained and used.

Comment: Figure 4: The caption seems incorrect, I would not expect rainfall of up to 700mm/day in any season over East Africa, also in the write-up it is written mm/year.

Response: This has been corrected (see Figure 3).

Comment: A discussion on the large scale drivers and malaria cases could be helpful in explaining any likely changes in the future of the reported clinical cases.

Response: Thank you for this suggestion. We have provided more information in lines 218-233.

Competing Interests: No competing interests were disclosed.