UMEÅ UNIVERSITET

Umeå University Medical Dissertations, New Series No 2331

CLIMATE SERVICES FOR MALARIA AND CHOLERA CONTROL IN MOZAMBIQUE

Developing climate-dependent models for early warning systems and projections of climate change impacts on disease burden

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Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av filosofie/medicine doktorsexamen framläggs till offentligt försvar i Salens namn eller beteckning, byggnad Triple Helix, Universitetsledningshuset
Fredag, 13 December 2024, kl. 09:00.
Avhandlingen kommer att försvaras på engelska.

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https://umu.zoom.us/j/62878331943
Password 112233

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Document type
Doctoral thesis

Date of publication
22 November 2024

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Title: Climate services for malaria and cholera control in Mozambique: Developing climate-dependent models for early warning systems and projections of climate change impacts on disease burden

Abstract

Background: The transmission of malaria and cholera depends a great deal on climatic and environmental conditions, which are modulated by socioeconomic conditions, so understanding the influence of lagged climatic factors while adjusting for socioeconomic factors affecting malaria and cholera risk can aid in the timely implementation of interventions to reduce disease burden and adapt to changing climate. The aim of this thesis was to identify climatic and socio–demographic factors that influence malaria and cholera incidence in Mozambique, to develop and evaluate a climate-driven spatio–temporal malaria prediction model that could potentially be used in an early warning system, and to project future malaria incidence in Mozambique based on climate and socioeconomic projection scenarios.
Methods: Bayesian spatio–temporal models with integrated nested Laplace approximation (INLA) in combination with distributed lag non-linear models (DLNMs) were used to assess the delayed and non-linear relationship between climatic and land use factors, on one hand, and malaria and cholera risk, on the other, while adjusting for socioeconomic conditions, spatio–temporal covariance, and seasonality. In addition, a spatio–temporal malaria prediction model was developed using lagged climatic covariates. The model's ability to distinguish between high and low malaria seasons was evaluated using receiver operating characteristic (ROC) analysis. Future projection of malaria incidence to the end of twenty-first century in Mozambique was conducted based on a spatio–temporal Bayesian model, considering an ensemble of climate models in a multi-scenario approach.
Results: In papers I and IV, we identified the delayed and non-linear influence of climatic and land use factors on malaria and cholera risk. We found that malaria risk significantly increased at temperatures between 20 and 26°C and then dropped afterwards with a delay of more than four months. However, we found no significant influence of temperature on cholera risk. We observed that precipitation below 100 mm elevated malaria risk with a longer delay of up to five months, while malaria risk decreased with higher precipitation above 400 mm with a delay of just one month. For cholera, risk increased with precipitation above 200 mm with a delay of zero to two months. We found the highest malaria risk was associated with relative humidity (RH) of 55%, while RH above 70% decreased the risk. At RH values of 50–60%, malaria risk was elevated for shorter lags below two months. Similarly, RH of 54–67% increased cholera risk with a lag of three to five months. We found diverging influences of the Normalized Difference Vegetation Index (NDVI) on malaria and cholera risk. NDVI values above 0.2 were associated with high malaria risk with a delay of three months, while NDVI values below 0.2 were associated with elevated cholera risk with a delay of two to four months. We show that a high proportion of asset ownership (e.g., radios and mobile phones), a proxy for high social economic status, was associated with low malaria and cholera risk. We also show that toilet sharing increases cholera risk. In Paper II, the selected spatio–temporal malaria prediction model included the non-linear functions of climate and NDVI variables with different lag combinations after adjusting for space and season, providing a lead time of up to four months. The model displayed high predictive accuracy with an R^2 of 0.8 between observed and predicted cases. The model's ability to classify high and low malaria months was also high with an overall area under the curve (AUC) of 0.83. In the third paper, we projected 21 million malaria cases, about a threefold (over 170%) increase by 2080, based on the SSP370 economic and emission scenario, relative to the baseline of 2018, when 7.7 million malaria cases were recorded. In the same period, mean temperatures in Mozambique are projected to increase by 3.6°C according to the SSP370 scenario.
Conclusion: In this thesis we employed advanced spatio–temporal Bayesian models to show that, when controlling for socioeconomic conditions, the lagged climate and land use factors impact malaria and cholera risk, following the biological mechanism of exposure before risk with some delay. We used the derived lag patterns to develop a spatio–temporal malaria prediction model with high skill, providing sufficient lead times up to four months, which could potentially be integrated into a malaria early warning system in Mozambique. Additionally, based on the developed prediction model, we show that climate change will triple the malaria burden in Mozambique in the future, so adequate actions to limit emissions should be taken. We show that combining climate services, disease surveillance, and advanced modelling can aid in adaptation to climate change.

The thesis contributes to key components of an early warning system, specifically on risk assessment and the use of surveillance data for predictive modeling, offering valuable guidance for malaria control initiatives in Mozambique and serving as a reference for low-resource settings.

Key words: malaria, cholera, mosquito, *Vibrio cholerae*, lag, prediction, projection, climate change, SSP, RCP, climatic factor, socioeconomic status, INLA, DLNM, public health, temperature, precipitation, RH, NDVI, and spatio–temporal models.

Language	ISBN	ISSN	Number of pages
English	print: 978-91-8070-544-8 PDF: 978-91-8070-545-5	0346-6612	79 + 4 papers