**Take-home assignment. Due March 30th, Midnight.**

**Use of climate data to improve regulation of vector and parasite within malaria models**

In this assignment, students will construct a dynamic climate-driven malaria transmission model from Ukawuba & Shaman 2022 “*Inference and dynamic simulation of malaria using a simple climate-driven entomological model of malaria transmission*”. You will use your understanding of climate regulated vector and parasite dynamics to simulate malaria and examine the influence of climate transmission. There are 2 sections of the assignment: 1) building the climate malaria model and 2) exploring climate’s influence on transmission. ***Please read the instructions for sections 1 and 2 carefully before beginning the assignment.***

**Before you begin, download the following files:**

* ‘Ukawuba\_and\_Shaman\_2022.pdf’ file for the journal article
* ‘moisture\_anomaly\_take\_home\_assignment.rds’ for the moisture anomaly data (i.e., the cDR variable)
* ‘temperature\_take\_home\_assignment.rds’ for the temperature data

Below is a schematic of the transmission model to be built. Note the set of ODE equations for the transmission system are at the end of this document (see equations 1–5). Note that malaria incidence is tracked in the transmission system by .



Figure 1. Flow diagram of the malaria transmission model.

**Section 1: building the climate malaria model**

Tasks

1. Construct the climate-driven malaria-model from Ukawuba & Shaman 2022 *Inference and dynamic simulation of malaria using a simple climate-driven entomological model of malaria transmission*. Be sure to read the malaria article carefully. Build the transmission model in R. Use equations 1–18 to guide you in building and the values in Table 1 to parameterize the model. The climate datasets, ’**moisture\_anomaly\_ take\_home\_assignment.rds**’, and ‘**temperature\_ take\_home\_assignment.rds’**, have been provided as well. Use them to regulate vector and parasite dynamics within the model. See table 1 for the list of equations (i.e., mosquito and parasite entomology, e.g., gonotrophy, sporogony, adult survival etc.) that require temperature and moisture regulation.
2. Run the completed model and generate a plot of malaria incidence over time. Track malaria incidence in the system by .
3. Submit the R file which you used to build and your graph, as part of the assignment (e.g., save R file as ‘yourlastname\_yourfirstname\_assignment\_climate\_model.R’, and your graph as “yourlastname\_yourfirstname\_assignment\_model\_plot.jpeg” ).

**Section 2: Exploring the influence of climate on transmission dynamics**

In questions 1-2 of this section, reflect on your understanding of the unique routes environmental drivers influence malaria outcomes via ecology of malaria mosquitoes and parasite. And use the seasonal climate data and the model you built in section 1 to assist you in deriving answers to the questions below. Save and submit your responses to the questions below in a word document (e.g.,” yourlastname\_yourfirstname\_assignment\_section2.docx”). Please submit your answers as part of your assignment.

1. How many more new cases occur when seasonal rainfall is accounted for? And how many more new cases occur when seasonal temperature is accounted for? To evaluate this:
   1. Run your climate model using annual average mean moisture anomaly and annual average temperature instead of their seasonal values (*note: you will need to calculate the annual averages from the seasonal values*). Let’s consider this the “null model”. What is the total number of malaria incidence under the null model?
   2. Now create a variant of the null model called the “moisture model”. Do this by replacing the annual average moisture anomaly in the null model with its seasonal values. Run the “moisture model”. How many more malaria incidence occur when you introduce moisture seasonality?
   3. Repeat step b to create a second variant called the “temperature model”. Do this by replacing the annual average temperature values in the null model (i.e., where both moisture anomaly and temperature are set to annual averages) with the seasonal values of temperature. Run the “temperature model”. How many more incidences of malaria occur when you introduce seasonal temperature values?
   4. Based on steps a-c, which variable of climate (temperature or moisture anomaly) has the most impact on malaria infections? Reflecting on the variation of climate of the region, explain why this outcome would be expected? [4-5 sentences.]
2. Here you will use the complete model to help you rank the following climate-regulated parameters based on their individual contribution to the seasonality of malaria transmission: Gonotrophic cycle (temperature), sporogonic cycle (temperature), adult probability of survival(temperature), subadult survivorship due to moisture (moisture anomaly), and subadult survivorship due to temperature. To do this:
   1. First, simulate malaria transmission using the seasonal moisture anomaly and temperature data to regulate all the parameters above. Let’s consider this the “full model”.
   2. Now replace the seasonal data in one only of the parameters above in the full model (e.g., gonotrophy) with the annual average temperature value. Let’s call this “model 1”. Then run your “model 1”. What is the level of predicted seasonal malaria incidence from “model 1”, now that seasonal influence of gonotrophy has been omitted? Use the Root Mean Squared Error (RMSE) to calculate how far the malaria incidence of “model 1” is from the level of malaria incidence of the “full model”.
   3. Repeat step b to create model 2, model 3, and model 4 by omitting the seasonal effects of the rest of parameters from the full model, and replacing with annual average values, one parameter after another. Calculate their RMSE.
   4. Rank your models from lowest RMSE to highest RMSE.
   5. Which parameter has the most impact on seasonal malaria incidence? Based on your understanding of climate variation and malaria ecology, explain why the outcome is expected? [4-5 sentences.]
3. Based on the above exercises, what can you conclude about the importance of climate conditions on annual malaria incidence and the seasonality of malaria transmission?

Table 1. Table of transmission parameters.

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Description** | **Value** | **Unit** |
|  | Birth rate | (57\*365)-1 | day |
| *, , ,* | Death rate | (53\*365)-1 | day |
| ⁑ | parasite incubation rate | 1/10 | day |
|  | Loss rate of treatment + prophylaxis protection | 1/30 | day |
|  | Rate of recovery of untreated infections | 1/7 | day |
|  | Fraction of infected receiving full treatment | 0.5 | - |
| ⁑ | Rate of patent/sub-patent return to susceptibility | 1/310 | day |
| PMH | Probability of transmission from mosquito to human | 0.5 | - |
| PHM | Probability of transmission from human to mosquito | 0.125 | - |
| qR | Infectivity of non-clinical cases relative to clinical cases | 0.32\*PHM | - |
| ε | Number of eggs laid per gonotrophic cycle | 50 | - |
| μM | Daily adult mortality rate | see eq. 10 | - |
| a.R | Egg-adult sensitivity to surface moisture | 2 | - |
| b.R | Mean anomaly of accumulated rainfall | 0.5 | - |
| c.RD | Cumulative rainfall conditions contributing to surface water levels | see moisture anomaly dataset | - |
| S | Population scaling factor | 1 | - |
| P | Total human population | 1e5 | - |
| S0, E0, I0, T0, R0 | Initial human states | 7000,19000,32000,22000,  20000 |  |
| EIR | Entomological inoculation rate | See eq. 6 |  |
| X | Proportion of infectious humans | See eq. 7 |  |
|  | Force of infection | See eq. 8 |  |
| m | Mosquito density | See eq. 9 |  |
| L | Adult mosquito birth rate | See eq. 11 |  |
| B | Lifetime number of eggs | See eq. 12 |  |
| GP | Duration of gonotrophy | See eq. 13 |  |
| PEA(R) | Egg-adult survival probability due to moisture | See eq. 14 |  |
| T | Air temperature | See temperature dataset |  |
| Tw | Water temperature | T + 2°C |  |
| PEA(Tw) | Egg-adult survival probability due to temperature | See eq. 15 |  |
|  | Egg-adult duration due to temperature | See eq. 16 |  |
| a(T) | Adult biting rate | See eq. 17 |  |
| n(T) | Duration of sporogony | See eq. 18 |  |

The set of ordinary differential equations representing the transmission system are as follows:

Note: incidence is tracked in the system by .

Equations relating temperature and moisture conditions to vector and parasite transmission variables.