Analysis of impacts of climate variability on malaria transmission in Sri Lanka and the development of an early warning system.
Overview

This collection of posters is a supplement to the main report on the project on Climate Impacts on Malaria and the Development of an Early Warning System in Sri Lanka that was undertaken with the support of the Climate Variability and Human Health Program jointly sponsored by NOAA, NSF, EPA and EPRI.

The collection puts together posters that had been prepared for various activities related to the project. They provide an overview of much of the preliminary work. The later findings from this project are not represented in this collection as much as in the main report.

The individual authors of each of the posters are acknowledged in the respective page. Posters prepared by students under the supervision of the PI are also included here. The support of the Research Experiences for Undergraduates Program under the direction of Dr. Dallas Abbott, and the Internship programs at the Earth Institute are acknowledged.

I acknowledge with gratitude the support of Zeenas Yahiya, Valentina Giannini, Shaky Sherpa, Francesco Fiondella and Jason Rodriguez in compiling these posters.

Lareef Zubair, Project Leader

Citation:

Posters - Contents

INTRODUCTORY MATERIAL
1. Project Overview

MALARIA
2. Monthly District-wise Variation of Malaria
3. Monthly District-wise Variation of Dengue
4. Seasonal Sub-District-Wise Variation of Malaria Incidence
5. Village Wise Malaria Incidence in Uva Province

CLIMATE
6. Climate Calendar
7. Rainfall Climatology
8. Temperature Climatology
10. Calibration of Satellite Rainfall Estimates
11. IRI Seasonal Climate Predictions
12. Downscaling of Seasonal Climate Predictions
13. Dynamical Regional Climate Modeling
14. Land Surface Modeling

STUDENT POSTERS
15. El Nino and Climate – Hyemin Yang
16. Climate and Malaria in South-Eastern Sri Lanka – Joseph Simonsen
17. Vulnerability Assessment – Malaria and Cattle – Lindsay Kaye Warren
18. Dengue, Malaria and Climate – Habibatu Jalloh

Malaria is endemic in 101 countries and about 40% of the world’s population is at risk. Sri Lanka spends approximately 60% of its public health budget on malaria control.

Geographic and seasonal specificity of impending malaria risk will be particularly useful in communicating with environmental managers such as irrigation engineers who can use water management techniques to reduce mosquito breeding in pools in river beds. A major constraint to a more focused approach to malaria control is the lack of a forecasting system.

While many factors play a role in the distribution of malaria and occurrence of malaria epidemics, climate is considered a major determinant. Temperature, rainfall, and humidity affect breeding and survival of vector mosquitoes and development of malaria parasites within the mosquitoes.

Historically many epidemics have occurred during drought, as river margins retreat leaving numerous pools suitable for vector breeding, or in the season following a drought when rains return to normal. This second scenario, the post-drought’ epidemic often poses a major public health problem among populations whose vulnerability is heightened due to a period of poor nutrition associated with drought and lowered agricultural output.

An association between ENSO and malaria for Sri Lanka drought and lowered agricultural output.

Stream water depth and vector breeding

There is a relationship between stream water depth and vector breeding in the Mahaweli and related catchments. IWMI has proposed intermittent irrigation releases during dry spells to flush out larvae.

El Nino conditions lead to dry seasons (JFMA and JJA) followed by wet months (May and OND) respectively. This leads to ponding in the land terrain and pooling in streams – providing breeding sites for mosquitoes.

During El Nino, Sri Lanka is warmer in general except in Summer. This helps Malaria transmission which is a spring and fall disease but not dengue transmission which is a summer disease.

A Collaborative Project

A collaborative project proposal between International Water Management, the Sri Lankan Anti-Malaria Campaign of the Uva Provincial Government and the IRI to study climate and malaria linkages and develop an early warning system in the Uva Province has been funded by the Climate Variability and Health joint call issued by NOAA, NSF, NASA and EPRI.

Objectives

- Evaluate microscale interaction between climate, hydrology and malaria transmission
- Evaluate macroscale relationships between climate, hydrology and malaria cases and fatalities
- Develop Models to Forecast Malaria Risk
- Produce Malaria Risk Maps
- Test the effectiveness of these maps
- Document, evaluate and disseminate

Malaria Cases and Deaths in Sri Lanka (1911-1990)

Streamflow during peak epidemic years (red) and least epidemic years (black) in the Kelani River

Example of Malaria Risk Maps (IWMI)

Example of Rainfall Prediction

Hydrological Model Development

Climate & Health:
Malaria and Dengue in Sri Lanka

Seasonality of Malaria

Dengue

Dengue is becoming an increasingly important public health hazard in Sri Lanka. Unlike malaria, which has seen many epidemics over centuries, Dengue's more virulent and deadly form, Dengue Hemorrhagic Fever (DHF) has only a history of two decades. Until recently, it was confined to the Colombo metropolitan area but since has emerged in other cities and suburbs.

A study on the link between climate and dengue in Sri Lanka is being carried out in collaboration with Prof. Aravinda De Silva of the Department of Epidemiology and Public Health of the University of North Carolina and Dr Marianne Heg of the IRI. Some of the preliminary analysis shows a strong seasonality of dengue incidence with the outbreaks being more prevalent during the boreal summer.

Dengue Incidence in Colombo

The International Research Institute for Climate and Society
Summary
Based on laboratory confirmed incidence data obtained from the Sri Lanka Anti-Malaria Campaign (AMC) for the period from 1963-2003, average malaria incidence by district was represented as the annual average in the figure below and as the average for each month in the figures to the left. The annual average figure also includes in it the monthly mean average from January to December for each district as a bar chart. Although in Sri Lanka incidences of malaria diagnosed at government hospitals are reported to the AMC, self treatment is common and there is increasingly some treatment at private hospitals that go unreported.

Malaria is predominantly found in the Colombo and Gampaha with more than 500 cases. Kandy has in the range of 200-500 cases and Kurunegala, Kalutara, Ratnapura and Matara districts had an annual average case load in the range from 200-500. These districts represent the most urbanized in Sri Lanka. Dengue incidence has a bimodal distribution with a main peak around June or July and a subsidiary peak in November, December or January.

Data
Microscopically confirmed DS division wise malaria cases were collected from Anti-Malaria Campaign for the period 1963-2003. The sum of DS division wise data was taken as the district data. The averages of district wise annual and monthly data for the above period were used to generate the maps. Where incidence data was missing at the sub-district level, corrections were applied based on the malaria incidence in the remainder of the district.
The monthly district-wise microscopically confirmed cases were either provided by the National Dengue Control Unit or obtained from the Epidemiological Unit of the Ministry of Health for the period from 1996 to 2005. The average annual and monthly malaria cases were mapped with a geographic information system.

Summary:
Average dengue incidence by district is represented as the annual average in the figure (below) and as the average for each month in the figures to the left. The annual average figure also includes the monthly mean average from January to December for each district as a bar chart.

Dengue is predominantly found in the Colombo and Gampaha with more than 500 cases. Kandy has in the range of 200-500 cases and Kandy, Ratnapura and Matara districts had an annual average case load in the range from 200-500. These districts represent the most urbanized in Sri Lanka. Dengue incidence has a bimodal distribution with a main peak around June or July and a subsidiary peak in November, December or January.

Data:
The monthly district-wise microscopically confirmed cases were either provided by the National Dengue Control Unit or obtained from the Epidemiological Unit of the Ministry of Health for the period from 1996 to 2005. The average annual and monthly malaria cases were mapped with a geographic information system.
Summary
The average malaria incidence by MOH (Medical Officer of Health) was represented as the annual average in the figure (below) and as the average for each month in the figures to the left. The annual average figure also includes in it the monthly mean average from January to December for each district as a bar chart. The Pv incidence is obtained from laboratory confirmed incidence data obtained from the Sri Lanka Anti-Malaria Campaign (AMC) for the period from 1963-2003. Although in Sri Lanka incidences of malaria diagnosed at government hospitals are reported to the AMC, self treatment is common and there is increasingly some treatment at private hospitals that go unreported.

Data
Microscopically confirmed DS division wise malaria cases were collected from Anti-Malaria Campaign for the period 1971-2003. The sum of DS division wise data was taken as the district data. The averages of annual and monthly data for the above period were used to generate the maps. Where incidence data was missing at the sub-district level, corrections were applied based on the malaria incidence in the remainder of the district.
Annual Average GND Wise Malaria Incidence in Moneragala

Upamala Tennakoon, Manjula Siriwardhana, H.M. Faizal, Lareef Zubair

Location Map

1997

1998

1999

2000

2002
**Climate Calendar For Sri Lanka**

**Introduction**

Sri Lanka is at the southern tip of the Asia located 5-10° north of the equator. It has a remarkable variation of topography and climate. The rainfall has bimodal seasonality. The variation of temperature is relatively modest. Relative humidity varies from 60% to 90%. Westerly winds prevail over the island from May to September and North-Eastery winds prevail from December till February.

**Seasonality**

The climate calendar is a succinct and novel representation of seasonality. The panels show by month (from top to bottom) mean and standard deviation of rainfall, mean temperature, mean zonal and meridional wind speeds, cyclone risk, flood risk for the eastern and western hill slopes, landslide risk, malaria risk, dengue risk and the agricultural seasons, Maha (October-March) and Yala (April-September).

**Climatology of Rainfall**

The map shows the average annual rainfall observed at 179 stations from 1960 to 1990. The bar charts show the monthly means from January to December for the main stations.

The island receives on average 1,800 mm of rainfall annually. The rainfall has a bimodal seasonality with peaks in November and May. The western and eastern hill slopes receive increased rainfall from May to October and December to February respectively. Storms and cyclones bring rain to the North-East around November.

**Climatology of Mean Temperature**

The map shows the annual mean temperature averaged from observations at 37 stations from 1960 to 1990. The bar charts show the monthly means from January to December for the main stations.

The mean annual island-wide temperature is around 27°C with lower temperatures in the mountains that rise to 2,500 meters. Temperature drops during December and January and increases from April to September. The mean daily range is approximately 6°C.

**Climatology of Rainfall**

The map shows the average annual rainfall observed at 179 stations from 1960 to 1990. The bar charts show the monthly means from January to December for the main stations.

The island receives on average 1,800 mm of rainfall annually. The rainfall has a bimodal seasonality with peaks in November and May. The western and eastern hill slopes receive increased rainfall from May to October and December to February respectively. Storms and cyclones bring rain to the North-East around November.
Average Seasonal Rainfall

Sri Lankan Rainfall
Given its size, Sri Lanka shows a remarkable variation of topography and rainfall among its regions which shapes much of the physical, biological and socio-economic landscape of the island. The variation in temperature is modest with the mean value being 27 degree centigrade with a mean daily range of 6° C. The relative humidity varies from 60% to 90%. Westerly winds prevail over the island from May to September and North-Easterly winds prevail from December till February.

Sri Lanka is relatively wet with an average annual rainfall of 1850 mm with marked regional contrasts. The significant climatic processes that bring rainfall to Sri Lanka are Inter-Tropical Zone (April to June) and (October to November), Easterly Jet (July and August), the monsoon (October to December), cyclonic storms from the Bay of Bengal (November to January) and orographic rainfall in the Western hillslopes (May to September) and in the Eastern hillslopes (December to January).

Mapping Sri Lankan Rainfall
Rainfall measurements are available for Sri Lanka from 1853 and there are a dozen stations which have a 130 year rainfall record and around 400 stations have been maintained. Rainfall data for 179 stations (marked in the map) that have long records were obtained from the Sri Lanka Department of Meteorology and other archives. The data was subjected to Quality control to ensure that suspect data were eliminated. Thereafter the monthly climatological average was estimated for each station. These monthly averages were along with an interpolation based on Inverse-Distance-Weighting to prepare rainfall maps. The seasonal rainfall maps were prepared for the first and second halves of the traditional cultivation seasons of Maha (October to March) and Yala (April to September).
Sri Lankan Temperature

The temperature in Sri Lanka is influenced by seasonal changes in solar radiation and large scale wind patterns. From November to February, the North-East trades starting in Northern Asian land mass brings in colder air and from May to September the winds from the West passing over the warm Arabian sea bring in warm air. Regional variation in temperature is modulated by elevation, local wind phenomenon such as the sea breeze and mountain induced winds and land use patterns. The seasonal variation in temperature within Sri Lanka is modest with an average of 27°C with a difference of 6°C between day and night.

Temperature Climatology of Sri Lanka

Quality controlled maximum and minimum temperature data for 18 Sri Lanka Department of Meteorology and 19 Department of Agriculture stations for the period from 1961 to 1990 were used as the basic input for the analysis. The monthly climatological minimum, maximum and mean temperature for each station was estimated. Thereafter for each month, the temperature values were adjusted to sea level using the empirically estimated lapse rate. Interpolation technique that did not take account of elevation provide unrealistic maps and here we have attempted a topographically informed interpolation technique. The interpolation was carried out so that values were assessed for a 1-km grid. Thereafter, the temperature at each grid was renormalized by using the lapse rate for that month so that it takes account of elevation. The best results were obtained when lapse rates were estimated separately for elevations above and below 100 m.
Rainfall Monitoring for Malaria Early Warning for Uva and Sri Lanka
Badra Nawarathna, Michael Bell, John Del Corral, Benno Blumenthal, Janaki Chandimala, and Lareef Zubair

NOTE: The recent short-term (e.g., 5-year) average of precipitation should not be interpreted as a climatological normal, which is typically based on a long-term (e.g., 30-year) time series. The length of this short-term average will increase over time as more data become available. An additional year of data will be included in the average during January of each year. Despite the limitations that the short-term average imposes, it may provide insight into changes in malaria risk in areas where precipitation anomalies are the principal cause of malaria epidemics by providing a recent historical reference.

Data Sources
Precipitation Estimates
Data: Dekadal precipitation on a 0.1 x 0.1 deg. lat/long grid, aggregated from daily estimates

Precipitation Estimate Short-Term Average
Data: Dekadal precipitation on a 0.1 x 0.1 deg. lat/long grid, aggregated from daily estimates

Cumulative dekad satellite-derived precipitation estimates (solid black line) and the cumulative recent short-term average precipitation (grey dotted line) for the most recent 12-month period in the selected region. The blue (red) bars are indicative of estimates that are above (below) the short-term average.
Validation of Satellite Rainfall Estimates over Sri Lanka
Badra Nawarathna$^{1,2}$, Janaki Chandimala$^3$, Manjula Siriwardhana$^2$, Michael Bell$^3$ and Lareef Zubair$^3$
Mahaweli Authority of Sri Lanka$^1$, Foundation for Environment, Climate and Technology, Sri Lanka$^2$ and International Research Institute for Climate and Society$^3$.

Introduction
Sri Lanka has invested heavily on irrigated agricultural infrastructure and success of this depends on the availability of rain water. Accordingly it is imperative to ascertain with significant reliability the fluctuations in the quantity, intensity and the spread of the rains. Recently the Climate Prediction Centre at NOAA has developed a rainfall estimate (RFE) at a 10 km grid. Here, the accuracy of the RFE is assessed by comparing with observations.

Methodology
First, the satellite estimates were interpolated for the location of the respective data stations. Scatter plots and time series were used to compare the station observations and the satellite estimates. The correlation of annual and seasonal values of observed data and the satellite estimated data were studied. Errors of mean annual and seasonal rainfall from the two sources were calculated.

Summary
There is good correspondence between satellite estimates when compared against station values. The mean of the satellite estimate is on average lower by a small amount from the observed. We have established that there is a significant correlation between satellite data and observed data. The correlation value lies between 0.3 and 0.7 when the entire island is considered. A significant correlation is represented in the coastal areas. The correlation between the two data sets gradually improves towards 2005. The accuracy is sufficient for the use of data in water resources, natural resources and agricultural management.
The International Research Institute for Climate and Society (IRI) has been issuing global climate forecasts at quarterly intervals in an experimental mode since October 1997. This is an agency supported by the National Oceanic and Atmospheric Administration and Columbia University that was established 5 years ago to promote the use of seasonal climate forecasts. Forecasts for rainfall and temperature are issued for the subsequent 3 months and 6 months. Forecasts are issued for rainfall and temperature in the categories of above normal, near-normal, and below-normal. The rainfall cut-offs for each category are based on the wettest, normal, and driest 10 episodes for the given season from 1960 to 1990. In addition, it provides warnings regarding extremes. These forecasts are based on global climate simulations by four Global Climate Models which are initialized based on observations of global ocean surface temperatures. These simulations are at a resolution of approximately 250 km and thus Sri Lanka is captured in two grid boxes. Seasonal climate forecasting is a new field and the skill obtained thus far is good for regions such as Indonesia, North-East Brazil, and East Africa. In general, the forecast skill for Asia and Europe is weaker than that for other continents. The regions with the most skill within Asia are South-East Asia and South Asia. However, the skill is likely to improve in the coming years based upon improved observations of Indian Ocean sea surface temperatures, land surface hydrology, Eurasian snow cover and the improvement of GCM performance over South Asia.

Given that the atmosphere is a high dimensional chaotic system, one could not even in the best circumstances, predict precisely the particular trajectory that the atmosphere will take. One can only interpret likelihoods of what the atmosphere may do and this likelihood’s may be captured by a probabilistic forecast. The probability forecasts also provide an explicit representation of the uncertainty of the forecasters to the users. However, there are several nuances in relation to how cut-offs are chosen and the impact of extreme weather events that has led some to misinterpret these forecasts.

Both modellers and potential users are quite concerned regarding extremes. These forecasts are based on global climate simulations by four Global Climate Models which are initialized based on observations of global ocean surface temperatures. These simulations are at a resolution of approximately 250 km and thus Sri Lanka is captured in two grid boxes. Seasonal climate forecasting is a new field and the skill obtained thus far is good for regions such as Indonesia, North-East Brazil, and East Africa. In general, the forecast skill for Asia and Europe is weaker than that for other continents. The regions with the most skill within Asia are South-East Asia and South Asia. However, the skill is likely to improve in the coming years based upon improved observations of Indian Ocean sea surface temperatures, land surface hydrology, Eurasian snow cover and the improvement of GCM performance over South Asia.

IRI Seasonal Climate Forecasts for Sri Lanka

IRI Multi-Model Probability Forecast for Temperature
February–March–April 2004 made January 2004

Schematic of
GCM Based Climate
Predictions Operations

Skill in South Asia
Mason et al – Heidke score of 5.2 for OND 1997.
For South Asia – Skill score of 12 for OND 1997.
Score for Sri Lanka over the 13 seasons from OND 1997 to OND 2000 was 53.
Score for Bangladesh was 8.

Predictions for Sri Lanka:
Hits and Misses
• When highest weighted category coincides with observations, a season is marked as a Hit.
• Skill is given using Heidke Score: Here, 0 is equivalent to guessing and 100 is perfect
• The top scoring regions in the World are listed in top-right
• The coverage specifies how often a prediction had been provided for a region
• Sri Lanka has relatively high skill as well as coverage

Hits and Misses for Sri Lanka
H/M – Refers to a Hit in Northern Sri Lanka and Miss in Southern Sri Lanka

Total Hits = 10.525 Heidke Score = 13.5
Objective

It is known that the large-scale atmospheric circulation across the Indian Ocean sector has a strong degree of predictability in the October-December season. Global climate model forecasts are archived at IRI from 1950 to present and are available to quantify this large-scale predictability. This provides a basis for investigating predictability at small spatial scale across Sri Lanka. We ask the question: for a given large-scale wind forecast across the region, what are the details of the rainfall pattern to expect across Sri Lanka? Two ways to answer this question are:

1. Run a high resolution climate model driven with the large-scale wind fields from the Global Climate Model.
2. Establish the statistical relationship between the details of the observed rainfall pattern and the large-scale wind forecast – using analysis over a large set of past years – and use these relationships to forecast each location in Sri Lanka, given a large-scale wind forecast.

Schemata

Summary

Predictions from Global Climate Models are at a coarse resolution (of around 250 km) at present, and there is a need to obtain estimates at fine scales for work such as malaria risk estimation. Here, we present a “downscaling” methodology to estimate rainfall at a scale of 25 km for Sri Lanka using retrospective analysis from 1960-2000. A retrospective analysis shows skillful predictions particularly over the Uva Province region.

GCM Model

The Global Climate Model results are the average of 24 forecasts made for each season 1950-1980 using the ECHAM4.5 model. These forecasts assume perfect knowledge of the Sea-surface temperature – for real-time forecasts there is a need to first forecast the sea-surface temperature – these skill evaluations can therefore be considered approximately representative of the skill achievable with short-lead time forecast (i.e. forecast made as the October-December season starts), since the relevant large-scale patterns of sea-surface temperature anomalies usually change only very slowly from September to December.

There is good indication that the increased skill found on the eastern side of Sri Lanka is physically based – since wetter years appear to be associated with SST forcing that enhances the easterly surface wind component across the region – which will hit the eastern side of the island first and give rise to particularly enhanced precipitation on eastward facing slopes, while the western side of the island, especially in the lee of mountains, may be less affected.
Abstract
The ensemble dynamic regional climate downscaling is studied by using a global atmospheric general circulation model ECHAM4.5 and a regional climate model RegCM3. The regional climate model with high resolutions of 100km and 20km grid downscales large-scale global model outputs to generate mesoscale climate information over South Asia. Here it is seen that simulations of regional climate with adequate fidelity are obtained only at a high resolution of 20-km.

The Regional Model

Fig.1 The 100km-grid (a) and 20km-grid (b) model domain and topography (m).

The RegCM3 was run over South Asia with 100km and 20km grid size, with its domain and the topography shown by Fig.1a and 1b, respectively. The domains are centered over Sri Lanka at (7.5N, 80.5E). The 20km-grid runs use a smaller domain than the 100km-grid runs because of the restriction of computational cost. Because of the strong orographic effect on the rainfall in Sri Lanka, fine resolution in the regional model is needed. Figure 1 shows that the 100km-grid resolution only gives a mountain top less than 200 m, but the 20km-grid shows a peak value over 1000 m. Due to the orographic effect, the climate over the western and eastern hillslopes of Sri Lanka strongly depends on the seasonal change of predominant wind directions.

RegCM3 is driven by lateral boundary conditions provided by the ECHAM4.5. To avoid discrepancies between the outer driving fields and the model internal physics, an exponential relaxation scheme (Giori et al. 1993, Qian et al. 2003) is applied in the lateral buffer zone with a width of 12 grid intervals, which consists of Newtonian and diffusion terms added to the model tendency equations for wind components, temperature, water vapor mixing ratio, and surface pressure.

Spatial Distribution

The resolutions of CMAP and TRMM data in the simulations shown in Figure 2 (panel a, b) are too coarse to represent the fine spatial structure of the topographic rainfall over Sri Lanka shown by the 0.5-degree gridded station precipitation in panel c. The 850hPa winds of the NCEP-NCAR reanalysis are also shown in Fig.2a, as a validation for the model simulated winds. In the RegCM3 simulation with 100km grids, the magnitude and direction of the winds are similar to its driving fields from ECHAM, and the resolution is still not fine enough to simulate the orographic effect on precipitation.

The runs with 100km grids led to maximum precipitation is in the northern Sri Lanka which differs from observations. The runs with 20km grids, which has a mountain top of 1000 m, produced orographic precipitation near the central mountain. However, the precipitation center is near the mountain top, while in the station observation, the rainfall maximum is on the windward side of the western hillslopes.

The wind field in the RegCM3 20km-grid runs is similar to that of the 100km-grid runs as well as the ECHAM4 simulations, indicating the dominant role of mechanical forcing from the GCM to the regional model.

Summary
By using a regional climate model RegCM3, the GCM ECHAM4.5 ensemble simulations have been downscaled over Sri Lanka. The high-resolution of 20km grid is needed for the RegCM3 to produce reasonable spatial distribution of precipitation which is strongly affected by the island's topography. The high-resolution regional model also corrects the intensity and seasonal trend of the precipitation.
1.1. Experiment Description

Experiment Description

1.2 Data

METEORLOGICAL FORCINGS

European Center for Medium Range Weather Forecast (ECMWF) global fields of reanalysis meteorological forcings have been bias-corrected with observed precipitation and radiation fields to generate a global forcings data set on a 0.5-degree 6-hourly temporal scale for the period 1979-1993.

Precipitation observations from 287 rainfall stations have been gridded at a resolution of 0.25-degree to obtain monthly precipitation totals for Sri Lanka (Figure 1.2a).

Minimum, mean and maximum 2m air temperature observations were obtained for 18 stations (Figure 1.2b and Table 1.2a).

Monthly streamflow observations at 10 sites (Figure 1.2b and Table 1.2b) were compared together with soil, vegetation and model specific parameters from the same convective fraction of the ECMWF forcings.

4. Discussion and Summary

We forced a state-of-the-art land surface model using global reanalyzed meteorological forcings merged with locally observed precipitations. The usability of model simulations for hydrological applications was also explored.

MODEL EVALUATION

If Fig. 2.1 shows that the diurnal variation of temperature is well represented by the model. The stations that had the highest deviations were in the hills.

If Fig. 2.2 and 2.3 show that the model has captured the seasonal cycle of streamflow and annual mean runoff efficiency is also well represented.

The success in the model evaluation led to the assumption that the model simulations represent the observed state of land surface variables. Thus, the simulated soil moisture may be well used for predictability studies. Nevertheless, the simulated soil moisture is known to be sensitive to model dependency. Varied sensitivity in the lag correlation of precipitation and streamflow anomalies (specifically at 1-2 months) in Table 2.3 underscores that the model has captured the time lag very well implying that the simulated soil moisture is a good measure.

SOIL MOISTURE MEMORY ANALYSIS AND SEASONAL STREAMFLOW PREDICTABILITY

If Fig. 3.1 shows that the lagged cross-correlation between simulated runoff efficiency and soil moisture showed predictability of streamflow up to 3 months in drier months (AMJ and JAS).

Fig. 3.1 shows that the lagged cross-correlation between simulated runoff efficiency and soil moisture showed predictability of streamflow up to 3 months in drier months (AMJ and JAS).

predicted streamflow anomaly and lagged runoff anomaly (specifically at 1-2 months) in Table 2.3 underscores that the model has captured the time lag very well implying that the simulated soil moisture is a good measure.

Soil Moisture Memory Analysis and Seasonal Streamflow Predictability

If Fig. 3.1 shows that the lagged cross-correlation between simulated runoff efficiency and soil moisture showed predictability of streamflow up to 3 months in drier months (AMJ and JAS).
Association of El Niño and Malaria Epidemics in Sri Lanka

Hyemin Yang, Columbia University
Advisor: Lareef Zubair, International Research Institute for Climate and Society

Abstract:

The global ocean-atmosphere phenomenon called El Niño was proposed as a predictor for malaria epidemic risk in Sri Lanka. We examined the relationships between El Niño, rainfall, and epidemics in Sri Lanka. From 1870 to 1945, El Niño and epidemics were significantly correlated. From 1945 to 1985, there was no relationship. During the two last decades, the relationship between El Niño and epidemics may have re-emerged. Changes in the relationship between El Niño and rainfall in around 1940 and 1980 may account for the changing relationship of epidemics to El Niño.

Introduction:

Malaria is one of the major public health concerns in the tropics including Sri Lanka.

Previous studies suggested relationships between malaria epidemics and numerous climate variables – rainfall, relative humidity, and temperature. Gill (1936) claimed that the decrease in rainfall during the first 5 months of the year was related to epidemics in summer, and the decrease in summer rainfall was related to winter epidemics.

Bouma and van der Kaay (1996) claimed a relationship between El Niño occurrences and malaria epidemics in Sri Lanka, and proposed El Niño as a predictor for epidemics. Here, we investigated the validity of the proposal to use El Niño as an instrument for a malaria early warning system in Sri Lanka.

Data:

Epidemiological Data

- Figure: Annual average of SST’s anomalies in the Nino 3.4 region. (Red bars: epidemic years, blue bars: non-epidemic years) From 1946 to 1985, epidemics were predominant for the years with positive SST anomalies. From 1946 to 1985, they were predominant for the years with negative SST anomalies.

Analysis:

Malaria Epidemics and El Niño

- Table 1: (a) Epidemic years in Sri Lanka in relation to El Niño years between 1870 and 1945. (b) Epidemic years in Sri Lanka in relation to El Niño years between 1946 and 2000.

Rainfall during El Niño episodes has changed during the three periods (1870-1945, 1946-1985, 1986-2003). From 1870 to 1945, the April-June rainfall during El Niño was higher than the normal rainfall. However, from 1946 to 1985, the difference of the April-June rainfall between El Niño episodes and normal years was indistinguishable.

Conclusion:

Epidemics in Sri Lanka coincided with El Niño for the period from 1870 to 1945, in a statistically significant manner. There is no relationship between El Niño and epidemics after 1945, but there may be a relationship after 1986. The relationships between El Niño and rainfall in Sri Lanka have changed in the 1940’s and 1980’s. These changes are a possible explanation for different relationships between malaria epidemics and El Niño.

References:


Abstract

I analyze the relationship between malaria morbidity and both rainfall and mean temperature in five districts in southeastern Sri Lanka. Three of these districts, Badulla, Batticaloa, and Moneragala, are placed at low elevations; while the other two, Badulla and Nuwara Eliya, are situated at higher altitudes. I find that climate is related to this variability in terms of the relationship of the mean annual cycle of rainfall and temperature to malaria incidence and in terms of statistically significant relationships in the inter-annual variation of rainfall, temperature and malaria.

Introduction

Climate influences the geographic range of malaria transmission both because the development of the disease-causing Plasmodium parasite is temperature dependent (Macdonald 1957, as cited in Bouma and van der Kaay 1996), and because the reproduction and survival of the Anopheles mosquito vector hinges on favorable rainfall and temperature conditions (Molineaux 1988). It is likely that the relationship between these climate variables also plays an important role in the timing and intensity of epidemics in regions where the disease is prevalent. A clarification of the mechanisms by which meteorological conditions affect malaria in these regions could lead to the development of early warning systems for disease prevention.

Data

Monthly malaria morbidity data for all five Sri Lankan districts was obtained from the Sri Lanka Anti Malaria Campaign. Rainfall and mean temperature station data was obtained from the Sri Lanka Department of Meteorology and the Sri Lanka department of Agriculture.

Methodology

I examine the mean annual cycles of malaria morbidity, rainfall, and mean temperature. Afterwards, I analyze the inter-annual variability of malaria morbidity and its relationship with rainfall and mean temperature in both the Maha (October-March) and Yala (April-September) seasons. Using the IRIS Data Library, I then compute Spearman Rank Correlations for the period 1972-2003 between malaria in each season and both rainfall and mean temperature.

Analysis of Mean Annual Cycles

1. The mean annual rainfall cycle is bimodal for all stations excluding Batticaloa. The first peak for each station occurs in the first half of the Maha season – between October and December – during the Northeast Monsoon. The second peak comes early in the Yala season, between April and June – during the Southwest Monsoon. Rainfall troughs occur in the latter half of each of the two seasons.
2. Mean monthly temperatures for all stations increase continuously from a single minimum to a single maximum, and then decrease continuously from peak to trough. Maximum mean monthly temperatures occur in May for all stations besides Moneragala.
3. The mean annual cycle of malaria morbidity is bimodal for all districts except Batticaloa. Peaks fall within each of the two Sri Lankan agricultural seasons: Maha, October through March, and Yala, April through September.

Analysis of Inter-Annual Variability


6. In Maha (Oct-Mar), malaria morbidity is negatively correlated with Yala (Apr-Sep) rainfall in Moneragala. This relationship may be explained by the increased prevalence of stagnant pools – favorable for mosquito reproduction – along stream margins due to increased discharge during droughts in late Yala, Moneragala’s driest time of year (Cif 1995).
7. Yala malaria morbidity in Moneragala is negatively correlated with rainfall from January to March and with rainfall from February to April. In nearby Badulla, however, morbidity during the same season is positively correlated with concurrent rainfall and rainfall from March to August. While the retreat of stream margins due to droughts may remain the cause of increased malaria in Moneragala, pools of water that accumulate in fields after heavy rainfall may be the more important determinant of malaria morbidity in Badulla.

Methodology

Climate influences the geographic range of malaria transmission both because the development of the disease-causing Plasmodium parasite is temperature dependent (Macdonald 1957, as cited in Bouma and van der Kaay 1996), and because the reproduction and survival of the Anopheles mosquito vector hinges on favorable rainfall and temperature conditions (Molineaux 1988). It is likely that the relationship between these climate variables also plays an important role in the timing and intensity of epidemics in regions where the disease is prevalent. A clarification of the mechanisms by which meteorological conditions affect malaria in these regions could lead to the development of early warning systems for disease prevention.

Data

Monthly malaria morbidity data for all five Sri Lankan districts was obtained from the Sri Lanka Anti Malaria Campaign. Rainfall and mean temperature station data was obtained from the Sri Lanka Department of Meteorology and the Sri Lanka department of Agriculture.

Methodology

I examine the mean annual cycles of malaria morbidity, rainfall, and mean temperature. Afterwards, I analyze the inter-annual variability of malaria morbidity and its relationship with rainfall and mean temperature in both the Maha (October-March) and Yala (April-September) seasons. Using the IRIS Data Library, I then compute Spearman Rank Correlations for the period 1972-2003 between malaria in each season and both rainfall and mean temperature.

Analysis of Mean Annual Cycles

1. The mean annual rainfall cycle is bimodal for all stations excluding Batticaloa. The first peak for each station occurs in the first half of the Maha season – between October and December – during the Northeast Monsoon. The second peak comes early in the Yala season, between April and June – during the Southwest Monsoon. Rainfall troughs occur in the latter half of each of the two seasons.
2. Mean monthly temperatures for all stations increase continuously from a single minimum to a single maximum, and then decrease continuously from peak to trough. Maximum mean monthly temperatures occur in May for all stations besides Moneragala.
3. The mean annual cycle of malaria morbidity is bimodal for all districts except Batticaloa. Peaks fall within each of the two Sri Lankan agricultural seasons: Maha, October through March, and Yala, April through September.

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Malaria is one of the major public health threats in Sri Lanka and in other third-world countries. It is endemic in 101 countries and about 85% of the world’s population is at risk (1). It causes 300-500 million infections worldwide and approximately 1 million deaths annually. In 1998 in the World Health Organization’s Southeast Asia region, the number of cases was 16 million, with 73,000 deaths.

In Sri Lanka, where most people face the same exposure to the disease, there are factors that can trigger and exacerbate the disease and factors that can control or reduce its severity. This project examines what these factors of vulnerability are.

**Methods**

- **Risk analysis**: A risk analysis was made possible by an already present database of malaria cases collected over the course of ten years from 1995 to 2003 by the Anti-Malaria Campaign in the Uva Province. Analysis were only performed for the district of Badulla in the Uva province to determine which factors affect malaria occurrence.

  **Data included**:
  - Malaria cases from the district of Badulla, verified by the positive blood tests in various hospitals between 1995 and 2003.
  - Socio-economic factors: the population for each subdivision (Grama Niladari Division) of the Badulla district, the amount of cases and deaths for each GND.
  - Environmental factors: the population for each subdivision (Grama Niladari Division) of the Badulla district, the number of positive cases from 1995 to 2003 by the Anti-Malaria Campaign in the Uva Province.

- **Correlating**: Analysis were only performed for the district of Badulla in the Uva province to determine which factors affect malaria occurrence.

- **Correlation**: Use of GIS 3.3 and GIS 9.1 to correlate data to appropriate geographic locations and to map out the density of malaria cases per area and the vulnerability factors driving this density.

**Introduction**

An early warning system would be highly valuable for those countries which do not have proper and/or efficient means to regulate the disease. The construction of an early warning system is dependent on knowledge of vulnerability factors.

- **In Sri Lanka**, where most people have the same exposure to the disease, there are factors that can trigger and exacerbate the disease and factors that can control or reduce its severity. This project examines what these factors of vulnerability are.

- **Vulnerability**
  - People have different levels of vulnerability and can exhibit varying responses to their environment. The different factors which may cause a varied vulnerability to malaria include:
    - **Socio-economic factors**: such as farming or logging can increases, the poor’s limited control over the land, non-availability of medicines or other medical supplies and control of host environments.
    - **Environmental factors**: lack of control and support against anti-malaria campaigns from the government, and vulnerable or poor quality and sanitation of infrastructure.

**Environmental factors**

- **Forests**: logged areas, forested
- **Land**: sandy soil within each GND
- **Cattle**: the amount of cattle present within the subdivisions.
- **Cows**: in the subdivision, the percentage of sand in the soil
- **Water**: elevation for each GND

**Results and discussion**

- **There is a significant positive correlation between malaria and the amount of cattle present within the subdivisions of Badulla province for the years 1997 to 2002 (Figure 5).** The close proximity with which farmers work with cattle may increase the chances of contracting malaria.

- **There is a significant negative correlation between malaria cases and the temperature of Passara, Badulla for the first six months of 2000 (Figure 7).** The mean temperature for Passara’s climate falls within mosquitoes’ susceptible range.

- **There was no correlation between the Badulla malaria cases and the annual rainfall, the percentage of sand in the soil, the elevation of the land area, population density for the major of the years, or the forest coverage area.**

**Conclusions**

- The type of rainfall in which a separate event might have significant impact on its vulnerability to malaria. Because the amount of cattle positive cases correlates with the amount of positive malaria cases, farming within a tropical area could increase the chances of contracting malaria.

- Although temperature has a negative correlation with malaria in the results, the temperature must be combined with rainfall for its effects to be significant.

**Key References**

Annual cycle of Temperature versus Dengue over Sri-Lanka

Both annual cycles of dengue versus temperature (upper panel) and Malaria versus rainfall (lower panel) show a lag between the climate maximum and disease maximum. This could imply a relationship cause-effect between climate conditions and occurrence of those two diseases. Temperature reaches its maximum during April-May-June season followed by the peak season of dengue in June-July. The main rainfall season occurs in Sri-Lanka during October-November-December and two months later peaks up the mortality rate of Malaria in December-January-February. The time lag between climate and diseases agrees with the epidemiology of those vectors of the disease because vector transmitting those diseases needs optimal environmental condition to develop in order to transmit the disease.

Introduction

It’s well established that certain environmental conditions could have an impact on the epidemiology of certain diseases. Rainfall and temperature can affect the life cycle and livelihood of vectors of some diseases like malaria and dengue. Sri Lanka, a tropical island in southern Asia, South of India, has warm climate expose to ocean wind and moisture. The mean temperature varies from 15.8ºC in the central Highland to 29ºC in the Northeast coast. January is the coolest month and May the hottest. There are two rainfall seasons in Sri Lanka driven by the two tropical monsoons, the Northeast Monsoon from Dec-Mar and South west Monsoon June-Oct. The two main vector borne diseases are Malaria and dengue. In this study we look at relationship between malaria and rainfall and dengue and temperature.

Annual cycle

We look at co-variability between rainfall in October and malaria in January during 1973-2003. It’s clear that during periods of drought, example in 1979-1983 and in 1994-2001, we have low cases of malaria and both malaria and rainfall follow the same negative trend. High variability in rainfall during 1986-1993 coincides also to high variability in the number of cases of malaria. So the general trend agrees but the year-to-year variation shows lots of discrepancies as the climate alone can not explain all cases of infection.

Conclusion

This study shows in Sri Lanka the main rainy season occurs in Oct-Nov-Dec and is followed by the peak of malaria infection in Dec-Jan-Feb. The hottest month in the season Apr-May-Jun is followed by high dengue disease. The correlations between Rainfall in October and number of cases of malaria are 0.20, 0.25, and 0.25 for respectively December, January and February. As climate is not the only causes for disease those results need to be studied further as other studies have confirmed that such relationship does exist in Sri Lanka.

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