2. Climate Adaptation and Impact Analysis Projects

2.1. Climate and Water Resources
- (a) Climate information needs
- (b) Project Setting
- (c) Hydrological Data base
- (d) Reservoir Modeling
- (e) Stream flow Prediction
- (f) Land surface Modeling

2.2. Climate and Agriculture
- (a) Rice
- (b) Tea
- (c) Coconut

2.3. Climate and Environment
- (a) Human-Elephant Conflict

2.4. Climate and Health
- (a) Dengue
- (b) Malaria

2.5. Climate and Disasters
- (a) Floods
- (b) Droughts
- (c) Landslide
- (d) Cyclone Risk
- (e) Multi-hazard Analysis
- (f) Vulnerability

Climate and Water Resources

Water Resources has an intimate link with climate via the hydrological cycle. Yet, until a few years back, water managers have made little use of the predictability of climate and the understanding of variability. We explored the usability of climate information and predictions for water resource and river basin management.

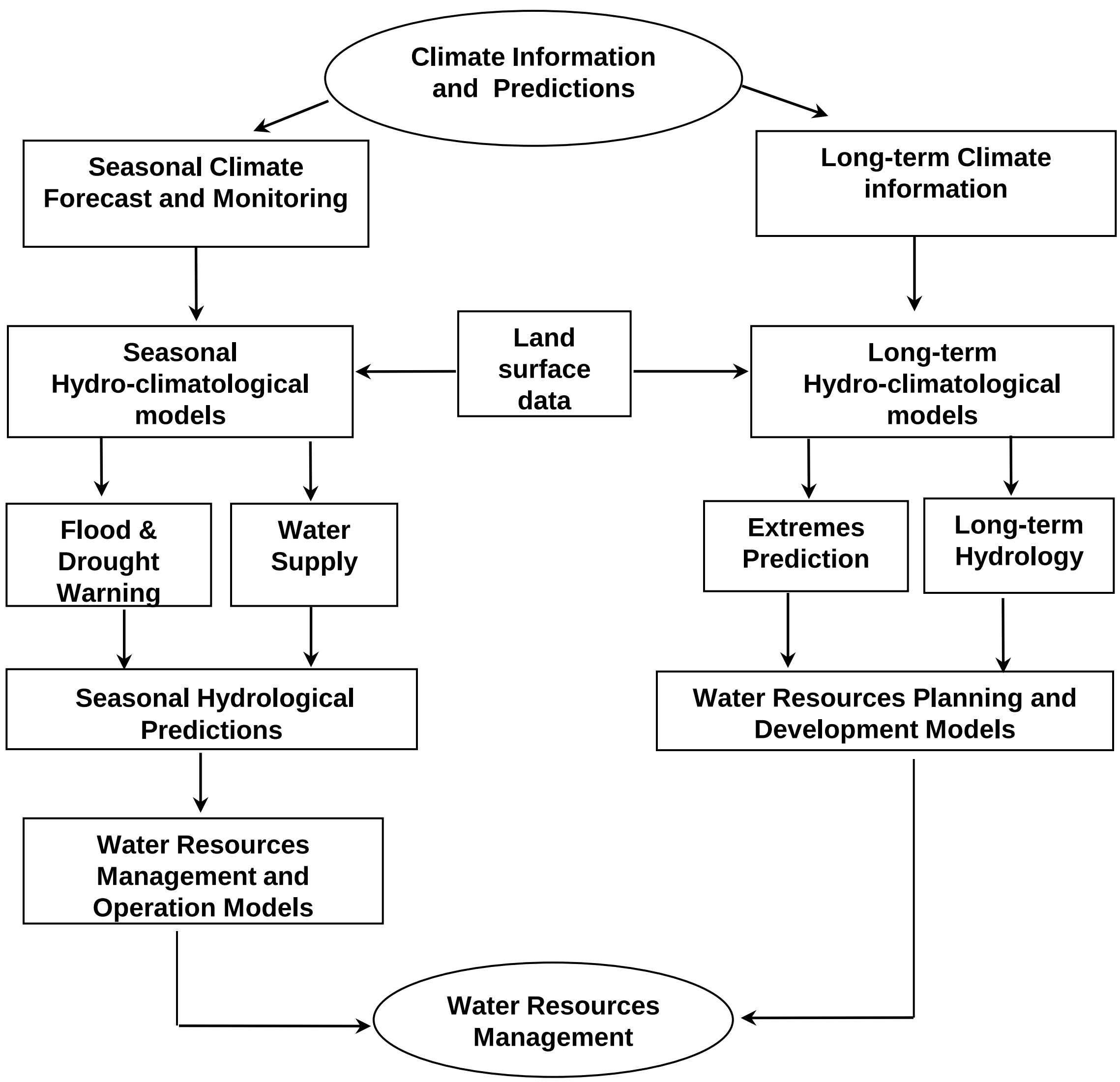
(a) Climate information needs for WRM
(b) Project Setting
(c) Hydrological Data base
(d) Reservoir Modeling
(e) Stream flow Prediction
(f) Land surface Modeling

Projects Status Report

Activity	Objectives	Partners	Status	Next Steps
Seasonal Climate Information for Water and Environmental Management in the Mahaweli Basin	(1) to identify necessary climate forecasts and information (2) to develop hydro-climatic models and analytical tools (3) to generate a framework to support decision-making	The Mahaweli Authority, Department of Irrigation, Interim National Water Resources Authority of Sri Lanka.	Supported the formation of a National Steering Committee on Seasonal Climate Predictions and Applications (NASCOM), provided climate information and forecasts, Research Paper on decadal changes of hydro-climatology in Sri Lanka under review.	Continued dissemination of climate information.
Land Surface Modeling	Relate meteorological model output into land surface properties	Sarith Mahanama, NASA Global Modeling and Assimilation Office, Greenbelt.	Land Surface models implemented and meteorological forcings refined for producing high-fidelity stream flow for Sri Lanka.	Implementation of model at IRI and at FECT. Publications.
Training of Mahaweli Engineers	To build technical capacity in climate analysis and hydro meteorological analysis techniques	Mahaweli Authority River Basin and Head works Divisions	Engineers Badra Nawaratne and Udayangani Palagama obtained training for two weeks at Polgolla. Since December, Engineer Badra Nawaratne commenced work full time.	Review of climate related design methods, hydro meteorological information systems.

Climate Information for WRM

It is illuminating to separate the climate inputs into water resources management (WRM) into the seasonal to inter-annual and longer term components. The seasonal component bears on operation of reservoirs and diversion points and seasonal management. The longer-term climate bears on water resources planning, the prediction of extremes and policy issues. The differences are captured in the following sketch diagram.



Project Setting

"In my kingdom are many paddy fields cultivated by means of water, but few indeed are those which are cultivated by means of perennial streams and great tanks. By rock, and by many thick forests, by great marshes is the land covered. In such a country, let not even a small quantity of water obtained by rain, go to the sea, without benefiting people."

- Parakrama Bahu, *King of Sihaladvipa (1153-1186 A.D.)*

In January 2000, we initiated a project to apply climate information and prediction for river basin management in the *Mahaweli* basin in Sri Lanka. The *Mahaweli* Authority is responsible for river basin management in the *Mahaweli* and adjacent rivers. This river basin provides half of Sri Lanka's electricity requirements, rice and tea production respectively. Climate information has entered into basin management in terms of historical statistics. Recently, however monitored climate information and seasonal climate predictions have become available. Such timely information provide an opportunity for adaptive basin management. The following were key steps:

- Characterization of climatology, climate variability and secular trends within the river basin. Strong spatial variability is evident.
- Evaluation of the skill of global climate predictions for Sri Lanka.
- Evaluation of predictability of in-situ rainfall and stream flow using global sea surface temperatures was undertaken and significant predictability was found.
- Development of localized rainfall predictions based on Global Climate Models
- Simulations using "downscaling" techniques resulting in predictions at a high resolution.
- Study of climate impacts on key sectors in the *Mahaweli* basin such as rice, tea, hydro-electricity, water supply, human-elephant conflict and malaria established high vulnerability to climatic anomalies.
- A study of climate information needs was carried out. Climate information and predictions is needed particularly at the start of the planting season in September and March.
- Capacity building for climatic analysis within Sri Lanka.

The River Basin setting

The 207 mile long *Mahaweli* river traverses from the so-called "Wet Zone" of the island to the "Dry Zone“. Of the annual precipitation in the basin of 28,000 MCM, 9,000 MCM is discharged to the sea. Its catchment spans 10,448 square km and feeds 1003 tanks. Water transfer has been augmented with dams, canals and tunnels during rapid development from 1978 onwards under the Accelerated *Mahaweli* Project. The *Mahaweli* project involves the generation of hydroelectricity, irrigation of the "Dry Zone", land settlement, employment generation and infrastructure development. There are four reservoirs in the main trunk of the river with a storage capacity of 1,500 MCM and there is a bigger storage capacity from trans-basin diversions. This project led to hydropower generation capacity of 470 MW and irrigation of an additional 365,000 ha of land in the Dry Zone. There are competing demands for water for irrigated agriculture in different areas, for hydro-electricity, for river and watershed ecology, for public health and for social welfare. The need for water for irrigation and domestic use is particularly acute in the downstream. Agricultural production in the dry zone varies dramatically with the availability of water. Drought has brought on scheduled power cuts in the national grid.

Water Management in the *Mahaweli* River Basin

Rice or Paddy is the principal subsistence crop and it needs large amounts of water. Rice cultivation is carried out in the main *Maha* season from October to March and in the subsidiary *Yala* season from April to September. Both seasons begin with the rainfall in September-October and April-May. However, the monsoon system results in higher rainfall in the *Maha* season and lower rainfall in the *Yala* season. There is high rainfall due to orographic influence in the South-West quadrant of the island in *Yala*. Hence rivers such as Mahaweli and *Walawe* which originate in the South-West and traverse elsewhere are important sources of irrigation during *Yala*.

From top: Kotmale Reservoir in January 2001, Kotmale Reservoir in June 2001 and Victoria Reservoir on one of five occasions of spilling.

Climate Predictions needed for Seasonal Decision-Making

An elaborate system of water management is in place. Water management is based on consultation at various geographic scales: that of the field, block, system, basin and island-wide. Climate information is needed weekly for system operation, seasonally for seasonal planning and in the long-term for infrastructure development and policy. Here are the seasonal intervention points.

- In September, decisions as to extent of rice cultivated for *Maha* cultivation season is decided based on water in storage, consultations with farmers. Short-term, 3-6 months climate predictions needed

- In April, Decisions as to extent of rice cultivated for *Yala* cultivation season is decided based on water in storage, consultations of farmers and irrigation managers. Short-term, 3-6 months climate predictions needed

- Around January, Energy Managers need 3-9 months prediction to determine whether reservoir storage is sufficient to meet hydro-electricity demands till October rains.

Summary

We have already found:

- Evidence for vulnerability to climate variability and climate change
- Evidence of climate sensitivity of water supply, rice and hydro-electricity production.
- Significant predictability for in-situ variables in the *Mahaweli* river basin.
- Climate information is needed at the start of the planting season in September and March and during the start of the dry spells in January and June.
- Climate variability, climate change and land use change needs to be considered in analyses.
- Climate information needs are multifaceted and vary from one management situation to another.

Our work has provided a proof-of-concept that seasonal climate information can be profitably introduced for basin management in a typical tropical setting. Work is ongoing towards a comprehensive project.

Hydrological database

Our work relies on extensive hydrological data sets. We have compiled relevant data sets and have a richer record than in global data sets. The stream flow observation sites is shown in the maps below.

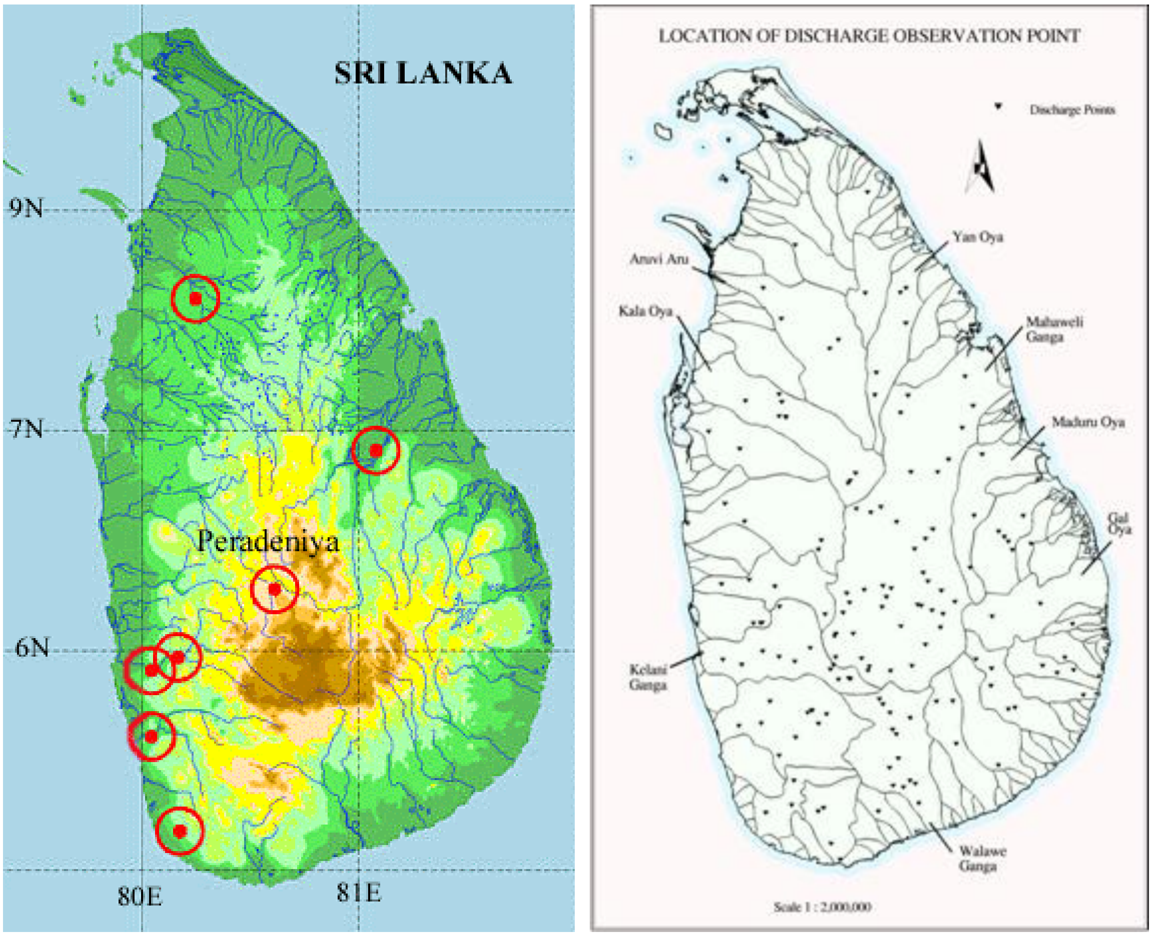


Figure: The stations for which stream flow records are available in global databases (left) and for which records are available locally (right).

Our data resources in hydrology are weaker than that in meteorology and we continue to build on it.

Catchment Modeling for WRM

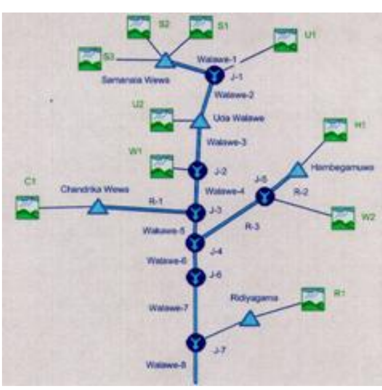
Stream flow forecasts can be used in conjunction with hydrological models for water resources decision making. Here, a hydrological model for the Walawe basin in the south is shown along with its layout and schematic of the simulation model. This model was used to construct reservoir operation rule curves that guide reservoir managers based on monitored stream flow and anticipated irrigation needs for the season ahead.

Walawe is indicated in pink.

Details of Walawe Basin

River Basin Characteristics

- 5 major reservoirs
- Two hydropower stations (3 and 30 MW)
- Primarily Agriculture
- Fed by Western and Eastern Slopes.

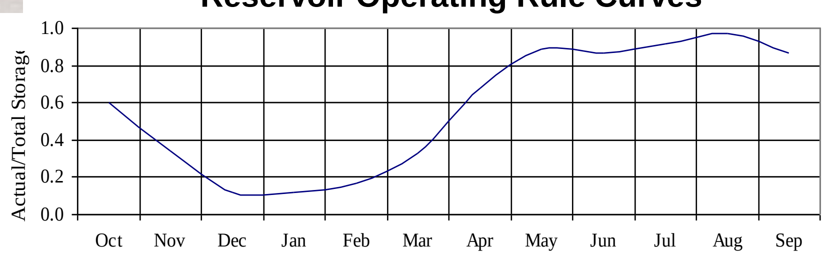


Schematic of Walawe Basin

Hydrological Modelling

We used historical hydro-meteorological data to assess the reliability of reservoir operating rule curves for Uda Walawe reservoir under different scenarios of cropping. The model may be used to test climate scenarios and predictions as well.

Reservoir Operating Rule Curves



- An example of a "Reservoir Operating Rule Curve" for selected hydro-climatic and agricultural demand distributions for the Uda Walawe reservoir is shown based on criterion of reliability.
- Reservoir operation rule curves may be generated conditional on stream flow and precipitation predictions.

Streamflow Prediction based on ENSO

The stream flow at Peradeniya on the Mahaweli River shows an ENSO influence from January to September.

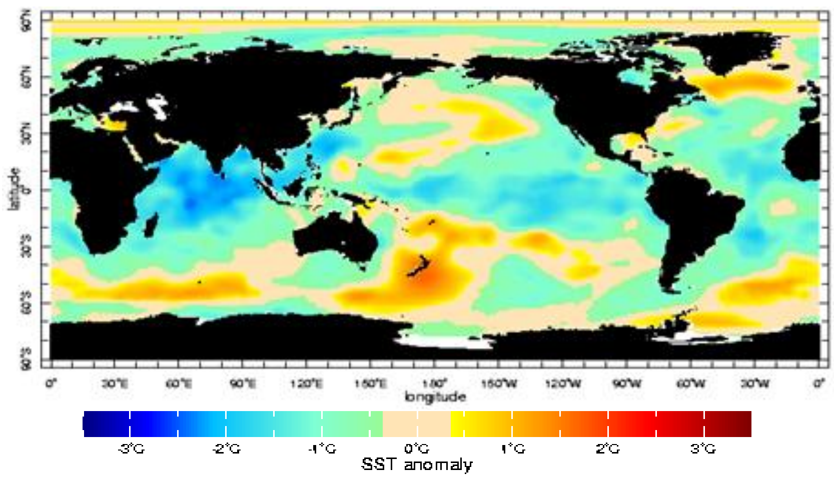


Figure: Correlation of Peradeniya stream flow from January to September with global SST. Note, significant correlation with western Indian Ocean and Eastern Pacific region (ENSO).

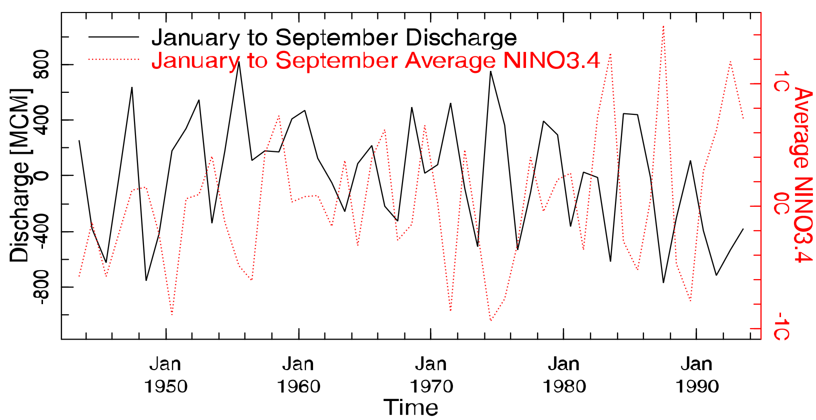


Figure: The January to September Discharge and concurrent ENSO index of NINO34 (SST in Eastern Pacific) show high anti-correlation.

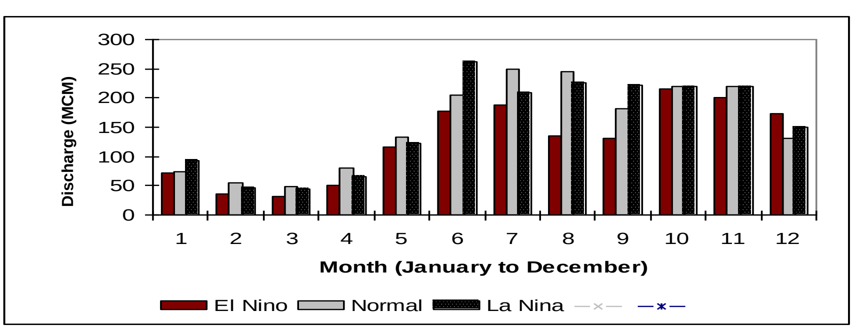


Figure: Mahaweli Discharge in El Niño, La Niña and Normal conditions from January to December. The figure shows a deficit of stream flow during El Niño periods from January until September and an increase by December. It also shows the converse pattern during La Niña periods except from January to April.

Seasonal Stream Flow Predictions

Stream flow Predictions

Stream flow at a specific site such as a reservoir, hydroelectric plant or water treatment plant intake is often the variable of direct interest to managers. Such on-site stream flow predictions may be derived from precipitation fields that are predicted by Global Climate Model's (GCM) after suitable downscaling and hydrological modeling. Where historical stream flow records are available, one may circumvent these steps by using the historical relationship between the global sea surface temperatures (SST) and stream flow. This approach works best when stream flow is aggregated into seasons during which similar climatic conditions prevail over the river basin. For each of these seasons, a sensitivity analysis of SST's and stream flow data can be conducted to identify the predictors of significance. Thereafter, multivariate techniques may be used to develop a prediction scheme that generates forecasts at the lead–time.

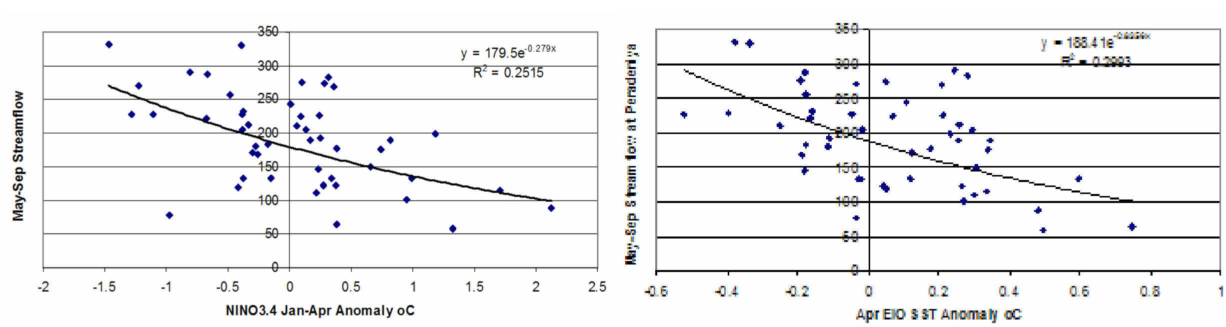


Figure: May-September stream flow is plotted against January to April NINO34 (Left) and Western Indian Ocean SST index (Left) for 1948-1993.

These scatter plots point to a significant correlation between the stream flow at Peradeniya and SST indices in previous months. These relationships were exploited to predict the seasonal stream flow from 1994 to 1999 below based on SST.

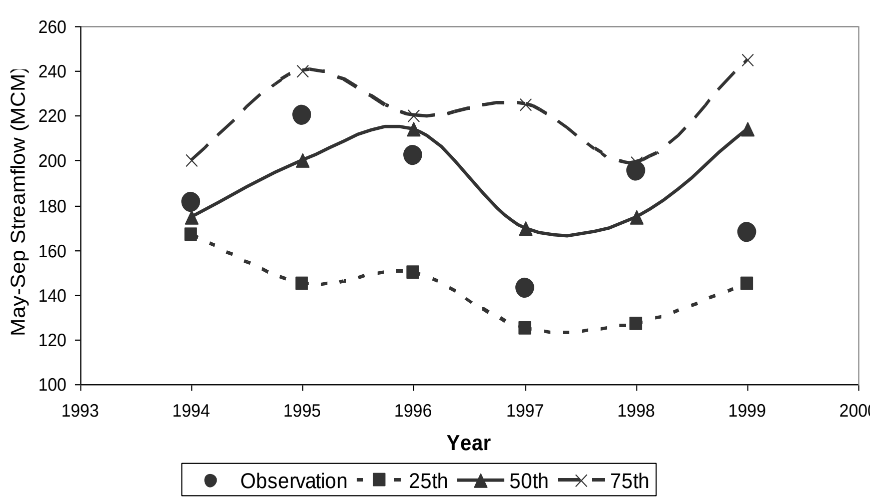
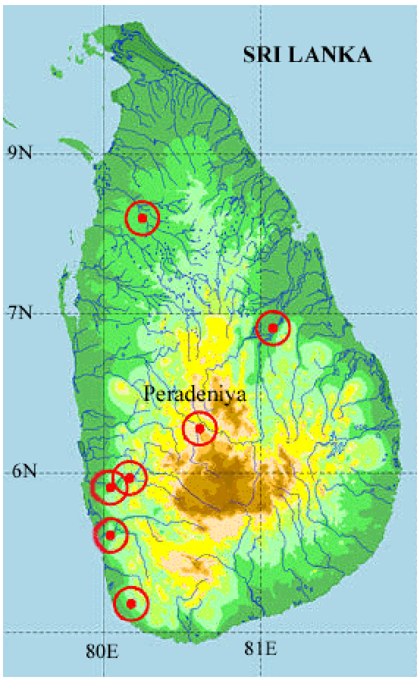


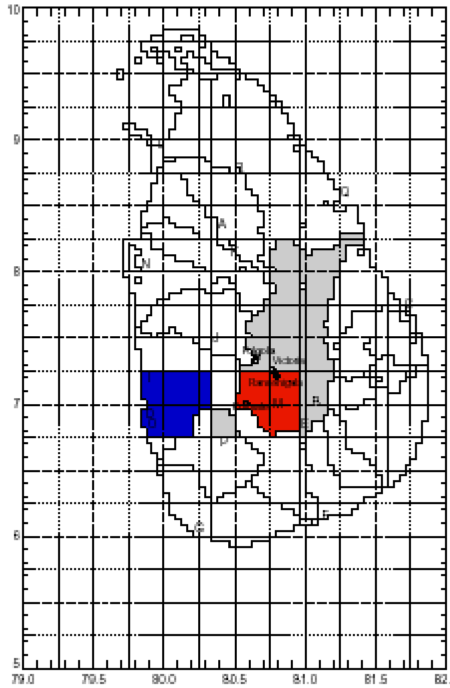
Figure: The May to September streamflow predicted within the 25th, 50th and 75th percentiles and the actual observations are shown.

Land Surface Modelling

Real-time information about land surface hydrologic features enters into a range of decision support settings where interventions to reduce the vulnerability of societies to climate risks are possible. One is information to support malaria early warning systems. Others include flood and land slides risk. Here we report on a land surface model to produce variables of interest such as stream flow, evaporation and soil moisture.



Map Left: Principal rivers in Sri Lanka. The background color is the topography which ranges up to 2500 meters. Some discharge stations are identified with Peradeniya labelled in the middle of the island.



Map Right: River Basins as represented in the Land Surface Model.

A high-resolution physically based land-surface model was driven by observed climate variations from the ECMWF re-analyses data which has been blended with a set of high-resolution gridded meteorological data for Sri Lanka. These computations were executed by Dr. Sarith Mahanama of the Global Modelling and Assimilation Office of NASA GSFC. The stream flow as simulated and observed at Peradeniya is shown below.

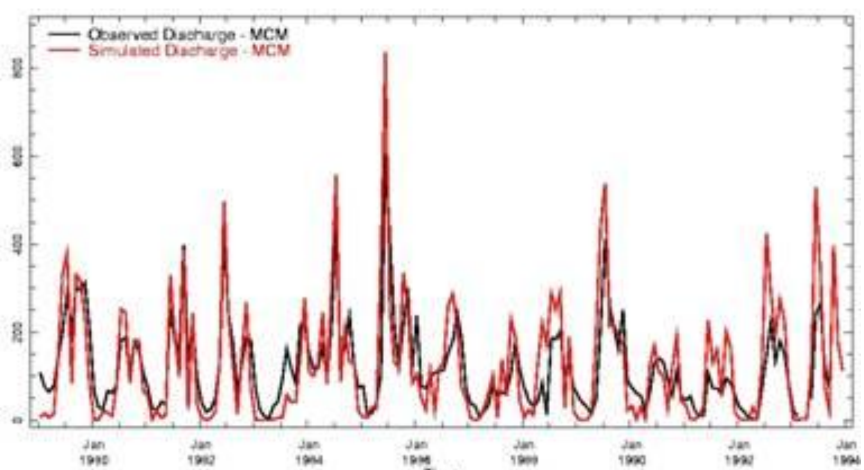


Figure Right: Observed and Simulated Discharge at Peradeniya. The simulation shows good fidelity to the observed records. The catchment model can generate soil moisture, evaporation and other hydrological properties.

Outputs

Publications

Papers

December 2005: Lareef Zubair and Janaki Chandimala, Epochal Changes in ENSO-Stream flow relations in Sri Lanka, in press, *Journal of Hydrometeorology*.
October 2005: Janaki Chandimala and Lareef Zubair, ENSO based Stream Flow and Rainfall Predictions for Water Resources Management in Sri Lanka, in revision, *Journal of Hydrology*.
Nov 2004: May 2003 disaster in Sri Lanka and Cyclone 01-B in the Bay of Bengal, *Natural Hazards*, 33: 303-318, 2004.
September 2003: Lareef Zubair, Sensitivity of Kelani Stream flow in Sri Lanka to ENSO, *Hydrological Processes*. 17 (12) 2439-2448.
January 2003: Lareef Zubair, ENSO influences on Mahaweli Stream flow in Sri Lanka, *International Journal of Climatology*. 23(1)91-102

Conference Proceedings

November 2004: Janaki Chandimala and Lareef Zubair, Predictability of Stream flow and Rainfall in the Kelani river basin in Sri Lanka using ENSO, *International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, United Nations University, Colombo, Sri Lanka
June 2003: Lareef Zubair, Ruvini Perera and Herath Mathrithillake, Using Climate Information for Mahaweli river basin management, *World Water and Environmental Resources Congress 2003*, Philadelphia.
October 2001: Seasonal stream flow predictions from sea surface temperatures: Application to Mahaweli river in Sri Lanka, *National Oceanic and Atmospheric Agency 26th Climate Diagnostics Workshop*, San Diego, California.
Nov 1999: Modelling of Irrigation Networks: Udawalawe in Sri Lanka, *Jubilee Congress of the Asian Institute for Technology*, Bangkok, Thailand, 1999, IV: 91-100, with R. Aloysius.

Feature Articles

Aug 2003: Lareef Zubair, What led to the May Flooding, *The Island*, Sri Lanka, August 23, 2003.
July 2002: Lareef Zubair, Questions for Climate Science from Mahaweli Water Managers, *Frontier Newsletter*, Japan

Reports

2005: Janaki Chandimala and Lareef Zubair, *FECT Technical Report-6*, Construction of rainfall indexes for the Kelani Catchment.

Presentations

January 2006: Advances in Climate Sciences for Mahaweli River Basin Management, *Head works Divisions, Mahaweli Authority*, Digana.
November 2005: Predictability of Climate around Sri Lanka and its Applications, *Global Modeling and Assimilation Office, National Aeronautical and Space Agency*, Greenbelt, Maryland.
November 2004: Climate Information for Mahaweli River Basin Management, *Head works Divisions, Mahaweli Authority*, Digana.
December 2003: Workshop on the Climate of Sri Lanka and Climate Applications for staff of the H*eadworks division of the Mahaweli Authority and the Central Engineering Consultancy Bureau* at Digana, Sri Lanka,
March 2003: Applications of Seasonal Climate Predictions, *National Water Resources Authority (Interim)*, Colombo.
January 2003: Climate Prediction for Water Resources Management in Sri Lanka, *Office of the Minister of Water Resources and Irrigation*, Colombo.
January 2003: Seasonal Climate Predictions and its Applications in Sri Lanka, *International Water Management Institute*, Colombo.
December 2002: Climate Predictions for Mahaweli River Basin Management, *Mahaweli Authority of Sri Lanka*, Colombo, Sri Lanka.
July 2002: Review of IRI-MASL projects and plans for the future, *Environment and Forestry Division, Mahaweli Authority of Sri Lanka*.
May 2002: Climate Change, Climate Variability and Water Resources, *School of Engineering, Tokyo University*, Japan.
May 2002: Climate Change, Climate Variability and Water Resources, *Frontier Research System for Global Change*, Yokohama, Japan.
October 2001: Seasonal stream flow predictions from sea surface temperatures, *26th Climate Diagnostics Workshop*, San Diego, CA
March 2001: Sri Lanka Water Resources Project, *International Scientific and Technical Advisory Committee of the International Research Institute*, Palisades, New York.
January 2001: IRI Water Resources Applications Project in Sri Lanka, *NOAA Office of Global Programs*, Silver Spring, Maryland.
August 2000: Climate Prediction for Water Resources Management, *International Water Management Institute*, Colombo, Sri Lanka.
August 2000: Climate and its Prediction in the Mahaweli Basin, *Environment and Forest Conservation Division, Mahaweli Authority of Sri Lanka*, Sri Lanka.
August 2000: Climate Prediction for the Mahaweli, *Water Management Secretariat, Mahaweli Authority of Sri Lanka*, Sri Lanka.
August 2000: Climate Prediction for Water Management, *Department of Irrigation*, Colombo, Sri Lanka.

Climate and Agriculture

Farmers and plantation managers are reliant on weather and climate patterns. The specific ways in which such information is needed by the farmers has to be investigated on a case by case basis. Here, we report on the climate impacts on rice and coconut production and the prediction of crop production.

(a) Rice
(b) Tea
(c) Coconut

Projects Status Report

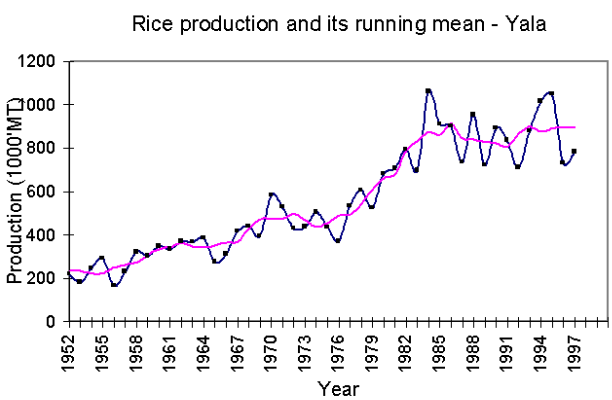
Activity	Objectives	Partners	Status	Next Steps
Climate and Rice Production in Sri Lanka	Identify climatic relationships with and rice production to assist with planning and forecasting	S. Somasundera, University of Peradeniya, Sri Lanka, Ruvini Perera, IRI	A relationship between the El Niño Southern Oscillation and Indian ocean Dipole phenomenon and rice production was established.	Publication of relationship with Indian Ocean Dipole and Rice Production.
Adaptation and Impact Assessment to Climate Change of Plantation Agriculture in Sri Lanka (START funded, 2002-2004)	(1) Develop Capacity for Climate Change Analysis (2) Undertake Impact Studies (3) Undertake Vulnerability Studies (4) Propose Adaptation Measures	Sri Lanka Department of Meteorology (DoM), Tea Research Institute (TRI), Coconut Research Institute (CRI) and University of Peradeniya.	Quality Control of Climate Data Completed. Mapping of Sri Lanka Climatology Completed. Climate Change Projections based on trends completed, Crop-Climate Studies in Coconut Sector Undertaken with Dr. Sarath Peiris (CRI) on his visit to IRI and provisionally accepted for publication. Final report completed	Publication of Papers.

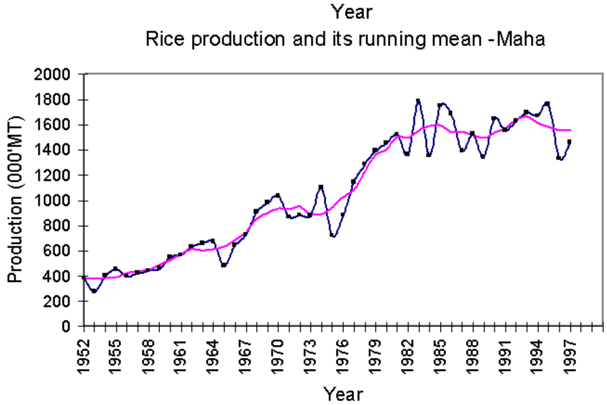
Rice

Rice is the staple food in Sri Lanka and it is cultivated by farmers on a small-scale in the rural regions. Rice production is acutely dependent on rainfall. The principal cultivation season, known as "Maha", is from October to March. During this season, there is usually enough water to sustain the cultivation of all rice fields. The subsidiary cultivation season, known as "Yala", is from April to September and usually there is only enough water for cultivating half the land extent.

There has been a steady increase in rice production in Sri Lanka from 1940 to 1990. This rise has been attributed to increased area under cultivation, increased irrigation, improved seed varieties, increased fertilizer application and higher purchase prices for rice. However, rainfall variations affects the inter-annual variability of rice production as distinguished from its long-term trends. El Niño and La Niña are states of unusual warm and cool tropical eastern Pacific ocean surfaces respectively.

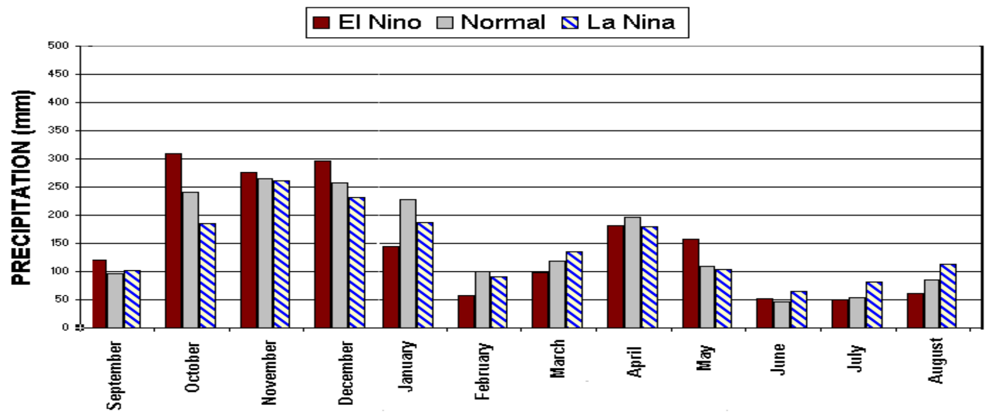
Two decades ago, it was discovered that the rainfall of Sri Lanka is affected by ENSO. Our work has confirmed that link and also uncovered a link between ENSO, rainfall and the production of rice. This provides a basis for using ENSO based predictions for agricultural policy formulation and management.



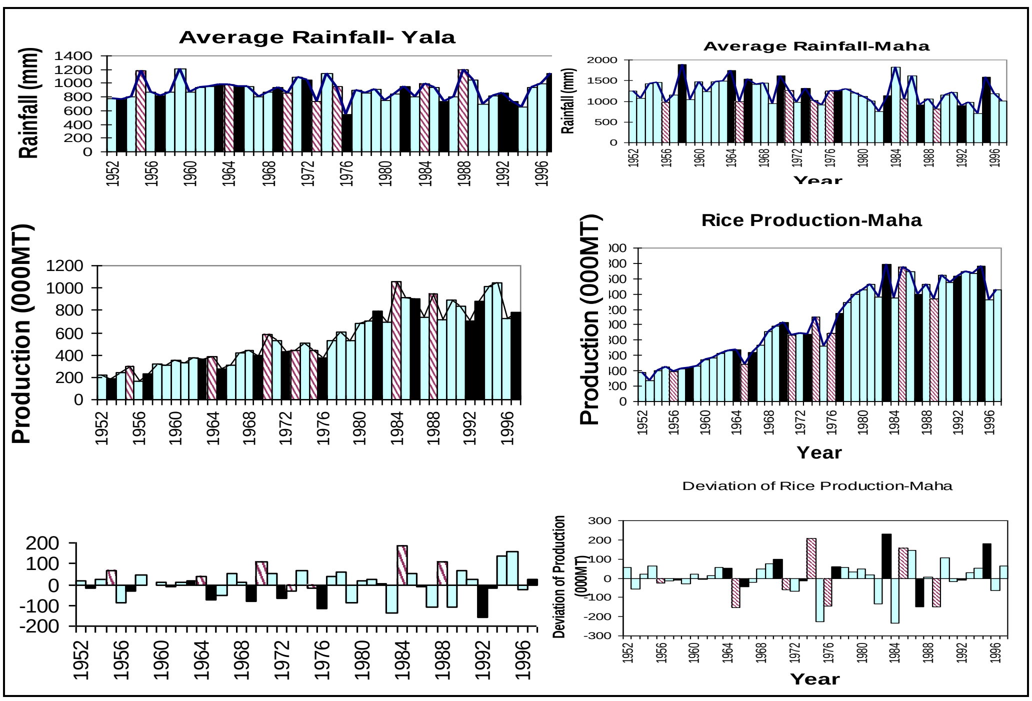


Graph – National Rice Production for the Yala (top) and Maha (bottom) seasons. The pink line shows the running mean

Map: Areas under rice cultivation is shaded in yellow



Graph: The average rainfall climatology during El Niño, Normal and La Niña conditions is shown above. It shows that the rainfall during October to December increases during El Niño but that it declines from January to April and from July to August.



Graphs: El Niño seasons are shaded solid and La Niña seasons are hatched.
Top panel: The average rainfall in rice producing areas in Sri Lanka
Middle panel: The rice production during each season.
Bottom panel: The rice production anomaly for each season.

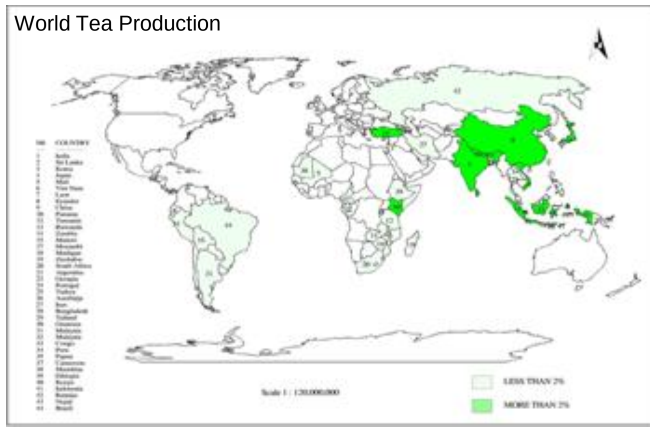
Summary

During 1952 - 1997, the Maha rainfall and rice production has dropped 10 out of the 15 years with El Niño and in 7 out of the 10 years with La Niña conditions. During the same period, the Yala rainfall and rice production have dropped in 8 and 10 years respectively out of 14 with El Niño and 6 years out of 8 with La Niña.

Tea Plantations

Tea in derives its distinctive flavours and reputation for quality from its particular climatic history during plant growth. Climatic anomalies thus have a direct bearing on tea. Over a million people depend on plantations for their livelihoods in Sri Lanka. Any decline in production or quality will have a direct impact on both livelihoods and on the economy. Tea and rubber accounted for 50% of national exports in 1986 – a fraction that declined to about 20% in 2002.

Map: Regions where tea is cultivated in Sri Lanka is shaded in green.



Map: The distribution of tea production in the world. Tea production is distributed in the Asia tropical and temperate regions with plantations established in such as Sri Lanka, Kenya and Tanzania in the last two centuries.

World Tea Production in 2001

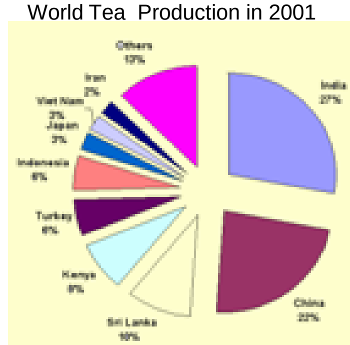


Figure: Pie chart of the major producers of tea in the world. Although Sri Lanka produces less tea than India and China, it is often the exporter of the largest volume of tea.

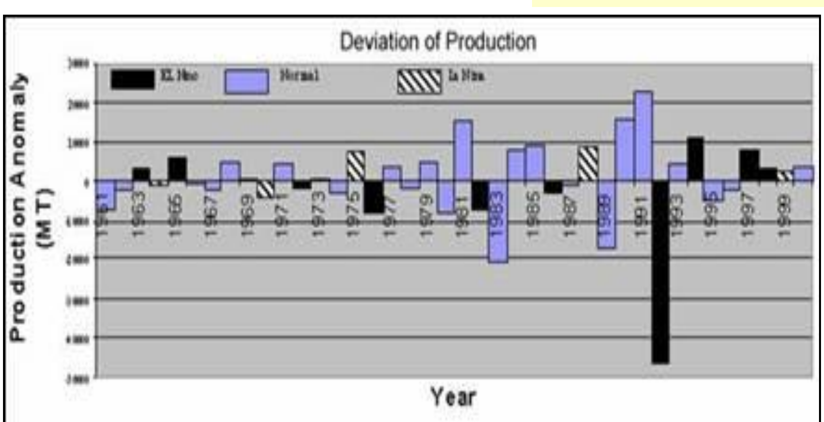
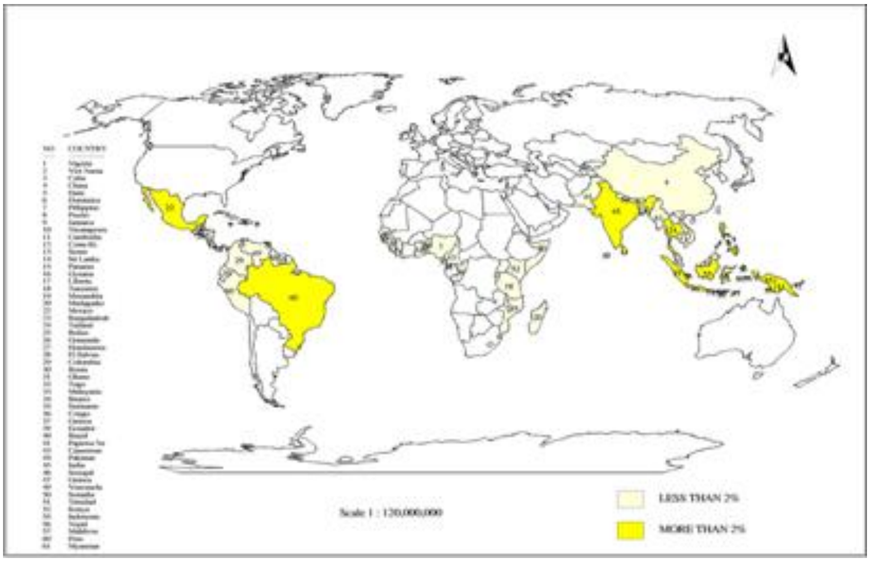


Figure: The inter-annual variation of tea production about the long-term mean. The years where the El Niño phase dominated are shown as black and those dominated by La Niña as hatched. There is no clear El Niño based signal at an annual scale

Coconut Plantations

Coconut is a perennial crop which has a prolonged reproductive phase of 44 months. Weather and climate affects all stages of the long development cycle extending to 44 months and thus there is likely to be extended predictability based on climate variability.



Map: Coconut is distributed in the tropical regions with large plantations in Indonesia, Philippines, India and Sri Lanka.

World Coconut Production in 2001

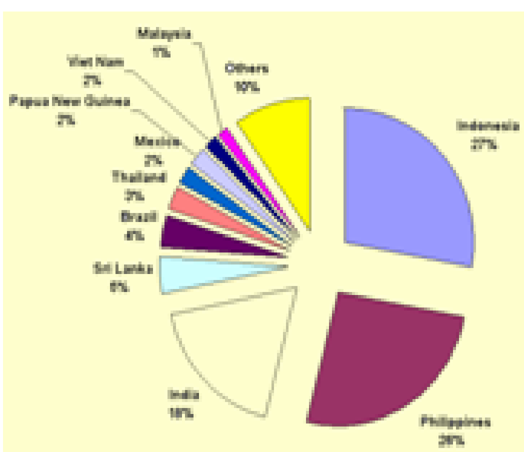


Figure : Pie chart of the major producers of coconut in the world. The global annual production is around 52 billion nuts. Sri Lanka ranks fourth in terms of the contribution to the world coconut production (6%) and land extent under coconut.

Map: Regions where coconut is cultivated are shaded in yellow. Coconut is principally grown in the lowlands.

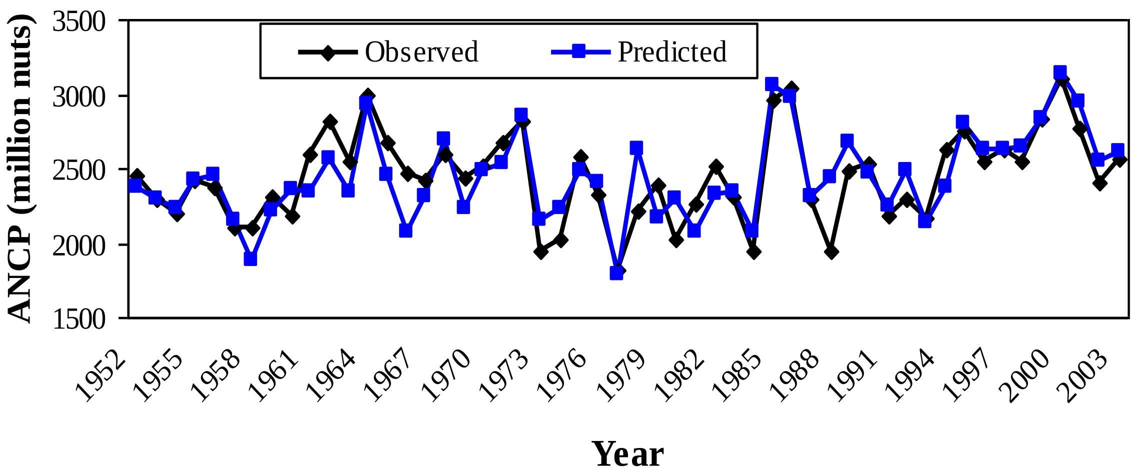
Project Progress

We have published two journal and two conference papers. We have also written four technical reports. Articles have been published in several newspapers, magazines and internet. We have presented our work at Universities, CRI, TRI and the Mahaweli Authority.

Dr. Sarath Peiris visited the International Research Institute for climate prediction for three weeks and Dr. Neil Fernando for a week. Dr. Peiris's visit there led to a research paper on crop-climate interaction in collaboration with Dr. James Hansen. Dr. Neil Fernando visit led to a draft on the valuation of climate impacts.

Prediction of Annual National Coconut Production based on Climate

Accurate forecasting of Annual National Coconut Production (ANCP) is important for national agricultural planning and negotiating forward contracts with foreign buyers. Climate and the long term trends (attributed to "technology") are major factors that determine ANCP. The climate effect was estimated by regressing production data that had been de-trended to remove the "technology effects" with quarterly rainfall in the year prior to harvest. The technology effect was estimated from the historical log-linear trends. A regression model that integrates both climate and technology effects developed to predict ANCP with high fidelity.



Graph: The predicted and observed annual coconut production based on a model that accounts for technological change and seasonal climate.

Outputs

Publications

December 2005: Sarath Peiris, James Hansen and Lareef Zubair, Use of Seasonal Climate Information to Predict Coconut Production in Sri Lanka, *International Journal of Climatology*, provisionally accepted.
February 2002: ENSO influences on Rice Production in Sri Lanka, *International Journal of Climatology*. 22 (2):249-260
July 2004: Empowering the Vulnerable, *TIEMPO*, 52:3-6, University of East Anglia, UK, Also, highlighted in *SciDev.net* as "Communities facing climate change need local science."
Apr 2004: Towards Developing Weather and Climate Prediction for Sri Lanka, *Journal of the Institute of Engineers*, Sri Lanka, XXXVII, 2:53-58.
September 2003: Saving Weather Data , *TIEMPO*, 49:16-22, University of East Anglia, UK.
May 2002: Development of Meteorology in Sri Lanka, *Journal of the Institution of Engineers*, Sri Lanka. 15(2):14-18.

Conference Papers

December 2004: Sarath Peiris, Lareef Zubair and C.H. Piyasiri, Forecasting National Coconut Production - A Novel Approach, *International Sri Lankan Statistical Conference*, Kandy, Sri Lanka, 28 – 30 December 2004.
November 2004: Lareef Zubair with Upamala Tennakoon and Manjula Siriwardhana, Climate Change Assessments for Sri Lanka from Quality Evaluated Data, *International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, United Nations University, Colombo, Sri Lanka.
December 2002: with Heli Bulathsinhala, Quality Evaluation of Mean Historical Temperature Data in Sri Lanka, *Sri Lanka Association for the Advancement of Science, 58th Annual Sessions*, University of Colombo, Colombo, Sri Lanka.

Feature Article

May 2004: Lareef Zubair, Was the bumper rice harvest for 2002/03 Maha due to El Nino? *Daily Mirror*, Sri Lanka.

Reports

June 2005: Lareef Zubair (PI), Kusalika Ariyaratne, Irugal Bandara, Heli Bulathsinhala, Janaki Chandimala, M.R.A. Siraj, Manjula Siriwardhana, Upamala Tennakoon and Zeenas Yahiya, Current Climate and Climate Change Assessments for Coconut and Tea Plantations in Sri Lanka, *AIACC/FECT report*, Submitted to IRI

Climate and Environment

We report on work in assessing the impact of climate on human-elephant-conflict in response to requests from the Environment and Forest Conservation Division of the Mahaweli Authority of Sri Lanka. We have also characterized NDVI data sets and their links to climate. We hope to collaborate on the impacts of weather and climate on rare species which are sensitive to drought.

a) Human Elephant Conflict
b) Remotely Sensed Vegetation Analysis

Projects Status Report

Activity	Objectives	Partners	Status	Next Steps
Climate and Habitat Interactions Affecting the Conservation and Management of Asian Elephants in Southeast Sri Lanka (Funded by IRI, 2002-2003)	Study the relationships between climate and elephant ecology, Develop geospatial databases, Assess long-term scenarios of the responses of habitat and elephant ecology to climate.	Center for International Earth Science Information Networks (CIESIN), Center for Environmental Research and Conservation (CERC), Mahaweli Authority of Sri Lanka (MASL).	Geospatial Databases have been developed, climatological mapping has been undertaken, statistical downscaling methodologies for downscaling from Global Climate Models have been developed, Project Report completed by May 2004.	Papers on downscaling to be submitted. Paper on climate-HEC relationship to be submitted.
Constructing Vegetation Climatologies (Funded by Earth Institute Internship and IRI) 2005.	(a) Assess utility of NDVI indices (b) characterize climatologies of NDVI and relationship with rainfall, temperature and ENSO	International Research Institute for Climate and Society (IRI) and the Earth Institute at Columbia University (EI)	NDVI data sets archived in IRI data library for Sri Lanka, climatologies constructed, exploratory data analysis shows utility, relationship between NDVI and climate indices documented.	Relationship with ENSO to be completed. Paper to be published.

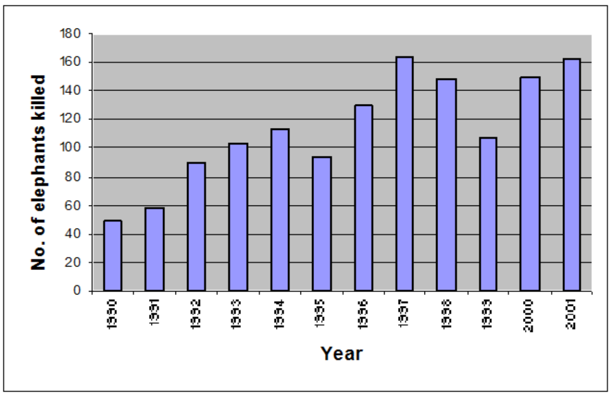
Human-Elephant Conflict

Global populations of the endangered Asian elephant (*Elephas maximus*) face an uncertain future due, in part, to their populations having been relegated to small and relatively isolated pockets throughout their historic range in southern and southeastern Asia. In Sri Lanka, their numbers have dwindled from 8-20,000 to some 3,000-4,000 individuals. Resource competition, especially over two of the most important climatically influenced variables in the habitat, vegetation and water, is driving much of the conflict currently engulfing humans and elephants. Understanding how interactions between climate and habitat can affect elephant ecology will be important for the long-term conservation and management of the species. As extreme conditions such as droughts repeat, wildlife becomes increasingly vulnerable to climate variability and climate change.

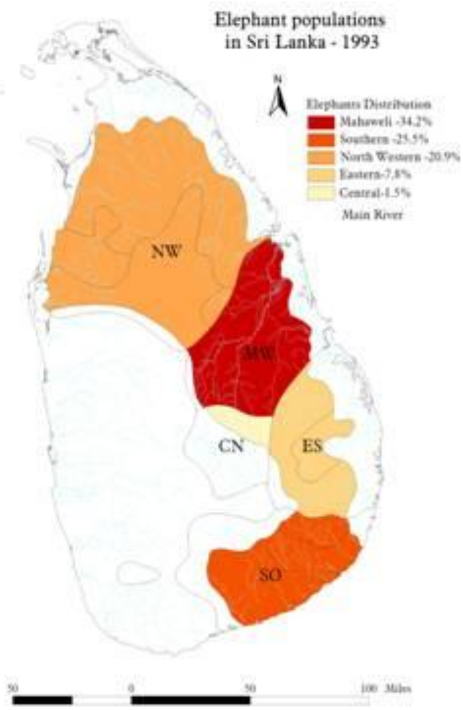
In our study, we have developed a database of fine-scale indices needed for wildlife management studies. These include a database of climatic parameters, hydrological parameters, vegetation indices, and drought indices.

Map: Composition of Elephants in 1990

Human Elephant conflict is at the heart of environmental conflict, regulation and protection in rural areas. Climate affects water availability, vegetation, agricultural practices and irrigation. All of these factors could under conditions (such as drought, certain patterns of irrigation or agriculture) lead to competition and conflict.



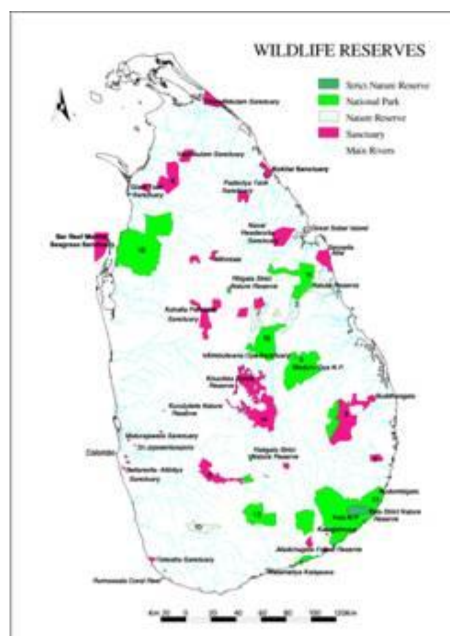
Graph: No. of elephants killed from 1990-2001 - Sri Lanka Department of Wildlife Conservation



Map: Elephant population in Sri Lanka

The sustainable coexistence of humans and elephants depends on:

- The maintenance of elephant population in numbers that ensure their genetic viability and resilience to occasional shocks
- The preservation of the habitat of elephants including the proper management of dual-use or non-conservation areas.
- The development of human societies in the peripheral areas so as to support their coexistence with the elephant populations and the minimization of human-elephant conflict.
- The management of longer term trends in demographics, environment, climate and land use.



Map: Wildlife reserves in Sri Lanka

Project Progress

We found that (a) the seasonality of elephant deaths peaked at the end of the dry season in April and August and declined in the wet seasons (b) both the long-term trends and inter-annual trends showed that there were greater elephant deaths during years which had dry periods and (c) that while climate was a significant factor in elephant deaths, other factors remain important too.

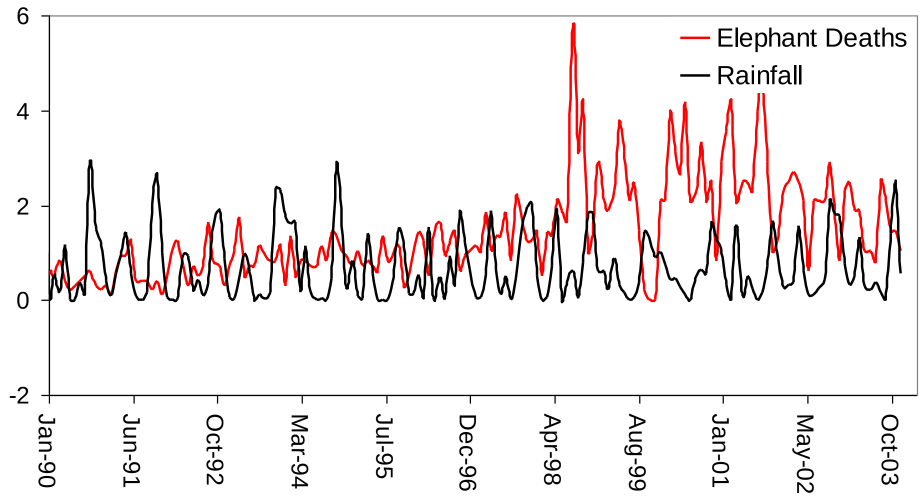


Figure: Monthly data on aggregate national elephant deaths and rainfall for the Eastern Region from 1990-2003.

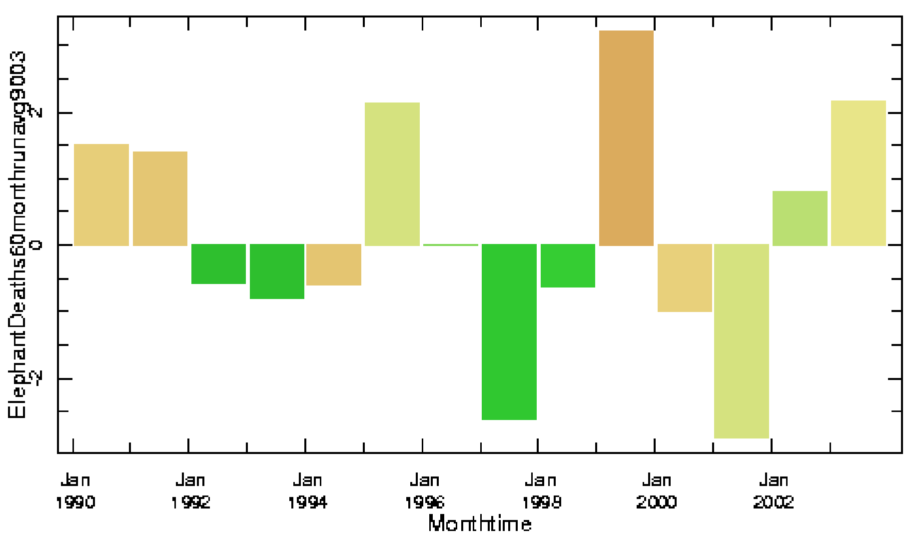


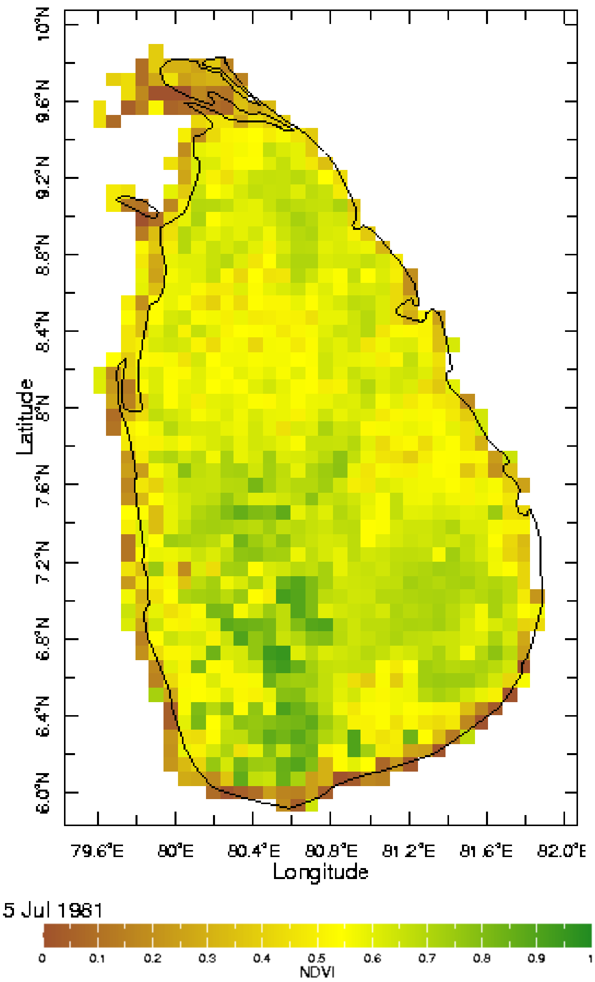
Figure: The year-to-year departures of elephant deaths from the long-term trend is shown as a bar chart. Each bar is colored by the January to July rainfall. This figure shows that during years that were dry elephant deaths increased in most instances. Therefore mitigatory options and vigilance should be taken when unseasonably dry conditions are anticipated from January to August.

Remotely Sensed Vegetation (NDVI)

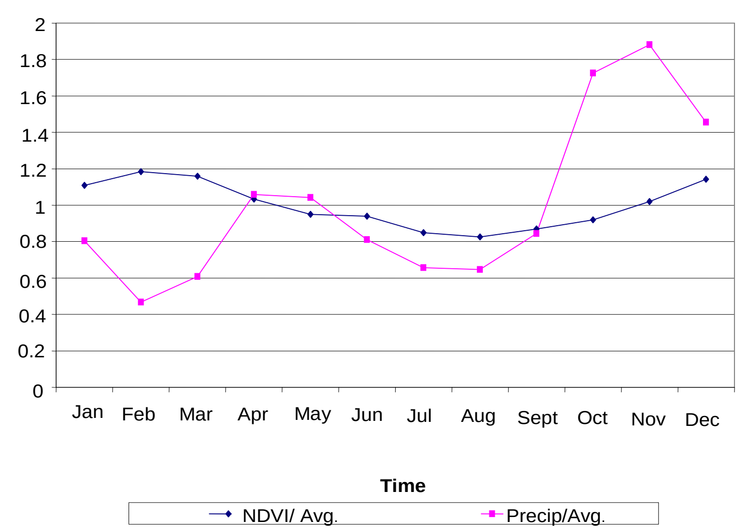
Remotely sensed vegetation indices have become available in the last 20 years providing additional data for analysis in such areas as human-elephant-conflict, agriculture and river basin management.

We have characterized the NDVI (Normalized Difference Vegetation Index) data sets from 1981 to 2003.

In general, the peak vegetation is from December to March and the vegetation loses intensity thereafter. The higher elevations lose their lush greenness first. However, the eastern hill slopes of the island retain lushness right through the year.



Map: Top right is an example of the NDVI data that was available for the first half of July 1981.



Bottom Left: Is a figure showing the average monthly rainfall and NDVI over the entirety of Sri Lanka of the Correlation between NDVI and

Outputs

Presentations

December 2005: Lareef Zubair, Presentation to *Centre for Research and Conservation*, Peradeniya, Sri Lanka.
December 2004: Lareef Zubair, Presentation to the *Environment and Forest Conservation Division of the Sri Lanka Mahaweli Authority* (in Sinhala), Polgolla.
November 2004: Lareef Zubair and Zeenas Yahiya, Personal presentation to Director (P. Kariyawasam) and Sociologist (Hendawitharana), *Sri Lanka Department of Wildlife Conservation*, Colombo 7.
October 2004: Lareef Zubair, Climate and Endangered: Humans and Elephants in Sri Lanka, *Open House, Lamont Doherty Earth Observatory*, Palisades.
June 2004: Prithiviraj Fernando, Center for Environmental Conservation and Research, "Elephant Management in Sri Lanka : A New Science Based Strategy", *IRI,* Palisades.

Conference Proceedings

December 2004: Lareef Zubair, Joshua Qian, Neil Ward, Ousmane Ndiaye, Janaki Chandimala, Ruvini Perera, Vidhura Ralapanawe and Benno Blumenthal, Complementary Dynamical and Statistical Downscaling from a GCM: Maha rainfall over Sri Lanka, *AGU Fall Meeting*, San Francisco.
November 2004: with Benno Blumenthal, Janaki Chandimala, Ousmane Ndiaye, Ruvini Perera, Vidhura Ralapanawe and Neil Ward, Downscaling of Sri Lanka's Maha Rainfall from a GCM, *International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, United Nations University, Colombo, Sri Lanka.

Reports

Lareef Zubair, Benno Blumenthal, Ousmane Ndiaye, Ruvini Perera, Neil Ward, Janaki Chandimala, Vidhura Ralapanawe, Upamala Tennakoon, M.R.A. Siraj, Zeenas Yahiya, H. Manthrithillake, W.L. Hendawitharna, Evaluation of Climate and Habitat Interactions Affecting the conservation and management of Asian Elephants in Southeast Sri Lanka, *Submitted to IRI*, March 2005.

Stacey Hirsh, Characterization of NDVI data over Sri Lanka and its relationship with climate, in draft form, 2005.

Climate and Health

Human health is intimately related to climate as described by Hippocrates (400B.C) in his advice to physicians,

"For knowing the changes of the seasons, the risings and settings of the stars, how each of them takes place, he will be able to know beforehand what sort of a year is coming. Having made these investigations, he will have full knowledge of each particular case. He must succeed in securing health, and be triumphant in the practice of his art. And if it shall be thought that these things belong rather to meteorology, it will be admitted, on second thoughts, that astronomy contributes not a little, but a very great deal, indeed, to medicine."

We are undertaking climate impact analysis on dengue and malaria in Sri Lanka with a view to develop early warning systems.

(a) Dengue
(b) Malaria

Projects Status Report

Activity	Objectives	Partners	Status	Next Steps
Malaria Early Warning Project (Funded by NOAA/NSF/ NASA/EPRI Joint Call on Climate and Health 2003-todate)	Establish relations between climate and malaria and develop malaria early warning system for the Uva Province in Sri Lanka.	International Water Management Institute, LDEO Climate Group, Anti-Malaria Campaign of Sri Lanka (AMC), NASA GMAO	Data collection substantially completed. Downscaling of work completed for main rainy seasons, physically based hydrology model implemented over project area, remote sensing work undertaken, preliminary climate-malaria linkages have been assessed.	Develop environment based malaria risk prediction methods, integrate the models into an early warning system.
Climate and Hydrological Impacts on Dengue Fever.	Establish relations between climate and dengue for Sri Lanka.	Marianne Hopp, University of Toronto, Aravinda de Silva, University of North Carolina	Data collection at aggregate level completed. Analysis underway. Data to be collected at various sub-national levels.	Solicit a formal project on Dengue Risk.

Dengue

Dengue is becoming an increasingly important public health hazard in Sri Lanka. Unlike malaria, dengue is prevalent mostly in the urban areas. 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 has emerged in other cities and suburbs.

A study on the link between climate and dengue in Sri Lanka was 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 Hopp. Some of the preliminary analysis shows a strong seasonality of dengue incidence with the outbreaks being more prevalent during the boreal summer. The seasonality of dengue transmission differs from malaria which is a spring and fall phenomenon.

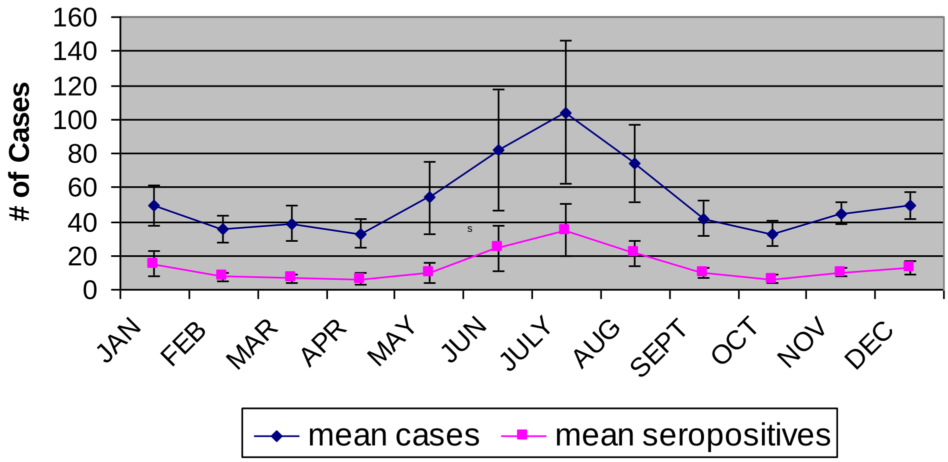


Figure Above: Monthly mean of 20 years of incidence data in Colombo.

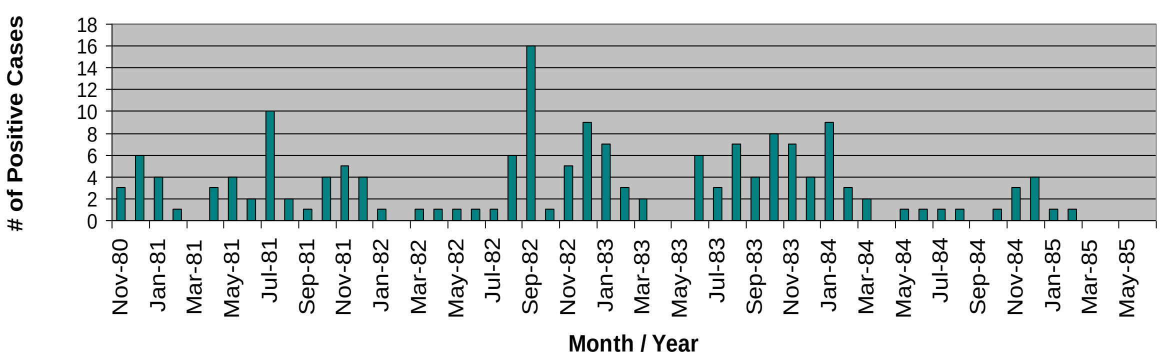


Figure Above: Time series of seropositives in Colombo as recorded at the MRI.

Summary

This analysis has already shown a seasonality with a June - August, an inter-annual relationship with seasonal climate. Work is ongoing to consolidate and extend this work.

Malaria

Malaria is endemic in 101 countries and about 40% of the world's population is at risk. In 1998, there were 273 million cases and 1.1 million deaths worldwide. In WHO's Southeast Asia region (which includes Sri Lanka), the case load was 16 million, with 73,000 deaths. Sri Lanka spends approximately 60% of its public health budget on malaria control. Malaria incidence in Sri Lanka has increased during the past 7 years. Plasmodium falciparum, which historically has been of low prevalence in Sri Lanka, has increased from 5% to about 25% of cases over the past decade and is increasingly resistant to the main anti-malarial drug, chloroquine. With an incidence rate of almost 12 per 1000 population Sri Lanka presently ranks as one of the most severely affected countries in Asia.

Sri Lanka has a history of malaria control dating to the 1920's, but was struggling until 2000 to contain the disease because of population increase, large-scale human settlement in disease-endemic areas, rapid agro-ecological change, and altered patterns of population mobility. Malaria in Sri Lanka is unstable and fluctuates in intensity both spatially and temporally. Thus resources have to be spread to cover all potential risk areas, regardless of whether an outbreak will occur or not at a given point in time. 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 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. Sri Lanka has operated very effective malaria control in the past, however it has also suffered several major epidemics which have been triggered by climatic and hydrological anomalies. Recent evidence suggests that ENSO-associated climate variability influences vector borne diseases such as malaria. However, studies at finer temporal and spatial resolutions are needed to establish the mechanisms by which ENSO and other causes of climate variability may influence the transmission of malaria.

Malaria Seasonality

Disease incidence is related to the rainfall seasonality. Peak months of incidence are May to June and November to January.

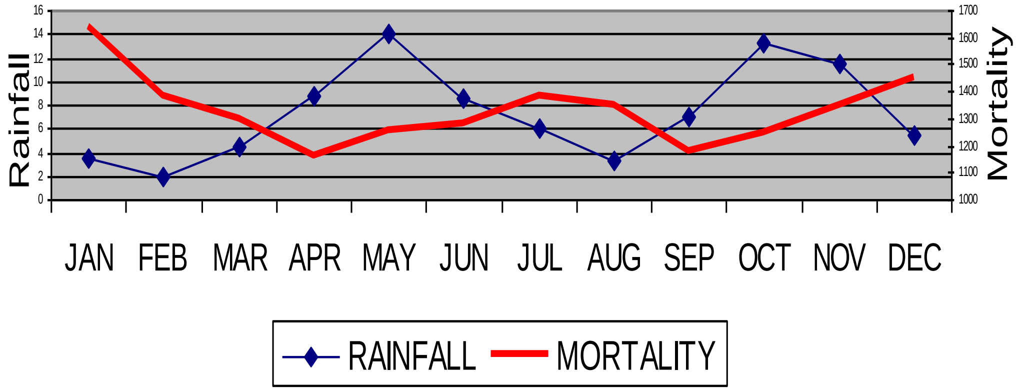


Figure Above: Mortality (red) and rainfall (blue) for Colombo district for 28 and 24 years respectively prior to 1934.

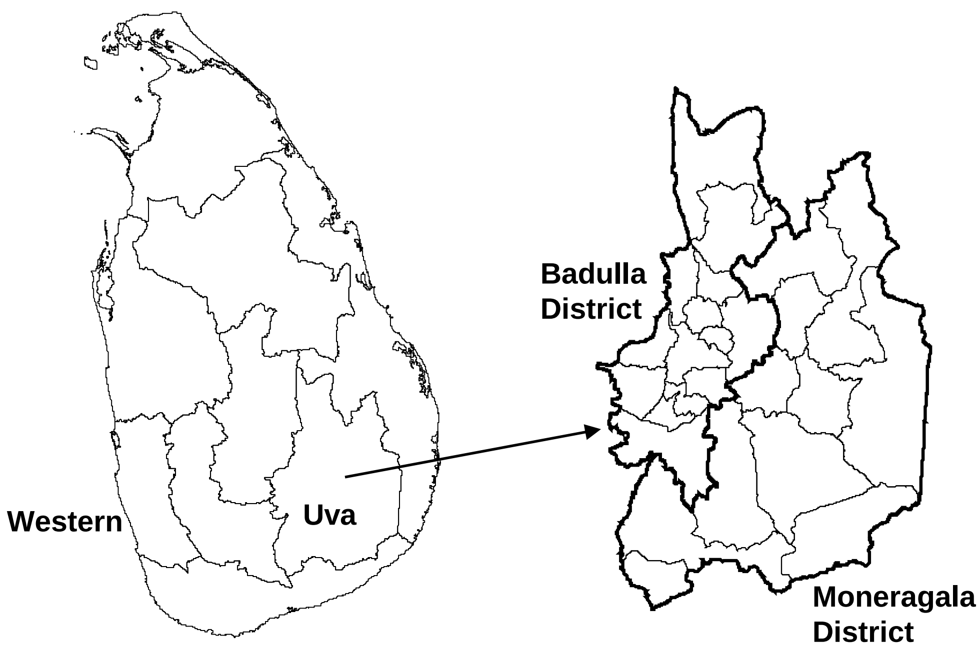
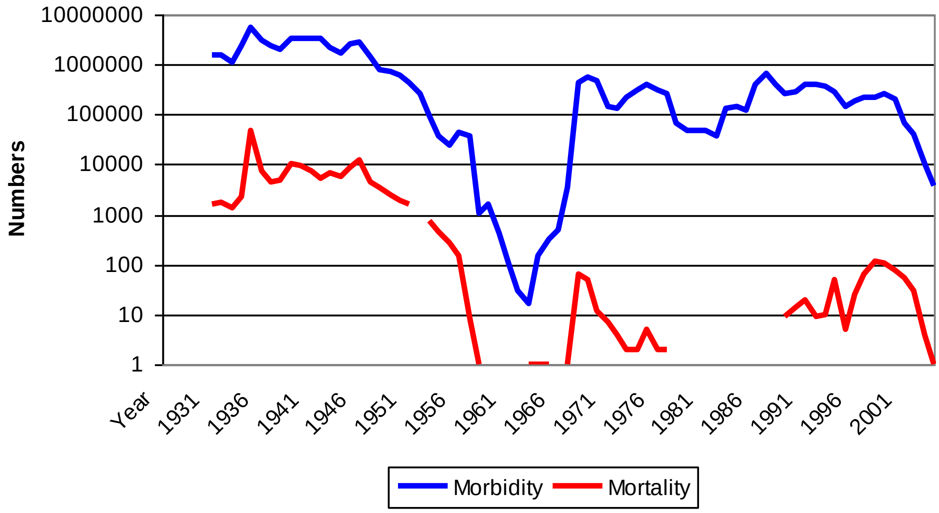


Figure: Sri Lanka and blow up of theUva Province.

Project Goals

- Evaluate micro scale interaction between climate and malaria transmission in Uva,
- Evaluate macro scale relationships between climate and malaria cases in Sri Lanka
- Develop models to forecast malaria risk
- Produce malaria risk maps
- Test the effectiveness of these maps at a pilot scale

We report here on macro scale studies of epidemics and climate links.



Graph: Annual island-wide morbidity and mortality due to Malaria from 1931 to 2002.

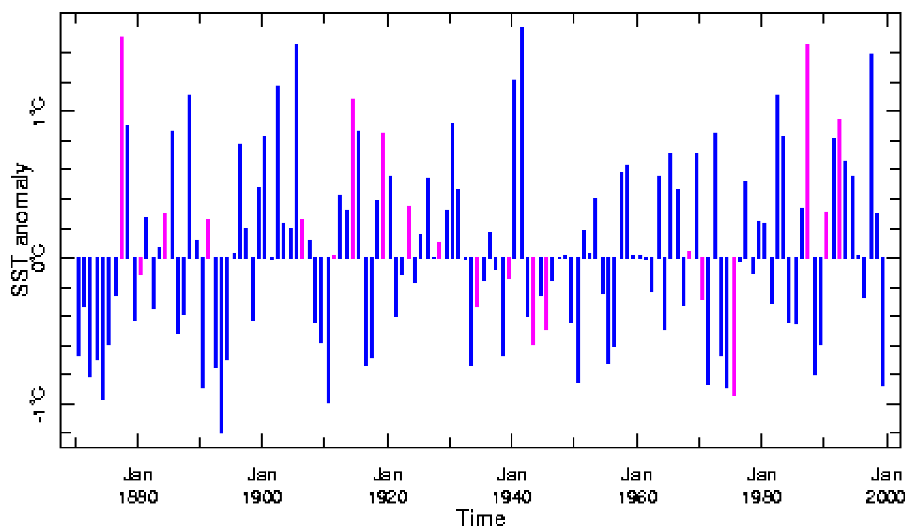


Figure: Epidemic years are identified in red on a time series of annual NINO34 which is an index of ENSO. NINO34 values above 0.4 may be taken as El Niño events. Even when NINO is lower, it could have been an El Nino for part of the year. After 1945, the relationship between ENSO and climate breaks down. The years in which epidemics occurred are marked in red. Previous work had suggested a strong link between malaria epidemics in Sri Lanka and El Niño events from 1880 to 1945. This result was replicated. However, a more careful analysis of the period when each El Niño events prevailed leads to a weaker result.

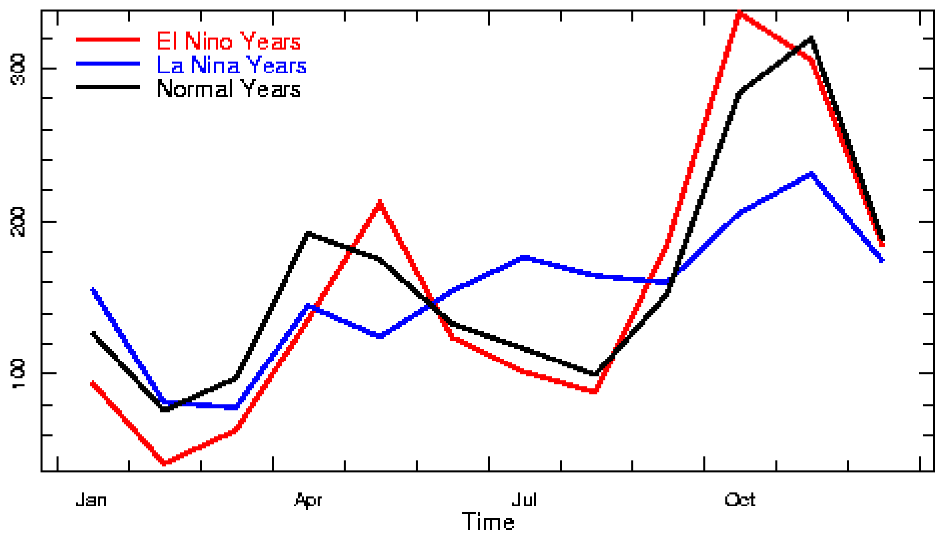


Figure: Monthly average rainfall in Sri Lanka from 1986 to 2000 during all years, during El Niño years and during La Niña years.

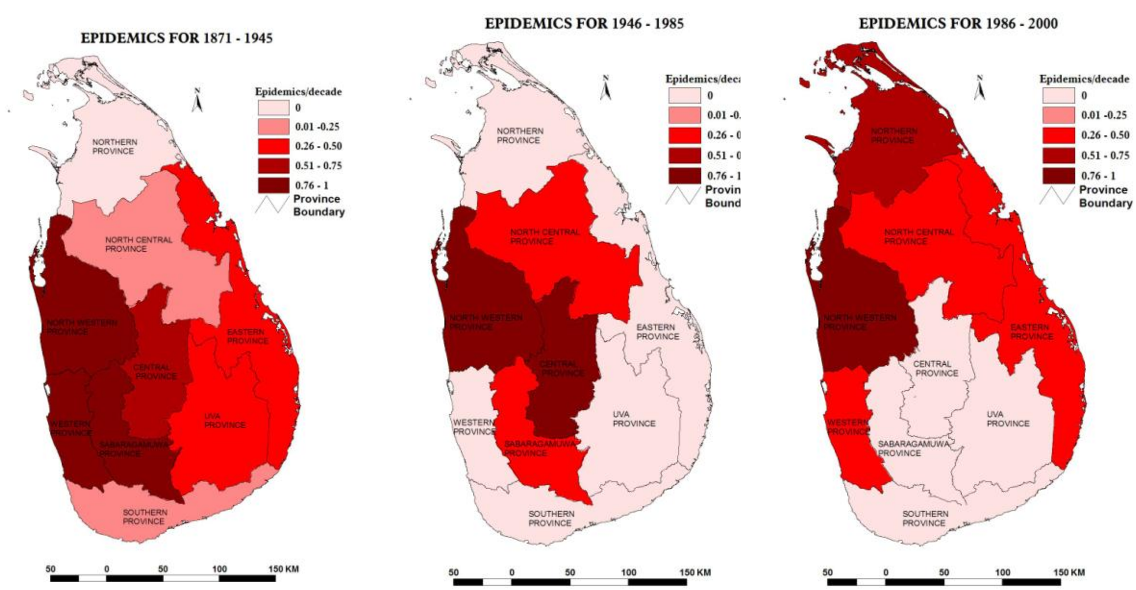


Figure: The relative spatial frequency of epidemics in three epochs (from L-R 1871-1945, 1946-1986, 1986-2000) period. The prevalence of epidemics has shifted from the Western and Sabaragamuwa Provinces to North-East. The relationship between malaria epidemics and El Niño which had broken down from 1946 to 1986 re-emerged after 1986.

Outputs

Publications

Journal Papers

2006: Lareef Zubair and C.F. Ropelewski, The strengthening influence of ENSO on North East Monsoon rainfall over Sri Lanka and Southern India, *Journal of Climate.19(8):1567-1575.*
2006: Lareef Zubair and Janaki Chandimala, in press, *Journal of Hydrometeorology*, Epochal Changes in ENSO-stream flow relationships in Sri Lanka.
2004: Lareef Zubair (2004a), Empowering the Vulnerable, *TIEMPO*, University of East Anglia, Volume 52. (developed from the presentation at the Climate and Health Meeting in the Maldives).

Papers under Review

2005: Janaki Chandimala and Lareef Zubair, in second revision, *Journal of Hydrology*, ENSO based predictions for Water Resources Management in Sri Lanka.

Conference Proceedings

2004: Janaki Chandimala and Lareef Zubair, Predictability of Stream flow and Rainfall in the Kelani river basin in Sri Lanka using ENSO, *International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, United Nations University, Colombo, Sri Lanka.
2004: Lareef Zubair, Joshua Qian, Neil Ward, Ousmane Ndiaye, Janaki Chandimala, Ruvini Perera, Vidhura Ralapanawe and Benno Blumenthal (2004), Complementary Dynamical and Statistical Downscaling from a GCM: Maha rainfall over Sri Lanka, *Annual Meeting of the American Geophysical Union*, San Francisco.
2004: Lareef Zubair (2004) Downscaling of Sri Lanka's Maha Rainfall from a GCM and Indian Ocean Dipole and ENSO influences, *International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, United Nations University, Colombo, Sri Lanka.
2004: Lareef Zubair (2004), Weather, Climate Variability and Climate Change, Workshop Report, *Synthesis Workshop on Climate Variability, Climate Change and Health in Small-Island States*, Bandos Island, Maldives, 1-4 December 2003, pages 13-14, World Health Organization, Bandos, Maldives.
2005: Lareef Zubair (2005), Climate Risk Management: Case Studies in Public Health, Natural Disasters and Renewable Energy, *Biennial Congress of the Association of Environmental Engineering and Science Professors*, Potsdam, New York.

Reports

Jun 2006: Manjula Siriwardhana, Yoosuf Ashraj, Devika Perera and Lareef Zubair, Malaria Incidence over the 19th and 20th centuries in Sri Lanka, in preparation.
Jun 2006: Upamala Tennakoon, Zeenas Yahiya and Lareef Zubair, Monthly maps of average malaria incidence in Sri Lanka by district and MOH division, in preparation.
Jun 2006: Upamala Tennakoon, Zeenas Yahiya, Manjula Siriwardhana, Yoosuf Ashraj, Siraj Razick. H.M. Faizal and Lareef Zubair, Spatial Atlas of Malaria Incidence in the Uva Province.
Jun 2006: Hyemin Yang, Gawrie Galapaththy, Stephen Connor and Lareef Zubair, Association between ENSO and Malaria epidemics in Sri Lanka.
Jan 2006: Sarith Mahanama, Randall Koster and Lareef Zubair, Implementation of the "Catchment" Land surface model for Sri Lanka.
Nov 2005: Janaki Chandimala and Lareef Zubair, Land surface model implementation for a catchment in the Uva.
Jun 2005: Year 2 Project Report on Progress, submitted to *NOAA, OGP*.
Jun 2004: Year 1 Project Report on Progress, submitted to *NOAA, OGP*.
Apr 2004: Olivier Briet**,** Zeenas Yahiya and Lareef Zubair, Compilation of Presentations at the inaugural meeting of the Climate and Malaria Project, Passara, Badulla.

Picture: Staff Members outside the conference hosting the inaugural workshop of the Climate and Malaria project at Passara, Uva Province on December 8, 2003. Left to Right: M.R.A. Siraj, I. Bandara, L. Zubair, S.B. Rajakaruna, Z. Yahiya, U. Tennakoon and J. Chandimala. Passara is in the highlands overlooking the plains of Moneragala which is in the background.

Climate and Disaster Management

Natural disasters not only result in death and destruction but can also undermine decades of development gains. The vast majority of the natural disasters affecting Sri Lanka are hydro-meteorological in origin. Sri Lanka is not known to be prone to earthquakes and volcanoes but is prone to tsunamis.

Advances in technology and a hazard warning system can be used to predict risk levels of floods, cyclones and landslides a few days in advance and the tendency to drought months in advance. The risk levels of these hazards can be predicted with a degree of confidence so as to be useful for natural resource managers, policy and decision makers.

(a) Floods
(b) Droughts
(c) Landslide
(d) Cyclone Risk
(e) Multi-hazard Analysis
(f) Vulnerability

Projects Status Report

Activity	Objectives	Partners	Status	Next Steps
Disaster Hotspots Project: Case Study of Sri Lanka	(1) high resolution disaster risk assessment for Sri Lanka (2) to study the relevance of the global disaster hotspots studies at local level (3) to develop methodologies to use climate information in disaster analysis	Center for Hazards and Risk Research (CHRR), Center for International Earth Science Information Network (CIESIN), The Earth Institute at Columbia University.	Presented at Open Meeting of International Human Dimensions Program, Montreal, Concluding Meeting of Disaster Hotspots Case Study at World Bank. Final report submitted to IRI. Paper on floods published in Natural Hazards. Paper in press as a World Bank publication.	Several papers due in technical literature. Funding to be solicited for proposal for early warning system studies and hazard monitoring.

Disaster Management

Flood Risk

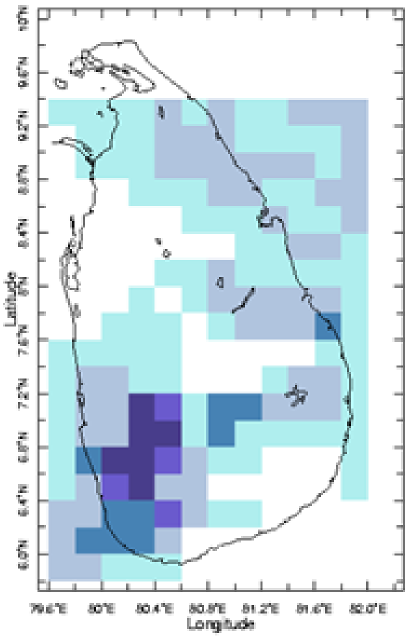
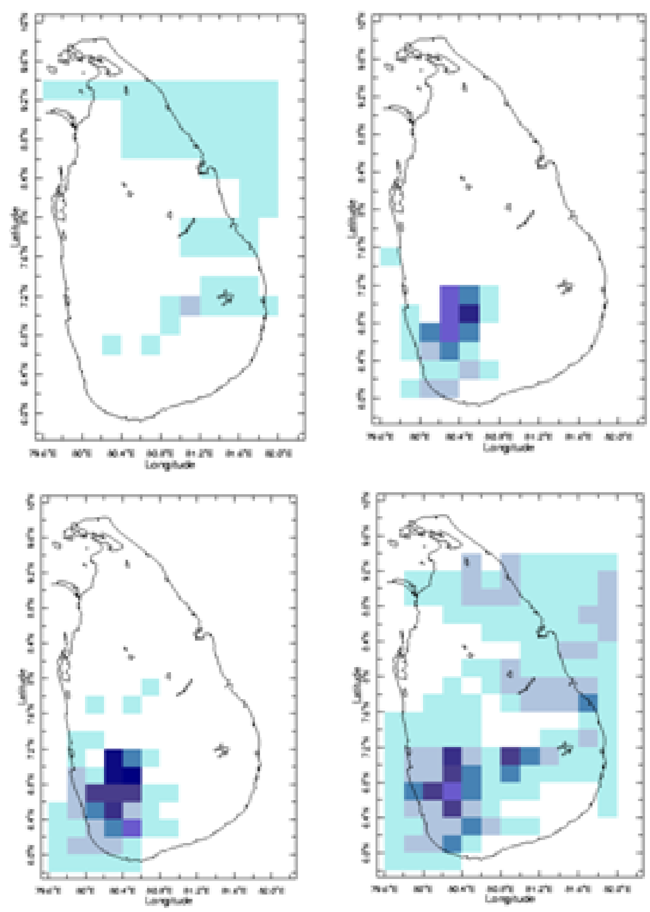


Figure: Flood risk map has been constructed using rainfall data for 40 years.

The flood hazard maps show high risk in western, south-western, northern, north-eastern and eastern parts of the country. The region with steep slopes facing the west and east are at risk. Floods occur in the Central Hill slopes and in the eastern coastal area during the *Maha* rainfall season from September to January. In the western slopes, floods occur in the *Maha* rainfall season but are more common in the mid-*Yala* season from May to August. These trends are reflected in hazard risk seasonal maps (right column).

Heavy rainfall climatology in the eastern and south-western slopes are a principal cause of the flood risk. In addition, the drainage and topography of certain districts and land use patterns are also significant factors.

Figures: Flooded streets in southwest of Sri Lanka



Figures Above: Flood risk maps (from top to bottom), for January to March, April to June, July to September and October to December.

Drought Risk

The rivers and the complex interconnected network of reservoirs that straddle the drier areas modulate the relationship between drought hazard and disaster incidence. Rivers on the western slopes are perennial while many in the other parts of the island are seasonal.

There is an increasing propensity for drought conditions. There is evidence that rainfall patterns of the country are changing. These trends have been investigated.

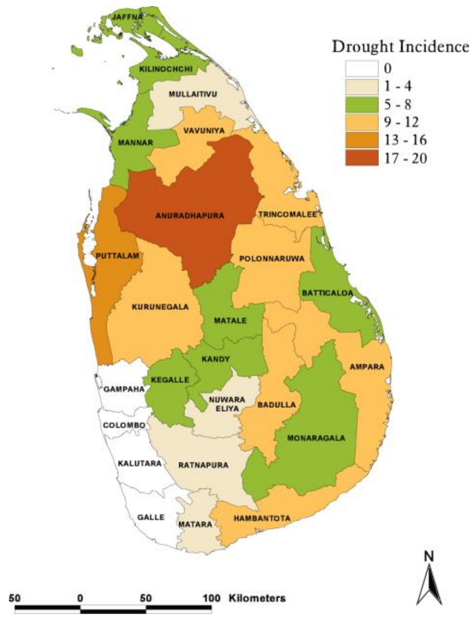


Figure Above: Drought disaster incidence frequency was constructed by aggregating the numbers of droughts that have been recorded in each district.

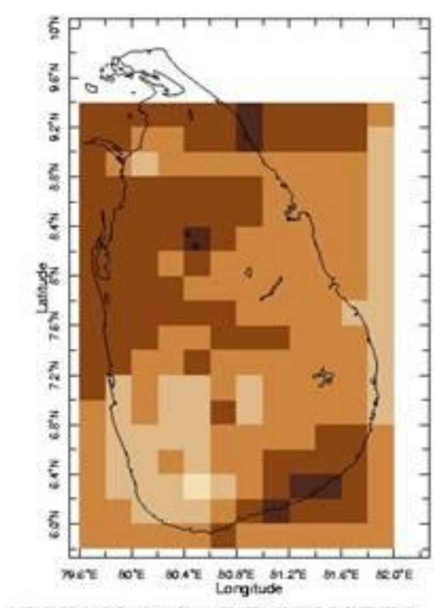


Figure : Drought hazard risk

Drought hazard risk is calculated using WASP indices developed by Brad Lyon using rainfall data of 40 years. The darker colours signify higher risk of drought.

The drought hazard risk map shows distinct spatial variability, salient features of which are

•Lower risk of drought hazard in the western slopes

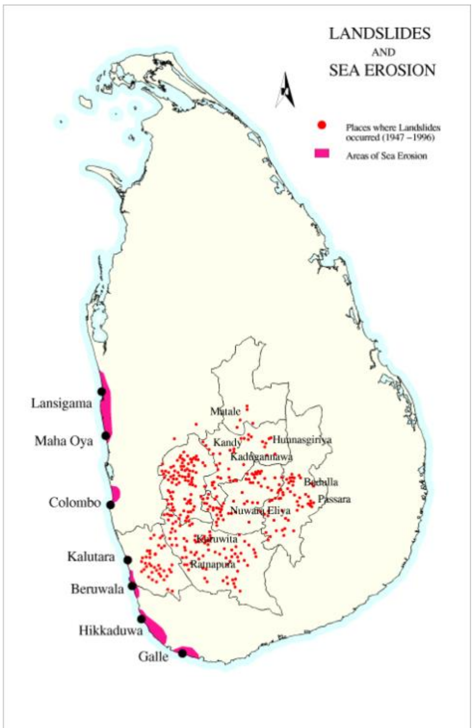
•High risk of drought in south-eastern, northern and north-western districts.

•*Puttalam*, *Anuradhapura, Hambantota, Mannar, Mullaitivu, Kilinochchi* and *Ampara* districts are high-risk areas.

The constructed drought hazard risk map and the drought disaster incidence map are similar.

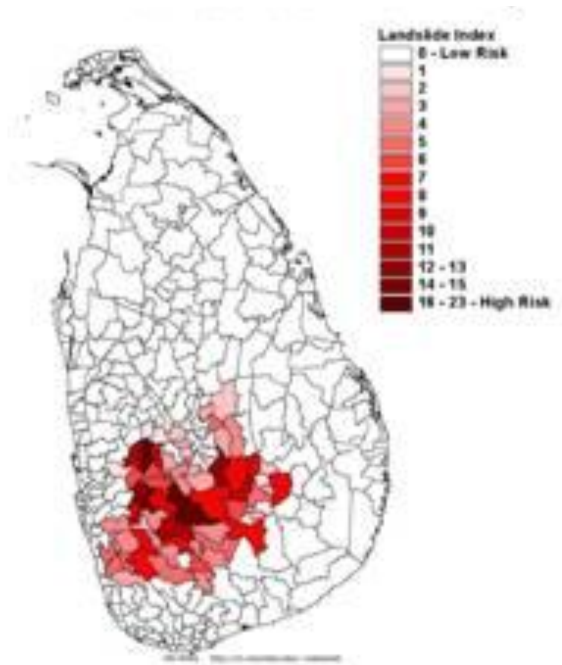
Landslide Risk

The frequency during the period 1947-1996 for each Divisional Secretariat Division was used as the risk factor for landslides.



Map: Areas of Landslides (1947 -1996) and Sea Erosions

Landslide Risk Map



Map: Landslide risk index

The landslide hazard is localized in eight districts in the central highlands. The western slopes (Kegalla, Ratnapura and Nuwara Eliya districts) show higher risk with marked spatial variability within each district. The frequency and magnitude of landslides have increased in recent years.

Landslide hazard index was calculated by plotting the recorded instances of landslides

Picture: Earthslip at Watawala in 1992. Photo courtesy of National Buildings Research Organization, Colombo, Sri Lanka

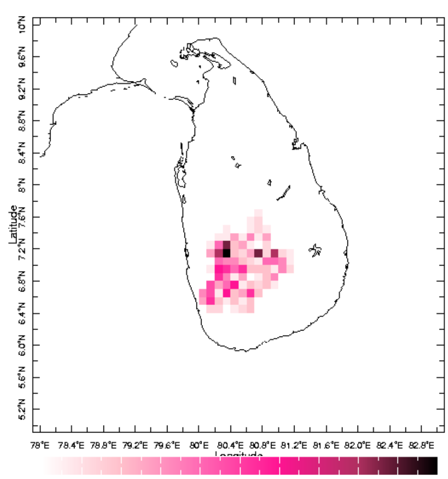


Figure: Landslide Hazardousness Index

Cyclone Risk

Storms and cyclones from the Bay of Bengal pass through the island preponderantly. There have been four severe cyclones during the last 100 years as well from November to January.

Using the available cyclone tracks for the last 100 years, a cyclone hazard risk map was constructed by counting how often a cyclone or storm passed through each district. Additional weight was given to the cyclones over the storms. The index was normalized by the area and mapped as shown.

The Eastern seaboard and the Northern part of the island are at greater risk. Cyclone incidence shows a strong seasonality. The main cyclone season is from November to December accounting for 80% of all occurrences.

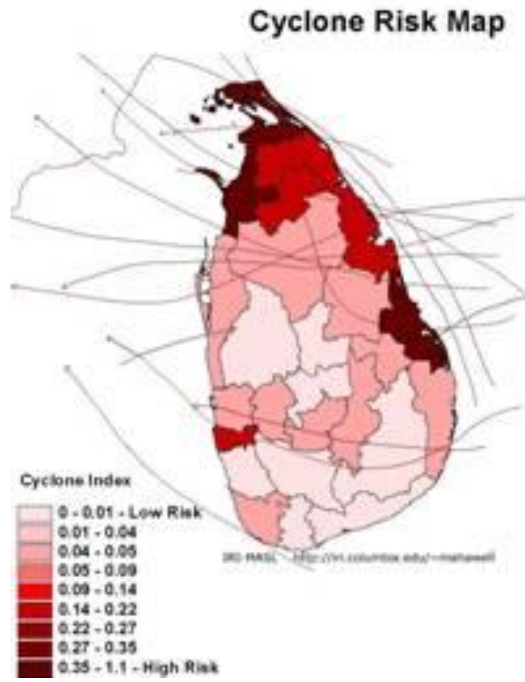
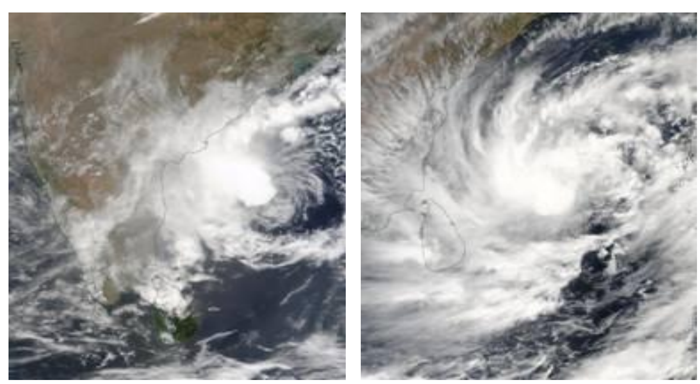
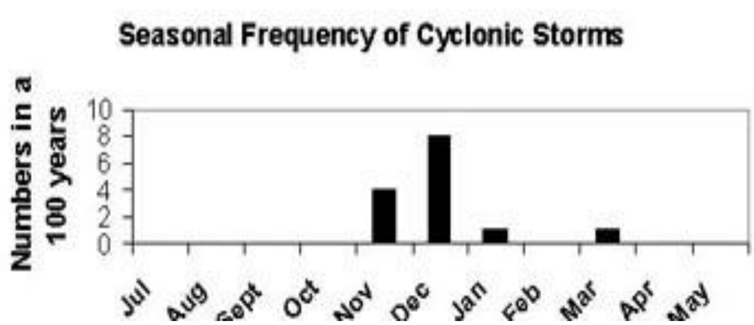


Figure: Cyclones passing through Sri Lanka. An index of cyclone risk by districts is shown as the background



Images: Satellite Images of the May 2003 cyclone which led to one of the most damaging disasters in Sri Lanka.

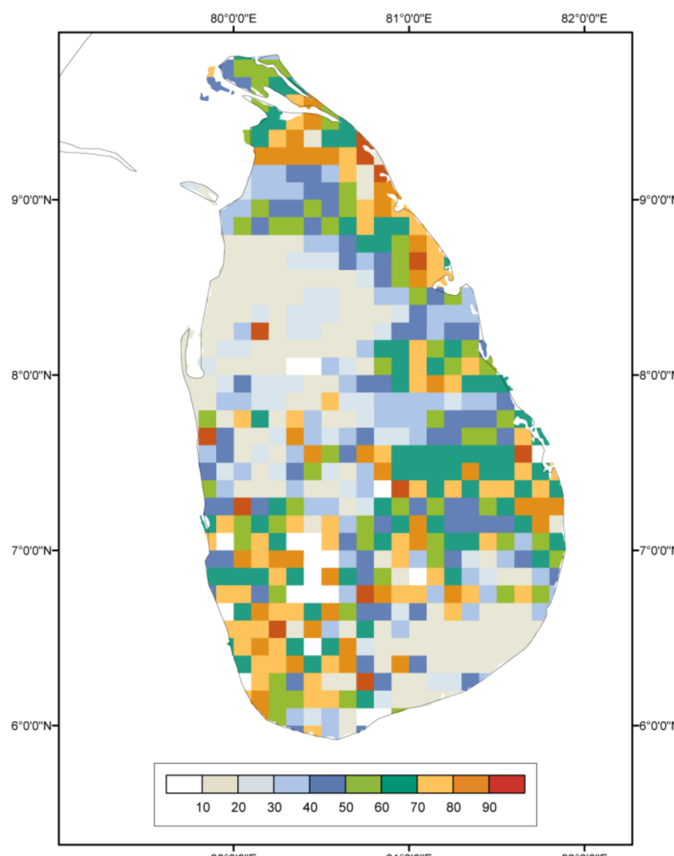


Multi-hazard Risk

A multi-hazard risk map was created by aggregating the hazard risk indices for drought, floods, cyclones and landslides. Each of the indices was standardized and added to create a multi-hazard risk map for the country.

Two distinct regions emerge as areas that have higher risk for hazards. One is the South-Western hill slopes region, and the other is the North-Eastern coastal region. *Kegalle, Ratnapura, Batticaloa, Ampara, Galle and Mullaitivu* Districts are prone to the highest risk.

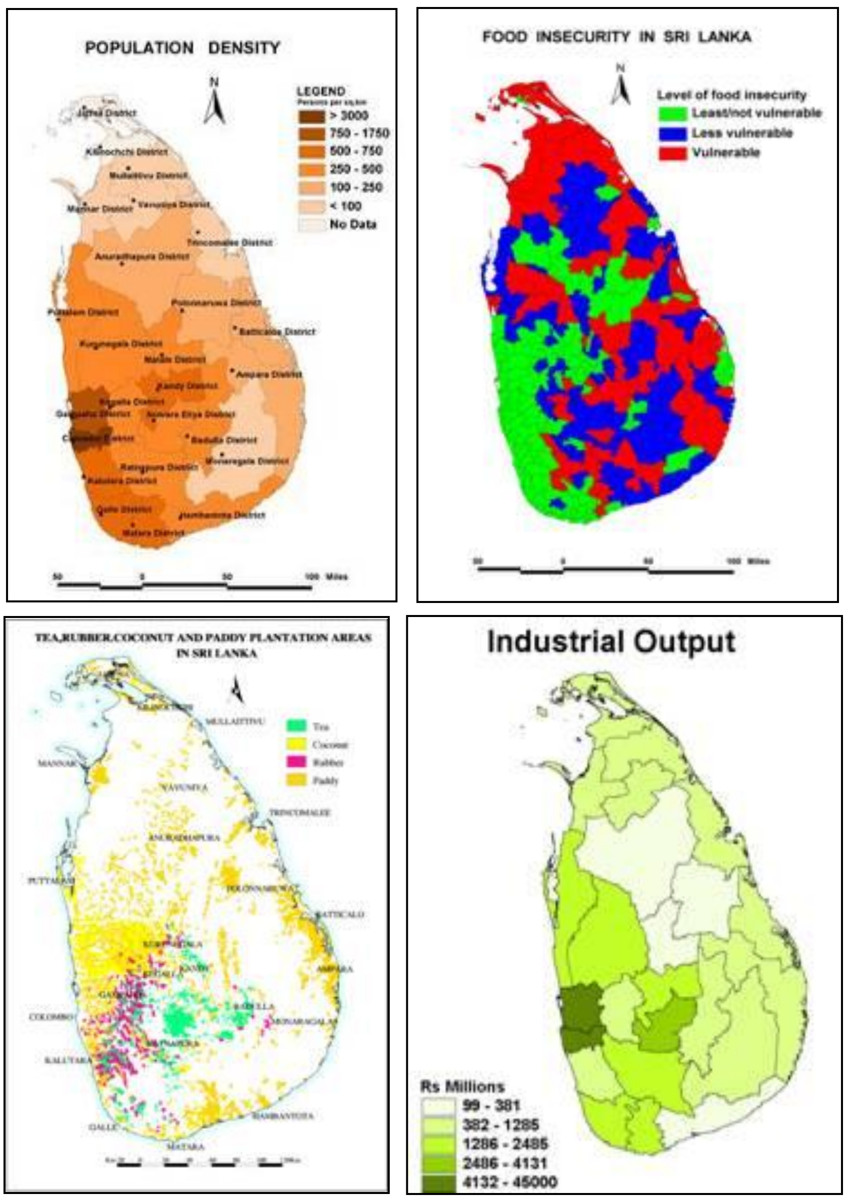
In the North-East region, the Eastern coastal belt along with *Anuradhapura, Mannar* and *Vavuniya* Districts show higher risk, albeit less than the Western slopes. In addition, the Southern districts of *Hambantota* and the North-Central district of *Puttalam* are also under risk from multiple hazards.



Map: Multi-hazard risk estimated by weighting each hazard index by incidence frequency (The result was rescaled to range between 0 and 100).

Vulnerability

Disasters occur when vulnerable communities and their infrastructure, economic activities and livelihoods are exposed to a hazard. Vulnerability can be estimated for people, economic activities and infrastructure as a measure of disaster proneness. Spatial proxies of vulnerability for Sri Lanka are shown below. Population density (top left) shows the relative human exposure to hazards. The food insecurity index calculated by the World Food Programme (map top right) shows the relative level of vulnerability. Industrial output and agricultural production maps (bottom right and left) indicate areas more vulnerable to disruption of economic activities.



From Top: Clockwise: District wise population density, sub-district wise food insecurity and industrial output, and pixel-wise agriculture (tea-green, coconut-yellow, rubber-red and rice-gold).

Outputs

Papers

June 2006: Lareef Zubair, Ralapanawe V., Tennakone, U., Yahiya, Z., and Perera, R., *Natural Disaster Risks in Sri Lanka: Mapping Hazards and Risk Hotspots*, Chapter 4, *Natural Disaster Hotspots Case Studies*, Washington, DC: World Bank.
November 2004: May 2003 disaster in Sri Lanka and Cyclone 01-B in the Bay of Bengal, *Natural Hazards*, 33: 303-318, 2004.
July 2003: with U. Tennakone, Z. Yahiya, J. Chandimala & M.R.A. Siraj, What led to the May 2003: Floods?, *Journal of the Institute of Engineers*, Sri Lanka, XXXVI (3): 51 – 56.
March 2003: Lareef Zubair, Vidhura Ralapanawe, Upamala Tennakoon and Ruvini Perera, Contributions to the Disasters Section of the National Atlas of Sri Lanka, forthcoming, 2nd Edition.

Feature Article

August 2003: What led to the May Flooding, *The Island*, National Newspaper, Sri Lanka, August 23, 2003

Conference Proceedings

Mar 2005: Lareef Zubair, Using Climate Information for Disaster Risk Identification in Sri Lanka, *Climate Prediction Applications Science Workshop* March 15-17, 2005, Palisades, New York.
December 2004: Lareef Zubair, Using Climate Information for Disaster Risk Identification in Sri Lanka, *Annual Meeting of the American Geophysical Union*, San Francisco.
October 2003: Vidhura Ralapanawe and Lareef Zubair, Assessment of High-Risk Natural Disaster Hotspots of Sri Lanka, *2003 Open Meeting of the Human Dimensions of Global Environmental Change Research Community*, Montreal, Canada.

Reports

Feb 2005: Lareef Zubair, Vidhura Ralapanawe, Upamala Tennakoon, Ruvini Perera, Fine Scale Natural Hazard Risk and Vulnerability Identification Identified by Climate, Submitted to *IRI*.
March 2003: Lareef Zubair, Zeenas Yahiya, Vidura Ralapanawa, Cyclone Hazards and Response in Sri Lanka, FECT report.