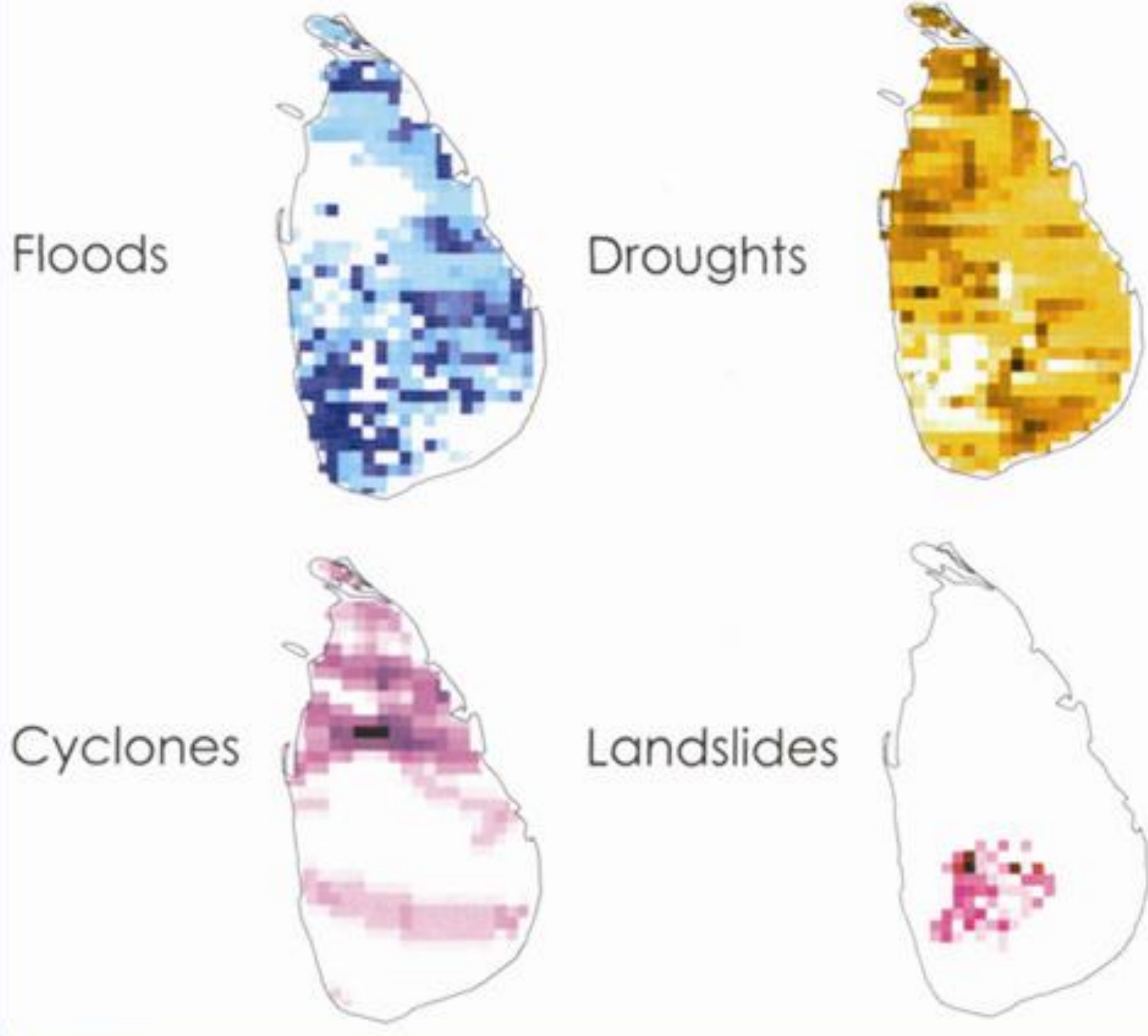
Fine Scale Natural Hazard Risk and Vulnerability Identification Informed by Climate in Sri Lanka



Foundation for Environment, Climate and Technology, SRI LANKA
Report sponsored by MacArthur Foundation under a grant to the University of Peradeniya

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Citation: Zubair, L., V. Ralapanawe, Z. Yahiya, R. Perera, U. Tennakoon, J. Chandimala, S. Razick and B. Lyon. Fine Scale Natural Hazard Risk and Vulnerability Identification Informed by Climate in Sri Lanka. Project Report: Foundation for Environment, Climate and Technology, Digana Village, August 2011.

Website:
http://www.climate.lk/
http://www.tropicalclimate.org/

Sponsors:
The preparation of this document was supported by a grant from the John D. and Catherine T. MacArthur Foundation to the University of Peradeniya to launch a new Master's in Development Practice Programme based on a model of rigorous, inter-disciplinary training and the curriculum recommended by the International Commission on Education for Sustainable Development Practice.

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Acknowledgements

This work was initiated with a seed grant from the Global Natural Disaster Hotspots project to conduct a case study on Sri Lanka. The grant was administered by the Center for Hazards and Risk Research of the Columbia Earth Institute. We are grateful for this support and useful interactions with members of the project consortium, particularly Maxx Dilley, Bob Chen and Kathleen Boyer. During this period the work was supported by the International Research Institute for Climate Prediction; and the Foundation for Environment, Climate and Technology at the Mahaweli Authority of Sri Lanka. This report also reflects further work from a subsequent "bridge grant" from the International Research Institute for Climate Prediction. We gratefully acknowledge the contributions made by Benno Blumenthal, Michael Bell and John Del Corral for assistance with advanced aspects of the IRI data library work.

We thank Amara Samarasinghe of the Department of Census and Statistics for collaboration on vulnerability analysis in Sri Lanka. Samitha Jayamaha, who was then attached to the Sri Lanka Ministry of Social Services, provided invaluable assistance. C.M. Madduma Bandara, Chairman of the Interim National Water Resources Authority of Sri Lanka, provided guidance during a visit to the IRI at the inception of the project. The assistance of Whitney Peterson and Jason Rodriguez of IRI; and Madhura Weerasekera, Sanjaya Ratnayake, and Sewwandhi Chandrasekera of the Foundation for Environment, Climate and Technology is gratefully acknowledged for helping to finalize this report.

We have presented these results in several venues in Sri Lanka, including at a meeting of heads of departments and senior officials convened by the Sri Lankan Minister of Water Resources and Irrigation. The outputs have been included in the 2nd edition of Sri Lanka's National Atlas.

The preparation of this document was supported by a grant from the John D. and Catherine T. MacArthur Foundation to the University of Peradeniya to launch a new Master's in Development Practice Programme based on a model of rigorous, inter-disciplinary training and the curriculum recommended by the International Commission on Education for Sustainable Development Practice.

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Summary

Although many natural disasters have hydro-meteorological antecedents, little advantage has been taken of the availability of weather and climate data, advanced diagnostics and seasonal predictions for disaster risk management. In this study, methodologies for use of hydro-meteorological data in hazard risk assessment are presented laying the ground work for future dynamic hazard predictions.

A high-resolution assessment of natural hazards, vulnerability to hazards and of multi-hazard disaster risk has been carried out for Sri Lanka. Drought, flood, cyclone and landslide hazards, and vulnerability were identified using data from Sri Lankan government agencies. Drought and flood prone areas were mapped using rainfall data that was gridded at a resolution of 10-km. Cyclone and landslide hazardousness were mapped based on long-term historical incidence data. Indices for regional industrial development, infrastructure development and agricultural production were estimated based on proxies. An assessment of regional food insecurity from the World Food Programme was used in the analysis. Records of emergency relief were used in estimating a spatial proxy for disaster risk. A multi-hazardousness map was developed for Sri Lanka. The hazardousness estimates for drought, floods, cyclones, landslides were weighted for their associated disaster risk with proxies for economic losses to provide a risk map or a hotspots map. Our principal findings are summarized below.

Useful hazard and vulnerability analysis can be carried out with the type of data that is available in-country. The hazardousness estimates for droughts, floods, cyclones and landslides show marked spatial variability. Vulnerability shows marked spatial variability as well. Thus, the resolution of analysis needs to match the resolution of spatial variations in relief, climate and other features. The higher resolution information is needed in planning and action for disaster management.

Multi-hazard analysis brought out regions of high risk in Sri Lanka such as *Kegalle* and *Ratnapura* Districts in the South West and *Ampara, Batticaloa, Trincomalee, Mullaitivu* and *Killinochchi* districts in the North-East, and the districts of *Nuwara Eliya, Badulla, Ampara* and *Matale* that contain some of the sharpest hill slopes of the central mountain massifs.

There is a distinct seasonality to risks posed by drought, floods, landslides and cyclones. Whereas the Eastern slopes regions have hotspots during the boreal fall and early winter, the Western slopes regions is risk prone in the summer and the early fall. Thus attention is warranted not only on Hot-Spots but also on "Hot-Seasons".

Climate data was useful in estimating hazardousness in the case of droughts, floods and cyclones and for estimating flood and landslide risk. The methodologies presented here for hazard analysis of floods and droughts present an explicit link between climate and hazard. The results from this study coupled with the high-resolution seasonal climate prediction techniques developed in a related study point the way to using historical,

current and predictive climate information to inform disaster management policy, and early warning systems.

Climate, environmental and social change such as deforestation, urbanization and war affect the hazardousness and vulnerability. It is more difficult to quantify such changes rather than the baseline conditions.

Our analysis was carried out for a period since 1960 that included a period of civil war after 1983. This war affected the North-East of the island in particular. To put things in context, while natural disasters accounted for 1,483 fatalities in this period, the civil wars accounted for over 65,000. Wars and conflict poses complications for hazard and vulnerability analysis. Yet, the vulnerabilities created by the war make such efforts to reduce disaster risks all the more important.

Technical details of our work have been included in a case study published by the World Bank and in journals listed in the outputs.

Introduction

The objectives for this study were i) to examine the methodologies needed for high-resolution assessments of hazardousness, vulnerability and hotspots, ii) to assess the interplay among hazards and vulnerability, and iii) to assess the consequence of combinations of multiple hazards and vulnerability factors. Note that in the terminology used here, a “natural disaster” occurs when the impact of a hazard is borne by “elements at risk” that may be vulnerable to the hazard. The elements considered in this study are simplified into categories as people, infrastructure and economic activities.

Sri Lanka has an area of 65,000 square kilometers and a population of 19.5 million (Department of Census and Statistics, 2001). The principal topographic feature is an anchor shaped mountain massif in the South-Central part of the island. The topography and differences in regional climate (figure 1) are underlying causes of the contrasts in many facets of the island.

The frequent natural hazards that affect Sri Lanka are drought, floods, landslides, cyclones, vector borne epidemics (malaria and dengue) and coastal erosion (Tissera, 1997). Volcanoes, earthquakes and tsunamis are infrequent but potentially with catastrophic losses and these are not addressed here. We (Foundation for Environment, Climate and Technology - FECT) have addressed only drought, floods, landslides and cyclones hazards here. We are mapping spatial risks of epidemics as a separate project to develop an early warning system.

Drought is the most significant hazard in terms of people affected and relief provided. The relief disbursements for drought between 1950 and 1985 were SL Rupees 89 million whereas floods accounted for only SL Rupees 7.5 million.

The prevalence of drought is surprising given that Sri Lanka receives on average 1,800 mm of rainfall annually. However, it is distributed unevenly spatially (figure 1) and temporally (figure 2). A large part of the island is drought-prone from February to April and on to September if the subsidiary rainy season from May to June is dry.

Disaster management is carried out in Sri Lanka by the Department of Social Services under the Ministry of Social Services. Relief work for disasters is the responsibility of the parent body, the Ministry of Social Welfare.

Our analysis is carried out in the context of civil wars that together extended from 1983 to 2002: While natural disasters accounted for 1,483 fatalities in this period, the civil wars accounted for over 65,000. War has devastated infrastructure, communities’ ability to deal with hazards, reduced incomes, weakened safety nets, and undermined capacity to recover from hazard events. For example, there has been a severe toll on hospital availability. Even though there has been peace since 2002, longer-term consequences such as unexploded landmines, war orphans and the war-disabled continue. The availability of data on hazards and vulnerability is restricted in the war zones. The twodecade long war poses complications for vulnerability analysis, which are inadequately addressed in this study. While the precision of our analysis may be affected by the history of war, vulnerabilities created by the war make efforts to reduce disaster risks all the more important.

The specific objectives for this study are;

- To undertake a high-resolution analysis of drought, floods, cyclones and landslides.
- To assess vulnerability to these hazards at a sub-national level.
- To assess multi-hazard risks and hazard hotspots at the sub-national level.
- To assess methodologies for incorporating climatic information into hazard analysis.

Disaster Management in Sri Lanka

Sri Lanka is governed by an elected executive and a government drawn from a parliament of 225 members. It has 9 provinces and there is partial devolution to these levels. In addition, each of the 9 provinces has 2-3 districts in them. Administration in each of these districts is under the central authority of the District Secretary (formerly Government Agent - GA). Each district comprises of perhaps 10-20 subdivisions called Divisional Secretariat divisions (formerly Assistant Government Agent divisions - AGA divisions) under the charge of a Divisional Secretary. Each subdivision has several dozen village units (Grama Niladhari Divisions - GND) comprising a few thousand people.

The Ministry of Social Services has been the lead organization on relief and rehabilitation co-coordinating directly with District and Divisional Secretaries. Disaster Management has been undertaken by the Department of Social Services under the Ministry of Women's Empowerment and Social Welfare, and its focus historically has been on rehabilitation, relief and monitoring. The ministry hosts the National Disaster Management Centre, whose role has been more oriented towards monitoring and relief.

A significant role is also played by the Ministry of Health, under which all the government medical facilities fall in. They have played a key role in providing medical help to affected areas and camps.

Hazards

The main hydro-meteorological hazards affecting Sri Lanka are drought, flood, landslides and cyclones. The seismic and tsunami hazards have been infrequent. Recent research has uncovered a tectonic plate boundary in the middle of the Indo-Australian plate, which had been one plate millions of years back. There is also a tsunami hazard evidenced by the impacts on Sri Lanka from the 1883 Krakatoa earthquake and the Tsunami of 2004.

Drought Hazard

Plate 1: Kotmale Reservoir in January 2001 (left) and June 2001 (right)

Drought is the most significant hazard in Sri Lanka in terms of people affected and relief provided. The relief disbursements for drought between 1950 and 1985 were Sri Lanka Rupees (SLR) 89 million whereas floods accounted for only SLR 7.5 million.

The prevalence of drought is surprising given that Sri Lanka receives on average 1,800 mm of rainfall annually. However, it is distributed unevenly spatially and temporally (figures 1 and 2).

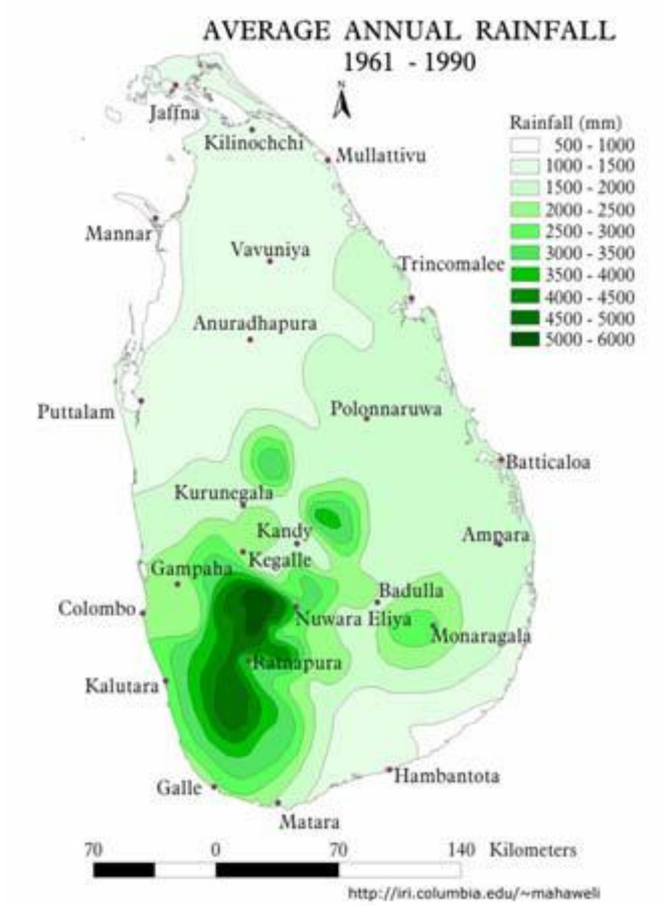


Figure 1: Average Annual Rainfall

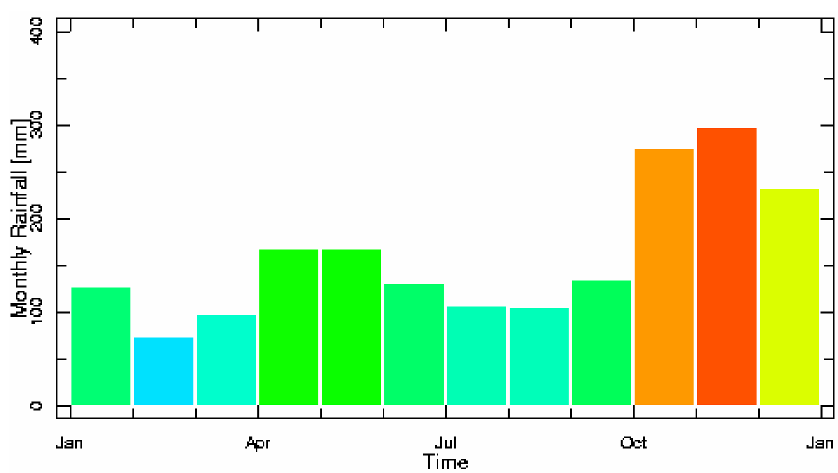


Figure 2: Average Monthly Rainfall

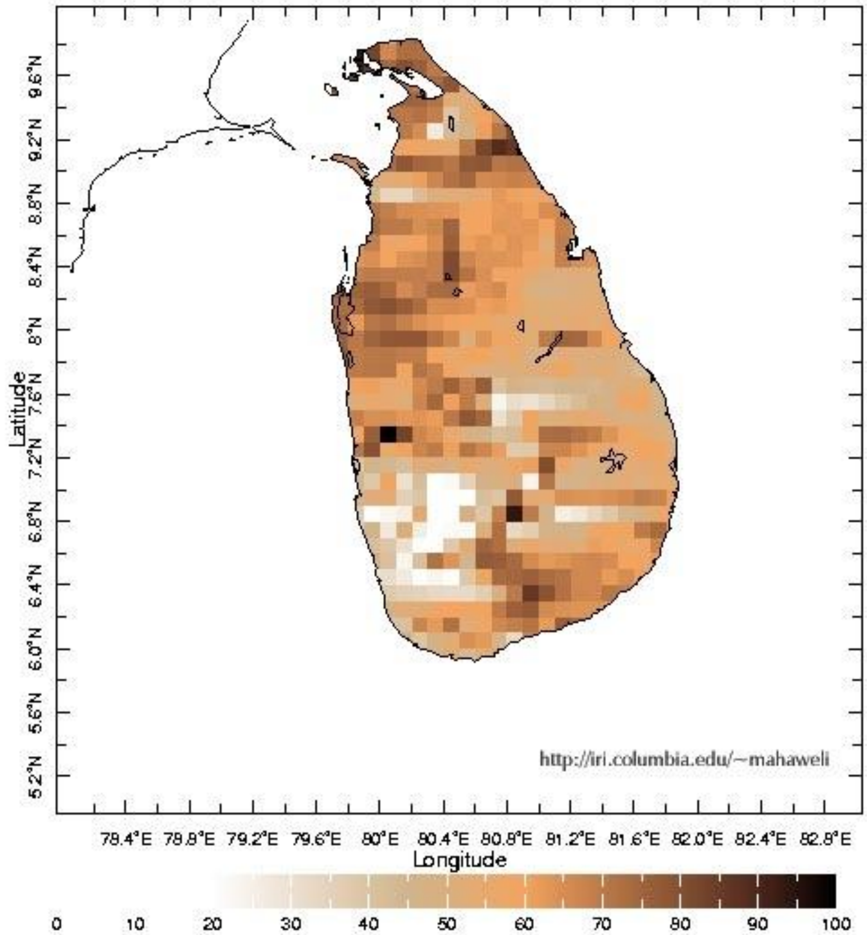


Figure 3: Drought Hazardous Index

A large part of the island is drought-prone from February to April and on to September if the subsidiary rainy season from May to June is dry.

Drought index was calculated using a variation of the WASP (Weighted Anomaly Standardized Precipitation) indices developed by Lyon, et al (figure 3). There is a stronger tendency to drought in the South- Eastern district of Hambantota and the North-Western region of Mannar and Puttalam. The drought tendency is markedly less in the South-West corner of Sri Lanka where there is heavy rainfall.

Flood Hazard

Plate 2: Tropical Cyclone 01B, 14th May 2003 which resulted in severe flooding and significant loss of life in southwest of Sri Lanka. flooded streets near Matara town, 20 May 2000 courtesy of http://www.fiscalstudy.com/ (right). Satellite photo courtesy of NASA Earth Observatory (left).

Heavy rainfall in the Eastern and South-Western slopes is a principal cause of the flood risk. In addition, the drainage and topography of certain districts and land use patterns are also significant factors. For example, the Districts of Kegalle and Ratnapura have people settled in flood plains and steep hill-slopes. Flooding disasters has now become almost an annual occurrence.

The flood index was calculated by aggregating the high rainfall instances across 40 years (figure 4). Flood seasonality maps were also created by using rainfall data for each quarter to highlight areas with high hazard risk for each quarter.

The Western slopes receive rainfall in both Maha (September to January) and Yala (May to August) seasons, and is prone to flooding in these periods. The Eastern slopes receive most of the rainfall during the Maha season (September to January). This is also the cyclone and storm season that can bring heavy rainfall in short time periods. Thus the two regions show distinct flood seasonality. The District of Vavuniya shows a higher flood probability due to cyclonic storms. Even though the annual rainfall is lower than the Western highlands, Vavuniya and Mullaitivu in the North of Sri Lanka have recorded the highest rainfall intensities in the island.

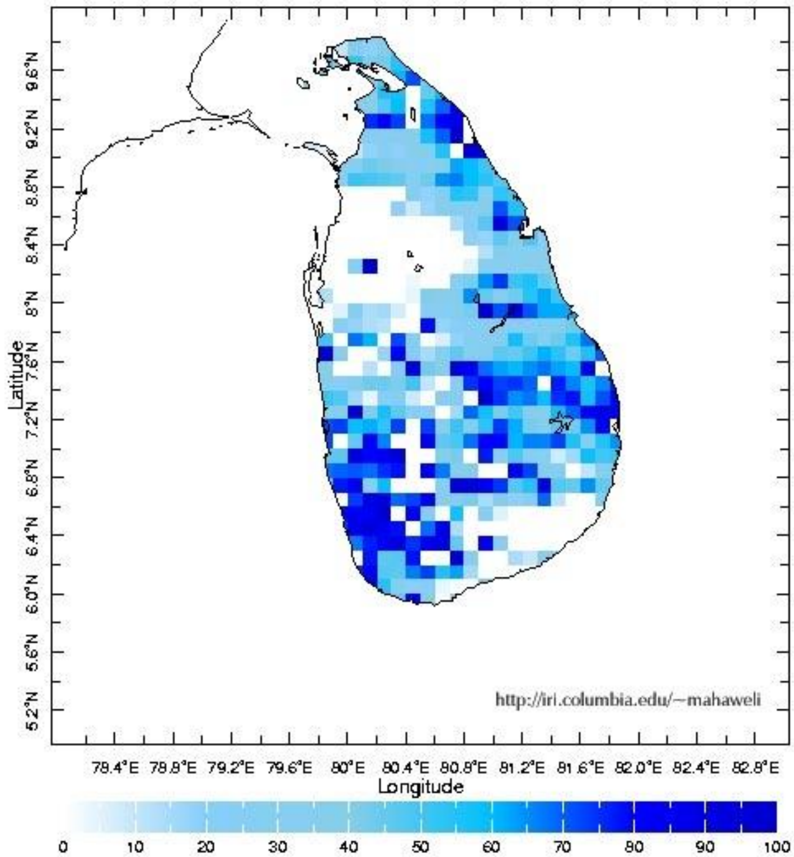


Figure 4: Flood Hazardousness Index

Landslide Hazard

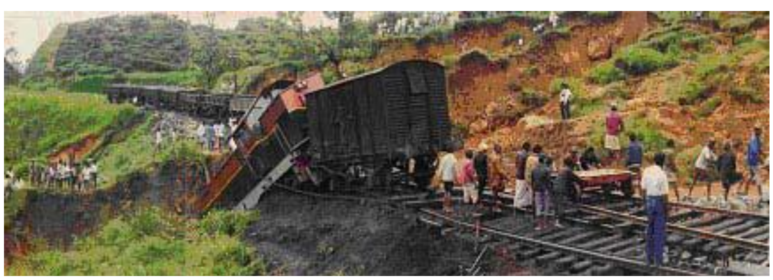


Plate 3: Earthslip at Watawala in 1992.
Photo courtesy of National Buildings Research Organization, Colombo, Sri Lanka.

Landslide hazard index was calculated by plotting the recorded instances of landslides (figure 5). Eight districts in the central highlands are at risk. The highest risk is in the Kegalle District followed by Ratnapura and Nuwara Eliya Districts. Even within these Districts there is spatial variability at Divisional Secretariat level. Kalutara, Kandy and Badulla Districts have moderate risk and Matale and Kurunegala Districts have slight risk.

The frequency of landslides has increased in the recent years and this may be due to changes in land use including cultivation of tobacco on steep slopes, land clearing in the hills, blocking of drainage ways and the impact of the large reservoir construction.

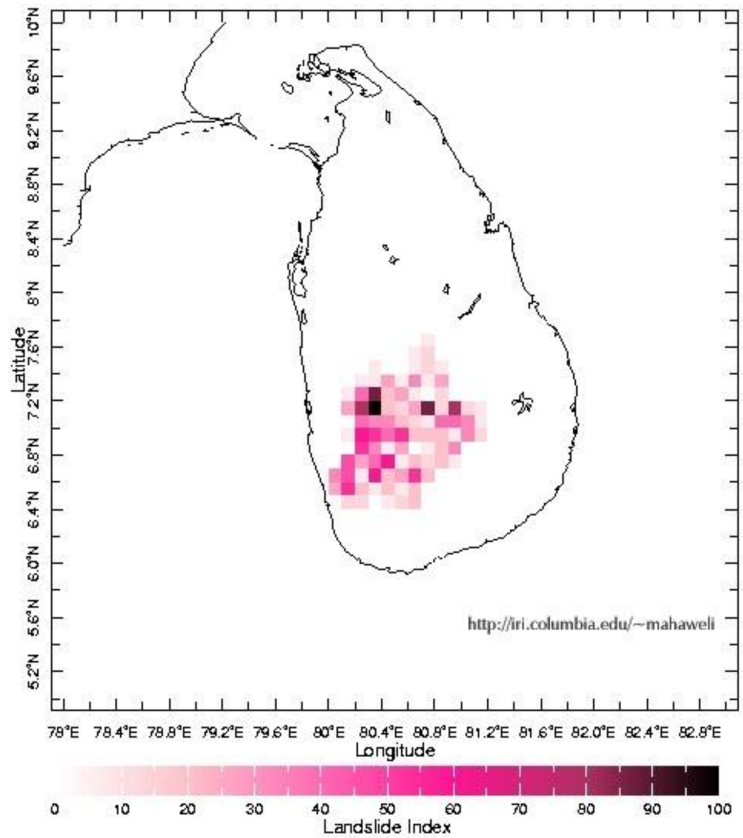


Figure 5: Landslide Hazardousness Index

Cyclone Hazard

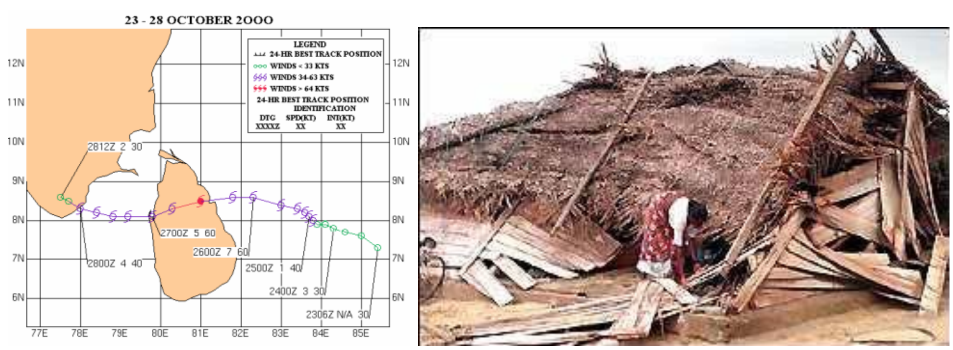


Plate 4: Tropical Cyclone 04B on 26th December 2000 created significant damage to Eastern coastal communities (right). Cyclone track by courtesy of JTWC. Photo of cyclone damaged house courtesy of BBC (left).

Cyclones and storms have made landfall only in the Eastern coast of Sri Lanka except for a single storm in 1967. The majority of cyclones and storms pass through the Northern and North-Central parts of the island. There have been a number of severe and moderate storms including four severe cyclones during the last 100 years. The cyclones that pass through Sri Lanka originate from the Bay of Bengal during the North-East monsoon which develops in November and lasts for a few months. Cyclone hazardousness index is calculated using the cyclone and storm tracks across Sri Lanka in the last 100 years (figure 6). Cyclone incidence shows a strong seasonality, and 80% of all cyclones and storms occur in November and December. Incidences of cyclones that pass through Sri Lanka in other seasons are rare due to the geography and the regional climatology.

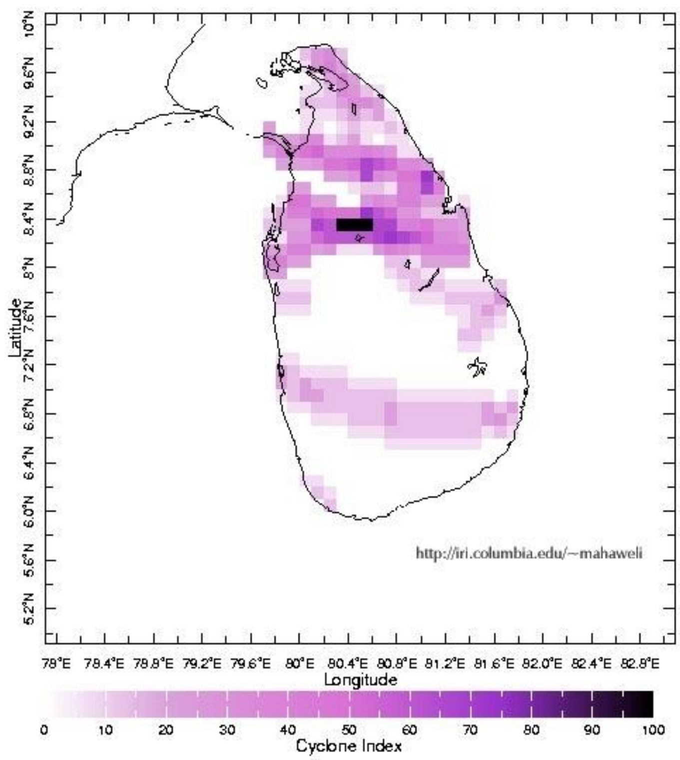
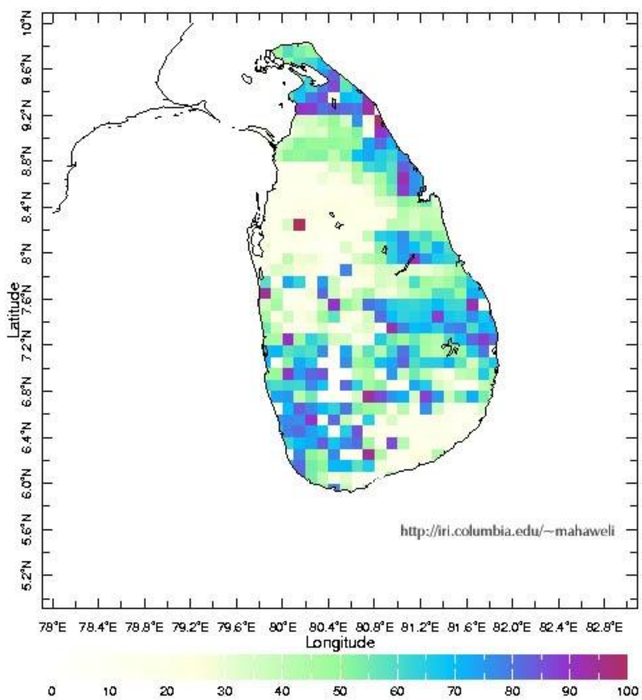


Figure 6: Cyclone Hazardousness Index

Multi-hazard Hotspots

Multi-hazard maps were created for Sri Lanka by factoring in the four hazard risk indices based on different criteria (figures 7and 8).



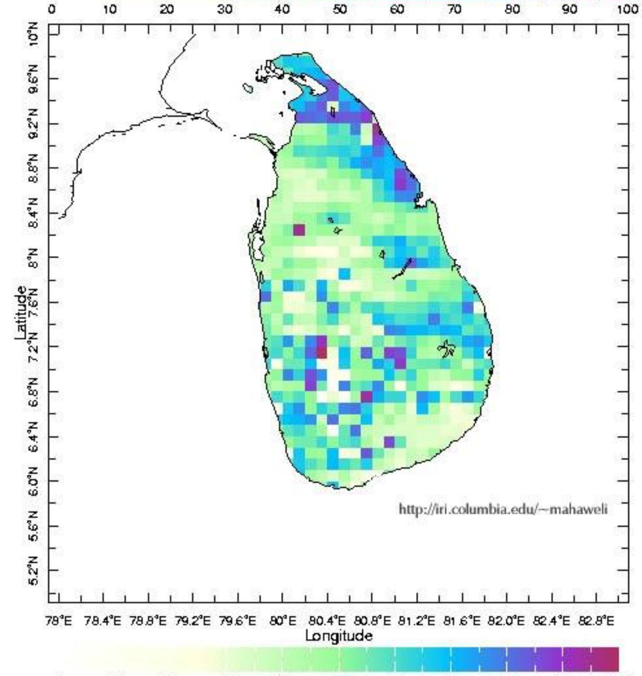


Figure 7(top): Multi-hazard index based on EM-DAT incidence data

Figure 8(bottom): Multi-hazard index based on Dept of Soc. Svcs incidence data

Vulnerability

Exposure and vulnerability can be assessed for people, economic activities and infrastructure.

People

Plate 4: Refugees at a camp after the floods in Eastern Sri Lanka on 17th December 2004 (these areas were also highly affected by the tsunami -9 days later). The Camp is Sithandy in Batticaloa.
(Photo: REUTERS / Anuruddha Lokuhapuarachchi)

Sri Lanka has a population of 19.7 million (2003) which is distributed unevenly (figure 9).

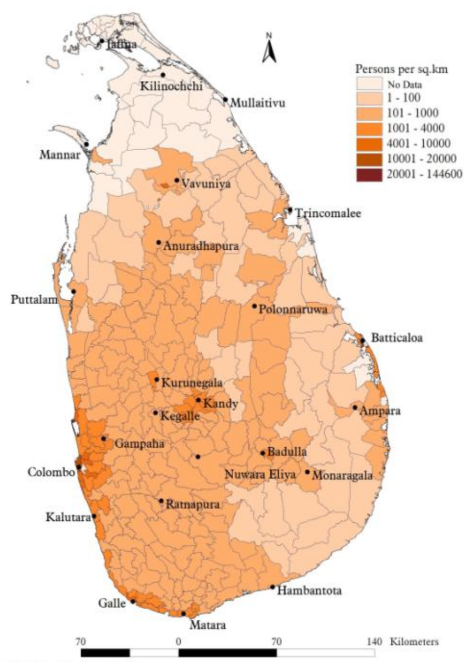


Figure 9: Population Density

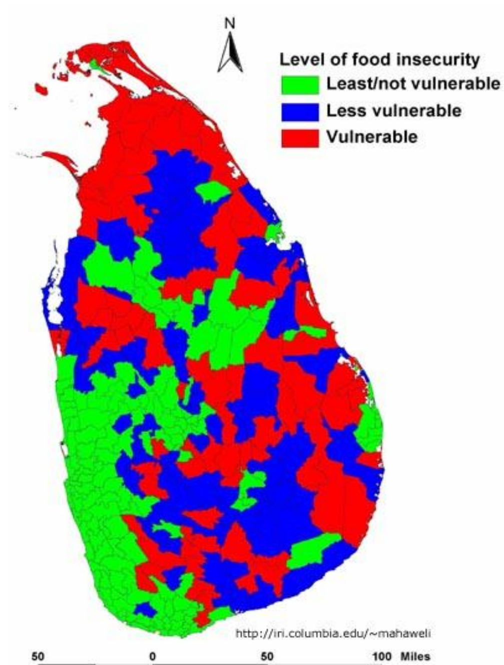


Figure 10: Food insecurity vulnerability

Food security is one indicator that measures a community's ability to withstand hazards as well as its resilience to the hazard. Food security calculated by World Food Program (WFP) Sri Lanka office in 2002 is based on availability of food, access to food and utilization of food, based on generally accepted food insecurity models. Food insecurity vulnerability shows the distribution of population who are likely to be worse affected (figure 10).

Economic Activity

The provincial GDP map shows that wealth is concentrated in the Western Province (figure11).

The main crop of Sri Lanka is Paddy, which is generally cultivated twice a year. The major cash crops are tea, rubber, coconut and spices (figure 12). The agrarian economy is highly susceptible to floods and droughts. The major industries are textile & apparel, food & beverage processing, chemical & rubber, and mining & minerals. Industry is heavily concentrated in the Western Province. Floods affect the industries in the west of Sri Lanka while drought in Central Highlands can affect industry drastically through deficits in hydro-power production.

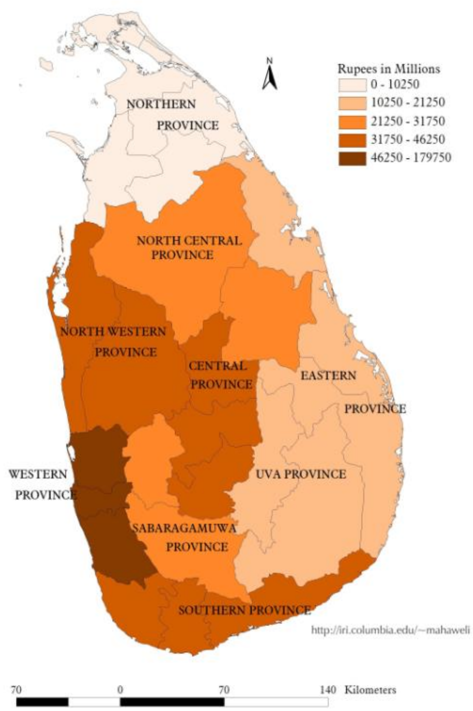


Figure11:Provincial GDP

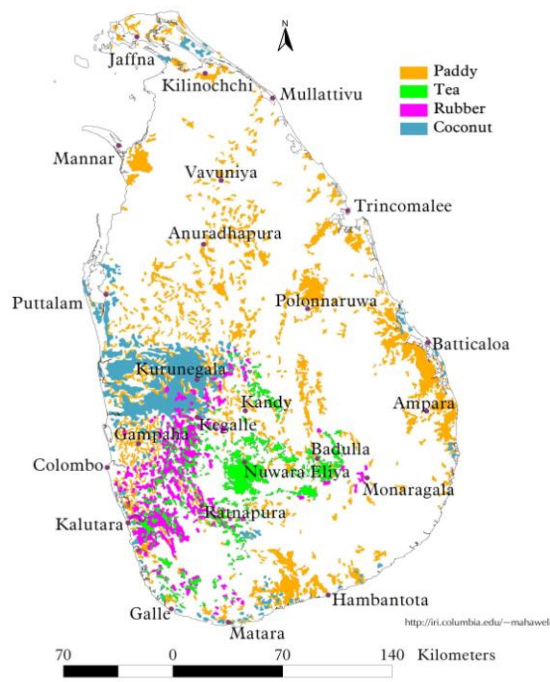


Figure12: Agriculture

Infrastructure

Infrastructure development too reflects a pattern of heavy development in the Western Province with subsidiary development in the metropolitan districts of Kandy and Galle. Due to the heavy concentration of telecommunication facilities there is a high concentration of infrastructure facilities in the District of Colombo (figure 13). In the Northern Province Electricity and telephone facilities have been severely disrupted due to the war, and there are no estimates of recent conditions. Thus interpretation of the infrastructure index for these areas needs to be tampered with caution.

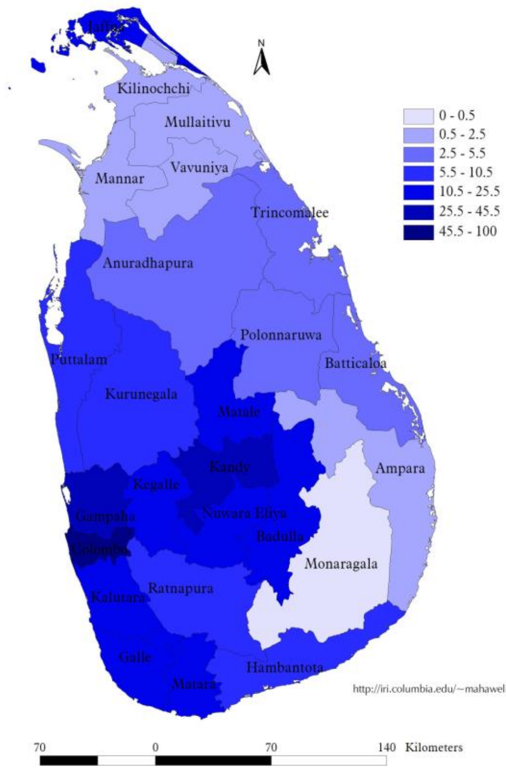


Figure 13: Infrastructure Index

Conclusions and Outcomes

Spatial Variability

The use of in-country data enabled the construction of detailed hazard maps and the investigation of trends. The spatial hazard and disaster risk mapping should be useful for local authorities as well as International relief organizations to monitor the disaster risks and adaptations.

Hazardousness mapping methodology

The hazardousness mapping methodology at the local scale needs to be fine-tuned to take advantage of the finer resolution of data and finer resolution of the results. An example, of a good use of multiple data sets is the landslide hazard-mapping project carried out by the Sri Lanka National Building Research Organization.

Vulnerability Analysis

Hazard specific vulnerabilities are needed at high resolution. Vulnerability analysis is more constrained by data limitations than hazard analysis. Notwithstanding these limitations, the vulnerability analyses provide a broad initial assessment of the nature of hazard risks and vulnerabilities at a national scale.

Seasonality

Strong seasonality was evident in drought, flood, cyclone, and landslide risks in Sri Lanka. Information as to the seasonal risk levels of different disasters is useful for disaster risk management and should be provided. Our work has shown that the risk factors change with climate variability such as due to El Nino. As the climate of Sri Lanka is relatively predictable, the ability to predict shifts in climate up to 6 months in advance provides an opportunity to engage in predictive risk mapping.

Long-Term Climate, Environmental and Social Change

Both climate and environmental changes such as deforestation and urbanization affect the hazard analysis, and should in ideal conditions have been taken account of in the analyses. Such work is needed in the future.

Further investigation is required to build comprehensive drought maps that take into account hydrological and physical conditions that contribute to drought. Our vulnerability analysis too can be improved by taking account of long-term changes in demographics, urbanization, migrations and the consequences of civil war.

We have presented an example of the use of physical and social data for high-resolution scale hazard and vulnerability analyses. This case study has demonstrated that the high-resolution provides a more useful analysis of risk which recognizes crucial regional variations rather than that based on data available at the global scale.

Vulnerability analysis is much less precise than hazard analysis. The approach adopted here of considering the specific elements of people, economic activity and infrastructure and estimating this based on proxies has been shown to be viable with the data that is available locally. Crucial spatial variations in vulnerability emerged in the higher-resolution maps that were not evident at coarser scales. Estimating hazard specific vulnerabilities had to be based on the assumption that long-enough records of the past give an indication of future spatial variability. This is a reasonable assumption when one considers that the topography, climate and terrain, which are basic causes of regional variability do not change substantively. However changes due to climate, environmental and social changes need to be investigated.

Multi-hazard mapping is subject to limitations in the types of data that are available particularly for exposure and vulnerability. There was multiple ways in which the different hazards could be weighted, each of which has arguments in its favor. These different maps can suit different purposes. Given the limitations in the methodology, it is useful to focus on the commonalities in these maps. In particular, three regions in the North-East, the South-West and the Hill-slopes in the mountains were identified broadly as hotspots.

We have presented methodologies for using fine-resolution rainfall for estimating droughts and floods and the use of past incidence data for estimating cyclones and landslides. The explicit identification of the association of climate with disasters may be used for predicting hazard risk for upcoming seasons based on seasonal climate predictions that is relatively skillful for Sri Lanka and other parts of the tropics.

Outputs

Papers

Jul 2003: Zubair, L., U. Tennakone, Z. Yahiya, J. Chandimala & M.R.A. Siraj, What led to the May 2003 Floods?, *Journal of the Institute of Engineers*, XXXVI (3): 51 – 56.

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March 2004: Ralapanawe, V. and Lareef Zubair, Identification of Global Natural Disaster Hotspots Review and Synthesis Meeting, World Bank, Washington, D.C.

Dissemination

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Posters: October 2004: Poster was presented at the Lamont Doherty Earth Institute's Open House.

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