

Chapter 4

Natural Disaster Risks in Sri Lanka: Mapping Hazards and Risk Hotspots

*Lareef Zubair and Vidhura Ralapanawe, Upamala Tennakoon,
Zeenas Yahiya, and Ruvini Perera*

Introduction

The goals for this case study of natural disasters in Sri Lanka were (1) to examine the methodologies needed for subnational assessments of hazard, vulnerability, and hotspots; (2) to assess the interplay among hazards and vulnerability; and (3) to assess the consequence of combinations of multiple hazards and vulnerability factors. 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 of people, infrastructure, and economic activities.

Sri Lanka has an area of 65,000 square kilometers and a population of 18.7 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 (figure 4.1). The topography and differences in regional climate (figures 4.2 a and b) are underlying causes of the contrasts in many facets of the island.

The most frequent natural hazards that affect Sri Lanka are droughts, floods, landslides, cyclones, vector-borne epidemics (malaria and dengue), and coastal erosion (Tissera 1997). Tsunamis are infrequent but have caused severe damage. Recent understanding of the tectonics of the Indian Ocean region points to an increasing risk of earthquakes. The risk of volcanoes is small. Here, we have addressed only those hazards related to droughts, floods, landslides, and cyclones. We are mapping spatial risks of epidemics in 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 Rs 89 million (approximately US\$1 million), whereas floods accounted for only SL Rs 7.5 million.

The prevalence of drought may be surprising given that Sri Lanka receives an average of 1,800 mm of rainfall annually. However, it is distributed unevenly both spatially (figure 4.2.a) and temporally (figure 4.2.b). A large part of the island is drought prone from February to April and, if the subsidiary rainy season from May to June is deficient, drought may continue into September. In our analysis, we use a regionalization of Sri Lankan climate into four climatologically homogeneous regions (Puvaneswaran and Smithson 1993)—western and eastern slopes and northern and southern plains—as shown in figure 4.2.a.

During the time frame of the study, disaster management has been 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. The Government of Sri Lanka is currently revising its organizational structure for dealing with and planning for natural and manmade disasters.

Our analysis is carried out in the context of civil wars that, together, extended from 1983 to 2002. During this period, natural disasters accounted for 1,483 fatalities, while civil wars accounted for more than 65,000. War has devastated infrastructure and 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. Although 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 vulnerability analysis

Figure 4.1. The district boundaries of Sri Lanka are shown over the topography

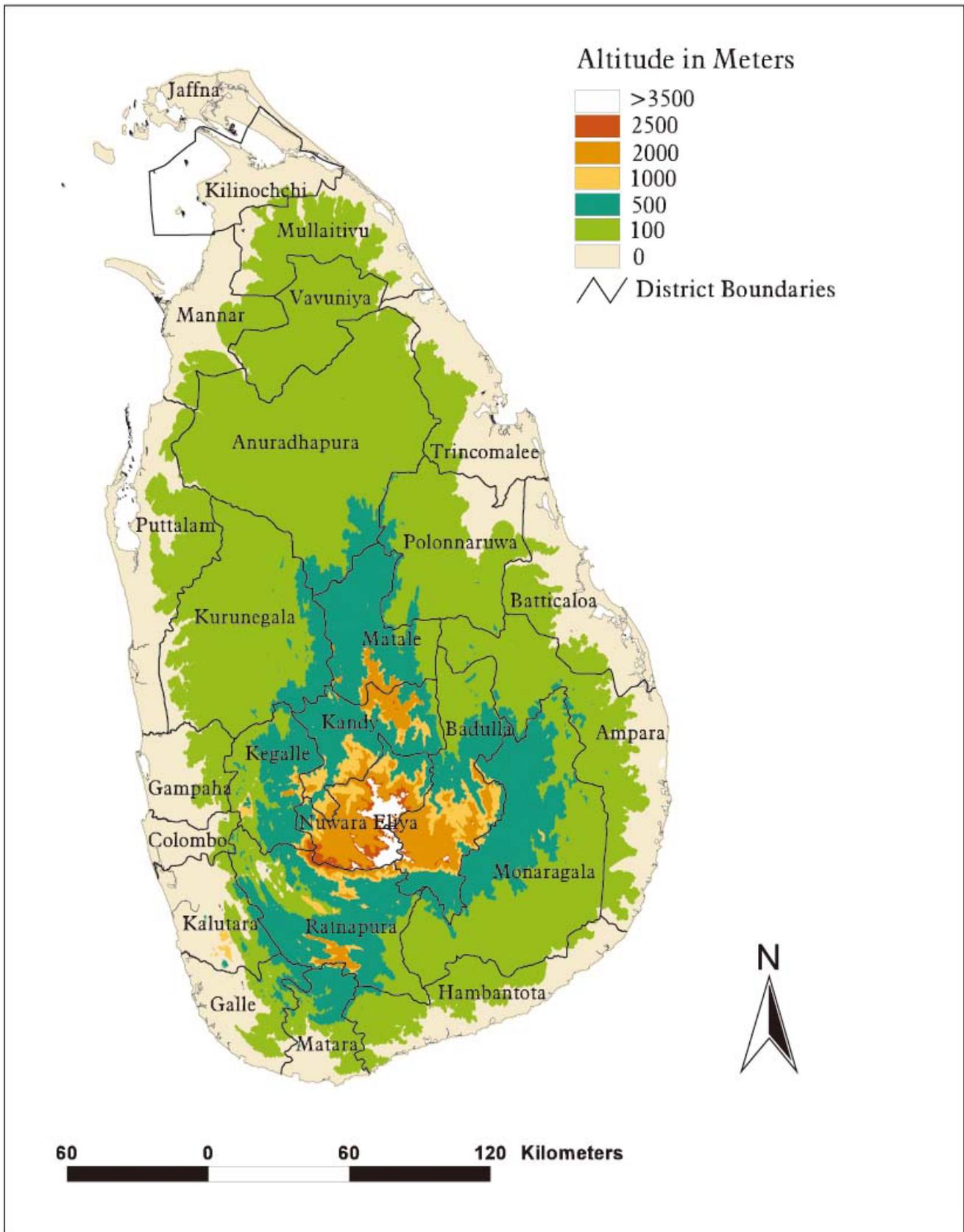


Figure 4.2.a. The average annual rainfall climatology estimated based on data from 284 stations in the period between 1960 and 1990. Homogenous climatological regions as proposed by Puvaneswaran and Smithson (1993) are overlaid.

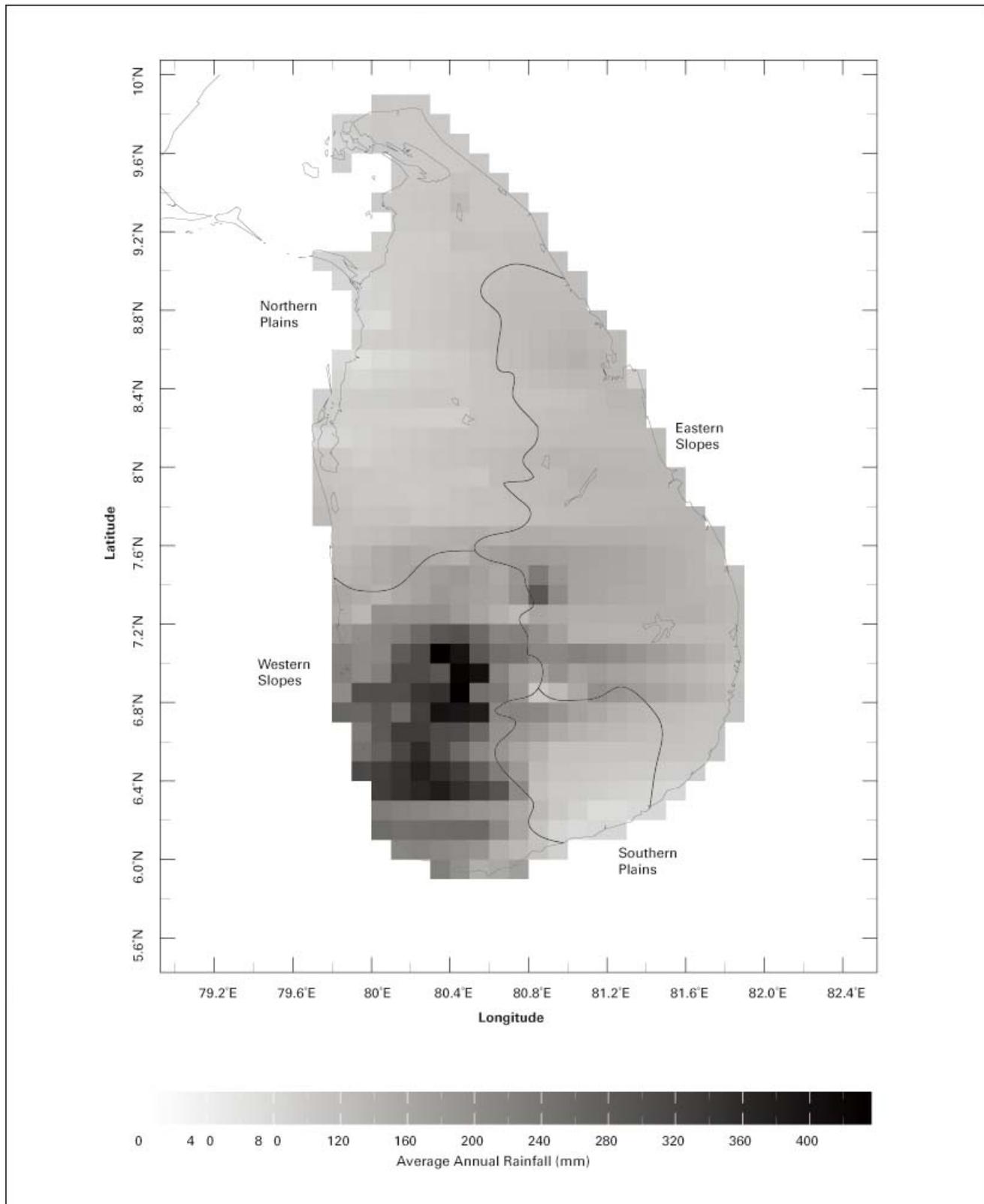
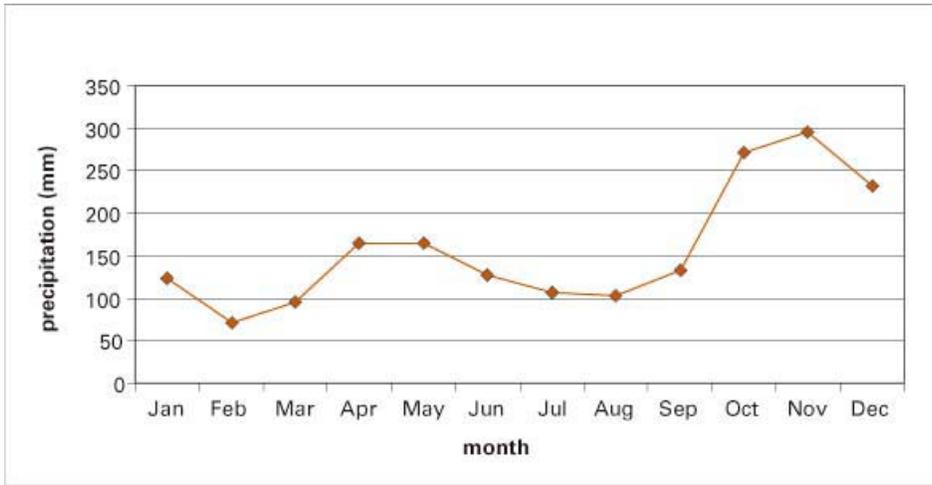


Figure 4.2.b. The average monthly rainfall between 1869 and 1998 for Sri Lanka

Disaster-Related Data: The sources of data were the Sri Lanka Department of Social Services, Sri Lanka Department of Census and Statistics, and the Central Bank of Sri Lanka. These data were of varying resolutions, ranging in scope from the district level (droughts, floods, and cyclones) to the DSD level (later instances of flood) to the GND level (landslides). Most disaster incidence data also contained relief expenditures.

is complicated by the two-decade-long war. 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 as follows:

- To undertake a subnational analysis of droughts, floods, cyclones, and landslides;
- To assess vulnerability to these hazards at the subnational level;
- To assess multihazard risks and hazard hotspots at the subnational level; and
- To assess methodologies for incorporating climatic information into hazard analysis.

We shall describe the data that were used, the methodologies used for hazard and vulnerability assessment, and the analysis of multihazard risk in the following sections.

Data

In-Country Data

The administrative divisions in Sri Lanka are provinces, districts, divisional secretariat divisions (DSDs), and Grama Niladhari (Village Officer) divisions (GNDs). There are 9 provinces, 25 districts, 323 DSDs, and 14,113 GNDs, organized hierarchically.

Climate Data: Data were obtained from the Sri Lanka Department of Meteorology and secondary sources. Although the country has around 400 functioning rainfall stations, only a subset of these possesses uninterrupted records. The records in the Northern Province were limited over the last two decades because of war. We used data from 284 rainfall stations from 1960 to 2000 to construct gridded data at a resolution of 10 km. Using 1960 to 1990 as the base period, monthly climatologies were calculated. Monthly anomalies were calculated by deducting the climatology from observed values (figure 4.2.a).

Hydrological Data: Data were obtained from the Sri Lanka Department of Irrigation and through secondary sources for monthly river flow measurements at 140 gauging stations. These data had numerous gaps.

Landslide Hazard-Related Data: Data were obtained through the National Building Research Organization of Sri Lanka.

Population, Social, Economic, and Infrastructure Data: The Department of Census and Statistics provided population data. Data at the DSD level were selected for comparison and analysis. Gross domestic product (GDP) measures, including regional GDP, were obtained from the Central Bank of Sri Lanka.

Food Security Data: An assessment of food security in Sri Lanka was conducted under the Vulnerability Assess-

ment and Mapping Program of the World Food Programme (WFP), Sri Lanka office. The identification of DSDs with three levels of food insecurity was obtained from their maps.

Hazards and disaster records had good identification of where these occurred, but often only the year when these occurred was available. The temporal resolution was improved by interrogation of multiple data sources and by consulting government officials.

Global Data Sources

Hazard Data—Floods: Dartmouth Flood Observatory carries an archive of large flood events from 1985 onward. This database contains specific dates of the floods, severity class, and affected area. However, the spatial resolution is coarse, as the data have been derived from the district level.

Climate Data: The data available at the International Research Institute for Climate and Society (IRI) Data Library with long coverage for Sri Lanka is lower in resolution (250 km grid).

Exposure Data—Population, Social, Economic, and Infrastructure Data: Center for International Earth Science Information Network's (CIESIN's) Gridded Population of the World (GPW2) dataset contains population data on a 5 km grid. The gridding methodology of GPW2 utilizes district-level population data. "Landscan 2001" contains gridded population data on a 1 km grid calculated using population, roads, slope, land cover, and nighttime lights.

Vulnerability Data: The United Nations Development Programme (UNDP) Human Development Reports provide a number of key indicators at the national level. The UNDP Human Development Report for Sri Lanka provides most of these indicators at the district level.

Disaster Data—EM-DAT: The Office of U.S. Foreign Disaster Assistance/Center for Research on the Epidemiology of Disasters (OFDA/CRED) International Disaster Database has recorded 48 natural disasters in Sri Lanka during the period from 1975 to 2001, including

four instances of epidemics. EM-DAT identifies 9 droughts, 2 landslides, 3 cyclones and storms, and 33 flood events (including floods caused by the cyclones). The dataset contains dates and affected areas and people. The United Nations Environment Programme/GRID (UNEP/GRID) datasets include global cyclone tracks for the period from 1980 to 2000.

Exposure and Vulnerability

Exposure and vulnerability may be assessed for the three categories of elements at risk—people, economic activity, and infrastructure.

People

Population: The population of Sri Lanka was 19.2 million in 1998 (293 persons per km²) with an uneven distribution (figure 4.3). Fifty-five percent of the population is concentrated in 20 percent of the land area (Department of Census and Statistics 2001). Thirty percent of the population resides in urban areas. The least-populated districts (covering 40 percent of the island) host 10 percent of the population. In these districts, population density ranges from 35 to 100 people per km², which is still high by global standards (De Silva 1997). The highest population is in the Colombo, Gampaha, and Kalutara districts of the Western Province. There is a secondary population center in the Kandy District in the Central Province and in the Galle District along the southern coast. The high density of people in the wet parts of the island increases the number of people who are vulnerable to floods and landslides.

Impoverishment and mortality are direct consequences of, as well as contributors to, natural disasters. In this context, food security measures a community's resilience to the hazards and often its exposure. Food security calculated by the WFP Sri Lanka office in 2002 was based on the availability of food, access to food, and utilization of food (figure 4.4). Based on this study, 93 DSDs out of 323 were categorized as "Most Vulnerable," 82 as "Less Vulnerable," and 148 as "Least/Not Vulnerable" (World Food Programme 2002). The spatial variability of the Least/Not Vulnerable category shows two contiguous regions and some scattered areas. One con-

Figure 4.3. The density of population in each of the 323 Divisional Secretarial Divisions based on data from the census of 2001

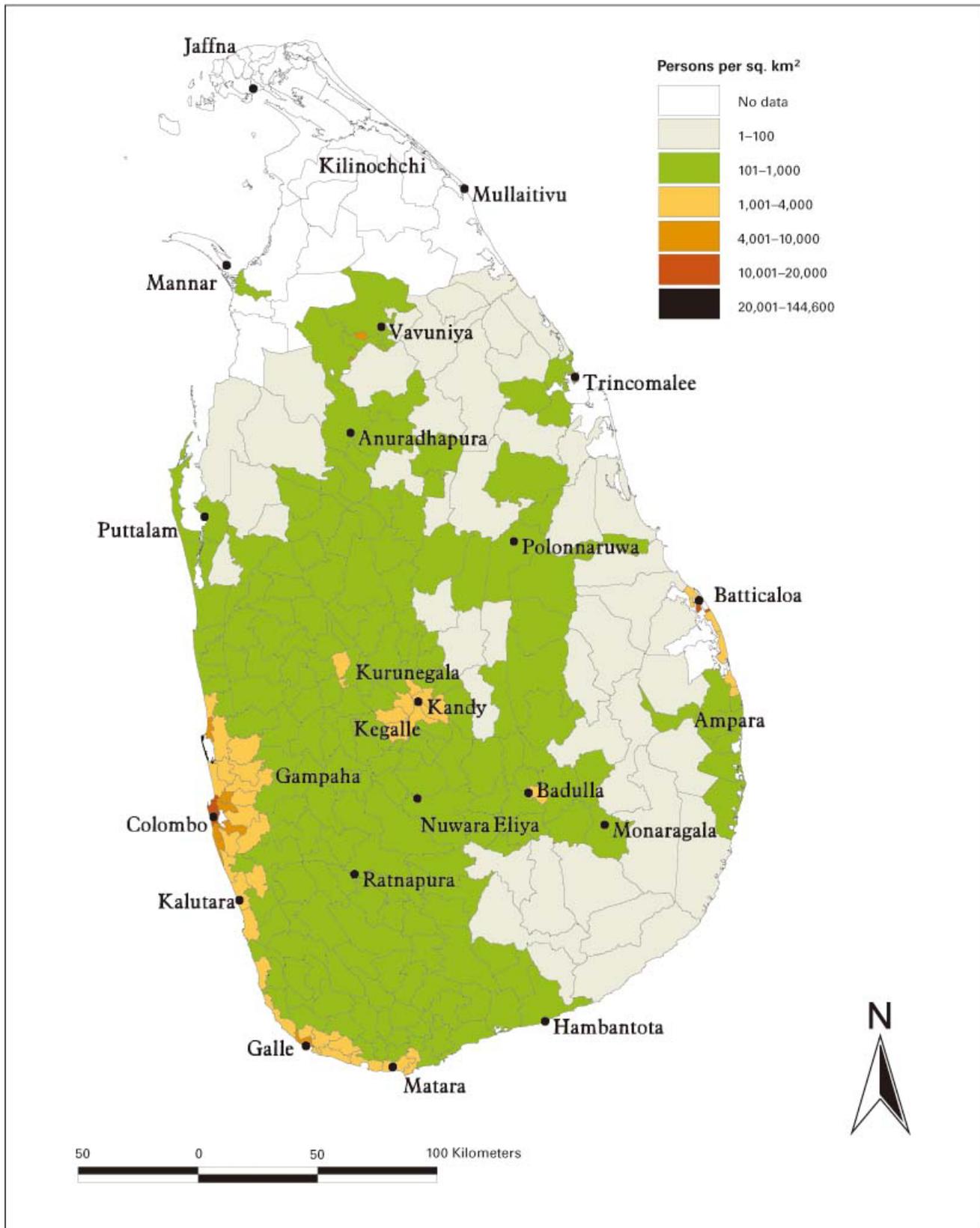
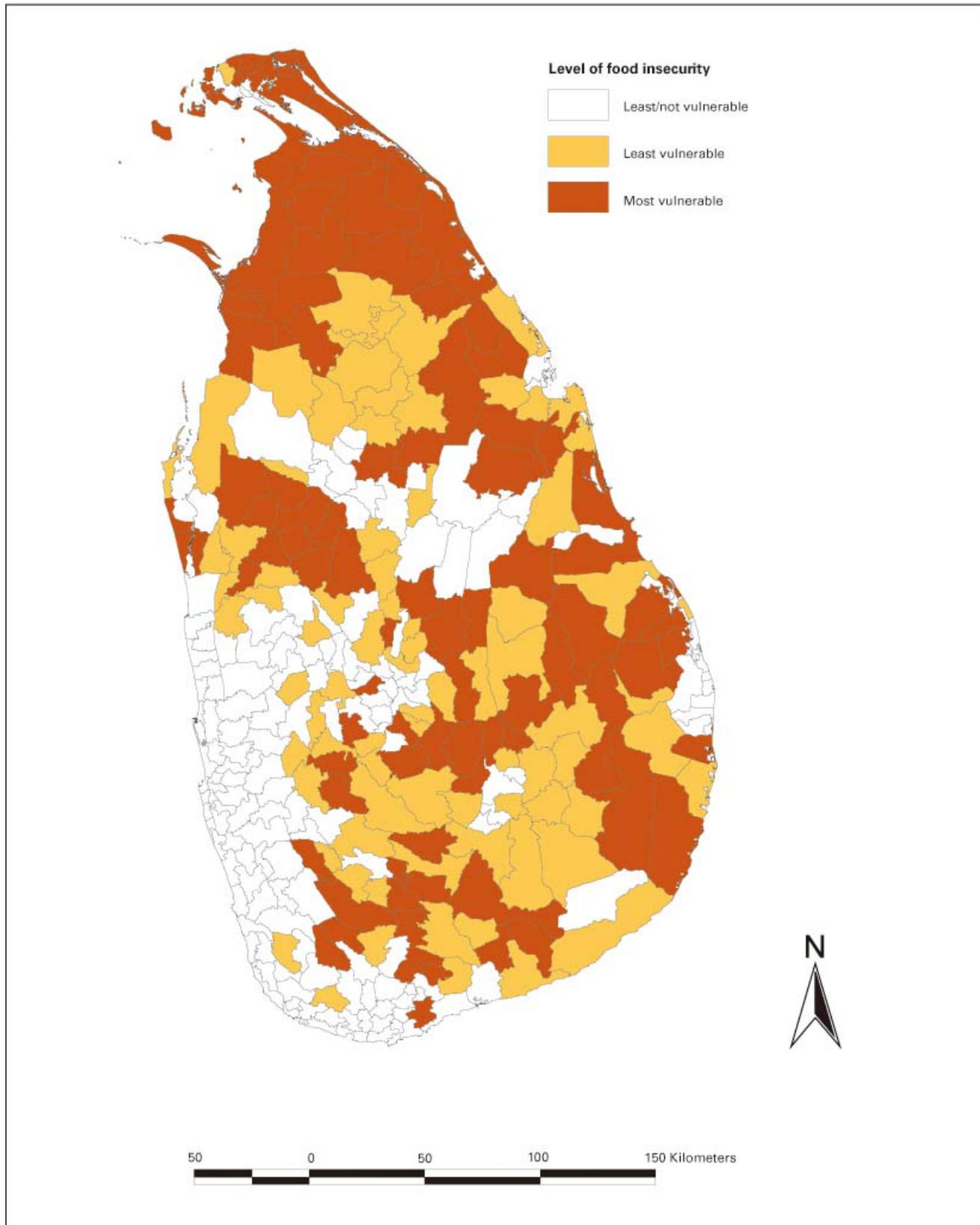


Figure 4.4. The food insecurity index of Divisional Secretariat Divisions (DSDs) as estimated by the World Food Programme



tiguous region is the western coastal region, which has higher rainfall, better infrastructure facilities, and industry. A second contiguous region with high food security is the area around Kandy which also has higher rainfall and better infrastructure facilities. A third contiguous areas is the region around Anurhadhapura, which has improved infrastructure, increased irrigation and lower population density. The higher food insecurity in the northern and eastern areas is due to a combination of war and dry climatic conditions punctuated by cyclones and heavy rainfall.

Economic activity

Industrial and infrastructure sectors account for the bulk of the national GDP (figure 4.5.a). Agriculture, animal husbandry, and fisheries provide livelihoods for one-third of the employed (figure 4.5.b), followed by employment in industries, infrastructure, and services. The disruption in agriculture, industry, and infrastructure caused by natural disasters is addressed below, along with descriptions of the salient features of these elements in relation hazards.

The Western Province had the largest provincial GDP (figure 4.6) with SL Rs 180 billion (US\$3.4 billion); the Central Province came in second with SL Rs 46 billion (US\$0.88 billion) at constant 1990 prices (UNDP 1998).

Agriculture: The primary food crop is paddy. The main *Maha* cropping season commences with heavy rainfall starting in late September and ends in March. A secondary season, *Yala*, extends from May to early September, and during this season only half of the agricultural land is cultivated because of limited supply of water. The major cash crops are tea, rubber, coconut, and spices; and their cultivation is largely in the wet regions. The agrarian economy is thus susceptible to disruption through droughts and floods. Our previous work has shown a link between rainfall variations and agricultural production (Zubair 2002). Note that there is an extensive irrigation network that modulates the spatial distribution of vulnerability.

Industry: The major industries are textile and apparel, food and beverage processing, chemical and rubber, and

mining and minerals. Industries are heavily concentrated in Colombo, Gampaha, and Kalutara in the Western Province. In the last two decades, industrial production has shifted from heavy industries for domestic consumption to export-oriented textile and other processing.

Industries are concentrated in a few regions in western Sri Lanka (figure 4.7) that are particularly prone to flooding. Drought in the Central Highlands can affect industry drastically through deficits in hydropower production. A quarter of the manufactured products are from the processing of agricultural products (tea, rubber, and tobacco). Thus, these industries could be affected by hazards that impact agricultural production.

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.

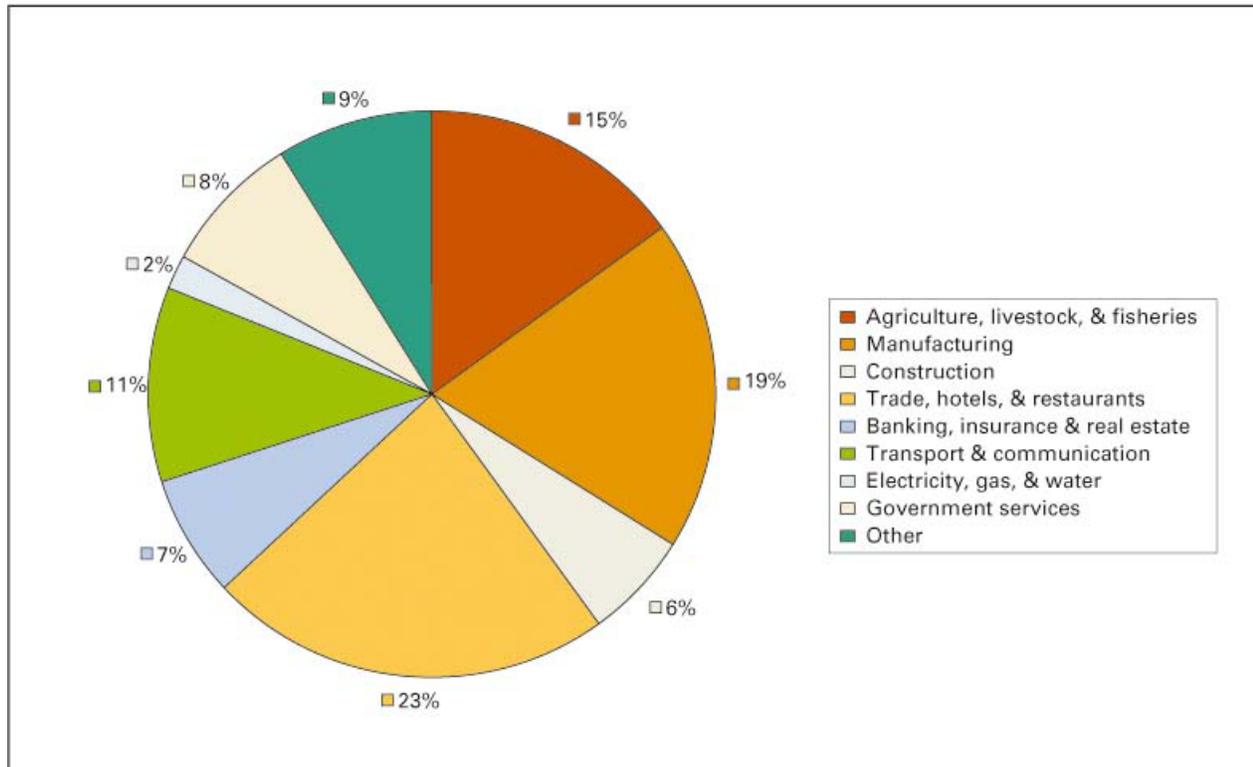
Roads: Sri Lanka has an extensive road network with better density and coverage compared with most developing countries.

Electricity Generation and Distribution: As of 1995, 53 percent of households had access to electricity. However, the spatial distribution of electricity availability ranges from more than 90 percent in Colombo and Gampaha to less than 40 percent for districts in the north and east (Gunaratne 2002). Of the total nationally generated electrical energy, approximately 60 percent comes from hydropower, putting it at high risk during drought periods. The droughts in 1995-96 and 2000-01 resulted in blackouts for the whole country.

Telephones: The density of telephones is low with 41 landlines and 23 cellular phones per 1,000 persons in 2000 (UNDP 1998). The spatial distribution of access indicates that Colombo has more than 50 percent of the landlines.

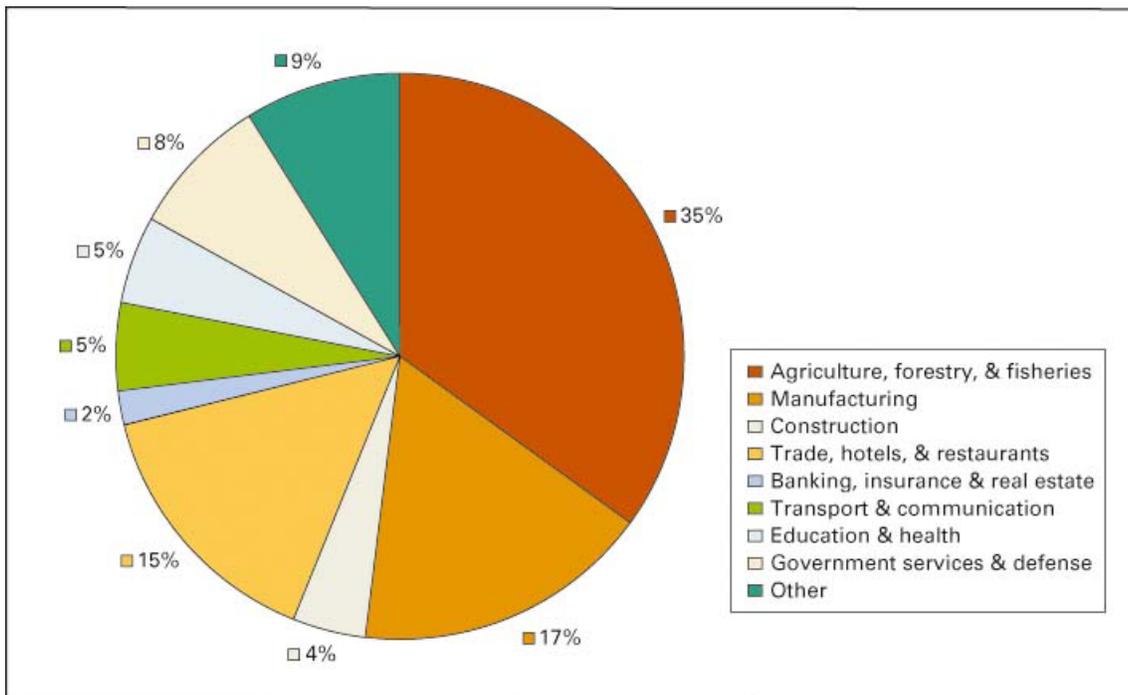
Separate indexes for roads, electricity, and telephone densities were analyzed to develop an infrastructure density index. The road index was constructed by nor-

Figure 4.5.a. Sectoral breakdown of the GDP for 2001



Source: Department of Census and Statistics 2001

Figure 4.5.b. Sectoral breakdown of the labor force for 2001



Source: Department of Census and Statistics 2001

Figure 4.6. The gross domestic product (GDP) by province for 1995

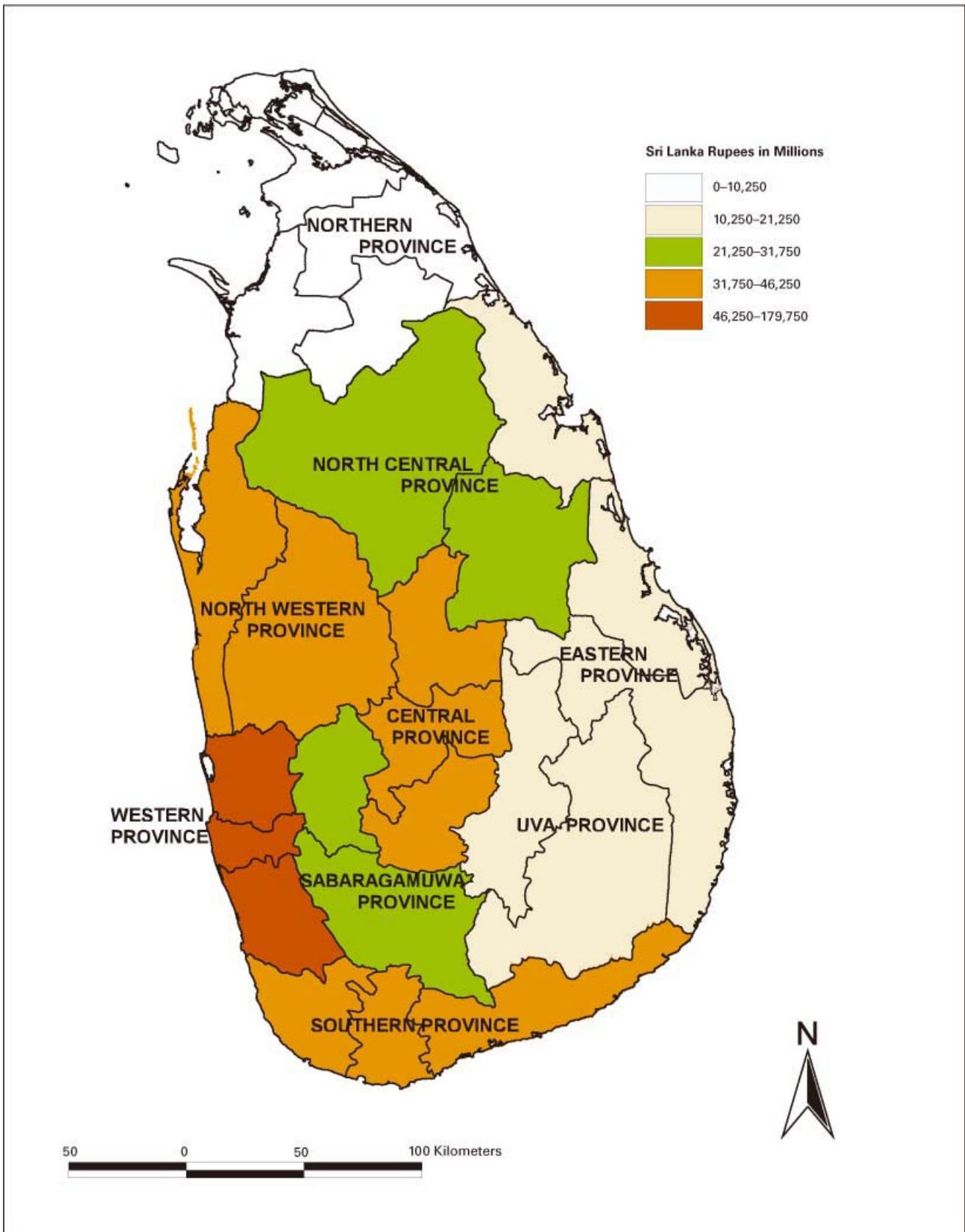
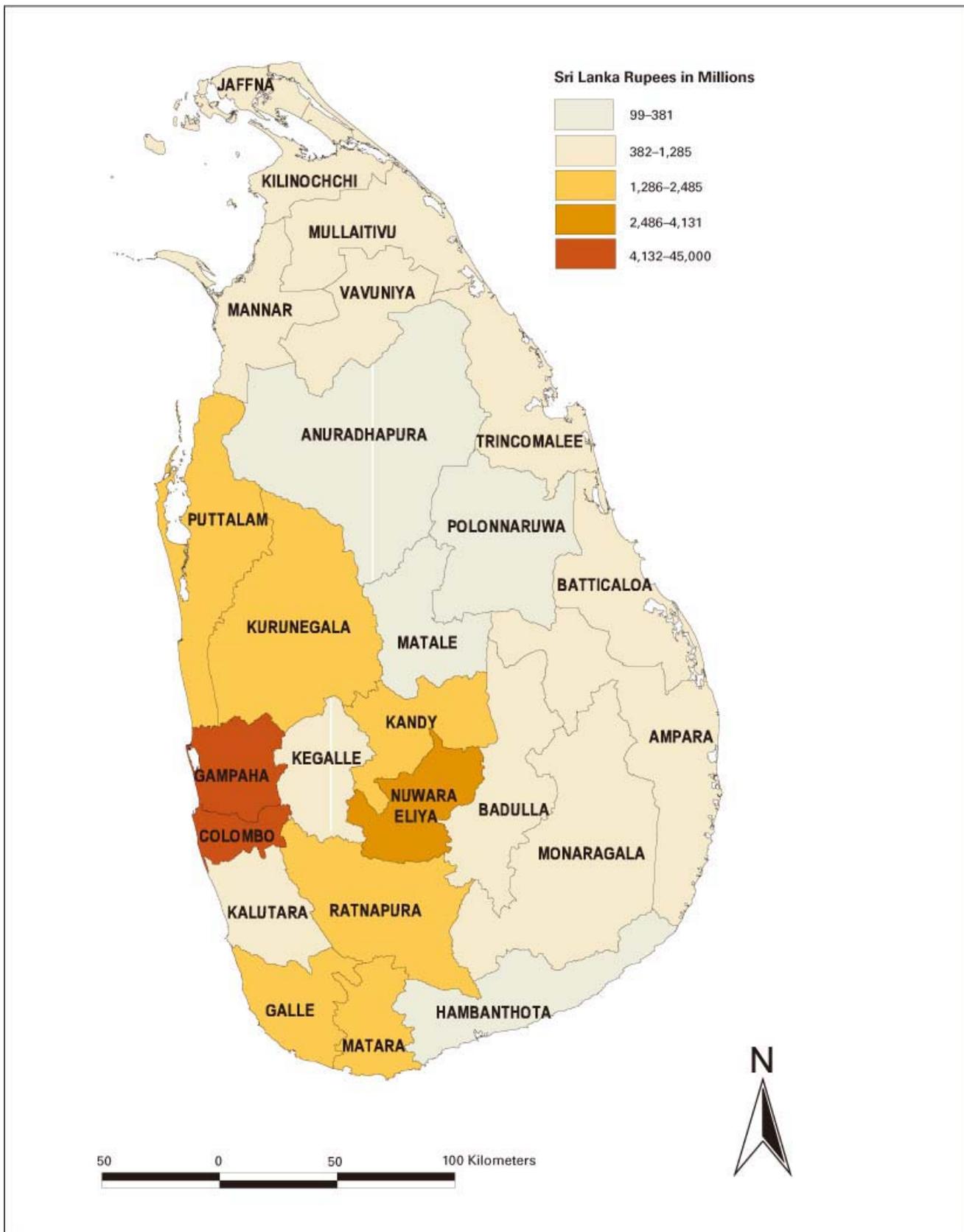


Figure 4.7. The estimate of industrial output in the districts in 1995



malizing the length of different categories of roads (classes A, B, and C) per district. The telephone and electricity indexes were constructed as the number of households that have access to these facilities in each district. These three indexes were evenly normalized and aggregated to create an infrastructure index (figure 4.8).

There is a high concentration of infrastructure facilities in Colombo. This skewed distribution is largely due to the heavy concentration of telecommunication facilities. Electricity and telephone facilities have been severely disrupted in the Northern Province because of the war, and there are no estimates of recent conditions. Thus, interpretation of the infrastructure index for these areas needs to be tempered with caution.

Infrastructure elements that are at risk from natural hazards include the road network (floods and landslides), electrical distribution system (floods, landslides, and cyclones), electricity generation (droughts), and telephones (floods, landslides, and cyclones).

Analysis of Individual Hazard Risks

Drought Hazard

Drought hazards can be estimated through the use of several methods. However the WASP indexes²³ developed by Lyon (2004) are the best option based on rainfall alone. Other indexes may be constructed by using stream flow, vegetation or soil moisture indexes, and so on, but these data are not available at adequate levels of resolution, reliability, and historical extent. Both 6- and 12-month WASP indexes were estimated for Sri Lanka (figure 4.9).

23. WASP is an acronym for the Weighted Anomaly Standardized Precipitation index. This index gives an estimate of the relative deficit or surplus of precipitation for different time intervals ranging from 1 to 12 months. In this case, analysis is based on 6-month and 12-month indexes. To compute the index, monthly precipitation departures from the long-term average are obtained and then standardized by dividing by the standard deviation of monthly precipitation. The standardized monthly anomalies are then weighted by multiplying by the fraction of the average annual precipitation for the given month. These weighted anomalies are then summed over varying time periods—here, 6 and 12 months. On the plots, the value of the given WASP index has itself been standardized. Regions with an annual average precipitation of less than 0.2 mm/day have been "masked" from the plot.

There is a stronger tendency toward drought in the southeastern district of Hambantota and the northwestern region, which includes the Mannar and Puttalam districts. The drought tendency is markedly less pronounced in the southwest corner of Sri Lanka where there is heavy rainfall.

A drought disaster risk map was constructed by weighting drought incidences for severity of the drought in terms of relief expenditure (figure 4.10). The drought hazard map constructed from rainfall data (figure 4.9) is similar to the drought disaster incidence map (figure 4.10), and this is evidence of the plausibility of hazard mapping. In the future, the drought mapping may be improved by taking into account factors such as surface water availability.

The drought disaster risk map shows marked spatial variability. There is low drought disaster risk in the western slopes and high drought disaster risk in the southeastern, northern, and northwestern regions. The highest drought disaster risk is in the Anuradhapura District followed by the Badulla and Batticaloa Districts.

Flood Hazard

Rainfall, river flows, and topographical data can be used to construct flood hazard maps. Such an effort needs hydrological modelling. An archive of satellite images, too, may be used to identify flood-prone areas with higher resolutions. However, the stream-flow data needed for hydrological modeling and satellite archives are not available with required consistency, resolution, and history to create high-resolution maps.

Given the purposes of this study and the 10 km resolution to which it is limited, flood hazards may be mapped by identifying instances in which extreme rainfall events were detected in the past. Flood hazard was estimated by identifying instances of monthly precipitation exceeding a threshold of 600 mm (figure 4.11).

A disaster incidence map of floods incurring losses was constructed by using the number of major floods in the last 50 years at district level using data from the Social Services Department and Dartmouth Flood Observatory (figure 4.12). The frequency was normalized over area and scaled from 1 to 100. There are similarities between the essential features of the flood hazard esti-

Figure 4.8. Infrastructure density index estimated for each district, as described in the text

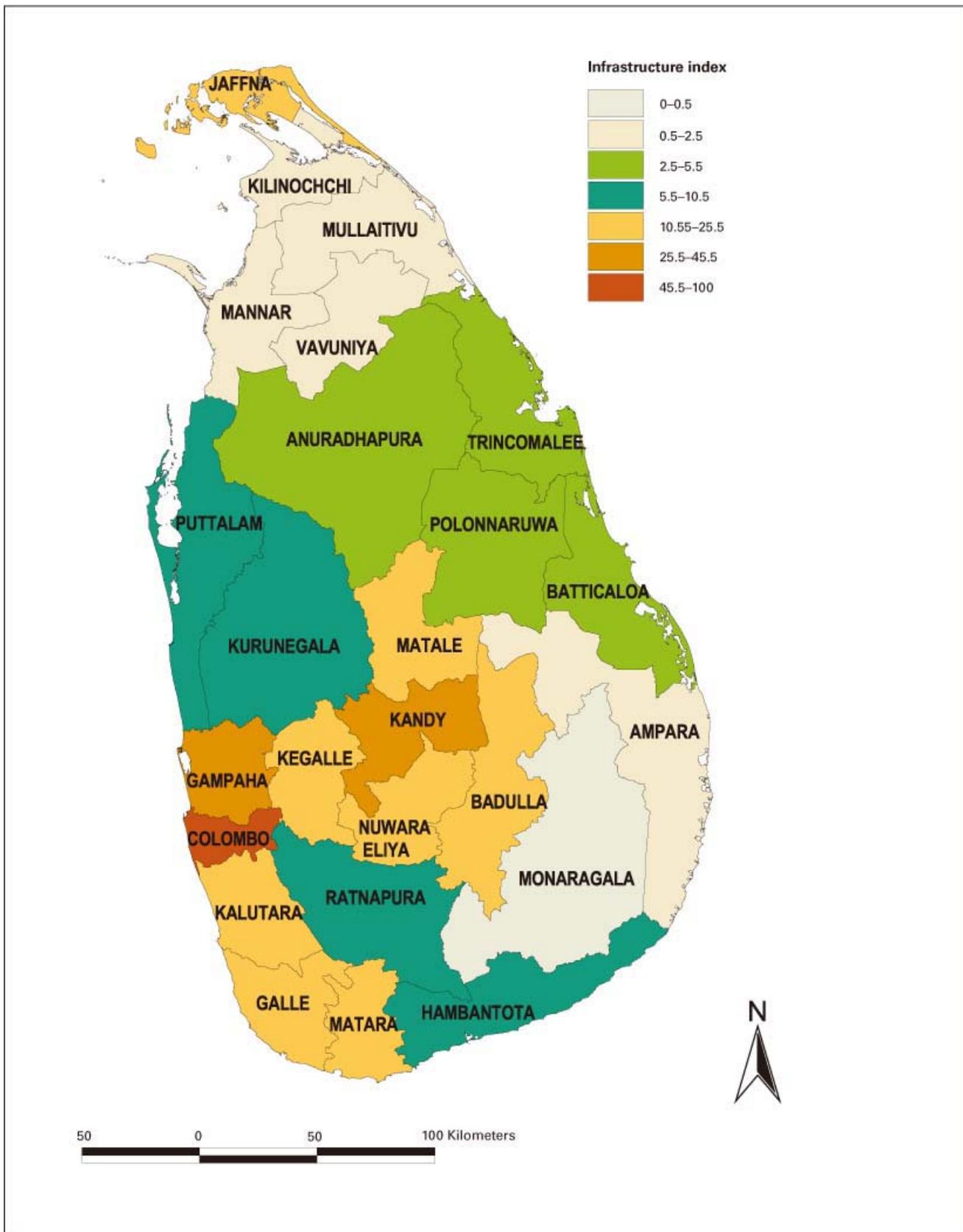


Figure 4.9. The drought hazard was estimated using a modified WASP index. The details of the WASP index are provided in the text. The negative WASP values (dry) were averaged over a 12-month period to identify drought prone regions. The hazard values were normalized so that they ranged between 0 and 100.

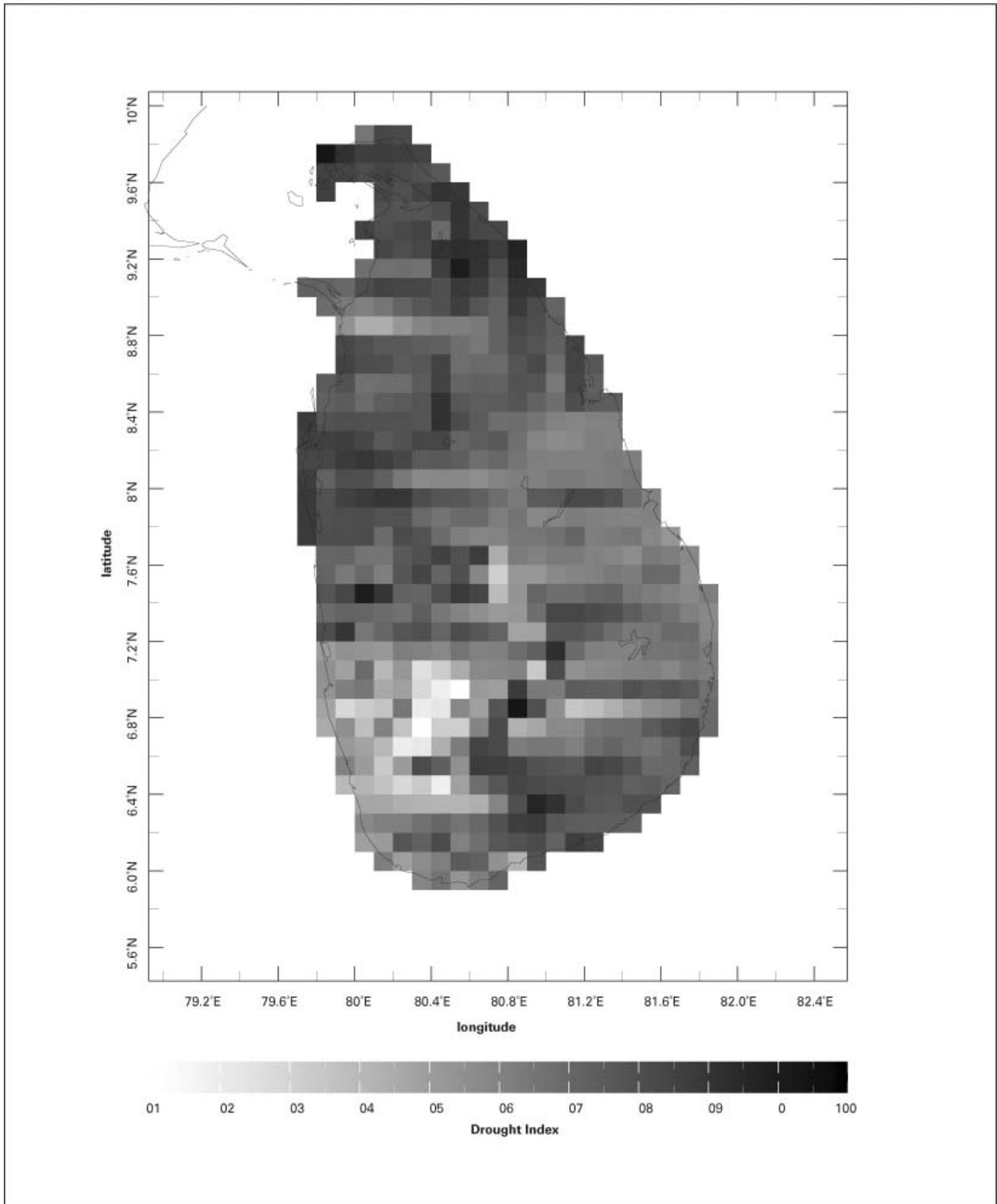


Figure 4.10. Drought disaster incidence frequency was constructed by aggregating the numbers of droughts that have been recorded in each district. Major droughts as categorized by the Department of Social Services were weighted by 1.5, medium droughts by 1.0, and minor droughts by 0.5

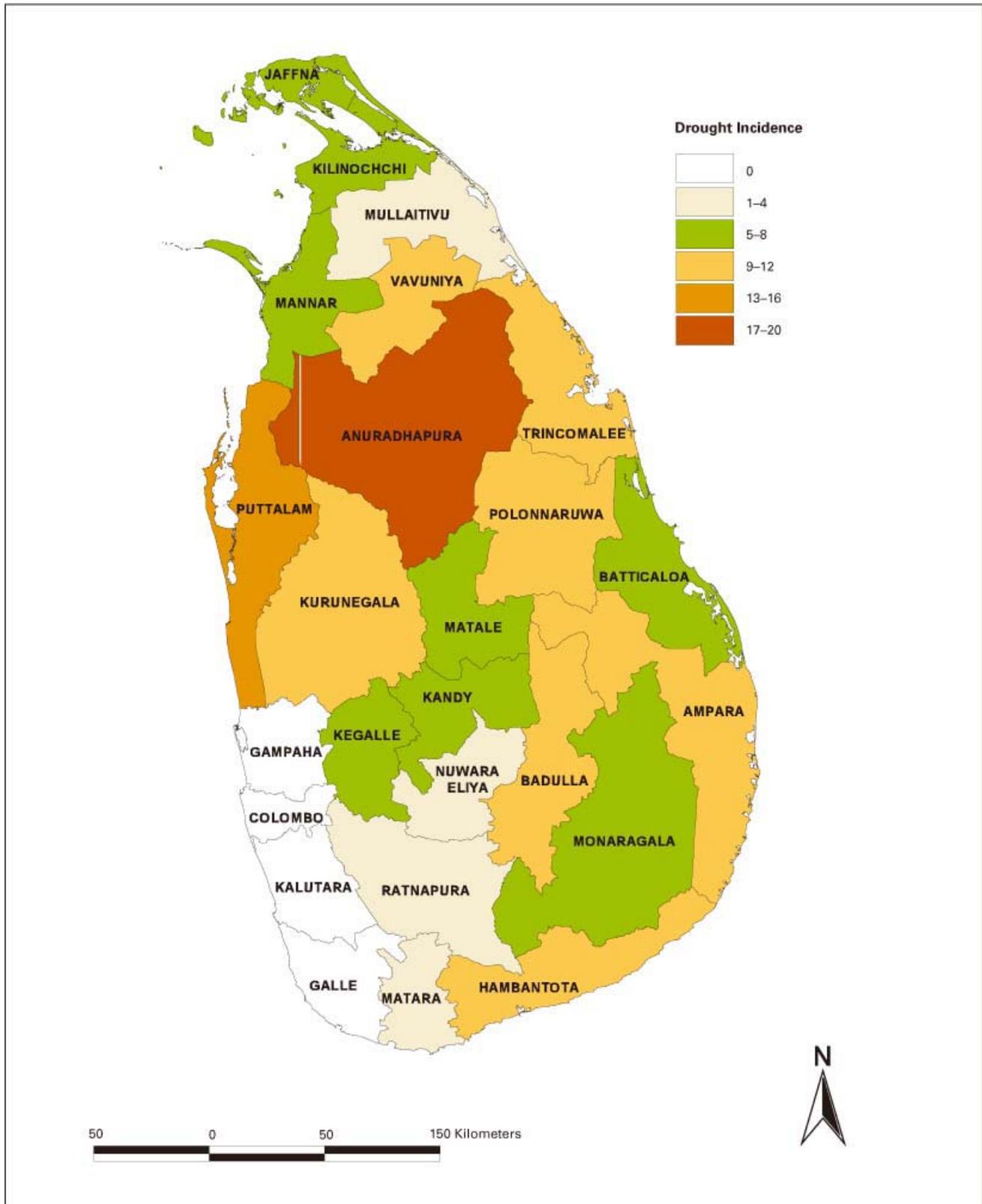


Figure 4.11. The flood hazard estimate based on the frequency of months of extreme rainfall using data between 1960 and 2000. The threshold chosen for extreme rainfall was 600 mm per month.

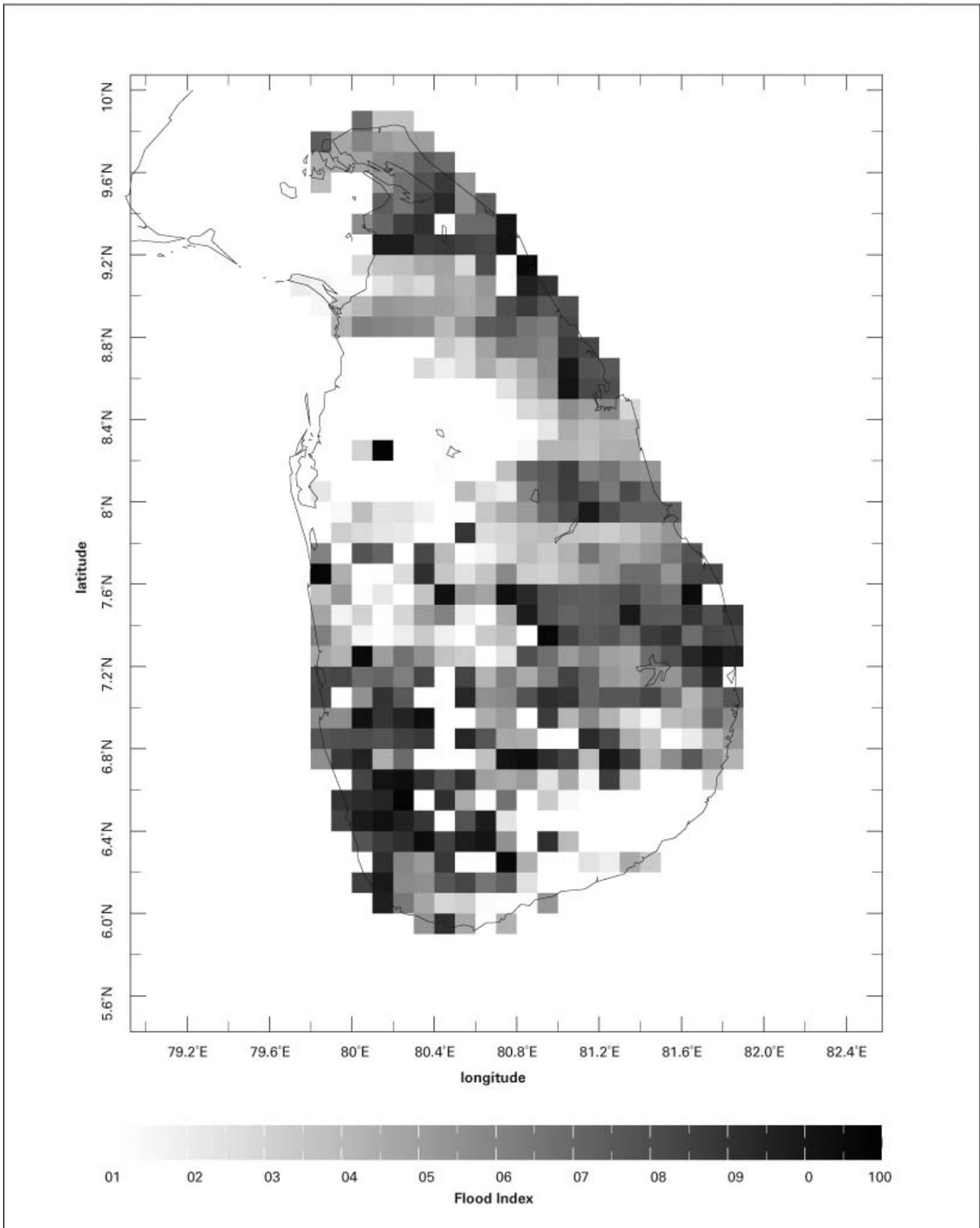
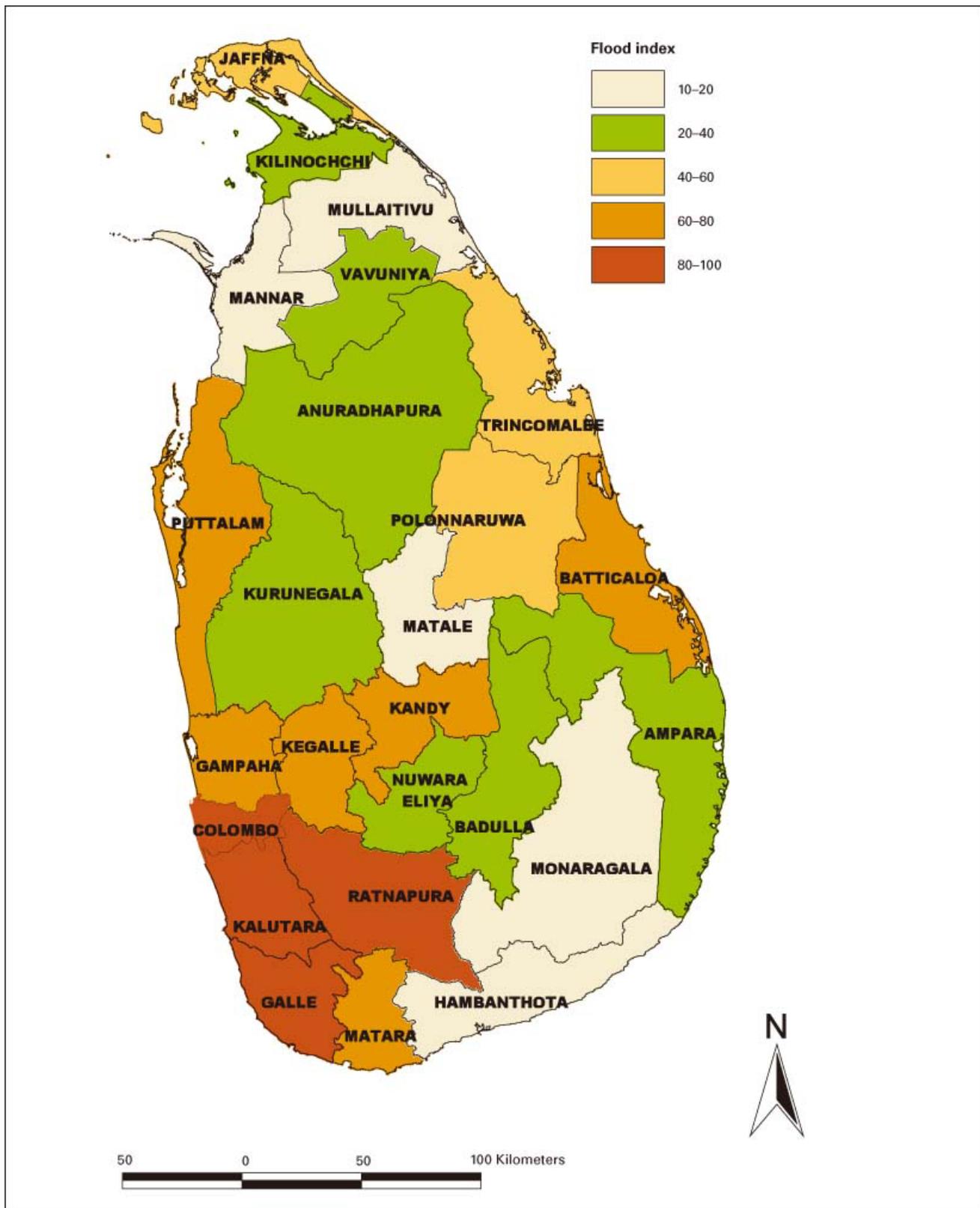


Figure 4.12. Frequency map of flood disaster incidence created by aggregating the numbers of floods recorded in each district between 1957 and 1995. Major floods, as categorized by the Ministry of Social Services, were weighted by 1.5 and minor floods were given a weight of 0.5. The index was normalized by area.



mates based on rainfall data and the above disaster incidence estimate.

We estimated the seasonal distribution of floods in the western and eastern regions separately (figure 4.13) based on 33 flood events in the EM-DAT database that had records of months of occurrence.

The flood hazard and disaster maps show high risk in the western, southwestern, northern, northeastern, and eastern parts of the country. The western slopes show the highest risk followed by the Batticaloa and Badulla Districts. The most flood-prone districts are Kegalle, Ratnapura, Kalutara, Kandy, Colombo, and Galle. These districts are located in the southwest part of the island. Flood occurrences in the eastern slopes and the northern plains coincide with the period of heavy rainfall (September to January) during the *Maha*. In the western slopes, floods do occur during the *Maha*, but are more common in the mid-*Yala* season, which lasts from May to August. These trends are also reflected in both hazard-risk and seasonal maps. Of the 33 flood events in EM-DAT, 20 events occurred in the November–January period (during the *Maha* rainfall season), including 3 cyclone-induced events. These flood events affected both the western and eastern parts of the island. Eleven events occurred during the May–July period (*Yala* rainfall season), which affected only the western slopes (figure 4.13).

Heavy rainfall in the eastern and southwestern slopes is a principal cause of the flood risk. The drainage and topography of certain districts and the land use patterns are also significant factors. For example, in the districts of Kegalle and Ratnapura, people have settled in flood plains and steep hill slopes. The eastern slopes receive most of the rainfall during the *Maha* season. This is also the cyclone and storm season that can bring heavy rainfall in short time periods. The Vavuniya District shows a higher flood probability caused by cyclonic storms. Even though their annual rainfall is lower than that of the western highlands, Vavuniya and Mullaitivu in the north have recorded the highest rainfall intensities on the island (Madduma Bandara 2000b).

Floods affect people, economic activities, and infrastructure. The high-risk regions in the western slopes have higher population densities, greater concentrations of industrial activity and infrastructure, and very high GDPs. The north-eastern high-risk region has high food insecurity.

Landslide Hazard

Landslide hazards affect people, infrastructure, and economic activities. Most high-risk DSDs (except in the Kalutara District) are within regions of high food insecurity. There is moderate economic activity in the high-risk regions. Transport by road and railway has frequently been affected, particularly in the hill country.

The National Building Research Organization (NBRO) has undertaken a detailed study of landslide risk in Sri Lanka. Landslide hazard mapping has been completed for five high-risk districts at a scale of 1:10,000. The NBRO methodology takes into consideration various factors, including slope-gradient, geology, soil cover, hydrology, and land use. Enhancement of this methodology is possible through the use of improved datasets for digital elevation modeling and hydroclimatic data and models.

For this study, the potential risk zones were identified at a resolution of 10 km in keeping with the resolutions of the other hazard and vulnerability data. Landslide incidence data from the NBRO was used to map the hazard risk. The event frequency data for each grid cell between 1947 and 1996 was used as the risk factor for landslides (figure 4.14).

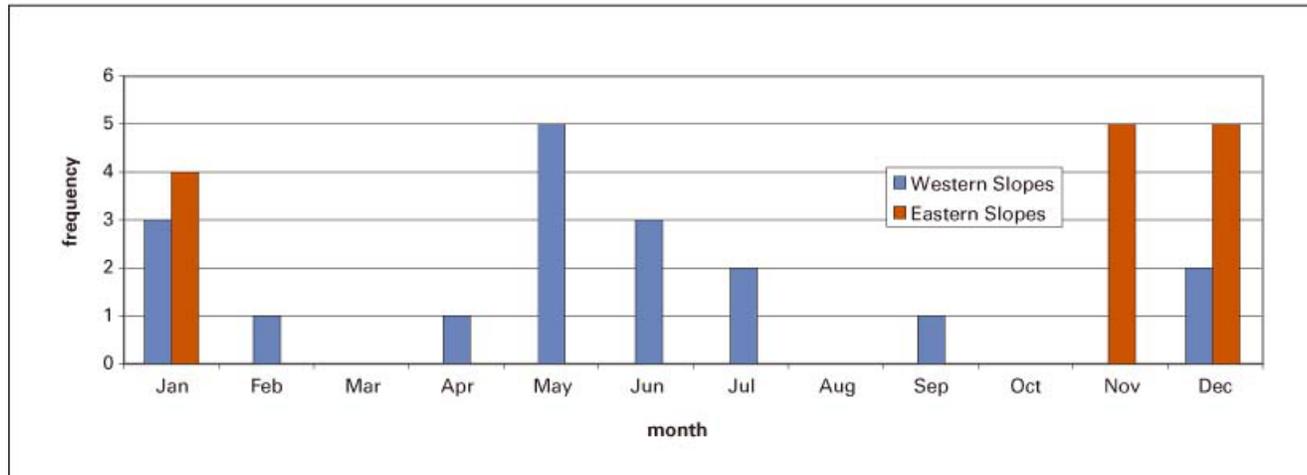
Eight districts in the central highlands are at risk. The highest risk is in the Kegalle District followed by Ratnapura and Nuwara Eliya Districts. Even within these districts there is spatial variability at the DSD level. The Kalutara, Kandy, and Badulla Districts have moderate risk, and Matale and Kurunegala Districts have slight risk.

The frequency of landslides has increased in recent years. 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—may be due to the increase. Sometimes, soil conservation programs, such as contour ditches, contribute to increases in landslide hazard risk by increasing soil saturation (Madduma Bandara 2000a).

Cyclone Hazard

Cyclones affect people, infrastructure, and economic activities. The high-risk areas in the north and the eastern seaboard have high food insecurity. Paddy fields are

Figure 4.13. EM-DAT data on floods from 1975 to 2001 were used to estimate the monthly frequency of floods in the Western Slopes and Eastern Slopes regions.



in high concentration in the hazard-prone region. The storm surge at landfall can be devastating. The storm surge of the 1978 cyclone extended up to 2 km inland in some areas. In addition to the storm surge, the intense gusting can be destructive. Intense rainfall that comes along with cyclones creates floods and flash floods.

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. The cyclones that pass through Sri Lanka originate from the Bay of Bengal during the northeast monsoon. Incidences of cyclones that pass through Sri Lanka in other seasons are rare due to geography and the regional climatology. There have been four severe cyclones during the last 100 years as well as a number of severe and moderate storms.

The available cyclone tracks from 1900 to 2000 were used to construct a map of cyclone hazard (figure 4.15). The frequency with which storms passed through a grid point was estimated. The immediate adjoining grid points were given an impact factor of half that given to grid cells that lay on the storm and cyclone track. Cyclones were weighted three times as heavily as storms. The northeastern seaboard has high hazard.

A cyclone seasonality graph was constructed by plotting the number of cyclones and storms that occurred in each month (figure 4.16). Cyclone incidence shows a strong seasonality, and 80 percent of all cyclones and storms occur in November and December.

Note that cyclone hazard mapping can be improved. Wind-speed modeling techniques that estimate deceleration after landfall can account for the diminishment of the intensity of storms over land. Wave and tidal models can be used to identify the risks from storm surges. Elevation maps and hydrological analysis can be used to identify flood-risk areas.

Assessing Multihazard Hotspots

A multihazard map was constructed by aggregating the hazard indexes for droughts, floods, cyclones, and landslides, with each hazard weighted equally (figure 4.17). This map shows the high risk of multiple hazards in the north. The Anuradhapura, Polonnaruwa, Batticaloa, and Trincomalee Districts in the northeast also feature high risk, as do the southwestern districts of Kegalle, Ratnapura, Kalutara, and Colombo. Regions with sharp gradients along the mountain massifs (Nuwara Eliya, Badulla, Ampara, and Matale) also show high risk of multiple hazards.

Disaster risk maps may be constructive by taking into account exposure and vulnerabilities in addition to hazards. Exposure and vulnerability are more difficult to quantify than hazards. A proxy for the combination of hazards and vulnerability may be constructed if it is assumed that the history of hazards provides a representation of future spatial variability. Such an approach needs long records of disasters and is based on the

Figure 4.14. A landslide hazard risk index was estimated based on frequency of incidence.

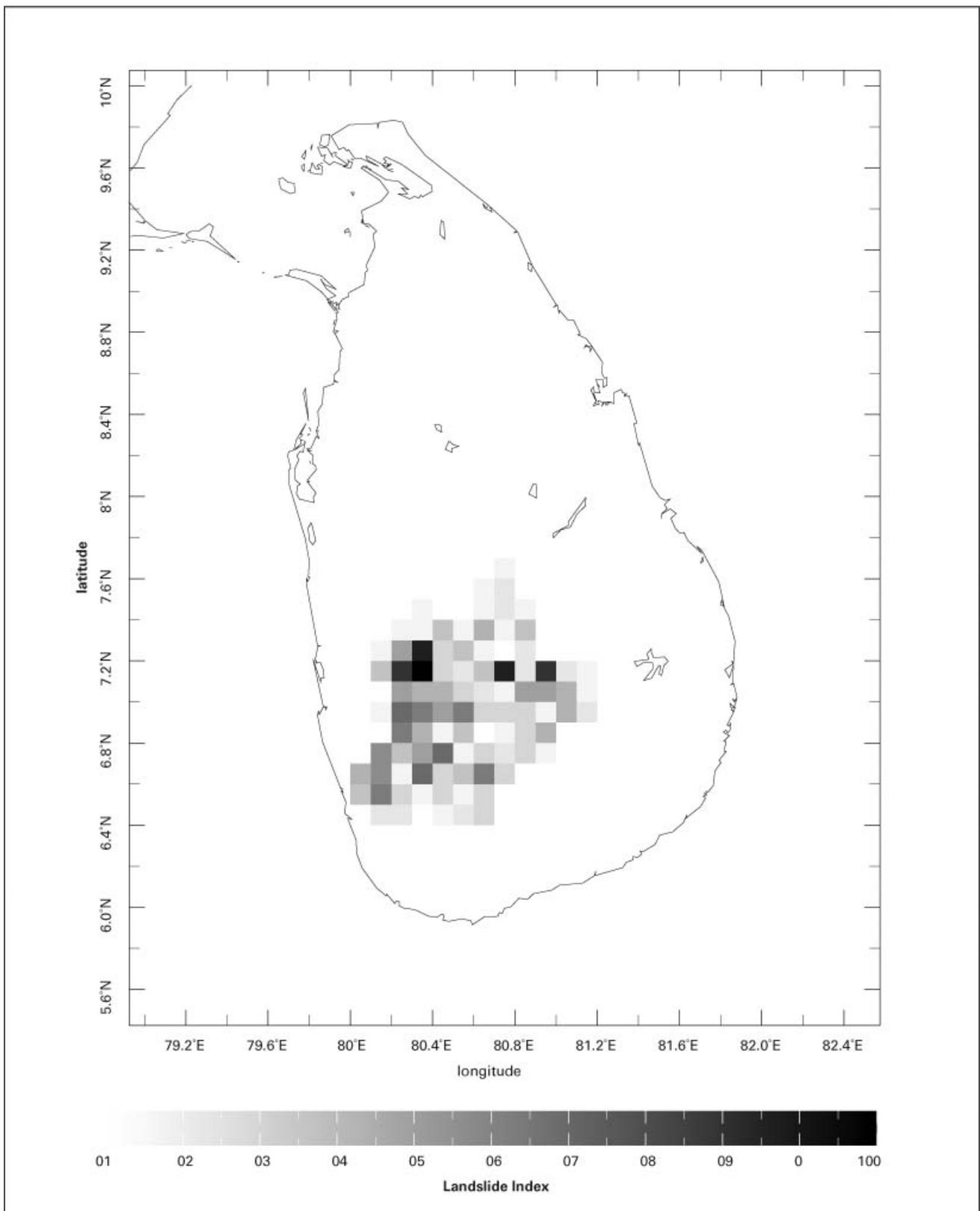


Figure 4.15. The storm and cyclone tracks for the last 100 years were used to create a cyclone hazard risk map.

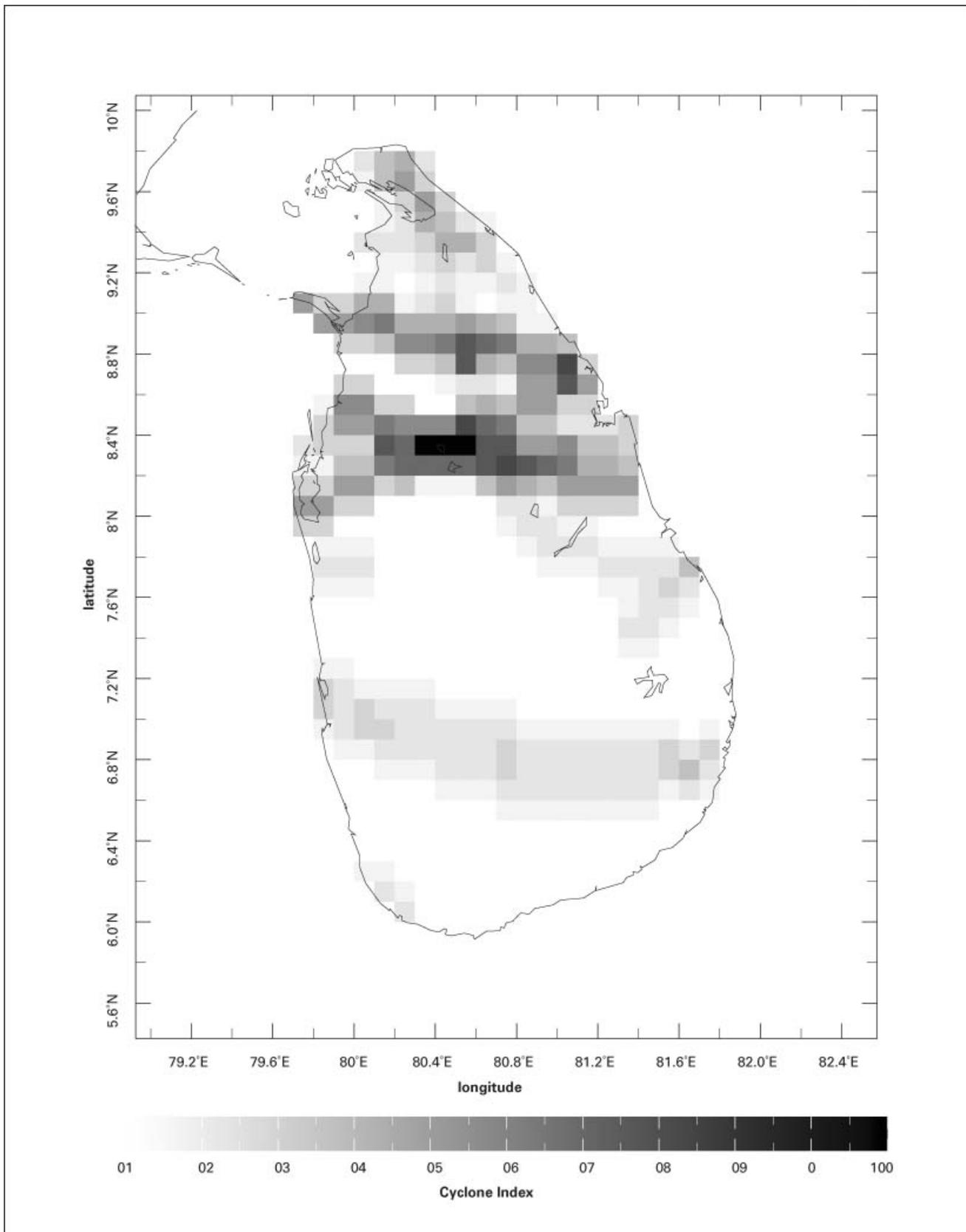
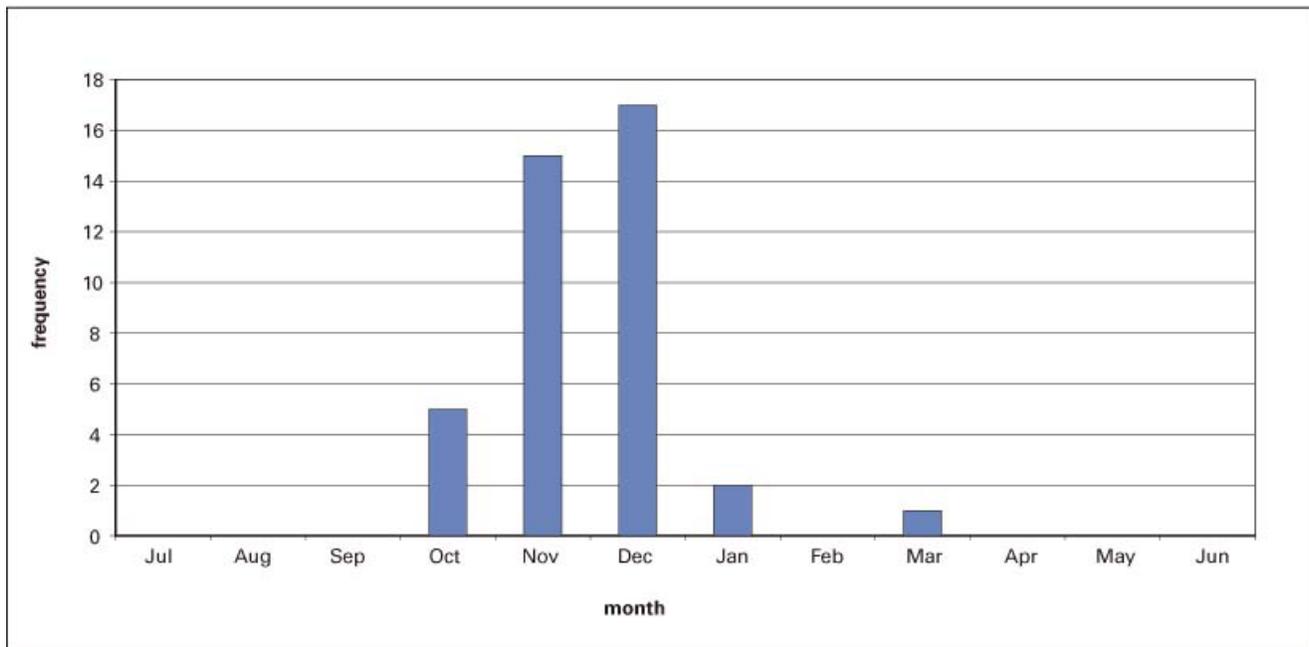


Figure 4.16. The monthly count of storms and cyclones between 1887 and 2000

assumption that the future occurrence of hazards, exposure, and vulnerability is similar to past occurrences. This assumption, while not precise, does enable us to provide an estimate of the variability of risk. More precise estimates must await more long-term data that have good spatial and temporal resolutions.

Subject to the highlighted limitations, records of disasters may be used to weight for exposure and vulnerability to particular hazards. Figure 4.18 shows the multihazard map with weights for each hazard based on the number of occurrences of each hazard from 1948 to 1992. Multiple landslides within a single year were treated as one event. This map gives greater weight to droughts and less weight to floods. The result, however, does not significantly differ from that produced with equal weight. There is high risk in some regions in the north and east in addition to the regions with the sharpest hill slopes in the south. The risks are also enhanced in the region around the Hambantota District in the south-east and around the Mannar District in the north-west.

The next figure (figure 4.19) is identical except that the data for the frequency of hazards were obtained from the EM-DAT database. There is high weight toward floods in this dataset. This map shows very low risk in the south-east and north-west and high risk in the north-eastern tip as well as the eastern and western slopes regions.

Note that for the period from 1948 to 1992, the EM-DAT data are weighted toward floods (Weights—Droughts: 9, Floods: 30, Landslides: 2, Cyclones: 3), whereas the data obtained from the Department of Social Services were weighted toward droughts and cyclones (Weights—Droughts: 27, Floods: 24, Landslides: 17, Cyclones: 10). The difference may arise from differing perceptions and criteria for identification as a disaster.

The final multihazard risk map (figure 4.20) was calculated by weighting each hazard index by the disaster relief expenditure for each hazard. This hotspots map is heavily weighted toward droughts and cyclones, with landslides receiving a meager weight. This hotspots map shows higher risk in the north and north-central regions and in the Hambantota District (south-east) compared with previous maps.

The various multihazard maps have differences but also show commonalities. Three regions emerge as having high risk in all maps. One is the region with sharp slopes in the south-west: the Kegalle District is the most risk prone, with significant risk of landslides and floods and moderate risk for droughts. The Ratnapura and Kalutara Districts also have high risk of floods and landslides. A second region is in the north-east: the Batticaloa, Trincomalee, Mannar, Killinochchi, and Jaffna Districts along the north-eastern coast show high multihazard risk.

Figure 4.17. Multihazard index constructed by aggregating the hazard indices and scaling the result to range between 0 and 100 (Weights: droughts: 1, floods: 1, landslides: 1, cyclones: 1)

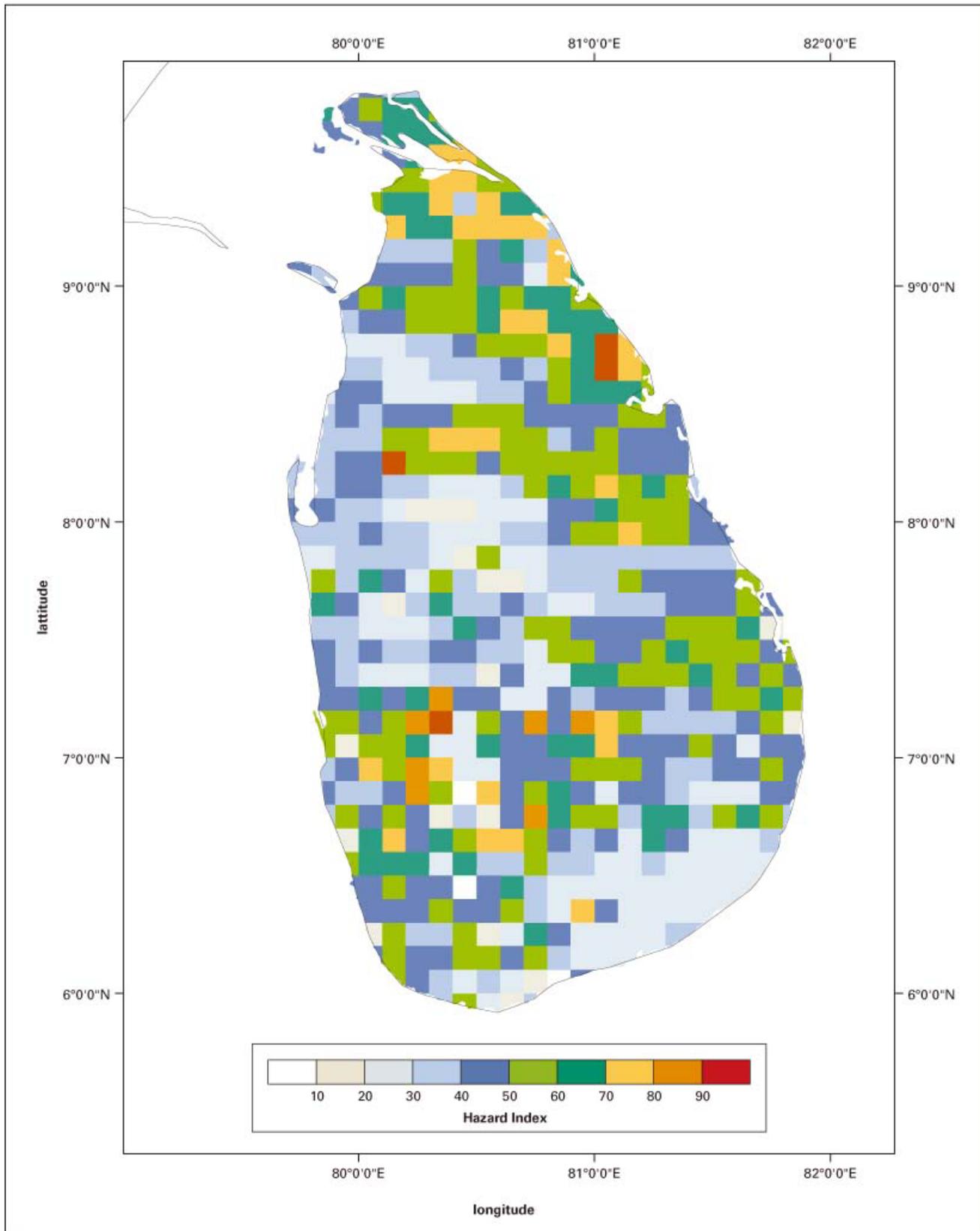


Figure 4.18. Multihazard risk estimated by weighting each hazard index by its frequency from 1948 to 1992 and rescaling the result to range from 0 to 100. The hazard incidence data was obtained from the Department of Social Services. (Weights: droughts: 27, floods: 24, landslides: 17, cyclones: 10)

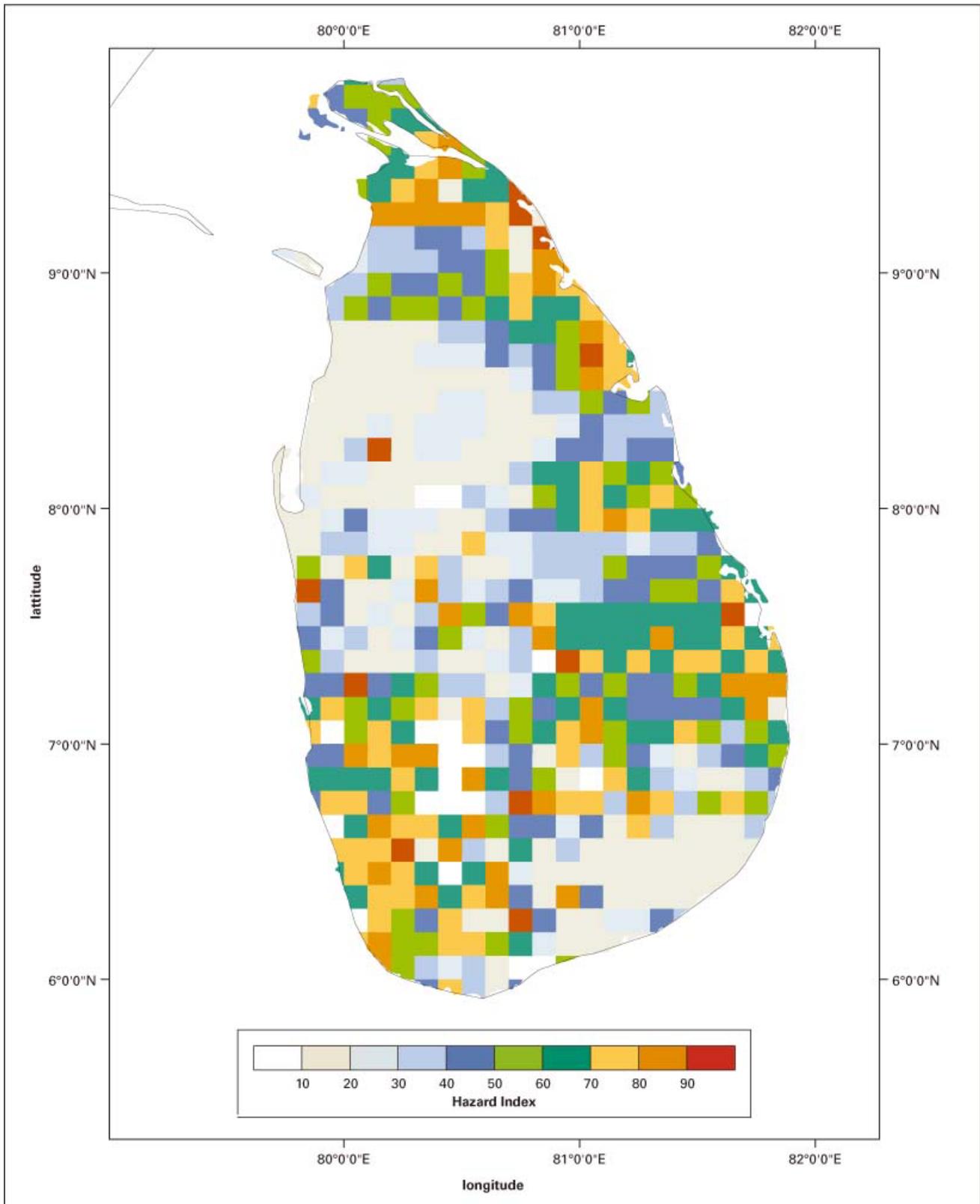


Figure 4.19. Multihazard risk estimated by weighting each hazard index by incidence frequency. (Weights: droughts: 9, floods: 30, landslides: 2, cyclones: 3) The result was rescaled to range between 0 and 100.

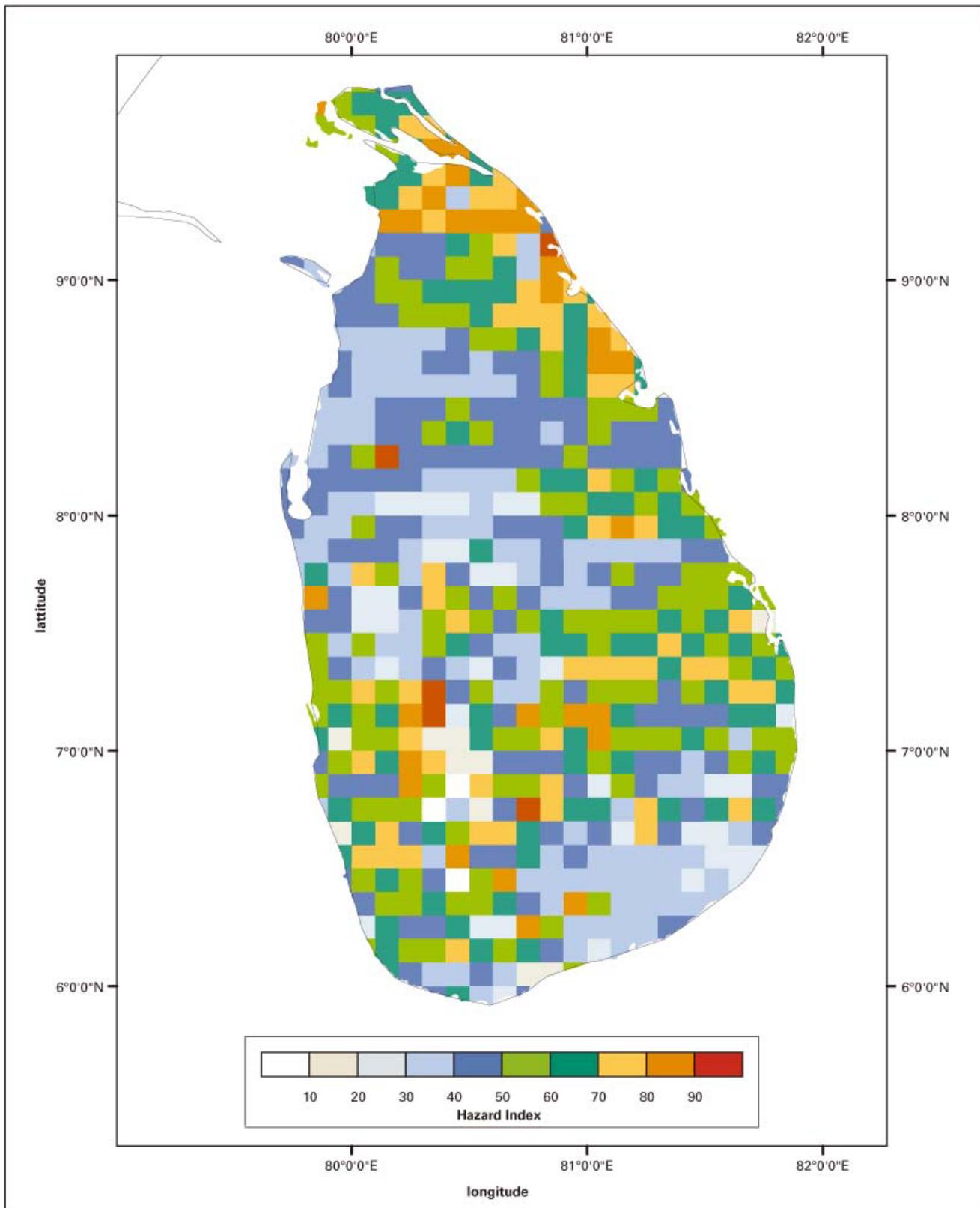
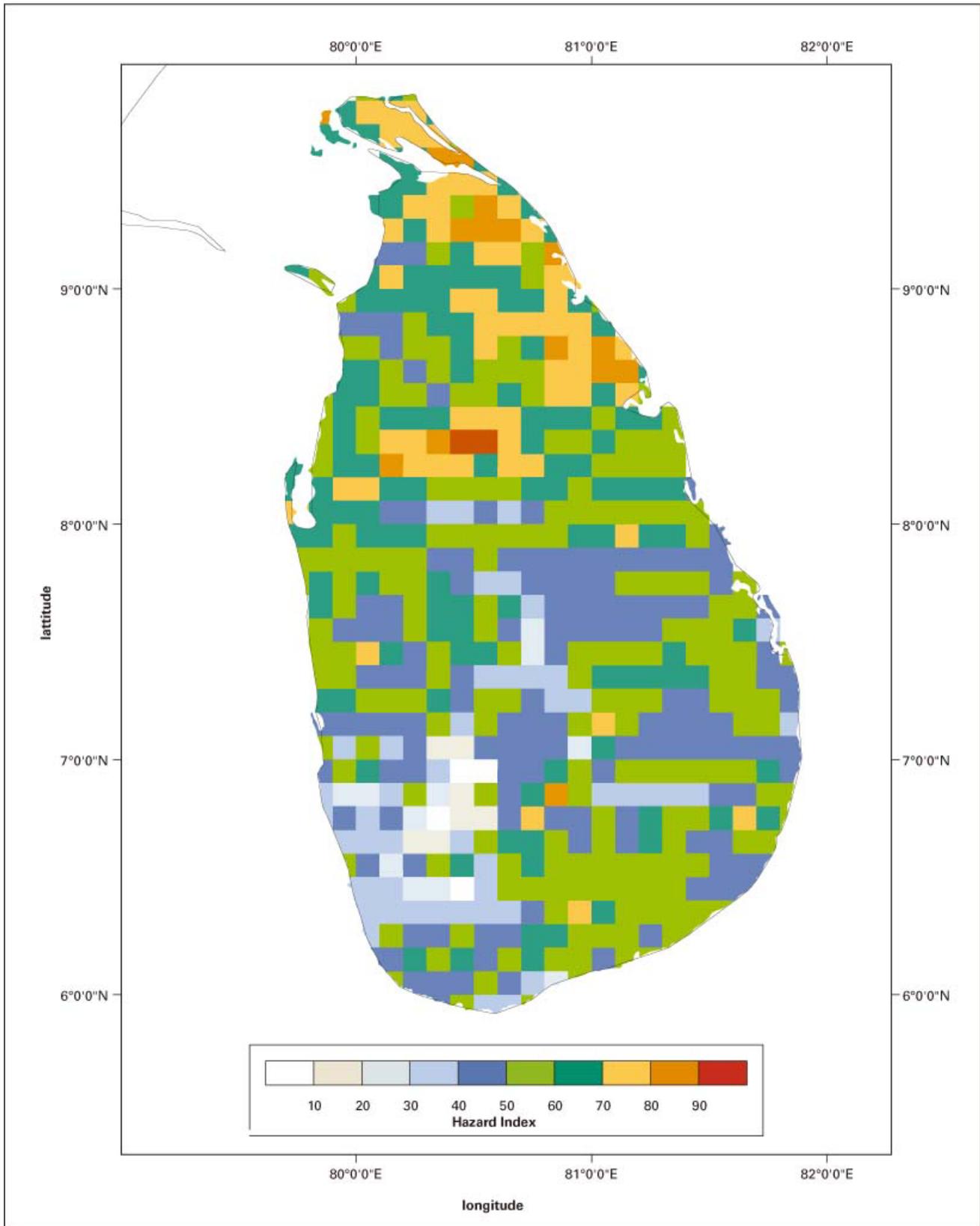


Figure 4.20. Multihazard risk estimated by weighting each hazard index by the associated relief expenditure between 1948–1992. (Weights: droughts: 126, floods: 25, landslides: 0.06, cyclones: 60)



A third region is along the mountain massifs with the sharpest hill slopes—this includes parts of the Nuwara Eliya, Badulla, Ampara, and Matale Districts.

Some of the high-risk regions have concentrations of economic output, agriculture, and industrial concentrations. Some regions in the southwest with high multihazard risk also have high food insecurity. The north shows high multihazard risk as well as high food insecurity. Rice cultivation in these regions is particularly vulnerable to drought and flood hazards.

Discussion

Spatial Variability

The use of data available in Sri Lanka 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.

Hazard Mapping Methodology

The hazard 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 datasets is the landslide hazard-mapping project carried out by the Sri Lanka NBRO.

Vulnerability Analysis

Hazard-specific vulnerabilities are needed at high resolution. Vulnerability analysis is more constrained by data limitations than by 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 about 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 cli-

mate variability (such as the effects of El Niño). The ability to predict shifts in climate up to six months in advance provides an opportunity to engage in predictive risk-mapping, as the climate of Sri Lanka is relatively predictable.

Long-Term Climate, Environmental, and Social Change

Both the climate and environmental change, such as deforestation and urbanization, affect the hazard analysis and, in ideal conditions, should have been included in the analyses. Such work is needed in the future. Here, we note that climate change is already making parts of Sri Lanka more vulnerable to drought. This is a development that shall have far-reaching ramifications.

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, migration, and the consequences of civil war.

Conclusions

We have presented an example of the use of physical and social data for fine-scale hazard and vulnerability analyses. This case study has demonstrated that the use of such fine-scale analyses recognizes crucial regional variations and is more useful than relying on currently available global-scale data.

We have presented methodologies for using fine-resolution gridded climate data to estimate droughts and floods and for using past-incidence data to estimate cyclones and landslides. Seasonal climate predictions can be factored into this methodology to yield hazard-risk predictions that exploit the emerging technology of seasonal climate predictions.

Vulnerability analysis is much less precise than hazard analysis. The approach adopted here considers the specific elements of people, economic activity, and infrastructure, and estimates these elements based on proxies, which has been shown to be viable with locally available data. Crucial spatial variations in vulnerability emerged in the higher-resolution maps that were not evident at coarser scales. Estimates of hazard-specific vulnerabilities had to be based on the assumption that

sufficiently long 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 the basic causes of regional variability, do not change substantively. However, long-term climatic, environmental, and social change needs to be investigated in the future and factored in the analyses.

Multihazard mapping is subject to limitations in the types of data that are available, particularly for exposure and vulnerability. There were multiple ways to weight the different hazards, 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 from the maps.

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