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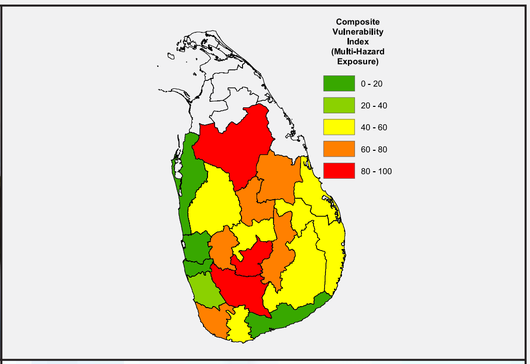
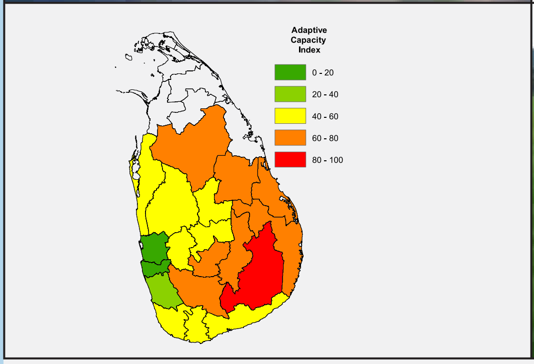
A Review and Preliminary Vulnerability Mapping

Nishadi Eriyagama, Vladimir Smakhtin, Lalith Chandrapala and
Karin Fernando





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Impacts of Climate Change on Water Resources and Agriculture in Sri Lanka: A Review and Preliminary Vulnerability Mapping

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Front cover photographs by Karen Conniff show the pure waters of a small tank near the Knuckles Range (top left) and the luscious green rice fields of Arankale (bottom right), both in Sri Lanka.

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Contents

Acronyms and Abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
CC	Climate change
CCD	Coast Conservation Department
CGCM	Canadian Global Coupled Model
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño-Southern Oscillation
EU	European Union
GCE	General Certificate of Education
GCM	General Circulation Model
GHG	Greenhouse gas
HadCM3	Hadley Centre Coupled Climate Model, version 3
IM1	First inter-monsoon
IM2	Second inter-monsoon
IPCC	Intergovernmental Panel on Climate Change
MAP	Mean annual precipitation
NEM	Northeast monsoon
NOAA	National Oceanic and Atmospheric Administration
PCM	Parallel Climate Model
PRECIS	Hadley Centre Regional Climate Modelling System
PSMD	Potential Soil Moisture Deficit
RCM	Regional Climate Model
RegCM3	REGional Climate Model, version 3
SWM	Southwest monsoon
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

Summary

There is ample evidence to suggest that Sri Lanka's climate has already changed. During 1961-1990, the country's mean air temperature increased by 0.016 °C per year, and mean annual precipitation decreased by 144 millimeters (mm) (7%) compared to that of 1931-1960. However, the bigger question of national importance is what Sri Lanka's climate will look like in 50 or 100 years and how prepared the country is to face such changes. Few studies attempted to project future climate scenarios for Sri Lanka and to identify climate change (CC) impacts on agriculture, water resources, the sea level, the plantation sector, the economy and health. This report reviews the status of CC research/activities in Sri Lanka in terms of observed and projected climatic changes, their impacts on water resources and agriculture (the two sectors most important for future food security), and CC mitigation and adaptation. The review suggests that Sri Lanka's mean temperature may increase by approximately 0.9-4 °C, over the baseline (1961-1990), by the year 2100 with accompanying changes in the quantity and spatial distribution of rainfall. These changes may lead to an increase in the *Maha* (wet) season irrigation water requirement for paddy by 13-23% by 2050 compared to that of 1961-1990. Future projections on coconut yield suggest that production after 2040 may not be sufficient to cater to local consumption. A reduction in the monthly rainfall by 100 mm could reduce productivity by 30-80 kilograms (kg) of 'made' tea per hectare (ha). The report also attempts to identify the country's agricultural vulnerability hotspots, as well as ascertaining existing knowledge gaps. This study developed a pilot level CC Vulnerability Index consisting of three subindices (Exposure, Sensitivity and Adaptive Capacity), which was subsequently mapped at district level. The maps indicate that typical farming districts such as Nuwara Eliya, Badulla, Moneragala, Ratnapura and Anuradhapura are more sensitive to CC than the rest of the country due to their heavy reliance on primary agriculture. Coupled with their low infrastructural and socioeconomic assets (or low adaptive capacity), and high level of exposure to historical hazards, these areas are the most vulnerable to adverse impacts of CC. The need for a more detailed assessment of vulnerability of the country's water resources and agriculture to CC is also advocated, as well as the need to formulate reliable future climate scenarios, and the setting up of a national water resources audit.

The Impacts of Climate Change on Water Resources and Agriculture in Sri Lanka: A Review and Preliminary Vulnerability Mapping

Nishadi Eriyagama, Vladimir Smakhtin, Lalith Chandrapala and Karin Fernando

Introduction

The Intergovernmental Panel on Climate Change (IPCC 2007) defines CC as "a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer." The definition refers to any change in climate over time, either due to natural variability or as a result of human activity. This differs from the definition of the United Nations Framework Convention on Climate Change (UNFCCC), where CC refers to "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (IPCC 2007). For the purpose of this study, the IPCC definition of CC is adopted, since generally research/ activities on CC that have been carried out in Sri Lanka do not differentiate between natural and human-induced variability. However, be it due to natural causes or human activity, a pronounced change in the country's climate is observed as evidenced by a number of recent studies (e.g., Chandrapala 1996b; Fernando and Chandrapala 1992; Basnayake et al. 2002; Zubair et al. 2005, Ratnayake and Herath 2005). Many of these studies were fed into the third and fourth assessment reports of the IPCC. After the Fourth Assessment Report (AR4) (IPCC 2007), which projected an alarming increase in global average temperature in the range 0.3-6.4 °C at the end of the twenty-first century, researchers have divulged even more disconcerting information on greenhouse gases (GHG) in the atmosphere (the build-up of which is the primary cause of global warming and associated changes in climate): Global carbon dioxide (CO_2) concentration in 2008 (387 parts per million (ppm)) was the highest on record in human history (NOAA 2009; Adam 2008); Present GHG emissions are 'far higher than even the worst case scenario' envisaged by the AR4 (Irwin 2009). In this context, limiting global temperature rise to 2 °C above pre-industrial levels (the EU long-term climate goal popularly regarded by many as 'the' climate target to achieve) is unlikely to be realized unless stringent reductions in GHG emissions are agreed on and adhered to. Such global changes are apt to impact the climate of individual countries even further. Sri Lanka, being an island state, is especially vulnerable to all identified impacts of CC including the rise in land and sea surface temperature, changes in the amount and pattern of precipitation, increase in extreme climate events, and sea level rise. These 'direct' impacts, in turn, trigger a wide variety of secondary effects on water resources, agriculture, livelihoods, health and well-being, the economy and nature. It is critically important that these impacts are identified, quantified, and suitable action is initiated to adapt to them. This report attempts to review the progress already made in this direction, especially with regard to water resources and agriculture, the two sectors most critical for ensuring Sri Lanka's future food security. An attempt is also made to map agricultural vulnerability hotspots, and identify key knowledge gaps and future research needs.

Present Climate, Observed Changes and Future Projections

Present Climate and its Observed Changes

Sri Lanka's long-term mean annual temperature in the lowlands is 27 °C while it is 15 °C at Nuwara Eliya (1,895 meters above mean sea level (amsl)) in the Central Highlands. Mean annual precipitation (MAP) ranges from under 1,000 mm in the northwestern and southeastern coastal areas to over 5,000 mm in the western slopes of the Central Highlands. The spatial pattern of precipitation is strongly influenced by topography and there are two seasonal wind regimes (Chandrapala 1996b). The Southwest monsoon (SWM) is from May to September and the Northeast monsoon (NEM) from December to February. There are two inter-monsoonal periods from March to April (first inter-monsoon (IM1)) and from October to November (second inter-monsoon (IM2)). The El Niño-Southern Oscillation (ENSO) is known to influence the country's rainfall (Suppiah 1996). Sri Lanka consists mainly of three climatic zones: the Wet Zone, Dry Zone and the Intermediate Zone (Figure 1(a)).

Time series of annual mean temperature anomalies from 1871-1990 show *a significant warming trend at most places in the country during the latter half of this period* (Chandrapala 1996b; Fernando and Chandrapala 1992). The rate of increase in temperature from 1961 to 1990 is 0.016 °C per year (Chandrapala 1996b) (the global average for the period 1956-2005 is 0.013 °C per year (IPCC 2007)). Sri Lanka's 100-year warming trend from 1896 to 1996 is 0.003 °C per year (IPCC 2001), while it is 0.025 °C per year for the 10-year period 1987-1996 (Fernando 1997), indicating a faster warming trend in more recent years. Seasonal mean temperatures for the *Yala* (April–September) and the *Maha* (October–March) agricultural seasons also display similar warming (Basnayake et al. 2002). Mean (annual and seasonal) daytime maximum and mean (annual and seasonal) nighttime minimum air temperatures have both increased during the period 1960-2001 (Basnayake et al. 2002; Zubair et al. 2005) with trends of 0.026 °C and 0.017 °C per year, respectively (Zubair et al. 2005). Scientists attribute this warming trend seen throughout the country to both the enhanced greenhouse (global) effect as well as the 'local heat island effect' caused by rapid urbanization (Basnayake 2008; Basnayake et al. 2003; Fernando and Basnayake 2002; Emmanuel 2001). Figure 1(b) shows the variation of observed warming trends in mean annual temperature across the country.

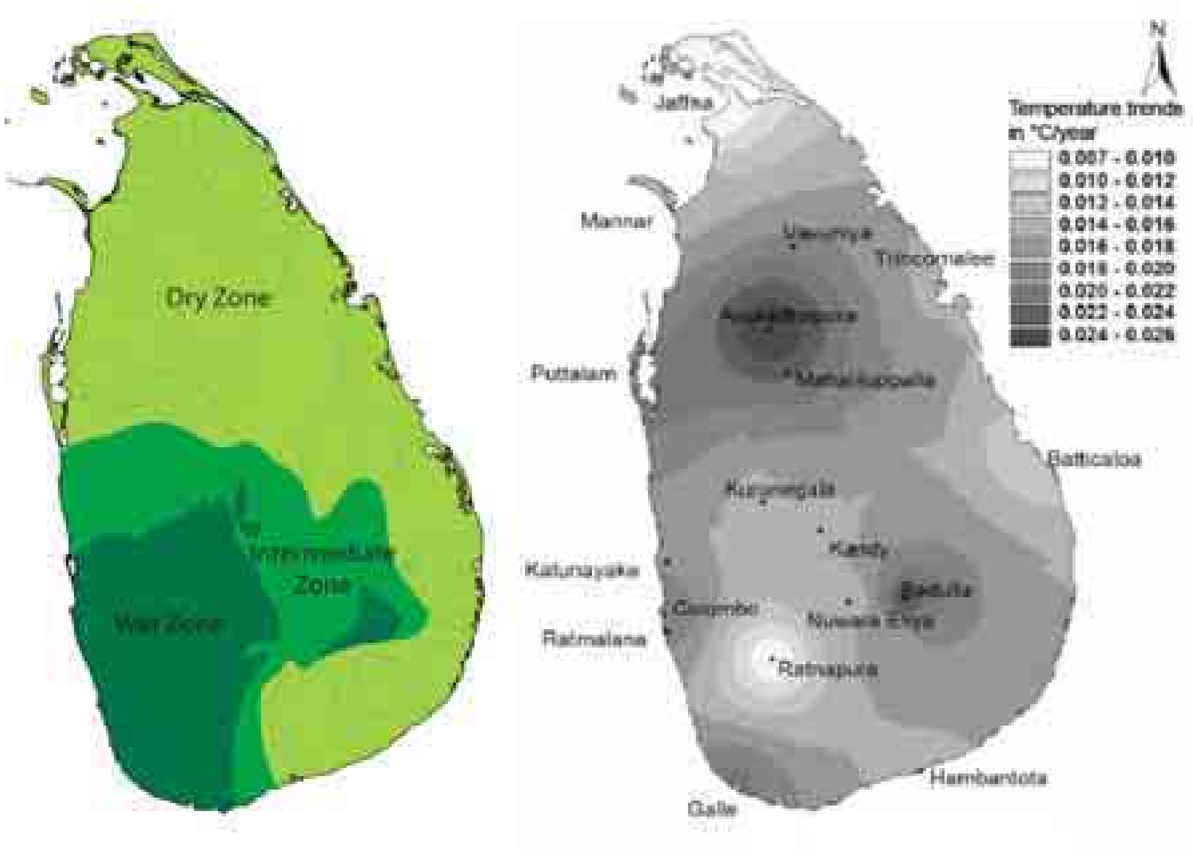


FIGURE 1. (a) Climatic zones of Sri Lanka and radial draining rivers; and (b) observed warming trends in mean annual temperature (*Source:* Zubair et al. 2005).

There is no significant trend in Sri Lanka's MAP during the last century although higher variability is evident (Jayatillake et al. 2005). However, the MAP of Sri Lanka, estimated using Thiesson Polygon Method, has decreased by 144 mm (7%) during the period 1961-1990 compared to that estimated for the period 1931-1960 (Chandrapala 1996a; Jayatillake et al. 2005); Rainfall data for the period 1949-1980 at 13 stations reveal decreasing trends with steeper downward trends in recent decades (Jayawardene et al. 2005). There is wide disparity in the magnitude of changes that have taken place in different rainfall seasons and different spatial locations. Although no significant changes in rainfall amount have been observed during the SWM (mean 546 mm) and IM2 (mean 548 mm), rainfall in the NEM (the *Maha* season when the majority of agricultural areas in the country receive rainfall - mean 459 mm) and IM1 (mean 260 mm) has reduced, with NEM showing increased variability (Jayatillake et al. 2005; Basnayake et al. 2002).

A few authors have made observations on rainfall in the Central Region. An analysis of interannual as well as intra-annual rainfall trends of the Central Region from 1964-1993 suggests that there is a decrease in MAP, with the highest decrease being shown during IM1 (Herath and Ratnayake 2004). Shantha and Jayasundara (2005) observe a 39% decrease in MAP in the Mahaweli headwater areas in the Central Highlands of the country from 1880 to 1974. Madduma Bandara and Wickramagamage (2004) indicate that rainfall on the western slopes of the Central Highlands has declined significantly from 1900 to 2002 due to a reduction in rainfall during the SWM in this region (western slopes of the hill country receive the highest MAP in the country, often exceeding 5,000 mm). *The reduction in observed rainfall in the Central Region is attributed to the interaction of both global and local factors* (Wickramagamage 1998). In the country as a whole, the number of consecutive dry days increased while the number of consecutive wet days reduced (Ratnayake and Herath 2005; Premalal 2009). Recent analysis of the spatial pattern of rainfall also indicates an expansion of the dry zone (MAP < 1,750 mm) (Figure 2).

In addition to the above, *the intensity and frequency of extreme climate events (floods and droughts) have increased* in recent times triggering an increase in natural disasters (Imbulana et al. 2006; Ratnayake and Herath 2005): the country has already experienced two years of serious drought and one major flood event within the first five years of the twenty-first century (Imbulana et al. 2006). The districts of Ratnapura and Kalutara generally experience floods twice a year. However, the number of incidences increased to four times (with one very severe event) during 2008, as a result of an unusually high number of heavy rainfall episodes. According to Ratnayake and Herath (2005), the daily rainfall intensity (amount of rainfall per rainy day) and the average rainfall per spell have both increased in most parts of the country. High correlation between areas having increasing rainfall intensities and the locations of past landslides is observed (Ratnayake and Herath 2005). Upward trends in the number of thunder days during IM1 has been observed in Colombo (annual mean 84) and Badulla (annual mean 79) over the period 1951-1990 (Fernando and Chandrapala 1994).

The current rate of sea level rise in coastal areas of Asia is reported to be 1-3 mm/year which is marginally higher than the global average (Cruz et al. 2007). Evidence also suggests an accelerated rate of sea level rise in Asia over the period 1993-2003 (3.1 mm/year) compared to that over the twentieth century as a whole (1.7 to 2.4 mm/year) (Cruz et al. 2007). However, the specific rate of rise in seas immediately surrounding Sri Lanka is not known.

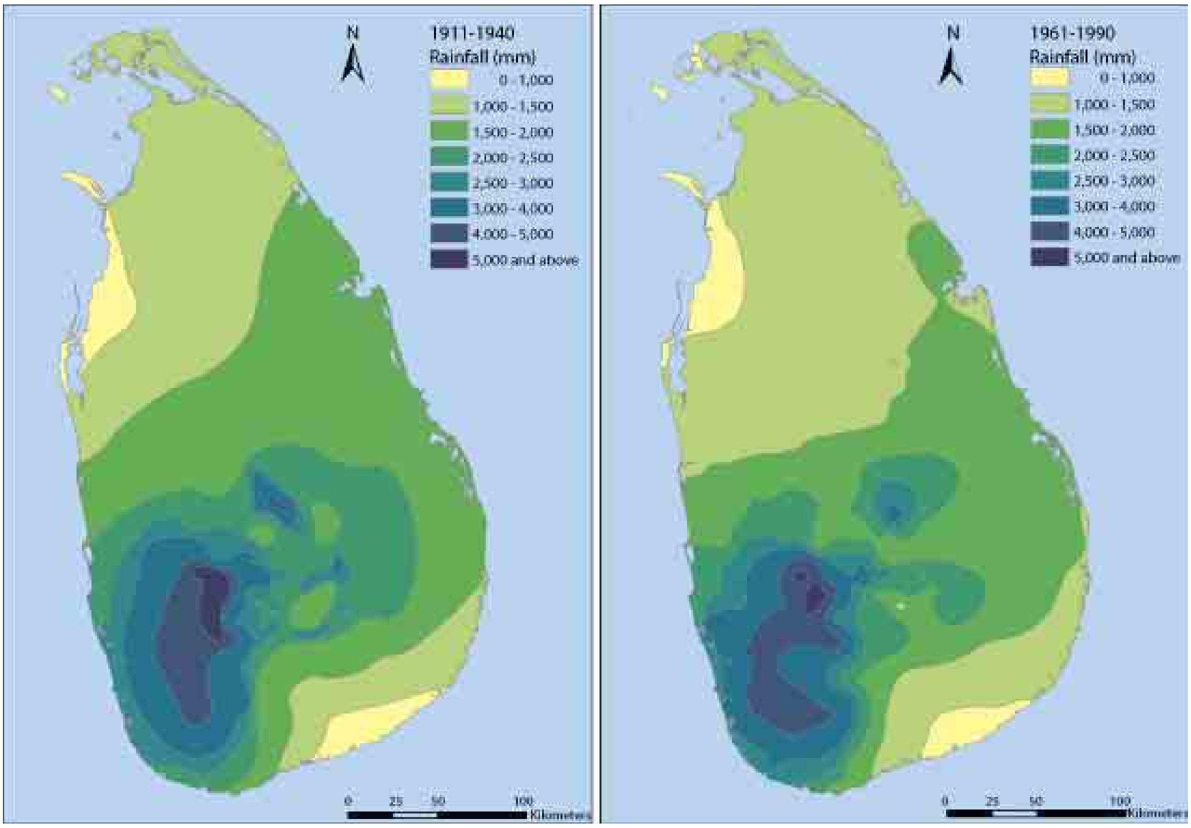


FIGURE 2. A comparison of average precipitation during (a) 1911-1940, and (b) 1961-1990, indicating expansion of the dry zone (MAP < 1,750 mm) (*Source:* Imbulana et al. 2006)(Prepared by U. R. Ratnayake, Department of Civil Engineering, University of Peradeniya, Sri Lanka).

Future Climate Projections

Studies which spell out future climate scenarios for Sri Lanka are scarce and even the ones that exist appear to have contradictory projections, especially with respect to future rainfall. However, a few projections for South Asia and Sri Lanka are available mainly from three modeling approaches: General Circulation Models (GCMs), Regional Climate Models (RCMs), and statistically downscaled GCM projections. GCMs try to numerically mimic complex, natural and dynamic climate processes occurring at the coarse global scale; they generally have a spatial resolution around 3° x 3° (latitude by longitude) (Santoso et al. 2008). The Hadley Centre Coupled Climate Model, version 3 (HadCM3) (*http://cera-www.dkrz.de/IPCC_DDC/IS92a/HadleyCM3/Readme.hadcm3*), the CSIRO Global Climate Model (*http://www.ipcc-data.org/sres/csiromk2_info.html*) and the Canadian Global Coupled Model (CGCM) (*http://www.ipcc-data.org/sres/cgcm1_info.html*) are examples of GCMs. The use of GCM projections for impact assessment at the local level, such as in a small country like Sri Lanka, requires disaggregation of the coarse resolution of GCMs to a finer resolution, known as downscaling or regionalization. One such method of downscaling is the creation of a RCM, which is a separate high resolution climate model simulated for a limited area, using GCM output as the boundary condition controlling the simulation (Santoso et al. 2008). PRECIS (*http://precis.metoffice.com/*) and RegCM3 (*http://users.ictp.it/RegCNET/model.html#History*) are examples of regional climate models. Statistical downscaling, on the other hand, identifies statistical relationships between local climate variables (surface air temperature, precipitation, etc.) and large-scale predictors; it then applies such relationships to simulate local climate characteristics from GCM experiments, with the assumption that these statistical relationships remain the same in the future (Santoso et al. 2008).

All climate models use scenarios or ‘storylines’ of possible future changes in the world. Scenarios published by the IPCC in its Special Report on Emissions Scenarios (SRES) are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways in terms of population and GDP growth, energy use, land use changes, fossil fuel use, etc., and resulting GHG emissions (IPCC 2000). The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI-highest future emissions), non-fossil energy sources (A1T) and a balance across all sources (A1B). B1 (lowest future emissions) describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change (IPCC 2000). Climate projections for South Asia and Sri Lanka are available for scenarios A1, A1FI, A2, B1 and B2 through the three modeling approaches described earlier (Table 1; Figure 3).

TABLE 1. Projected increase in mean annual temperature by 2100.

Source	Model	Scenario	Base year	Change at end of the twenty-first century (unless otherwise stated)
Cruz et al. 2007 IPCC 2007	AOGCM	A1FI	1961-1990	+5.44 °C (South Asia)
		B1	1961-1990	+2.93 °C (South Asia)
Kumar et al. 2006	RCM (PRECIS)	A2	1961-1990	+2.5 to +4 °C (spatially across Sri Lanka)
		B2	1961-1990	+2 to +3 °C (spatially across Sri Lanka)
Islam and Rehman 2004	RCM (PRECIS)	A2	1961-1990	+2.5 to +4 °C (spatially across Sri Lanka)
Basnayake et al. 2004	Statistical downscaling of GCMs (HadCM3, CSIRO, CGCM)	A1FI	1961-1990	+2 to +3 °C (range by three models for Sri Lanka as a whole)
		B1	1961-1990	+0.9 to +1.4 °C (range by three models for Sri Lanka as a whole)
		A2	1961-1990	+1.7 to +2.5 °C (range by three models for Sri Lanka as a whole)
De Silva 2006b	Statistical downscaling of GCMs (HadCM3)	A2	1961-1990	+1.6 °C by 2050s (Sri Lanka)
		B2	1961-1990	+1.2 °C by 2050s (Sri Lanka)

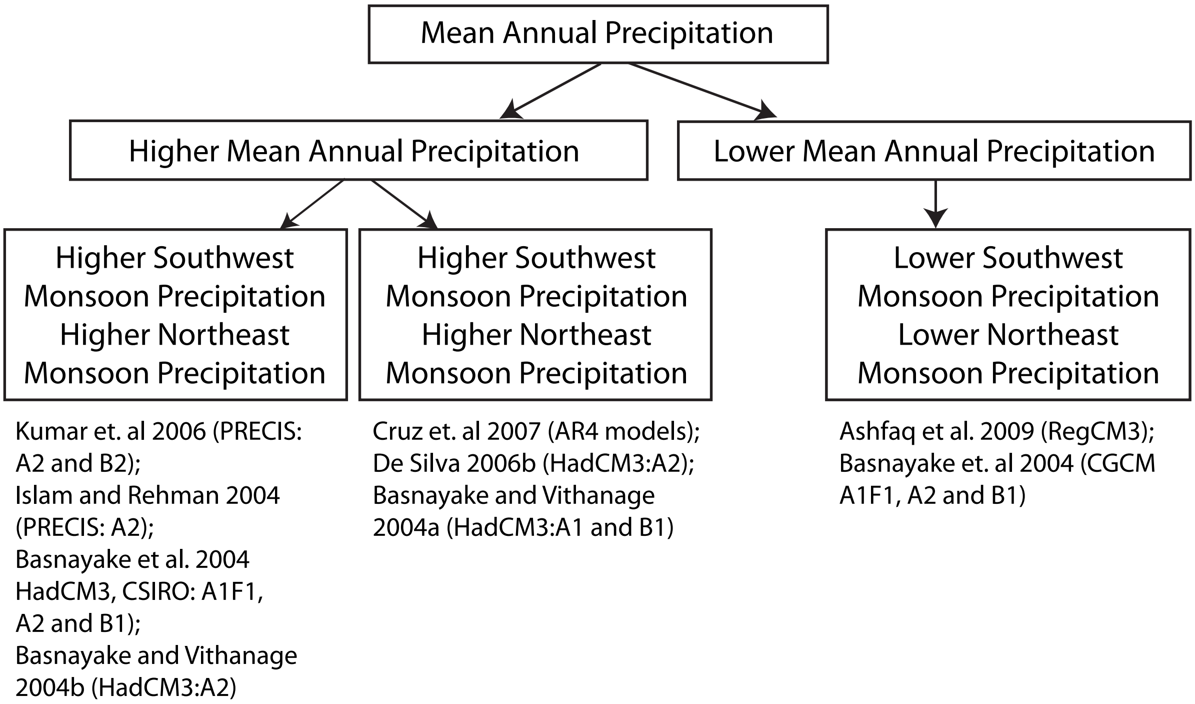
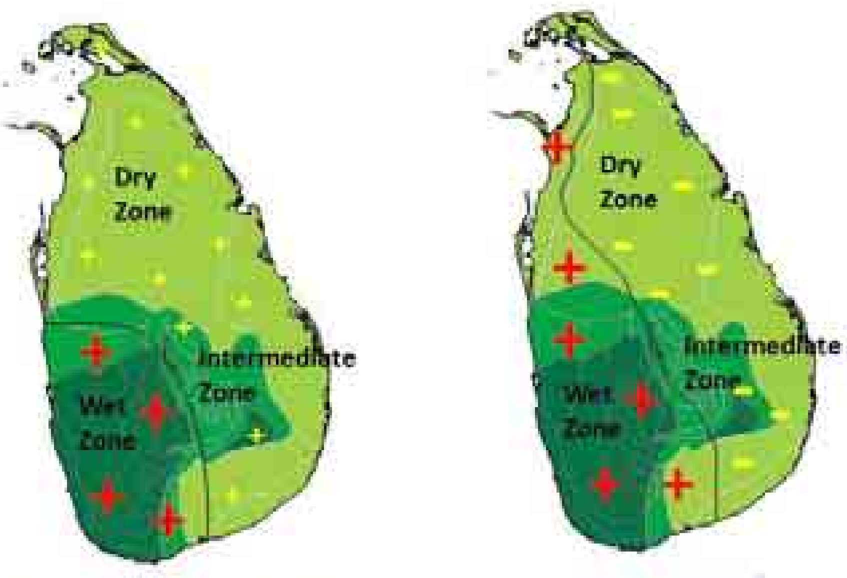


FIGURE 3. Summary of annual and seasonal rainfall projections for the twenty-first century.

There is general consensus among future projections that Sri Lanka will become increasingly warmer during the twenty-first century, although the projected magnitude of temperature increase differs from study to study (Table 1). IPCC regional projections based on AR4 GCMs suggest a significant acceleration of warming in Asia over that observed during the twentieth century. Warming will be stronger than the global mean in South Asia while higher warming is projected during the NEM than during the SWM (Cruz et al. 2007). In comparison with the period 1961-1990, a temperature increase of 5.44 °C and 2.93 °C is projected for the two IPCC emission trajectories A1FI and B1, respectively, over South Asia during the NEM in 2070-2099 (Cruz et al. 2007). Two RCM experiments over South Asia (using PRECIS) also project widespread warming in the region including in Sri Lanka (Table 1) towards the end of the twenty-first century (Kumar et al. 2006; Islam and Rehman 2004). Although the two experiments have different model and analysis domains (India in Kumar et al. 2006; Pakistan in Islam and Rehman 2004), both cover Sri Lanka. The two studies confirm projections made by the IPCC of higher warming during the NEM and lower warming during the SWM.

In addition to the above, a few studies have attempted to statistically downscale projections of GCMs over Sri Lanka. These studies project mean temperature increments of varying magnitudes (ranging from 0.9 to 3 °C) by 2100, which are summarized in Table 1. When considering intra-annual variation of temperature, Basnayake (2008) suggests higher increases (+2.9 °C) in the NEM season and lower increases (+2.5 °C) in the SWM season. De Silva (2006b) envisages temperature increases mainly in the northern, northeastern and northwestern regions of the country (all within the dry zone). Meanwhile, Jayatillake and Droogers (2004) suggest a 0.5 °C increase in the period 2010-2039 and a 2-3 °C increase in the period 2070-2099 within the Walawe Basin in southern Sri Lanka. Zubair et al. (2005) constructed 1 km resolution present climatology fields for minimum, mean and maximum annual average temperatures, and projected future minimum and maximum annual average temperature climatology fields for 2025 and 2050 by assuming that the 1960-2001 trends (minimum temperature: +0.017 °C per year and maximum temperature: +0.026 °C per year) will continue. However, they did not specifically consider the effects of CC.

Rainfall projections for Sri Lanka within this century appear to be confusing and sometimes contradictory. While these projections are described in the next few paragraphs, summarized forms of seasonal and spatial projections are presented in Figures 3 and 4 for ease of understanding. The majority of models project higher MAP, but a few project lower MAP. Out of those models that project higher MAP, some, such as the AR4 models (Cruz et al. 2007), statistically downscaled projections from HadCM3 by De Silva (2006b) and statistically downscaled projections using SimCLIM (a computer model facilitating downscaling of GCM outputs: http://www.climsystems.com/simclim/about.php) by Basnayake and Vithanage (2004a), envisage an increase in rainfall during the SWM (the season when rainfall is confined mainly to the wet zone) and a decrease in NEM rainfall (the season when the majority of the dry zone receives rainfall) for a range of IPCC scenarios (A1, A1FI, B1, A2 and B2). De Silva (2006b) further elaborates that these changes by the 2050s (with reference to the period 1961-1990) will be of the following magnitudes: MAP – increase by 14% for A2 and 5% for B2; NEM rainfall – decrease by 34% for A2 and 26% for B2; SWM rainfall – increase by 38% for A2 and 16% for B2. On the other hand, statistically downscaled projections from HadCM3 by Basnayake and Vithanage (2004b), and from HadCM3 and CSIRO models by Basnayake et al. (2004), suggest increases in rainfall during both the SWM and NEM (for a range of IPCC scenarios from A1 to B2), with higher increases during the SWM than during the NEM. In contrast to the above, downscaled CGCM model projections (Basnayake et al. 2004) indicate decreases in MAP, as well as decreases in rainfall during the SWM and NEM for scenarios A1FI, A2 and B1. However, the authors do not provide any indication of the percentage change in the SWM and NEM rainfall in the latter two cases. Hence, it remains unclear whether these changes will be significant. A recent study by the Purdue University (Ashfaq et al. 2009), especially on the South Asian Summer Monsoon, using RegCM3, also projects a weakened and delayed (by 5-15 days by the end of the twenty-first century) SWM over the majority of South Asia.



Basnayake et al. 2004

De Silva 2006b

FIGURE 4. Spatial patterns of rainfall projections for 2050 (plus/minus signs and their size indicate increase/decrease and variation amplitude in rainfall).

The spatial pattern of rainfall projections also displays similar contradictions (Figure 4). De Silva (2006b) projects enhanced rainfall in the wet zone, northwestern and southwestern dry zones; reduced rainfall in other dry zone areas (such as Anuradhapura, Batticaloa and Trincomalee), and increased rainfall (2%) in the intermediate zone; all by the 2050s for scenario A2. Basnayake and Vithanage (2004b) and Basnayake et al. (2004), who project increases in rainfall throughout the country during both monsoon seasons (with HadCM3 and CSIRO models), envisage much higher increments of rainfall on the western and southwestern parts of the island, including the windward side of the central hills and lesser increments on the rest of the areas by 2025, 2050 and 2100 for scenarios A1FI, A2 and B1, respectively. Image results of future projections by Ashfaq et al. (2009) suggest increased rainfall during the SWM in western Sri Lanka (which is generally wetter than the east) and decreased rainfall in the eastern part. This spatial trend has also been noted by De Silva (2006b) and Basnayake and Vithanage (2004a). It is worthwhile to note that almost all available projections agree on increased MAP in the wet zone of the country, which could trigger beneficial impacts (to agriculture) as well as harmful impacts (in the form of increased floods and landslides). Meanwhile, Jayatillake and Droogers (2004) project a somewhat wetter situation, with simultaneously more variation in annual precipitation in the Walawe Basin. Shantha and Jayasundara (2005) envisage a 17% reduction in rainfall in the Upper Mahaweli watershed in the Central Highlands by 2025.

The IPCC envisages an increase in the occurrence of extreme weather events, including heat waves and intense precipitation events in South Asia within this century; interannual variability of daily precipitation during the SWM is also projected to increase (Cruz et al. 2007). A recent study by Ahmed et al. (2009) predicts that the frequency of extreme wet events (precipitation events exceeding the 1961-1990 95th percentile) may increase by as much as 400% in India and Sri Lanka during 2071-2100 compared to 1971-2000. An increase of 10-20% in tropical cyclone intensities (for a rise in sea surface temperature of 2-4 °C relative to current threshold temperature), amplification of storm surge heights (due to stronger winds), with increase in sea surface temperatures and low pressures associated with tropical storms, could contribute to enhanced risk of coastal disasters (Cruz et al. 2007).

The above review suggests that considerably more work is needed to verify and further refine available climate projections for Sri Lanka. Scientists are of the view that since South Asia, in general, is unique from the rest of the world with a very complex topography, global models like the ones featured in the IPCC reports have difficulty capturing some of the more subtle atmospheric processes, so that they disagree on what might happen to the monsoon patterns of the region as well as on whether precipitation will increase or decrease; understanding the potential impacts of future CC in this region requires an improved understanding of a host of climate processes (Ashfaq et al. 2009). Moreover, the region is highly susceptible to climate variability and natural disasters (World Bank 2009). Even within the South Asian region, Sri Lanka is unique considering the fact that unlike most other countries which rely on the summer monsoon (SWM-May to September), Sri Lanka receives the major share of its annual precipitation from the winter monsoon (NEM-December to February) (World Bank 2009). Therefore, it is desirable that projections from detailed high-resolution RCMs are used to obtain reliable climate scenarios for Sri Lanka. Accurate quantification of CC impacts and identification of adaptation strategies both depend on it.

Impacts of Climate Change

Impacts on Water Resources

There are 103 distinct radial draining river basins in Sri Lanka (Figure 1(a)) with considerable variations in hydrological characteristics. Sixteen (16) out of the 103 are classified as wet zone rivers and carry approximately half the annual runoff in the country (Arumugam 1969). One half of all rivers have zero or negligible flow during the *Yala* (dry) season (Amarasinghe et al. 1999). Sri Lanka depends primarily on its surface water resources for agricultural, domestic and industrial uses. Agriculture is largely sustained by direct rainfall and irrigation water extractions from rivers while 42% of electricity is generated from hydropower sources. However, groundwater use is also rapidly increasing in the country (IWMI 2005). In this context, accurate quantification of CC impacts on water resources will be the key to successful adaptation, as Sri Lanka transforms gradually from an agriculture-oriented society to a more industrialized one. It will face the dual challenge of adapting to CC while meeting rising demands on water resources due to a growing population and increased allocations to sectors other than agriculture. Although, it is difficult to reach any consensus regarding CC impacts on water resources due to contradicting rainfall projections, the dominant school of thought is that while Sri Lanka will actually gain in terms of mean annual water availability due to CC, its increased variability and inequitable spatial distribution (wet areas getting wetter and dry areas getting drier: Basnayake 2008; Basnayake et al. 2004; Basnayake and Vithanage 2004b; De Silva 2006b) will negatively impact agriculture and food security.

The brunt of the impact of CC on water resources is expected to be borne by the northeastern and eastern dry zone of the country; they may become even drier by the 2050s (De Silva 2006b). The changes in rainfall and temperature, together with other climatic factors, may increase the average reference evapotranspiration (ET_0) (1-2% for scenarios B2-A2) and maximum annual potential soil moisture deficit ($PSMD_{max}$) (4-11% for scenarios B2-A2) across the country by the 2050s (De Silva 2006b; De Silva et al. 2007). Potential Soil Moisture Deficit (PSMD) in any month of the year is calculated by adding the difference between potential evapotranspiration (of short grass) and rainfall in the present month, with previous month's PSMD. Estimation of PSMD starts in January when the soil moisture deficit is usually zero in Sri Lanka due to the commencing of the wet season rainfall in October (De Silva 2006b). The maximum PSMD of the 12 months of the year is the maximum annual PSMD ($PSMD_{max}$) (De Silva 2006b). The corresponding rainfall and ET_0 datasets for the baseline scenario (1961-1990) and the A2 and B2 scenarios for the 2050s have been used to estimate the differences in $PSMD_{max}$ across the country between the two time slices (De Silva 2006b). The projected changes will be significant in the dry zone, where some of the agriculturally intensive areas are located and the availability and reliability of water resources are already under severe pressure (De Silva 2006b). The observed reduction and the increase in variability of the NEM rainfall (Jayatillake et al. 2005; Basnayake et al. 2002), through which these areas receive the better part of their agricultural water requirements, suggest the possibility of even further increases in water stress. The areas with higher baseline $PSMD_{max}$ (1961-1990) are located in the North and the East, notably in Jaffna, Mannar, Vavuniya, Trincomalee, Anuradhapura and Batticaloa, while Colombo, Galle, Ratnapura and Nuwara Eliya, which cover the western and southwestern parts of the country (Figure 5), have lower baseline $PSMD_{max}$. In general, northern, eastern and southeastern areas (covering the whole of the dry and intermediate zones) will see substantial increases in $PSMD_{max}$ by the 2050s (De Silva 2006a). Expected changes in $PSMD_{max}$ for some locations are shown in Figure 5. The worst affected area within the dry zone will be Batticaloa, on the eastern coast, with increases of 25% for A2 and 13% for B2. However, among the dry zone areas, Hambantota in the southern tip of the island is expected to see a decrease in $PSMD_{max}$ (5% for A2 and 2% for B2), while also gaining in MAP (De Silva 2006a; Jayatillake and Droogers 2004).

FIGURE 5. Spatial distribution of areas with higher baseline $PSMD_{max}$ (location name shown in red) and areas with lower $PSMD_{max}$ (shown in blue) with expected change in $PSMD_{max}$ by the 2050s for some of them (shown by A2 and B2 values in green) (*Source:* De Silva 2006a).

As stated earlier, a reduction in rainfall in the Central Highlands has been observed and projected by several authors. Since the Central Highlands contribute the largest volume of water for hydropower generation and subsequently for irrigation (e.g., through multipurpose reservoirs in the Mahaweli Basin), negative climatic changes in this region will very likely result in significant negative economic impacts. The Kotmale, Victoria, Randenigala and Rantembe reservoirs constructed in the heart of the Upper Mahaweli watershed supply 29% of the national power generation and 23% of irrigation water supplied by major irrigation schemes (Shantha and Jayasundara 2005). Since the Mahaweli is a multipurpose water supply scheme, the potential of hydroelectricity generation of associated power stations is governed by downstream irrigation requirements. These requirements, being highly seasonal, tend to constrain the operation of power stations during certain periods of the year (Shantha and Jayasundara 2005). In the event of a decline in river discharge, water allocation between the two sectors will be problematic. This emphasizes, even more, the need for reliable climate projections for the country so that they may provide an indication of how much alternative power (other than hydroelectricity) will be required in the future, without compromising allocations to the irrigation sector.

Notably absent are research on CC impacts on groundwater resources in Sri Lanka both in terms of quantity and quality, except perhaps in the Walawe Basin (e.g., Ranjan et al. 2007). The country's dry zone area suffers from excess fluorine (Seneviratne and Gunatilaka 2005) while sea level rise due to CC is expected to increase salinity in coastal aquifers. A global scale evaluation of fresh groundwater resources has found that groundwater resources in South Asia are highly vulnerable to saltwater intrusion due to global warming (Ranjan et al. 2007). Some other unanswered questions are whether Sri Lanka will be able to satisfy its national water needs (agricultural, industrial and domestic) and how its surface water quality will vary during the twenty-first century amid increased warming.

Impacts on Agriculture

Impacts of CC on Agriculture maybe broadly categorized into three areas: impact of temperature, CO_2, and precipitation on crop growth. In general, higher temperatures are associated with higher radiation and higher water use. Two effects of temperature have been distinguished (Jayatillake and Droogers 2004): physiological effects (at the level of plants and plant organs) and the crop phenology effects (at the level of the field or at the region). Efforts have been made to quantify the impact on crop growth due to the combined effects of enhanced atmospheric CO_2 and increased temperatures, both globally as well as within Sri Lanka. According to results of worldwide experiments, combined and collected by the Center for the Study of Carbon Dioxide and Global Change in Tempe, Arizona (*http://www.co2science.org*), increases in potential crop growth (Table 2) are indicated for rice, Sri Lanka's staple food, and other vegetables (Jayatillake and Droogers 2004). Meanwhile other studies within the country show mixed results. According to Vidanage and Abeygunawardane (1994), a 0.1-0.5 °C increase in temperature can reduce rice yield by approximately 1-5%. According to Punyawardena (2007), as cultivated crops in Sri Lanka are already operating at optimum temperature ranges, crop injuries are possible with temperature increases. For paddy, ambient temperature, exceeding over 35 °C even for just 60–90 minutes at the flowering stage, can cause crop damages. He also states that recent agro-meteorological observations have shown that the frequency of such temperature events increased significantly in the dry and intermediate zones, especially during the *Yala* (dry) season and this has resulted in a high rate of unfilled grains due to increased spikelet sterility. However, another experiment carried out in Sri Lanka suggests that rice yields respond positively (increases of 24 and 39% in the two seasons) to elevated CO_2 even at higher growing temperatures (>30 °C) in subhumid tropical environments (De Costa et al. 2006).

TABLE 2. Increases in potential crop growth as a result of enhanced CO_2 levels in percentages.

Crop	Period	IPCC Scenario A2 (%)	IPCC Scenario B2 (%)
Rice	2010-2030	20	10
	2070-2100	40	20
Beet	2010-2030	10	5
	2070-2100	20	10
Tomato	2010-2030	15	8
	2070-2100	30	15

Source: Jayatillake and Droogers 2004

The real threat to rice cultivation might be the third factor impacting crop growth, namely, changes in the amount of precipitation and temporal distribution. Nearly 72% of paddy production is grown during the *Maha* (wet) season in dry areas where water resources are already stressed (De Silva et al. 2007). De Silva et al. (2007) suggest that, by 2050, average paddy irrigation water requirement during the *Maha* season will increase by 23 and 13%, respectively, for the A2 and B2 scenarios due to reductions in average rainfall, increase in potential evapotranspiration and early ending of rainfall; the hardest hit will be the dry and intermediate zones of the country. The worst affected in this regard will be Batticaloa on the eastern coast, with increases of 45% for A2 and 15% for B2 scenarios. Irrigation water requirements for other field crops cultivated in the dry and intermediate zones during the *Yala* season will also significantly increase (De Silva 2006a). However, positive impacts are shown in the extreme south in Hambantota (De Silva et al. 2007; Jayatilleke and Droogers 2004) where paddy irrigation water requirement is expected to decrease by 2 and 4% for A2 and B2 scenarios, respectively, by the 2050s (De Silva et al. 2007). According to Jayatilleke and Droogers (2004), rice yields in the Walawe Basin will increase as a result of enhanced CO_2 levels and higher precipitation, although a substantial variation in yield is expected; Overall, the impact on food production will be positive in the Walawe Basin. Figure 6 shows the spatial variation in expected changes in the *Maha* season paddy irrigation requirement (PIR) from the baseline period (1961-1990) to A2 and B2 scenarios for the 2050s.

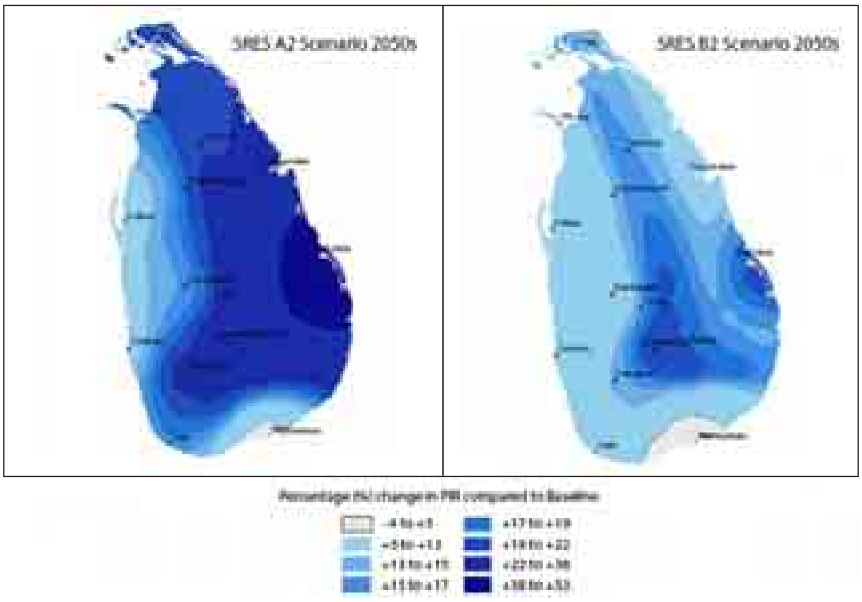


FIGURE 6. Spatial variation in expected changes in the *Maha* (wet) season paddy irrigation requirement (PIR) from the baseline period (1961-1990) to A2 and B2 scenarios for the 2050s (*Source:* De Silva et al. 2007).

Plantation crops, tea, rubber and coconut, are the next most important crops to Sri Lanka's economy, being some of the main foreign exchange earners while also generating income to the majority of unskilled laborers in the country. Several studies have been undertaken to assess the impact of CC on plantation crops. Wijeratne et al. (2007) found that tea cultivations at low and mid-elevations are more vulnerable to the adverse impacts of CC than those at high elevations. They also found that the optimum temperature for tea cultivation is 22 °C, and the optimum rainfall varies from 223 to 417 mm per month in different tea growing regions of the country. Reduction of monthly rainfall by 100 mm could reduce productivity by 30-80 kg of 'made' tea per hectare (Wijeratne et al. 2007). Yield projections also show that rising temperatures and diminishing rainfall reduce tea yield in many tea growing regions, except in the up-country wet zone (Wijeratne et al. 2007).

Coconut is almost exclusively grown as a rainfed crop in Sri Lanka. Rainfall and temperature are the important climatic factors influencing coconut yield (Peiris et al. 1995; Mathes and Kularatne 1996). Future yields in coconut production under six different climate scenarios using integrated crop models (mathematical description of accumulation of coconut biomass in terms of temperature, rainfall, solar radiation and certain soil properties, integrated with SimCLIM climate model) suggest that the projected coconut production after 2040 in all climate scenarios (when other external factors are non-limiting) will not be sufficient to cater to local consumption (Peiris et al. 2004). Studies on the response of coconut yield to climate variations in the past have shown that extended dry spells and excessive cloudiness during the wet season can reduce coconut yield so that annual losses can range between US$32 and US$73 million (Fernando et al. 2007). However, on the other hand, during a high rainfall year, the economy could gain by US$42-US$87 million due to high coconut yields (Fernando et al. 2007). Among the different stakeholders in the coconut industry, the coconut oil industry will be the most vulnerable to CC: increasing air temperatures will increase the future pest and disease problems on coconut (as well as on all other crops), and as a result increased investment in pest control would be required (Peiris et al. 2004).

CC is expected to affect Sri Lanka's forest distribution as well, with increases in tropical very dry (5%) and tropical dry forest (7%) and a decrease in tropical wet forest (11%) areas (Somaratne and Dhanapala 1996). Sea level rise as a result of global warming poses another threat to coastal agricultural areas due to inundation and salinity intrusion of coastal wetlands and aquifers. Weerakkody (1996) states that inundation will be in the range 41 square kilometers (km^2) for a rise of 0.3 meters (m) and 91.25 km^2 for a rise of 1 m for lowlands along the southwest coast. The Galle District (one of Sri Lanka's 25 administrative districts – location shown in Figure 5), situated along the southwest coast, is further subdivided into 18 district secretariat (DS) divisions. Pilot studies suggest that sea level rise could inundate about 20% of the land area of Galle's five coastal DS divisions (Wickramarachchi n.d.). The damage caused could be of a higher magnitude if the combined effects of beach erosion (presently 0.3-0.35 m per year (Ministry of Forestry and Environment 2000)), storm surges, and coastal flooding are considered along with inundation due to sea level rise. However, on a positive note, a recent study by the WorldFish Center, Malaysia, which compared the vulnerability of 132 national economies to potential CC impacts on fisheries in 2050, under IPCC scenarios A1FI and B2, finds that Sri Lanka's vulnerability is low in this respect (Allison et al. 2009). This is primarily due to the fact that, according to projections made using the HadCM3 climate model for 2050, Sri Lanka's overall exposure (one of the three components which make up this vulnerability index, the other two being sensitivity and adaptive capacity) to CC is considered very low compared to that of other countries (Allison et al. 2009).

CC impacts on agriculture invariably impact the country's economy. Seo et al. (2005) find that nationally, the impact on agriculture (rice, tea, rubber and coconut) will result in economic impacts in the range of LKR -11 billion rupees (US$96.4 million: -20%) to LKR +39 billion rupees (US$342 million: +72%) depending on the climate scenarios. To calculate the economic impacts, the authors used temperature and precipitation projections for 2100 using five GCMs (HadCM3, CSIRO, CGCM, PCM (*http://www.cgd.ucar.edu/pcm/*) and CCSR (*http://www.ipcc-data.org/is92/ccsr_info.html*) and two simple uniform change scenarios of 2 °C rise in temperature and 7% increase in precipitation (all five GCMs indicate an increase in MAP and mean annual temperature by 2100 (Seo et al. 2005)). Beneficial and harmful impacts due to an increase in precipitation and temperature, on paddy, tea, rubber and coconut, are evaluated based on their past sensitivity to climate variability. They reconfirm that CC impacts could be large in tropical developing countries, but are highly dependent on the climate scenario. In a similar study on the impact of climate change on the smallholder agriculture sector in the country, Mendelsohn et al. (2004) finds that, with mild warming and a large increase in precipitation, net revenue per hectare may increase by 22%. On the other hand, with medium warming and only a small increase in precipitation, losses of 23% are projected. These impacts are, however, highly location-specific. The largest adverse impacts are projected to be in the northwestern and southeastern lowlands in the dry zone, while the wet, high elevation areas are expected to benefit from climate change. Changes in precipitation may have more impact than temperature changes, especially during key agricultural production months (Mendelsohn et al. 2004).

Mitigation and Adaptation to Climate Change

Climate Change Mitigation

Sri Lanka is a signatory to the UNFCCC and has ratified the Kyoto Protocol on CC. Therefore, under its obligation to contribute to efforts to mitigate CC, Sri Lanka made its Initial National Communication on Climate Change in October 2000. Its Second National Communication is under preparation (C. Panditharatne, Ministry of Environment, pers. comm.). According to Sri Lanka's latest GHG inventory (1994), annual emissions stand at 33,630.22 gigagrams (Gg) of CO_2, 1,098.38 Gg of Methane (CH_4) and 162.8657 Gg of Nitrous Oxide (N_2O) (Ministry of Forestry and Environment 2000). The largest contribution to GHG emissions (CO_2) is through the change in forest and woody biomass stocks, forest grassland conversion, liming and organically amended soils. The largest source of CH_4 is from treatment and handling of waste, while the energy sector also contributes on a small-scale through the incomplete burning of fossil fuel (Ministry of Forestry and Environment 2000). Biomass (47%), petroleum (45%) and hydropower (8%) are the main primary energy resources used in the country (ADB 2006).

Sri Lanka has initiated a host of activities aimed at reducing its GHG emissions including afforestation, reforestation, sustainable energy development and incorporation of emission reduction strategies to the transport sector. Studies have been conducted to assess the carbon sequestration potential of Eucalyptus plantations in the up-country region, and in-situ Gliricidia plantations providing innovative thermal energy to desiccated coconut mills in Sri Lanka (e.g., Nissanka and Ariyaratna 2003; Fernando and Jayalath 2003). Efforts have also been made to introduce renewable energy such as small hydropower plants, solar and wind energy (Weerakoon and De Silva 2006; Prasad 2006), and biofuels (Ambawatte and Kumara 2007; Ambawatte et al. 2007) to the energy sector. Some innovative projects aimed at mitigating CC impacts are, the planting of 73,000 trees to offset carbon emissions generated by the tourism industry which is carried out as part of a 'Carbon Clean Sri Lanka' campaign, and the installation of ten trial base stations using solar and wind power by Dialog Telekom, a mobile telecommunications provider (Anderson 2009). A number of non-governmental organizations are also active in the country implementing community based projects aimed at reducing GHG emissions to the atmosphere, such as through the Small Grants Programme of the Global Environment Facility (GEF).

Apart from the Initial National Communication, Sri Lanka has also developed a Clean Development Mechanism (CDM) policy and strategy, and a few CDM projects in the form of small hydropower stations are already underway. Introduction of Vehicle Emission Standards and the 'Green Lanka' program are other initiatives taken in this direction. The country is also contemplating the introduction of new strategies into the transport sector (heavily dependent on fossil fuels at present), such as promoting public transport instead of private transport within major cities.

Climate Change Adaptation and Policy

Adaptation to CC is any 'Adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2007). Although there are a number of environmental policies, legal enactments and plans that contain provisions that could contribute to reducing or mitigating the effects of CC in the country, the subject of CC has not been directly addressed in any of these documents (Ministry of Forestry and Environment 2000). Therefore, the Initial National Communication recommends the incorporation of CC considerations into existing policies. Munasinghe (2008) proposes adoption of the 'sustainomics' framework (developed by the World Bank) and its tools to integrate CC policies into Sri Lanka's development strategy, and to help make the transition from the risky 'business-as-usual' scenario to a safer and more sustainable future. Sustainomics seeks to provide a comprehensive, practical framework for making present and future development efforts more sustainable. Using one of its tools called the 'Action Impact Matrix,' Munasinghe (2008) identifies the vulnerability of Sri Lanka's water resources and agricultural output as the key challenge to national food security in the wake of CC. Hence, the island's successful adaptation depends on accurate projections of CC impacts on its water resources and agriculture, and finding ways to manage and adapt to such projections. Some examples of initiatives already undertaken in this regard are explained in the next paragraphs. However, a more comprehensive national study on river basin or district scale covering the assessment of existing water resources and the vulnerability of water resources and agriculture to impacts of CC is an urgent need for the country.

Understanding the present climate is imperative in projecting future climate changes. Hence, a significant number of attempts have been made to understand and quantify the effect of climate parameters such as ENSO and Sea Surface Temperature (SST) on Sri Lanka's present climate (e.g., Zubair et al. 2008; Pathirana et al. 2007; Zubair and Ropelewski 2006; Suppiah 1996). Some of these attempts (e.g., Zubair et al. 2008) propose short and medium term rainfall predictions based on ENSO and SST. Tools for predicting annual coconut production (Peiris et al. 2008) and seasonal water availability within the Mahaweli scheme (Zubair 2003) make use of such short and medium term rainfall predictions.

Rainwater harvesting and storage during higher rainfall seasons, especially in the dry and intermediate zones, is a viable solution for utilizing available water resources throughout the year. De Silva (2006b) suggests the provision of a rainwater harvesting system to all households in drought-prone areas, making it a prerequisite to receive drought relief. Renovating the existing tanks to store excess rainfall during the SWM and devising methods to store and transfer excess rainfall in the wet zone to the dry zone are other available alternatives for water resources adaptation when considering the country as a whole (De Silva 2006b). Both rainwater harvesting, and restoration of existing tanks, are "no regrets" adaptation interventions that simultaneously deliver climate resilience and address current development needs. Development of sustainable groundwater, promotion and adoption of micro-irrigation technologies, wastewater reuse, increasing water use efficiency and change of allocation practices are other adaptation options under consideration in the water resources sector. A greater shift towards alternative energy sources from hydropower and fossil fuels is advocated in the energy sector (Shantha and Jayasundara 2005), while the Coast Conservation Department (CCD) is in the process of formulating a Climate Change Action Plan for adapting to sea level rise (B. Wickramarachchi, CCD, pers. comm.). However, equally important is creating awareness among different stakeholders on vulnerabilities, impacts and adaptation options, as well as the encouragement of farmers to take individual or communal action to prepare for CC.

Studies on crop adaptation are mainly carried out by six research institutes in the country, conducting research on rice, field crops, horticultural crops, tea, rubber and coconut. Table 3 provides information on crop adaptation strategies (against CC), under consideration or already implemented for each type of crop, gathered from documented evidence and personal communication with relevant officers. Apart from the above, the introduction of micro-irrigation technologies (e.g., Peiris et al. 2006; Aheeyar et al. 2005), shifting from rice to field crops (e.g., Chandrika et al. 2004), and crop diversification (Nanthakumaran 2004) are other strategies being tested across the diverse spectrum of crops found in Sri Lanka. Adaptation strategies focussed on two alternative development approaches (sustaining food security versus enhancing environmental quality) have been proposed for rice farmers in the Walawe Basin by Jayatillake and Droogers (2004).

TABLE 3. Crop adaptation strategies by type of crop,

Rice	Field crops	Tea	Coconut
Development of varieties that respond positively to increased air temperature and humidity, increased atmospheric CO_2, moisture stress conditions, increased salinity and submergence (Weerakoon, W. M. W. RRDI, pers. comm.; Piyadasa et al. 1993)	Development of high-yielding improved varieties of field crops, dry zone vegetables and fruits suitable for irrigated and rainfed conditions with pest, disease and drought resistance quality (Department of Agriculture 2006)	Use of hardy tea clones resistant to drought, pests and diseases (Wijeratne 1996)	Adopt moisture conservation methods, such as cover crops, organic manure, burying coconut husks and contour drains to minimize the effects of less rainfall (Mathes and Kularatne 1996)
Development of short-term (low water consuming) rice varieties, suitable for shorter growing seasons (e.g., Harris and Shatheeswaran 2005)	Development of improved soil and water conservation methods and soil fertility management practices (Department of Agriculture 2006)	Improvement and implementation of soil conservation measures (Wijeratne 1996)	
Partial shift of present locations to areas projected to receive more beneficial rainfall (De Silva et al. 2007)	Investigation of the impact of increased temperatures, humidity and moisture stress on field crops (e.g., Inpadevy and Mahendran 2003; Weerasinghe et al. 2001; Peiris et al. 1993)	Proper shade management, and expansion of multicropping systems (Wijeratne 1996)	
Changing planting time to suit altered rainfall onset times, especially in the dry zone (De Silva et al. 2007)			

Mapping Climate Change Vulnerability

The previous sections looked at the observed and projected climatic changes, their impacts on the water resources and agriculture sectors (the two most important sectors in terms of the country's food security), and mitigation and adaptation options for Sri Lanka. The review revealed that limited attempts have been made so far to identify agricultural vulnerability hotspots within Sri Lanka. Therefore, a rather 'coarse' pilot study was carried out to map the vulnerability of Sri Lanka's agriculture sector to CC on a district scale. It is important to emphasize the word 'coarse', since only publicly available datasets (such as those downloadable via the internet) were used in mapping. For this purpose, information on similar mapping exercises carried out elsewhere in the world were collected and analyzed. The intention of collecting this information was to formulate a CC vulnerability index applicable to Sri Lanka, considering data availability and its suitability to Sri Lankan conditions. Subsequently, a CC Vulnerability Index, similar to ones constructed by Yusuf and Francisco (2009) and Gbetibouo and Ringler (2009), was designed and mapped here. In addition to indices developed by Yusuf and Francisco (2009) and Gbetibouo and Ringler (2009), the information collected on other similar indicators is also presented in Appendix 1, in order to demonstrate the wide range of possibilities available in constructing CC vulnerability indices. It is hoped that the coarse scale maps presented here, together with Appendix 1, will lead the way to more detailed assessments at finer scales in the future.

Data and Methods

Vulnerability is defined as: "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2001). Therefore, vulnerability can be expressed as a function of exposure, sensitivity, and adaptive capacity (Equation 1).

$$\text{Vulnerability} = f(\text{exposure, sensitivity, adaptive capacity}) \qquad (1)$$

This study proposes an index of CC vulnerability, composed of three other subindices representing exposure, sensitivity and adaptive capacity, in order to identify hotspots of agricultural vulnerability in Sri Lanka.

IPCC (2001) defines *exposure* as "the nature and degree to which a system is exposed to significant climatic variations". Thus, exposure relates to climate stress upon a particular unit of analysis (Gbetibouo and Ringler 2009). In our assessment, climate stress is represented by frequency of climate extremes (Figure 7). The Exposure Index uses frequency of exposure to historical climate hazards as a proxy for future climate hazard exposure, and computes Exposure Indices for droughts, floods, cyclones and multi-hazards (considering combined frequency of droughts, floods and cyclones) for each district (Table 4). Typically, a more complete measure of exposure to future CC would require consideration of projected changes in climate in each analysis unit. However, given the existing ambiguity in CC projections for Sri Lanka, inclusion of such projections in our analysis is not realistic at present. Therefore, this assessment relies on historical climate data. It is likely that this vulnerability will only increase under future climatic changes.

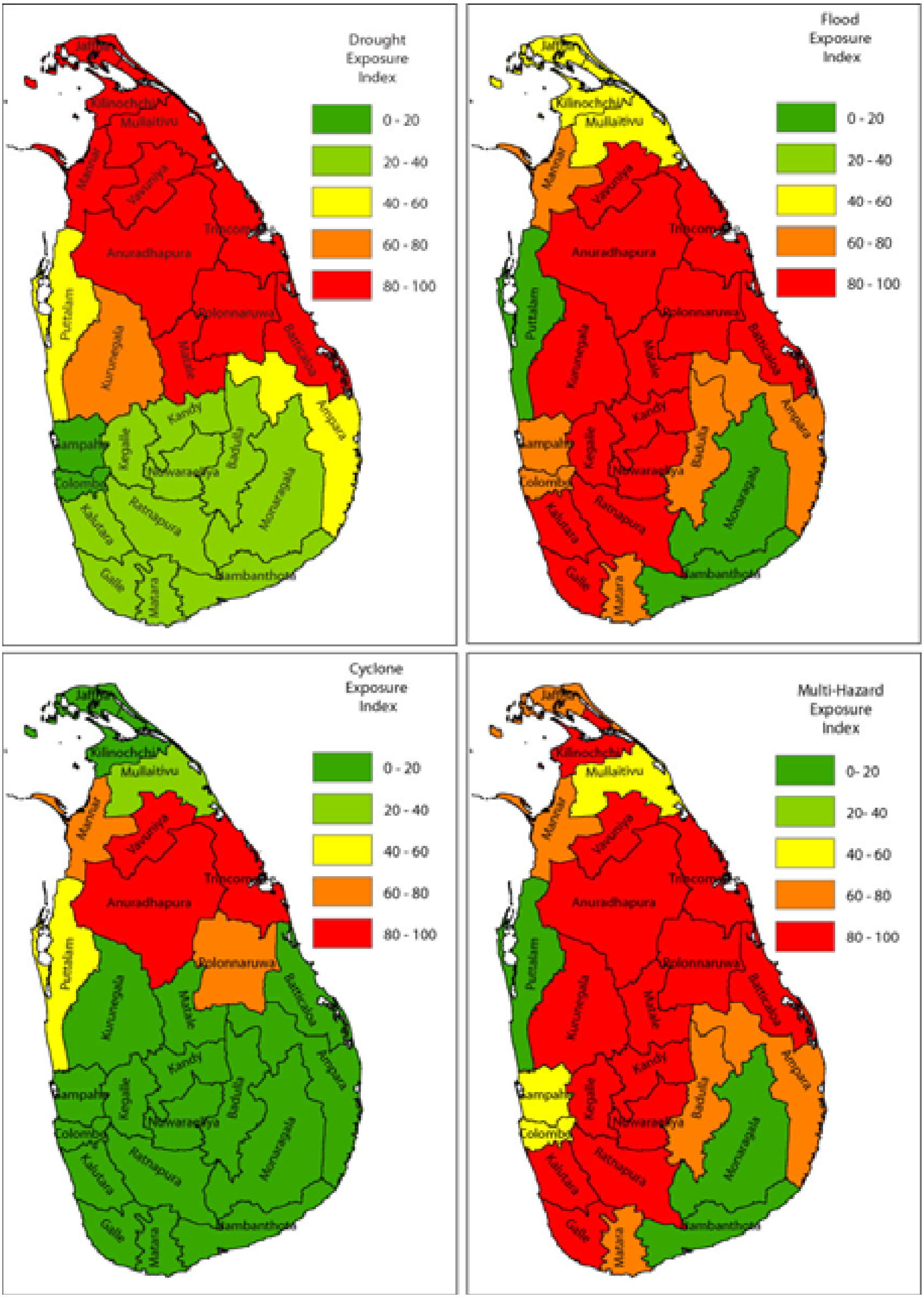


FIGURE 7. Exposure indices for droughts, floods, cyclones and multi-hazards for each district in Sri Lanka.

TABLE 4. Vulnerability indicators, proxy variables and data sources.

Determinant of vulnerability	Component indicator and weight (in parenthesis)	Proxy variable and weight (in parenthesis)	Hypothesized functional relationship between indicator and vulnerability	Data source
Exposure	Exposure	Frequency of exposure to droughts, floods, cyclones and multi-hazards (number of events from 1961-2004 as recorded in EM-DAT)	The higher the frequency of climate extremes, the higher the vulnerability level.	Natural Disaster Hot spots project led by the World Bank (2.5' resolution grid data) (*http://www.ldeo.columbia.edu/chrr/research/hotspots/*)
Sensitivity	Human sensitivity (0.25)	Rural population density (population/km^2)	The likelihood of being vulnerable to climate shocks is greater in rural areas and the higher the population density, the larger the number of lives exposed to climate shocks. Therefore, the higher the vulnerability level.	Department of Census and Statistics – Sri Lanka: Statistical Abstract 2008 (estimated 2006 data)
	Livelihood sensitivity (0.75)	Percentage employed in agriculture (0.5)	The higher the percentage employed in agriculture, the higher the vulnerability to climate shocks.	Department of Census and Statistics – Sri Lanka: Sri Lanka Labor Force Survey 2008 (*http://www.statistics.gov.lk/samplesurvey/annual.htm*)
		Percentage of paddy area served by major irrigation schemes (0.25)	The higher the land under irrigation, the lower the vulnerability level, since the availability of irrigation acts as a buffer against short-term variability in precipitation.	Department of Census and Statistics – Sri Lanka: Average Paddy Statistics for 2004-2008 (*http://www.statistics.gov.lk/agriculture/Paddy%20Statistics/PaddyStats.htm)*
		Farm diversity: a composite index consisting of Crops Diversity Index (Jülich (2006)), livestock number and fish production quantity (metric tonnes) (0.25)	The higher the diversity in farming, the lower the vulnerability level.	Department of Census and Statistics – Sri Lanka: Average Paddy Statistics for 2004-2008 (*http://www.statistics.gov.lk/agriculture/Paddy%20Statistics/PaddyStats.htm*); Highland Crops Time Series (*http://www.statistics.gov.lk/agriculture/hcrops/index.html*); Census of Agriculture 2002 (*http://www.statistics.gov.lk/agriculture/EstateSector/index.htm*); Livestock Statistics (average for 2003-2008) (*http://www.statistics.gov.lk/agriculture/Livestock/LivestockPopulationSubnational.html*); National Aquatic Resources Research & Development Agency: Sri Lanka Fisheries Year Book 2007 (average production for 1997- 2007) (*http://www.nara.ac.lk/Year%20Book-2007/index.html*)

(Continued)

TABLE 4. Vulnerability indicators, proxy variables and data sources. (Continued)

Determinant of vulnerability	Component indicator and weight (in parenthesis)	Proxy variable and weight (in parenthesis)	Hypothesized functional relationship between indicator and vulnerability	Data source
Adaptive capacity	Socioeconomic assets (0.5)	Percentage population passing GCE (Ordinary Level) Examination (0.25)	The higher the level of education, the higher the comprehension ability, and the lower the vulnerability level.	Department of Census and Statistics – Sri Lanka: Census of Population and Housing 2001 (*http://www.statistics.gov.lk/PopHouSat/Pop_Chra.asp*)
		Poverty Headcount Index (0.25)	The higher the incidence of poverty, the higher the vulnerability level.	Department of Census and Statistics – Sri Lanka: Poverty Indicators 2006/2007 (*http://www.statistics.gov.lk/poverty/PovertyIndicators.pdf*)
		Poverty Gap Ratio (0.25)	The higher the income inequality, the higher the vulnerability level.	Department of Census and Statistics – Sri Lanka: Poverty Indicators 2006/2007 (*http://www.statistics.gov.lk/poverty/PovertyIndicators.pdf*)
		Share of agricultural GDP (%) (0.25)	The higher the share of agricultural GDP, the higher the vulnerability level.	Central Bank of Sri Lanka: Annual Report 2008 (2006 data) (*http://www.cbsl.gov.lk/pics_n_docs/10_pub/_docs/efr/annual_report/ar2008e/ar08_content_2008_e.htm*)
	Infrastructural assets (0.5)	Road Density (km/km^2) (0.33)	The higher the road density, the higher the connectivity and access to markets; and the lower the vulnerability level.	Ministry of Finance and Planning (1998 data) (*http://www.treasury.gov.lk/FPPFM/ddf/pdfdocs/mcaconceptpaper.pdf*)
		Percentage number of houses having an electricity connection (0.33)	The higher the electricity coverage, the higher the opportunities for industrial growth and value adding activities; and the lower the vulnerability level.	Department of Census and Statistics – Sri Lanka: Poverty Indicators 2006/2007 (*http://www.statistics.gov.lk/poverty/PovertyIndicators.pdf*)
		Communications Index: a composite index consisting of the number of landlines, number of cellular subscribers, and number of internet users, per 100 population (0.33)	The higher the Communications Index, the higher the opportunities for information flow; and the lower the vulnerability level.	Department of Census and Statistics: Millennium Development Goals (MDG) Indicators of Sri Lanka, 2008 (http://www.statistics.gov.lk/MDG/Mid-term.pdf)

Sensitivity is defined as “the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli” (IPCC 2001). It describes the human-environmental conditions that can either worsen the climate hazard or trigger an impact (Gbetibouo and Ringler 2009). The present study considers sensitivity to be twofold in the context of those employed in agriculture, namely, Human Sensitivity and Livelihood Sensitivity (Figure 8). In this assessment, Human

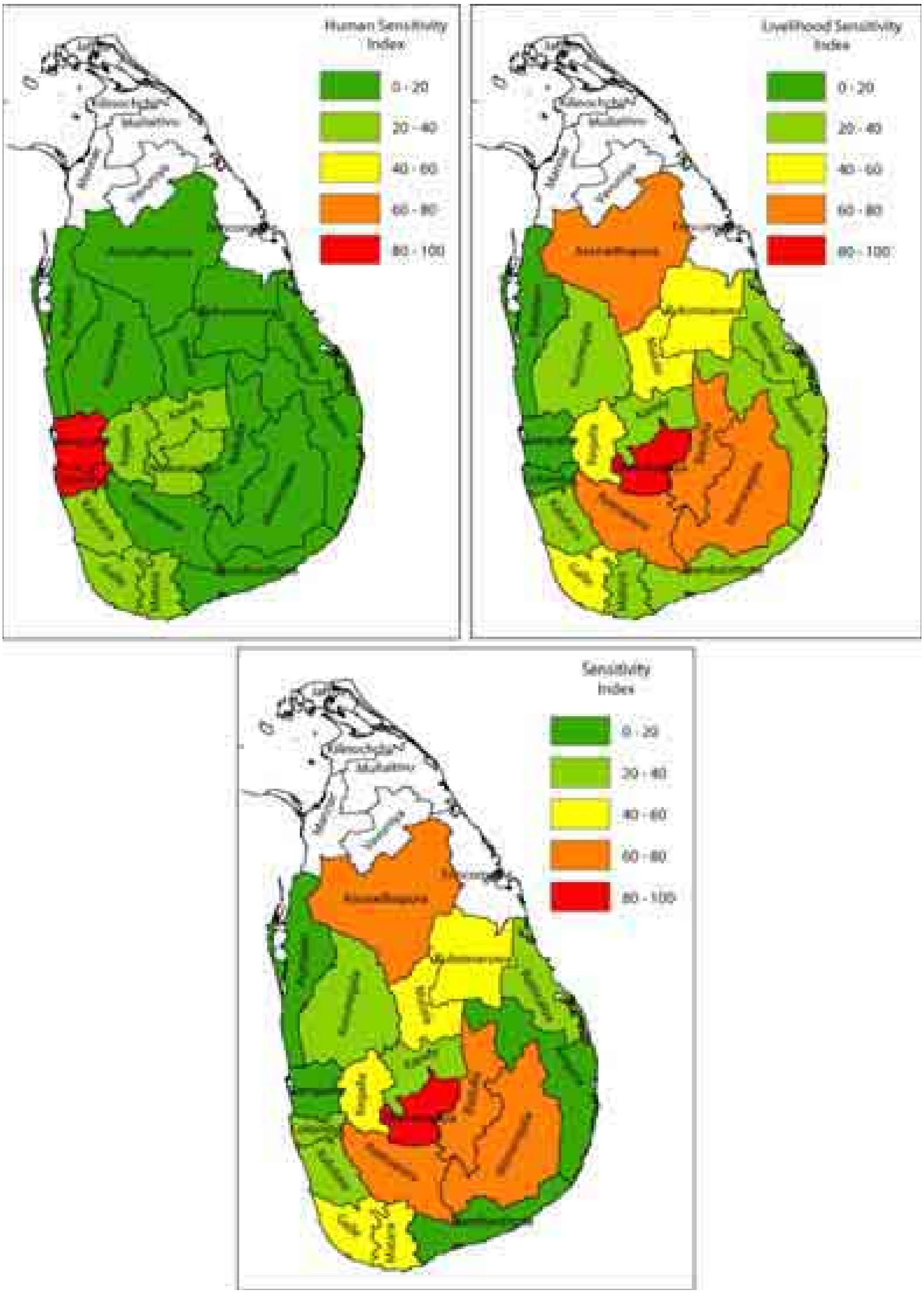


FIGURE 8. Components of sensitivity index and the composite sensitivity index for each district in Sri Lanka.

Sensitivity is represented by rural population density. Rural areas (where most of the agricultural endeavors in Sri Lanka are concentrated) with high population density are more sensitive to climate shocks, both because they expose a larger number of people to climate disasters while at the same time they are lacking in capacity and infrastructure to deal with such disasters effectively. Livelihood Sensitivity is characterized by a number of proxies such as: percentage of the population employed in agriculture, percentage of paddy area served by major irrigation schemes, and agricultural diversity (crop diversity and degree of engagement in non-crop endeavors such as livestock farming and fishing). The rationale here is that while a population with a greater reliance on agriculture is more sensitive to changes in climate, availability of irrigation and diversity in farming, in terms of both crop variety as well as engagement in non-crop endeavors, will collectively lower its climate sensitivity. However, in calculating the Livelihood Sensitivity Index, a higher weight is attributed to the percentage of the population employed in agriculture, since the importance of agricultural resilience to any district depends upon the extent to which agriculture contributes to its employment and income (Table 4). The overall Sensitivity Index (Figure 8) carries a higher weight on livelihood sensitivity since the impact of CC on the livelihoods of farmers is expected to be more severe than the direct impact on human lives.

Adaptive capacity is "the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2001). It is considered to be "a function of wealth, technology, education, information, skills, infrastructure, access to resources, stability and management capabilities" (IPCC 2001). This assessment considers adaptive capacity to be a function of Socioeconomic asset ownership as well as Infrastructural asset ownership (Figure 9). High asset ownership implies higher adaptive capacity while low asset ownership implies lower adaptive capacity. Socioeconomic assets are measured in terms of education (percentage of the population passing the GCE (Ordinary Level) Examination), poverty incidence (poverty headcount index), income inequality (poverty gap ratio) and share of agricultural GDP; Infrastructural assets are measured in terms of road density, electricity coverage (percentage number of houses having an electricity connection) and the communications index (a composite index consisting of the number of landlines, number of cellular subscribers, and number of internet users, per 100 population) (Table 4).

The assessment considers all districts in Sri Lanka except those lying within the Northern Province and the Trincomalee District in the Eastern Province. The study relies on historic data to assess vulnerability. Hence, it was felt that, given the altered conditions prevalent in the recent conflict zone in the North, use of historic data to assess present vulnerability in these areas will serve no justifiable purpose. Therefore, out of the Northern and Eastern provinces, only the Batticaloa and Ampara districts, which have been somewhat politically stable in the recent past, have been included in the study.

The procedure of constructing the index is similar to that of the Human Development Index (UNDP 2006), in which the values of each component indicator is normalized to the range of values in the dataset (see equations 2 and 3). Each component indicator and the final CC Vulnerability Index will have a value of 0-100 with 100 implying maximum vulnerability. The CC Vulnerability Index (Figure 10) is the average of the three subindices: the Exposure Index, the Sensitivity Index and the Adaptive Capacity Index. Although this index does not represent absolute damage risk and is only a comparison of the level of risk between districts, it does indicate where to prioritize strategic planning and investment in CC adaptation. Such prioritization is essential for policymakers to base their decisions on investment.

$$Index = \frac{AcV - MinV}{MaxV - MinV} \times 100 \qquad (2)$$

For indicators hypothesized to increase vulnerability, and

$$Index = 100 - \frac{AcV\ \text{-}\ MinV}{MaxV - MinV} \times 100 \qquad (3)$$

For indicators hypothesized to decrease vulnerability.

where: $Index =$ Index Value; $AcV =$ Actual Value; $MinV =$ Minimum Value in dataset, and $MaxV =$ Maximum Value in dataset

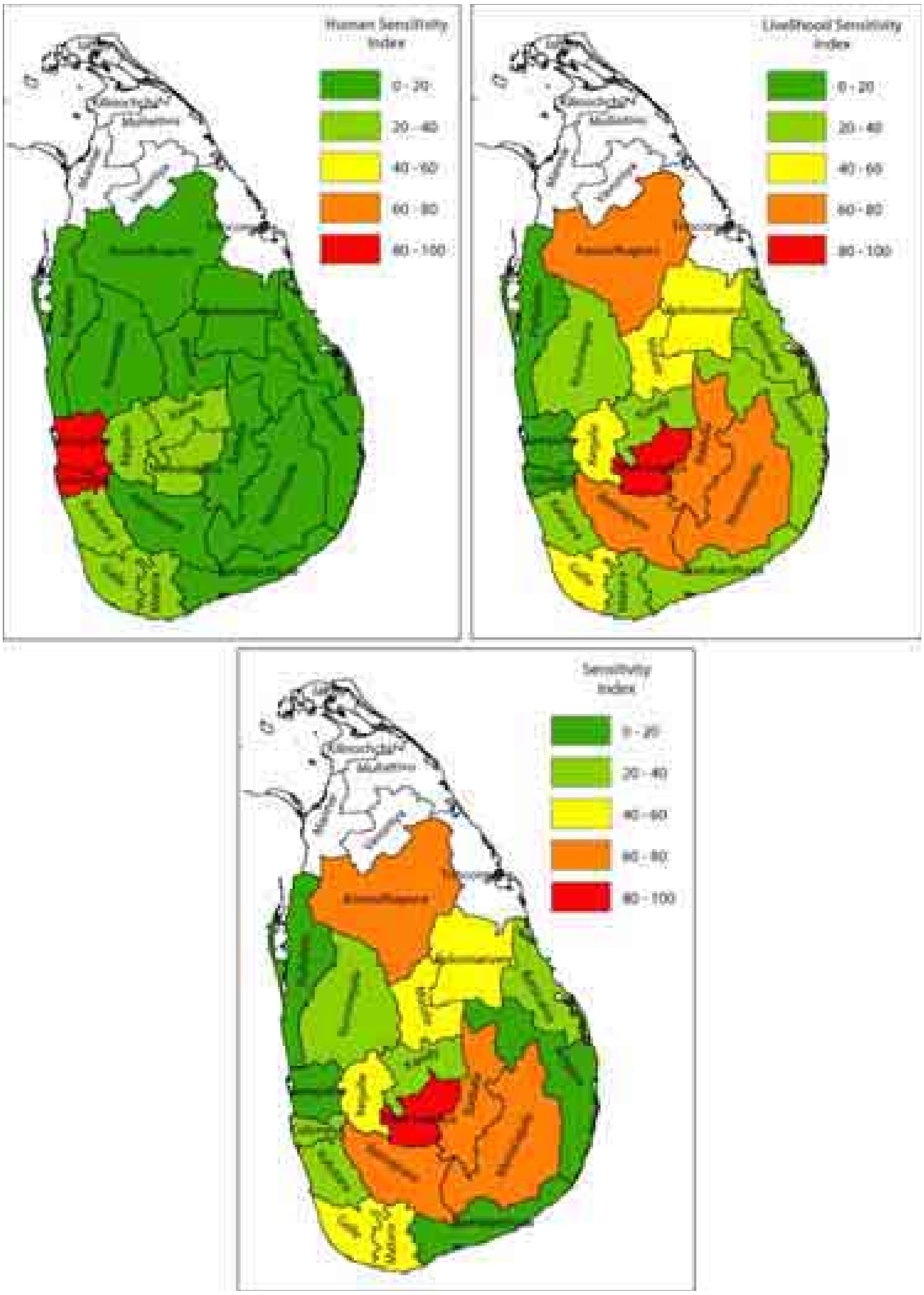


FIGURE 9. Components of adaptive capacity index and the composite adaptive capacity index for each district in Sri Lanka.

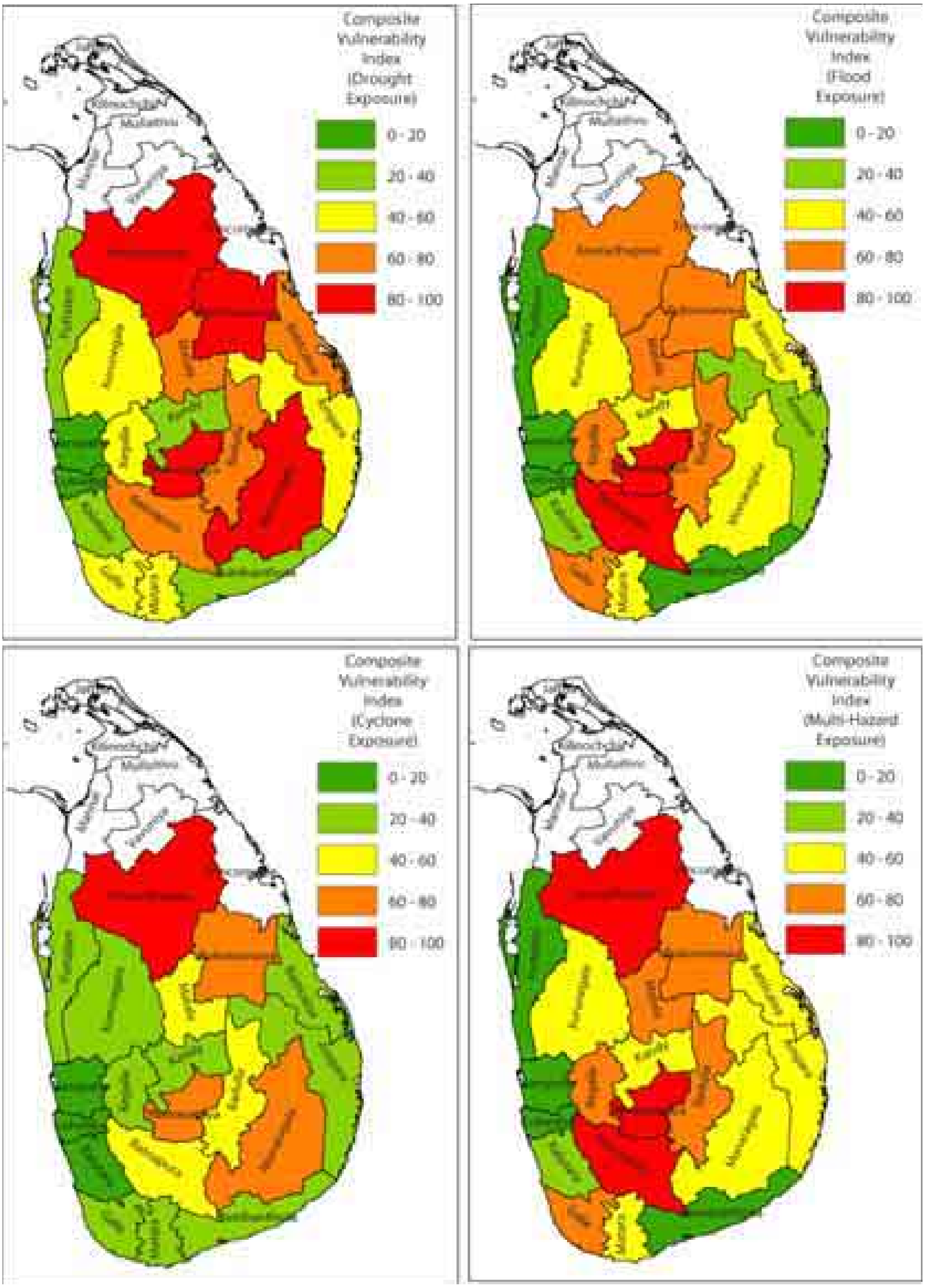


FIGURE 10. Composite vulnerability indices for drought, flood, cyclone and multi-hazard exposure for each district in Sri Lanka.

To ensure that high index values indicate high vulnerability in all cases, the index values are calculated using equation 3, in the case of indicators hypothesized to decrease vulnerability. All subindices thus calculated (using values of proxy variables) are then combined, by applying the weights shown in Table 4, to form the three main component indicators and the final vulnerability index. Four vulnerability indices were constructed in this manner, one each for exposure to droughts, floods, cyclones and, finally, multi-hazards (Figure 10).

Results and Discussion

According to Figure 7, many districts in the country are exposed to high levels of climate hazards: the number of districts within the 80-100 range in the Multi-hazard Exposure map is quite high. Therefore, it may be reasonably expected that these districts will be exposed to the same or higher levels of climate extremes in the future too. Digital data on historical exposure to climate hazards, covering the whole of Sri Lanka, exists only with the World Bank's Natural Disaster Hotspots Project (*http://www.ldeo.columbia.edu/chrr/research/hotspots/*) at present, and were used in this study. The Natural Disaster Hotspots Project relies on records in the EM-DAT global database (Emergency Events Database: http://www.emdat.be/) to construct its digital datasets. A more accurate assessment should consider verification and refinement of these digital datasets, and local agencies should be able to provide historical data records on climate-related disasters in Sri Lanka. One aspect of coverage here which can definitely be improved is the Cyclone Exposure Map. The reason being, although Batticaloa is considered to be one of the districts highly exposed to cyclones along with Trincomalee, its exposure level here is shown as being very low. The main cause for this discrepancy between the actual situation and the dataset could be the exclusion of some disasters in the EM-DAT database (due to non-reporting, or non-recognition as disasters by the EM-DAT criteria: 10 or more people killed, 100 or more people affected, declaration of a state of emergency or call for international assistance). Therefore, the development of a more accurate digital dataset on historical climate hazards in Sri Lanka is extremely important to make reliable future assessments on climate vulnerability.

Human Sensitivity (or rural population density) is extremely high in Colombo and Gampaha, in sharp contrast to the rest of the country (Figure 8). These densely populated rural areas (areas coming under the purview of *Pradesheeya Sabhas*) are highly vulnerable to extreme climate events (such as floods) since they harbor a greater number of people reliant on fewer resources (land per capita, etc.). Although Colombo and Gampaha have low livelihood sensitivity (due to higher levels of non-agricultural employment) (Figure 8), and higher adaptive capacity (higher socioeconomic and infrastructure levels) (Figure 9), crowding poses a threat to their climate resilience. Typical farming areas such as Nuwara Eliya, Badulla, Moneragala, Ratnapura and Anuradhapura have a higher Sensitivity Index than the rest of the country on account of their higher livelihood sensitivity to CC (Figure 8). They also tend to have low socioeconomic assets (higher levels of poverty, low education levels and higher reliance on agriculture for income), as well as low infrastructural assets, leading to lower adaptive capacity (Figure 9). Hence, infrastructural development, employment diversification and socioeconomic upliftment of the highly sensitive districts may help to lower their sensitivity to CC and increase their adaptive capacity. At the same time, it may also help to lower the human sensitivity of the more affluent districts of Colombo and Gampaha, by luring more and more people to live away from these highly congested areas.

Figure 9 illustrates the spread of infrastructure development in Sri Lanka. The two eastern districts of Ampara and Batticaloa along with Moneragala are the worst performers on this index. The Western Province (consisting of Colombo, Gampaha and Kalutara districts) is well-endowed with infrastructural assets, while the districts more reliant on agriculture seem to lag behind in infrastructure development. Infrastructural assets in terms of road density, communications facilities and electricity coverage enable market access, information flow, growth of agro-industries and employment diversification from primary agriculture, leading to more secure agricultural livelihoods and lower climate vulnerability. Hambantota is one district which has grown steadily over time in this respect, showing greater diversity in income generating activities (low sensitivity) and average adaptive capacity (Figures 8 and 9).

Four districts stand out in terms of drought vulnerability (Figure 10): Moneragala, Nuwara Eliya, Anuradhapura and Polonnaruwa, which are generally subject to frequent droughts. Ratnapura and Nuwara Eliya show the highest flood vulnerability while these two districts and Anuradhapura show the highest vulnerability in terms of multi-hazards. Despite not being severely affected by historical cyclones, Nuwara Eliya and Moneragala show high vulnerability to cyclone exposure (Figure 10) since their high sensitivity and low adaptive capacity influence the overall vulnerability index. Colombo, Gampaha, Puttalam and Hambantota show the lowest multi-hazard vulnerability.

The main limitation of this assessment is its inability to capture projections of CC and socioeconomic conditions for the coming years. However, given the ambiguity that exists with regard to CC projections and future socioeconomic conditions for Sri Lanka, such an analysis is not feasible at present. The inclusion of factors such as, severity of land degradation; land tenure; and future water availability under CC, as subindices in the sensitivity index, would have made the overall CC vulnerability index more reasonable. However, in the absence of such data on a district scale for Sri Lanka, we are compelled to rely on variables such as the percentage employed in agriculture, present irrigation water availability and crop diversity as proxies representing sensitivity of the agriculture sector to CC and associated impacts. Also, we have not considered the threat posed by sea level rise to coastal districts in this assessment. Collection of detailed sub-national information on the various component indicators will enable mapping even on a finer scale, ideally at *Grama Niladari* (GN) division level. In this study, rural population density is represented by the population density of *Pradesheeya Sabhas* in each district. However, this proxy may not be appropriate to districts like Colombo where the *Pradesheeya Sabhas* are peri-urban. Therefore, a better way to represent rural population density would be to consider all areas within GN divisions, with a density below a certain threshold, to be rural. Hence, there is ample room for fine-tuning this assessment to take into account scientifically acceptable projections of future CC impacts, projected changes in socioeconomic conditions and detailed local level information on climate hazards, biophysical factors, and indicators of adaptive capacity.

Conclusions

It is evident that Sri Lanka's climate has already changed: During the period 1961-1990, the country's mean air temperature increased by 0.016 °C per year; MAP decreased by 144 mm (7%) compared to the period 1931-1960, although no significant trend is observed in MAP. The review suggests that although a few attempts have been made to project Sri Lanka's climate during the twenty-first century, these attempts lack consensus and are even contradictory. While there is agreement among available projections that gradual warming will be experienced throughout the country within this century (0.9-4 °C increase in mean annual temperature), there is no such agreement regarding rainfall. However, many available projections indicate that CC impacts can be large in the dry zone, especially in the Northeast and the East, where some of the agriculturally intensive areas are located and are already experiencing water stress. The expected changes may lead to an increase in the *Maha* (wet) season irrigation water requirement for paddy by 13-23% by 2050 compared to that of 1961-1990. Observed and projected reduction in rainfall in the Central Highlands is likely to create conflicts between irrigation water supply and hydropower generation from the multipurpose Mahaweli scheme (supplying 29% of national power generation and 23% of irrigation water that is supplied by major irrigation schemes).

Tea cultivations at low and mid elevations appear to be more vulnerable to adverse impacts of CC than those at high elevations. Reduction of monthly rainfall by 100 mm could reduce productivity by 30-80 kg of 'made' tea per hectare. Future projections on coconut yield suggest that production after 2040 may not be sufficient to cater to local consumption. Studies on the response of coconut yield to past climate variations have shown that extended dry spells and excessive cloudiness during the wet season can reduce yield so that annual losses can range between US$32 and US$73 million. However, on the other hand, during a high rainfall year, the economy could gain by US$42-US$87 million due to high coconut yields. The expected impacts on water resources and the agriculture sector may in turn trigger serious impacts on the country's food production, livelihoods and the economy. A recent study finds Sri Lanka to be one of the hotspots of food insecurity in the Asia-Pacific region (ESCAP 2009), while another suggests yet further decreases (0-15%) in agricultural productivity by 2080 (Nellemann et al. 2009).

The preliminary agricultural vulnerability mapping suggests that typical farming areas such as Nuwara Eliya, Badulla, Moneragala, Ratnapura and Anuradhapura (many of them in the dry zone) are more sensitive to CC than the rest of the country, due to their heavy reliance on primary agriculture. At the same time they have lower levels of infrastructural and socioeconomic assets (much lower than those of Colombo and the Western Province as a whole), resulting in lower adaptive capacity, and hence, higher vulnerability. Therefore, apart from food insecurity, CC may worsen the existing economic and social inequities and widen the gap between the developed core (Colombo Metropolitan Region) and the less developed areas. On the other hand, the more affluent districts of Colombo and Gampaha are also highly sensitive to climate extremes (which are expected to exacerbate in the future), simply due to the fact that they harbor disproportionately high population densities than the rest of the country.

In this context, reliable and detailed quality-controlled climate scenarios for the country are urgently needed, in order to obtain a better idea of the risks and benefits of CC and for strategic planning towards adaptation. It may require revisiting and quality controlling of the existing studies and resolving the apparent ambiguity with respect to future climate projections (especially for precipitation) and/or the setting up of a RCM experiment considering Sri Lanka as the analysis domain. A comprehensive national study on the vulnerability of Sri Lanka's water resources and agricultural sectors to CC on a river basin or district scale should follow. This study should not only include surface water, but also groundwater, covering both water quality as well as water quantity issues. It is equally important that such a study takes stock of Sri Lanka's present water resources in the form of a national water resources audit, such as the prototype audit developed by IWMI, available at: *http://idistest.iwmi.org:8080/slwa/*. However, the future success of this tool depends upon the collaboration and support of national agencies in incorporating data and information into it. Only if the combined impact on agriculture, of increased temperature, increased CO_2 in the atmosphere and increased/decreased rainfall, is quantified, can a true picture of the benefits or costs of CC on agriculture, food security and the economy be projected. Appropriate adaptation measures may be implemented based on such a study.

A digital database on historical climate hazards in Sri Lanka is another extremely important requirement for the country in order to facilitate reliable future assessments on climate vulnerability. Central to any research on CC is the need for data sharing and cooperation among different stakeholder agencies. The Water Resources Board, which already has the mandate to act as the leading coordinating authority in Sri Lanka's water sector, could play a pivotal role as the central agency facilitating such research, including maintenance of a data depository.

Appendices

Appendix 1. Indicators of climate change vulnerability.

Indicator	Computation	Data required	Source
Social Vulnerability Index (SVI) Vulnerability of agricultural sector of a country to climate change measured in social terms	$SVI = \frac{I_1 + I_2 + I_3 + I_4 + I_5}{5}$ I_1 = Agricultural Dependency Index; I_2 = Landlessness Index; I_3 = Education Index; I_4 = Female Disadvantage Index; I_5 = Female Literacy and Child Survival Index I_1 to I_5 calculated as follows: $I_1 = \frac{A_{actual} - A_{min}}{A_{max} - A_{min}} x\ 100$ $I_2 = \frac{L_{actual} - L_{min}}{L_{max} - L_{min}} x\ 100$ $I_3 = 100 - \frac{E_{actual} - E_{min}}{E_{max} - E_{min}} x\ 100$ $I_4 = 100 - \frac{F_{actual} - F_{min}}{F_{max} - F_{min}} x\ 100$ $I_5 = 100 - \frac{I_{actual} - I_{min}}{I_{max} - I_{min}} x\ 100$ A = Percentage of workers employed in agriculture; L = Percentage of landless laborers in agricultural workforce; E = Adult literacy rate; F = "Missing girls" (less than 48.5% girls in 0-6 population representing female disadvantage); I = Female literacy rate Max and Min values to be obtained from available country data Final SVI will have a score of 0 to 100, with 100 being highly vulnerable	Percentage of workers employed in agriculture Percentage of landless laborers in agricultural workforce Adult literacy rate Missing girls (less than 48.5% girls in 0-6 population representing female disadvantage) Female literacy rate	O'Brien et al. (2004) Thornton et al. (2006) Already carried out for India at district level – may be applied globally.
Technological Vulnerability Index (TVI) Vulnerability of agricultural sector of a country to climate change measured in technological terms	$TVI = \frac{I_6 + I_7}{2}$ I_6 = Irrigation Index; I_7 = Infrastructure Development Index $I_6 = 100 - \frac{I_{r\ actual} - I_{r\ min}}{I_{r\ max} - I_{r\ min}} x\ 100$ $I_7 = 100 - \frac{I_{f\ actual} - I_{f\ min}}{I_{f\ max} - I_{f\ min}} x\ 100$ I_f = Irrigation rate (net irrigated area as a percentage of net sown area) I_f = Composite Index of Infrastructure Development (An index derived for Indian States by the Centre for Monitoring Indian Economy (CMIE). Please see Appendix 2 for an explanation of this index). All TVI values will have a score of 0 to 100, with 100 being highly vulnerable.	Irrigation rate Composite Index of Infrastructure Development (See Appendix 2 for data requirement)	

Indicator	Computation	Data required	Source
Biophysical Vulnerability Index (BVI) Vulnerability of agricultural sector of a country to climate change measured in biophysical terms	$BVI = \frac{I_8 + I_9}{2}$ I_8 = Soil Quality Index; I_8 = Groundwater Scarcity Index $I_8 = \frac{DS + SD}{2}$ $DS = 100 - \frac{DS_{actual} - DS_{min}}{DS_{max} - DS_{min}} \times 100$ $SD = \frac{SD_{actual} - SD_{min}}{SD_{max} - SD_{min}} \times 100$ $I_9 = 100 - \frac{Rg_{actual} - Rg_{min}}{Rg_{max} - Rg_{min}} \times 100$ *DS* = Depth of Soil Cover; *SD* = Soil Degradation Severity; *Rg* = Replenishable groundwater available for future use (in million cubic meters); all BVI values will have a score of 0 to 100, with 100 being highly vulnerable.	Depth of Soil Cover Soil Degradation Severity Replenishable groundwater available for future use	
Adaptive Capacity of Agricultural Sector of a country to climate change (combining all three indicators above)	$\frac{SVI + TVI + BVI}{3}$ All values will have a score of 0 to 100, with 100 being highly vulnerable.		
Ecological Vulnerability (EV) Determination of vulnerability to drought using ecological variables	$EV = 0.3 \times R + 0.15 \times V + 0.15 \times S + 0.2 \times LD + 0.2 * GH$; $R = \frac{In + C + NR}{3}$; $V = Pf$; $S = 0.25 \times Sp + 0.25 \times Sd + 0.25 \times Sdr + 0.25 \times St$; $LD = \frac{Sl + Lf + Dd}{3}$; $GH = \frac{Pm + Gp + Gl}{3}$ *R* = Rainfall; *V* = Vegetation; *S* = Soil; *LD* = Landform and Drainage; *GH* = Geohydrology Subindices: *In* = Inter-spell duration gaps greater than 8 days; *C* = Commencement of sowing rain June 15-28; *NR* = Normal annual rainfall; *Pf* = Percentage of forest cover; *Sp* = Soil particle size; *Sd* = Soil depth; *Sdr* = Soil drainage; *St* = Soil taxonomy; *Sl* = Slope; *Lf* = Land forms; *Dd* = Drainage density; *Pm* = Parent material; *Gp* = Estimated utilizable groundwater potential; *Gl* = Groundwater level All subindices are calculated by considering max and min values as explained earlier, and a score of 0 to 100 is assigned for each. Final EV value will have a score of 0 to 100 with 100 being highly vulnerable	Average annual rainfall Inter-spell duration gaps greater than 8 days Commencement of sowing rain June 15-28 Percentage of forest cover Soil particle size Soil depth Soil drainage Soil taxonomy Slope Land forms Drainage density Parent material Estimated utilizable groundwater potential Groundwater level	Gupta (2002) Already applied to Chhattisgarh, India.

Indicator	Computation	Data required	Source
Production System Vulnerability (PV) Determination of vulnerability to drought using production system variables	$PV = 0.7 \times AS + 0.3 \times LU;\quad AS = \frac{Ia + Ca}{2};\quad LU = \frac{F + Cw + Cu}{3}$ *AS* = Agricultural System; *LU* = Land Use Subindices: *Ia* = Gross irrigated area as a proportion of gross cropped area; *Ca* = Gross cropped area as a proportion of the net sown area; *F* = Fallows as a proportion of the net sown area; *Cw* = Cultivable wastes as a proportion of the net sown area; *Cu* = Cultivable area as a proportion of net sown area All subindices are calculated by considering max and min values as explained earlier, and a score of 0 to 100 is assigned for each. Final PV value will have a score of 0 to 100 with 100 being highly vulnerable	Gross irrigated area as a proportion of gross cropped area Gross cropped area as a proportion of the net sown area Fallows as a proportion of the net sown area Cultivable wastes as a proportion of the net sown area Cultivable area as a proportion of net sown area	Gupta (2002). Already applied to Chhattisgarh, India
Socioeconomic Vulnerability (SV) Determination of vulnerability to drought using socioeconomic variables	$SV = 0.5 \times SO + 0.5 \times EC;\quad SO = \frac{Pt + Pp}{2};\quad EC = \frac{Wp + Pa}{2}$ *SO* = Social; *EC* = Economic Subindices: *Pt* = Proportion of non-scheduled tribes and scheduled caste population; *Pp* = Percentage of people below poverty line; *Wp* = Workforce participation ratio; *Pa* = Percentage of population dependent on agriculture; All subindices are calculated by considering max and min values as explained earlier, and a score of 0 to 100 is assigned for each Final SV value will have a score of 0 to 100 with 100 being highly vulnerable	Proportion of non-scheduled tribes and scheduled caste population Percentage of people below poverty line Workforce participation ratio Percentage of population dependent on agriculture	Gupta (2002). Already applied to Chhattisgarh, India
Drought Vulnerability (DV) Vulnerability of a country to drought (combining all three indicators above)	$DV = 0.5 \times EV + 0.25 \times PV + 0.25 \times SV$ Final DV value will have a score of 0 to 100 with 100 being highly vulnerable		

Indicator	Computation	Data required	Source
Vulnerability of Farming Households to Drought (FV)	FV=AC+DR+LO+GH+LD+AI+DP+EB+LD+TH+SF+FS+QH Subindices: AC = Acreage under cultivation (hectares); DR = Dependency ratio (number of dependents); LO = Livestock ownership (number of livestock units); GH = Gender of household head (HH); LD = Livelihood diversification (number of non-agricultural income generating activities); DP = Drought preparedness (value given to use of drought resistant crops and livestock and receipt of drought related information and advice); AI = Annual cash income; All above sub-indices except GH and DP are calculated as: Sub-index value = $\frac{Actual\ \text{-}\ Min}{Max\ \text{-}\ Min}$ *or* $1 - \frac{Actual\ \text{-}\ Min}{Max\ \text{-}\ Min}$ And each sub-index will have a value of 0 to 1 with 1 being more vulnerable GH = 0 if HH = male and GH =1 if HH = female DP will have a value of 0-1 based on judgment EB = Educational background of the household head (value given to highest school level attained by the head of the household) LT = Land tenure situation (value given to land tenure situation) TH = Type of house (value given to type of house lived in) SF = Self-sufficiency in food production (number of years surplus foodstuff were sold minus number of years foodstuff were bought in the past 10 years) FS = Family and social networks (value given to strength of family and social networks) QH = Quality of household (number of able persons/number of disabled and/or sick persons in the household) Each of the above subindices will have a value from 0 to 0.5 either as calculated above or based on judgment The Final FV value will have a score of 0-10	Acreage under cultivation Dependency ratio Livestock ownership Gender of household head Livelihood diversification Drought preparedness annual cash income Educational background of the household head Land tenure Type of house Self-sufficiency in food production Family and social networks Quality of household	Adepetu (2003) Premchander and Müller (2006) Already applied to Nigeria
Index of Economic Well–being (EW) Social vulnerability to climate change-induced variations in water availability measured in terms of economic variables	$EW = \frac{PL + CU}{2}$; $PL = \frac{pl_{actual} - pll_{min}}{pl_{max} - pl_{min}}$; $CU = \frac{cu_{actual} - cu_{min}}{cu_{max} - cu_{min}}$ PL = Standard of Living; CU = Change in percentage of urban population; pl = percentage of the population living below the specified poverty line in 2000; cu = change in the percentage of urban population between 1975 and 2000, based on mid-year population of areas defined as urban in a country. EW will have a value of 0 to 1 with 1 indicating higher vulnerability	Percentage of the population living below the specified poverty line in 2000 Change in the percentage of urban population between 1975 and 2000, based on mid-year population of areas defined as urban in a country	Vincent (2004) Already applied to Africa

Indicator	Computation	Data required	Source
Demographic Structure Index (DS) Social vulnerability to climate change-induced variations in water availability measured in terms of demographic variables	$DS = \frac{DP + PHIV}{2}$; $DP = \frac{dp_{actual} - dp_{min}}{dp_{max} - dp_{min}}$; $PHIV = \frac{phiv_{actual} - phiv_{min}}{phiv_{max} - phiv_{min}}$ *DP* = Dependent Population; *PHIV* = Proportion of the working population with HIV/AIDS; *dp* = Population under 15 and over 65 as a percentage of the total; *phiv* = Adults aged 15-49 living with HIV/AIDS as a percentage of the population aged between 15-49 in 2001 DS will have a value of 0 to 1 with 1 indicating higher vulnerability	Population under 15 and over 65 as a percentage of the total Adults aged 15-49 living with HIV/AIDS as a percentage of the population aged between 15-49 in 2001	
Institutional Stability and Strength of Public Infrastructure Index (IP) Social vulnerability to climate change-induced variations in water availability measured in terms of institutional variables	$IP = \frac{HE + TL + CR}{3}$; $HE = 1 - \frac{he_{actual} - he_{min}}{he_{max} - he_{min}}$; $TL = 1 - \frac{tl_{actual} - tl_{min}}{tl_{max} - tl_{min}}$ *HE* = Public health expenditure as a proportion of GDP; *TL* = Telephones; *CR* = Corruption; *he* = Public health expenditure as a percentage of GDP in 1998; *tl* = number of mainland telephone lines per 100 population in 2000; *CR* = Composite Index using data from various sources; IP will have a value of 0 to 1 with 1 indicating higher vulnerability	Public health expenditure as a proportion of GDP Number of mainland telephone lines per 100 population in 2000 Corruption (composite index, 2002)	
Global Interconnectivity Index (GI) Social vulnerability to climate change-induced variations in water availability measured in terms of global interconnectivity	*GI* = *TB*; *TB* = Trade Balance; $TB = 1 - \frac{tb_{actual} - tb_{min}}{tb_{max} - tb_{min}}$; *tb* = Net trade in goods and services (1999) GI will have a value of 0 to 1 with 1 indicating higher vulnerability	Net trade in goods and services (1999)	
Natural Resources Dependence Index (ND) Social vulnerability to climate change-induced variations in water availability measured in terms of dependence on natural resources	*ND* = *RP*; *RP* = Rural population; $RP = 1 - \frac{rp_{actual} - rp_{min}}{rp_{max} - rp_{min}}$; *rp* = Percentage of rural population (1999) ND will have a value of 0 to 1 with 1 indicating higher vulnerability	Percentage of rural population (1999)	
Social Vulnerability Index (SVI) (Combining all five indicators above)	SVI = 0.2 *EW + 0.2 * DS + 0.4 * IP + 0.1 * GI + 0.1*ND		

Indicator	Computation	Data required	Source
Vulnerability of natural resource-based livelihoods to climate variability (including long term climate change	Composite Indicator combining 14 vulnerability indicators based on the sustainable livelihoods approach: *http://www.ifad.org/sla/* **Natural Capital Vulnerability Indicators** Crop suitability; Soil degradation severity; Internal water resources by subbasin; **Physical Capital Vulnerability Indicators** Accessibility to markets **Social Capital Vulnerability Indicators** Human Poverty Index; Governance **Human Capital Vulnerability Indicators** Stunting (percentage of children under 5 years who are stunted); Infant mortality rate; percentage of children under 5 years who are underweight; Malaria risk (climatic suitability for endemic malaria); public health expenditure; HIV/AIDS prevalence **Financial Capital Vulnerability Indicators** Agricultural GDP; Global interconnectivity Original study carried out by principal component analysis	Crop suitability, Soil degradation severity, Internal water resources by subbasin Accessibility to markets, Human Poverty Index, Governance Stunting (percentage of children under 5 years who are stunted), infant mortality rate percentage of children under 5 years who are underweight, Malaria risk (climatic suitability for endemic malaria), public health expenditure, HIV/AIDS prevalence (proportion of working population with HIV/AIDS) Agricultural GDP, global interconnectivity (the difference between all exports and imports)	Thornton et al. (2006) Already applied to Africa
Exposure Index (EPI)	Index based on the composite risk of cyclones, droughts, floods, landslides and sea level rise (equally weighted). Index scores are from 0 to 100 with 100 implying maximum exposure similar to above	Risk of cyclones, droughts, floods, landslides and sea level rise	Yusuf and Francisco (2009) Already applied to Southeast Asia
Sensitivity Index (SI)	SI = 0.7 *PD + 0.3 * PA; PD = Population Density PA = Percentage of protected areas	Population Density Percentage of protected areas	

Indicator	Computation	Data required	Source
Adaptive Capacity Index (ACI)	$ACI = 0.5 * SE + 0.25 * TECH + 0.25 * IF$ $SE = 0.5 * HDI + 0.28 * PI + 0.22 * II$ $TECH = 0.53 * EC + 0.47 * EI$ $IF = 0.5 * RD + 0.5 * C$ SE = Socioeconomic Index; TECH = Technology Index; IF = Infrastructure Index; HDI = Human Development Index; PI = Poverty Incidence; II = Income Inequality; EC = Electricity Coverage; EI = Extent of Irrigation; RD = Road Density; C = Communications Index Index scores are from 0 to 100 with 100 implying lowest adaptive capacity similar to above	Human Development Index Poverty incidence Income inequality Electricity coverage Extent of irrigation Road density Communications coverage	
Climate Change Vulnerability Index (CCVI)	Average of all three indices above $CCVI = \frac{EPI + SI + ACI}{3}$ Index scores are from 0 to 100 with 100 implying maximum vulnerability similar to above		
Exposure Index2 (EPI2)	$EP12 = \frac{EV + CC}{2}; \quad CC = \frac{T + P}{2}$ EV = Frequency of droughts or floods; CC = Projected change in climate; T = Projected change in temperature (degrees) from base (2000); P = Projected percentage change in precipitation from base (2000); Weights applied to subindices can change; Index scores are from 0 to 100 with 100 implying maximum exposure similar to above	Frequency of droughts or floods Projected change in temperature (degrees) from base (2000) Projected percentage change in precipitation from base (2000)	Gbetibouo and Ringler (2009) Already applied to South Africa
Sensitivity Index2 (SI2)	$SI2 = \frac{IL + LDI + FO + RPD + CDI}{5}$ IL = Percentage of irrigated land; LDI = Land degradation index; FO = Percentage of small-scale farming operations; RPD = Rural population density; CI = Crop diversification Index; Weights applied to subindices can change; Index scores are from 0 to 100 with 100 implying maximum sensitivity similar to above	Percentage of irrigated land Land degradation index Percentage of small-scale farming operations Rural population density Crop diversification Index	

Indicator	Computation	Data required	Source
Adaptive Capacity Index2 (ACI2)	$SI2 = \frac{SC + HC + FC + PC}{4}$ *SC*= Social Capital (farm organization); *HC* = Human Capital (literacy rate, HIV prevalence); *FC* = Financial Capital (access to credit, farm income, percentage below poverty line, farm holding size, percentage of agriculture GDP, farm assets, access to credit); *PC* = Physical Capital (Infrastructure Index) Weights applied to subindices can change; Index scores are from 0 to 100 with 100 implying minimum adaptive capacity similar to above	Farm organization (number of farmer members of organized agriculture) Literacy rate, HIV prevalence (percentage of people infected with HIV) Amount of credit received, net farm income, unemployment rate, average farm size, share of agricultural GDP, total value of farm assets Infrastructure Index	
Climate Change Vulnerability Index2 (CCVI2)	Average of all three indices above $CCVI2 = \frac{EPI2 + SI2 + ACI2}{3}$ Weights applied to subindices can change; Index scores are from 0 to 100 with 100 implying maximum vulnerability similar to above		

Appendix 2. Composite Index of Infrastructure Development derived by the Centre for Monitoring Indian Economy (CMIE).

Sector (subindices)	Weight	Indicators	Calculation of subindices	Comment
Transport facilities (T)	26	Railway route length per 100 km^2 of area (R)	$R = \frac{R_{actual} - R_{min}}{R_{max} - R_{min}} x\ 100$	Max and min values to be obtained from the country data range for each indicator
		Surfaced roads per 100 km^2 of area (S)	$S = \frac{S_{actual} - S_{min}}{S_{max} - S_{min}} x\ 100$	$T = \frac{R + S + U}{3}$
		Unsurfaced roads per 100 km^2 of area (U)	$U = \frac{U_{actual} - U_{min}}{U_{max} - U_{min}} x\ 100$	
Energy (E)	24	Villages electrified (V)	$E = \frac{V_{actual} - V_{min}}{V_{max} - V_{min}} x\ 100$	
Irrigation facilities (I)	20	Gross irrigated area as a percentage of gross cropped area (G)	$I = \frac{G_{actual} - G_{min}}{G_{max} - G_{min}} x\ 100$	
Banking facilities (B)	12	Bank branches per lakh of population (BN)	$B = \frac{BN_{actual} - BN_{min}}{BN_{max} - BN_{min}} x\ 100$	
Communication infrastructure (C)	6	Post offices per lakh of population (P)	$P = \frac{P_{actual} - P_{min}}{P_{max} - P_{min}} x\ 100$	$C = \frac{P + TL}{2}$
		Telephone lines per 100 persons (TL)	$TL = \frac{TL_{actual} - TL_{min}}{TL_{max} - TL_{min}} x\ 100$	
Educational institutes (ED)	6	Primary schools per lakh of population (PS)	$ED = \frac{PS_{actual} - PS_{min}}{PS_{max} - PS_{min}} x\ 100$	
Health facilities (H)	6	Hospital beds per lakh of population (HB)	$HB = \frac{HB_{actual} - HB_{min}}{HB_{max} - HB_{min}} x\ 100$	$H = \frac{HB + PH}{2}$
		Primary health centers per lakh of population (PH)	$PH = \frac{PH_{actual} - PH_{min}}{PH_{max} - PH_{min}} x\ 100$	
Total	100			

$$\textbf{Composite Infrastructure Index} = \frac{26xT + 24xE + 20xI + 12xB + 6xC + 6xED + 6xH}{100}$$

References

Adam, D. 2008. World carbon dioxide levels highest for 650,000 years, says US report. *The Guardian*: May 13, 2008.

ADB (Asian Development Bank). 2006. *Country synthesis report on urban air quality management: Sri Lanka*. Discussion Draft, December, 2006. Asian Development Bank.

Adepetu, A. 2003. Rural households and drought in the Sahel Region of West Africa: Vulnerability and effective mitigation measures. Second progress report research grant No. AIACC_AF92. Assessments of Impacts and Adaptation to Climate Change (AIACC).

Aheeyar, M. M. M.; Kumara, S. K.; Samarasinghe, G. G. de L. W. 2005. *The application of micro irrigation technologies in the small farming sector in Sri Lanka*. HARTI.

Ahmed, S. A.; Diffenbaugh, N. S.; Hertel, T. W. 2009. Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters* 4 034004. doi: 10.1088/1748-9326/4/3/034004

Allison, E. H.; Perry, A. L.; Badjeck, M.; Adger, W. N.; Brown, K.; Conway, D.; Halls, A. S.; Pilling, G. M.; Reynolds, J. D.; Andrew, N. L.; Dulvy, N. K. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*. Blackwell Publishing Ltd. doi: 10.1111/j.1467-2979.2008.00310.x

Amarasinghe, U. A.; Mutuwatta, L.; Sakthivadivel, R. 1999. *Water scarcity variations within a country: A case study of Sri Lanka*. Research Report 32. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Ambawatte, H. C.; Kumara, P. O. A. D. 2007. Experimental investigation of jatropha oil based bio-diesel in compression ignition engines. *Proceedings of the 63rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1.

Ambawatte, H. C.; Palayangoda, L. I.; Pathirathna, O. U. A. 2007. Design and development of a domestic lamp for lighting using jatropha/castor oils. *Proceedings of the 63rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1.

Anderson, T. 2009. Green mobile network for rural Sri Lanka under trial. *Science and Development Network (SciDev.Net) News*: March 18, 2009.

Arumugam, S. 1969. *Water resources of Ceylon*. Colombo, Sri Lanka: Water Resources Board.

Ashfaq, M.; Shi, Y.; Tung, W.; Trapp, R. J.; Gao, X.; Pal, J. S.; Diffenbaugh, N. S. 2009. Suppression of South Asian summer monsoon precipitation in the 21st century. Geophysical Research Letters 36(L01704). doi:10.1029/2008GL036500

Basnayake, B. R. S. B. 2008. Climate change: present and future perspective of Sri Lanka. Available at Meteorological Department of Sri Lanka website: *http://www.meteo.gov.lk/Non_%20Up_Date/pages/ccinsl_1.htm* (accessed May 05, 2009).

Basnayake, B. R. S. B.; Vithanage, J. C. 2004a. Future climate scenarios of rainfall and temperature for Sri Lanka. *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. pp 222.

Basnayake, B. R. S. B.; Vithanage, J. C. 2004b. Rainfall change scenarios for Sri Lanka under the anticipated climate change. *Proceedings of the International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, November 17-19, 2004, Colombo, Sri Lanka.

Basnayake, B. R. S. B.; Fernando, T. K.; Vithanage, J. C. 2002. Variation of air temperature and rainfall during Yala and Maha agricultural seasons. *Proceedings of the 58th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. pp 212.

Basnayake, B. R. S. B.; Punyawardena, B. V. R.; Vithanage, J. C. 2003. An investigation of ambient air temperature trends at Hambantota – Angunakolapelassa and Nuwara Eliya - Thalawakele. *Proceedings of the 59th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. pp 194.

Basnayake, B. R. S. B.; Rathnasiri J.; Vithanage J. C. 2004. Rainfall and temperature scenarios for Sri Lanka under the anticipated climate change. Paper presented at 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, Philippines.

Chandrapala, L. 1996a. Calculation of areal precipitation of Sri Lanka on district basis using Voronoi Tessalation Method. *Proceedings of National Symposium on Climate Change*, Central Environmental Authority, Colombo, Sri Lanka. March 7-8, 1996.

Chandrapala, L. 1996b. Long term trends of rainfall and temperature in Sri Lanka. In:*Climate Variability and Agriculture*, Abrol, Y. P.; Gadgil, S.; Pant, G. B. (eds.). New Delhi, India: Narosa Publishing House. Pp 153-162.

Chandrika, R. I.; Jayasinghe, A. P. R.; Mahinda, W. 2004. Evaluation of alternative crops for a water short irrigation system: A case study of "Kirindi Oya irrigation and settlement project". *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 127.

Cruz, R. V.; Harasawa, H.; Lal, M.; Wu, S.; Anokhin, Y.; Punsalmaa, B.; Honda, Y.; Jafari, M.; Li, C.; Huu Ninh, N. 2007. Asia. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M. L.; Canziani, O. F.; Palutikof, J. P.; van der Linden, P. J.; Hanson, C. E. eds. Cambridge, UK: Cambridge University Press. pp 469-506.

De Costa, W. A. J. M.; Weerakoon, W. M. W.; Herath, H. M. L. K.; Amaratunga, K. S. P.; Abeywardena, R. M. I. 2006. Physiology of yield determination of rice under elevated carbon dioxide at high temperatures in a subhumid tropical climate. *Field Crops Research* 96(2-3): 336-347.

De Silva, C. S. 2006a. Impacts of climate change on potential soil moisture deficit and its use as a climate indicator to forecast irrigation need in Sri Lanka. In: *Symposium Proceedings of the Water Professionals' Day, 2006*, ed., Dayawansa, N. D. K.

De Silva, C. S. 2006b. Impacts of climate change on water resources in Sri Lanka. Paper presented at the 32nd WEDC International Conference, November 13-17, 2006, Colombo, Sri Lanka.

De Silva, C. S.; Weatherhead, E. K.; Knox, J. W.; Rodriguez-Diaz, J. A. 2007. Predicting the impacts of climate change – a case study of paddy irrigation water requirements in Sri Lanka. *Agricultural Water management* 93(2007): 19-29.

Department of Agriculture. 2006. Field Crops Research and Development Institute (FCRDI). Website of Department of Agriculture (http://www.agridept.gov.lk/doa/menudata.php?mMenu=Field%20Crops&sMenu=Field%20Crops%20Research%20and%20Development%20Institute%20(FCRDI). Accessed in September 2009).

Emmanuel, R. 2001. The thermal comfort effects of urbanization: bio-climatic and land-use changes in the Colombo Metropolitan Region (CMR). *Proceedings of the 57th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section C. pp. 113.

ESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2009. *Sustainable agriculture and food security in Asia and the Pacific.*

Fernando, M. T. N.; Jayalath, K. V. N. N. 2003. Shifting from furnace oil dendrothermal energy in desiccated coconut industry of Sri Lanka: An ex-ante environmental economic analysis. Paper presented at the 2003 International Conference on Tropical Forests and Climate Change, Manila, Philippines.

Fernando, M. T. N.; Zubair, L.; Peiris, T. S. G.; Ranasinghe, C. S.; Ratnasiri, J. 2007. *Economic value of Climate Variability Impacts on Coconut Production in Sri Lanka*. AIACC Working Paper No. 45.

Fernando, T. K. 1997. Recent variations of rainfall and air temperature in Sri Lanka. *Proceedings of the 53rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. Pp. 318.

Fernando, T. K.; Basnayake, B. R. S. B. 2002. A comparative study of the ambient air temperature at Anuradhapura and Mahailluppallama. *Proceedings of the 58th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. Pp. 213.

Fernando, T. K.; Chandrapala, L. 1992. Global Warming and Rainfall Variability – Sri Lankan Situation. *Proceedings of the 47th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. Pp. 138.

Fernando, T. K.; Chandrapala, L. 1994. Study of thunder activity over some parts of Sri Lanka. *Proceedings of the 49th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. Pp. 191-192.

Gbetibouo, G. A.; Ringler, C. 2009. *Mapping South African farming sector vulnerability to climate change and variability: A sub-national assessment*. IFPRI Discussion Paper 00885. Washington, DC, USA: International Food Policy Research Institute (IFPRI).

Gupta, S. 2002. *Water policy for drought proofing Chhattisgarh*. Institute for Human Development, New Delhi, India.

Harris, K. D.; Shatheeswaran, T. 2005. Performance of improved four test rice entries of short duration (2.5 months) in the eastern region of Sri Lanka. *Proceedings of the 61st Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 21.

Herath, S.; Ratnayake, U. R. 2004. Monitoring rainfall trends to predict adverse impacts - a case study from Sri Lanka*. Global Environmental Change* 14: 71-79.

Imbulana, K. A. U. S.; Wijesekera, N. T. S.; Neupane, B. R. eds. 2006. *Sri Lanka National Water Development Report*. MAI&MD, UN-WWAP, UNESCO and University of Moratuwa, Sri Lanka, Paris and New Delhi.

Inpadevy, S.; Mahendran, S. 2003. The effects of soil moisture stress on the leaf area and yield of maize var. ruwan at different growth stages. *Proceedings of the 59th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 53.

IPCC (Intergovernmental Panel on Climate Change). 2000. *Emission Scenarios*. Nakicenovic, N.; Swart, R. (eds.). A Special Report of IPCC Working Group III. Cambridge, UK: Cambridge University Press.

IPCC. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. *Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, McCarthy, J.; Canziani, O.; Leary, N.; Dokken, D.; White, K. (eds). Cambridge, UK: Cambridge University Press.

IPCC. 2007. *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, Pachauri, R. K; Reisinger, A. (eds.). Geneva, Switzerland: IPCC. 104 pp.

Irwin, A. 2009. Climate change 'more serious' as emissions soar. *Science and Development Network*. Available at: *http://www.scidev.net/en/news/climate-change-more-serious-as-emissions-soar.html* (accessed on April 30, 2009).

Islam, S. U.; Rehman, N. 2004. Assessment of future change in temperature and precipitation over Pakistan (Simulated by PRECIS RCM for A2 Scenario) available at the Hadley Centre, UK website: *http://precis.metoffice.com/docs/final-results-monthly_siraj.ppt#1* (accessed on May 11, 2009).

IWMI (International Water Management Institute). 2005. *Planning groundwater use for sustainable rural development*. Colombo, Sri Lanka: International Water Management Institute.

Jayatillake, H. M.; Droogers, P. 2004. Will there be sufficient water under internal and external changes? Walawe Basin (Sri Lanka). In: *Climate change in contrasting river basins*, Aerts, J. C. J. H.; Droogers, P. (eds.). UK: CABI.

Jayatillake, H. M;, Chandrapala, L.; Basnayake, B. R. S. B.; Dharmaratne, G. H. P. 2005. Water resources and climate change. *Proceedings of Workshop on Sri Lanka National Water Development Report*. Wijesekera, N. T. S.; Imbulana, K. A. U. S.; Neupane, B. eds. Paris, France: World Water Assessment Programme (WWAP).

Jayawardene, H. K. W. I.; Sonnadara, D. U. J.; Jayewardene, D. R. 2005. Trends of Rainfall in Sri Lanka over the Last Century. *Sri Lankan Journal of Physics* 6(2005): 7-17.

Jülich, S. 2006. Drought risk indicators for assessing rural households. Presentation made at global water hotspots: Water-related social vulnerabilities and resilience-building, Summer Academy for Social Vulnerability. Hohenkammer, Germany: United Nations University and Munich Re Foundation. Available at *http://www.ehs.unu.edu/file.php?id=165* (accessed in December 2008).

Kumar, K. R.; Sahai, A. K.; Krishna Kumar, K.; Patwardhan, S. K.; Mishra, P. K.; Revadekar, J. V.; Kamala, K.; Pant, G. B. 2006. High-resolution climate change scenarios for India for the 21st century. *Current Science* 90(3): 334-345.

Madduma Bandara, C. M.; Wickramagamage, P. 2004. Climatic change and its impact on upper watersheds of the hill country of Sri Lanka. *Proceedings of International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region, November 17-19, 2004*. Colombo, Sri Lanka.

Mathes, D. T.; Kularatne, J. D. J. S. 1996. Uncertainties in rainfall and the impact of the coconut industry in Sri Lanka. Paper presented at the regional workshop on climate change vulnerability and adaptation in Asia and the Pacific, Manila, Philippines.

Mendelsohn, R.; Dinar, A.; Basist, A.; Kurukulasuriya, P.; Ajwad, M.; Kogan, F.; Williams, C. 2004. *Cross sectional analyses of climate change impacts*. World Bank Policy Research Working Paper 3350. World Bank.

Ministry of Forestry and Environment. 2000. *Initial national communication under the United Nations Framework Convention on Climate Change – Sri Lanka*. Final Draft.

Munasinghe, M. 2008. Rising temperatures, rising risks. *Finance and Development* 45(1).

Nanthakumaran, A. 2004. Crop diversification of paddy lands under minor irrigation systems in the dry zone of Sri Lanka (a case study from Vavuniya District). *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. pp. 33.

NOAA (National Oceanic and Atmospheric Administration). 2009. Greenhouse gases continue to climb despite economic slump: carbon dioxide, methane increased in 2008. Available at: *http://www.noaanews.noaa.gov/stories2009/20090421_carbon.html* (accessed on April 30, 2009).

Nellemann, C.; MacDevette, M.; Manders, T.; Eickhout, B.; Svihus, B.; Prins, A. G.; Kaltenborn, B. P. eds. 2009. *The environmental food crisis – the environment's role in averting future food crises.* A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, Available at www.grida.no.

Nissanka, S. P.; Ariyaratna, C. H. K. 2003. Estimation of growth, volume accumulation and carbon sequestration of Eucalyptus grandis plantations in up country region of Sri Lanka. Paper presented at the 2003 International Conference on Tropical Forests and Climate Change, Manila, Philippines.

O'Brien, K.; Leichenko, R.; Kelkar, U.; Venema, H.; Aandahl, G.; Tompkins, H.; Javed, A.; Bhadwal, S. 2004. Mapping Vulnerability to Multiple Stressors: Climate Change and Globalization in India. *Global Environmental Change* 14(2004): 303-313.

Pathirana, A.; Herath, S.; Yamada, T.; Swain, D. 2007. Impacts of absorbing aerosols on South Asian rainfall. *Climatic Change* 85(1-2): 103-118.

Peiris, H. K. W.; Gunasena, C. P.; Navaratne, C. M. 2006. Comparative study of three different micro irrigation systems for their suitability for home gardens in Mapalana Area in Matara.

Peiris, R.; Kariyawasam, G.; Jayawardena, S. D. G. 1993. A promising heat-tolerant tomato variety for high temperature areas in Sri Lanka. *Proceedings of the 48th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 134.

Peiris, T. S. G.; Hansen, J. W.; Zubair, L. 2008. Use of seasonal climate information to predict coconut production in Sri Lanka. *International Journal of Climatology* 28(1): 103-110.

Peiris, T. S. G.; Thattil, R. O.; Mahindapala, R. 1995. An analysis of the effect of climate and weather on coconut (*cocos nucifera*). *Experimental Agriculture* 31: 451-460.

Peiris, T. S. G.; Wijeratne, M.; Ranasinghe, C. S.; Anandacumaraswamy, A.; Fernando, M. T. N.; Jayakody, A.; Ratnasiri, J. 2004. Paper presented at 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, Philippines.

Piyadasa, C.; Sumanasinghe, V. A.; Abeysiriwardhena, D. S. de Z. 1993. Varietal screening of rice for tolerance to salinity at early growth stages. *Proceedings of the 48thAnnual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 95.

Prasad, R. 2006. Green power to the Sri Lankan people. *The Guardian*, December 21, 2006.

Premalal, K. H. M. S. 2009. Weather and climate trends, climate controls & risks in Sri Lanka. Presentation made at the Sri Lanka Monsoon Forum, April 2009. Department of Meteorology, Sri Lanka.

Premchander, S.; Müller, C. (eds.). 2006. Gender and sustainable development: Case studies from NCCR North-South. Perspectives of the Swiss National Centre of Competence in Research (NCCR) North-South, University of Bern, Vol. 2. Bern: *Geographica Bernensia*. 364 pp.

Punyawardena, B. V. R. 2007. Impacts of climate change on agriculture in Sri Lanka and possible response strategies: Impacts, adaptation and mitigation. National Conference on Climate Change 2007. Centre for Climate Change Studies.

Ranjan, P.; Gupta, A. D.; Kazama, S.; Sawamoto, M. 2007. Assessment of aquifer-land use composite vulnerability in Walawe River Basin, Sri Lanka. *Asian Journal of Water, Environment and Pollution* 4(2): 1-10.

Ratnayake, U.; Herath, G. 2005. Changes in water cycle: effect on natural disasters and ecosystems. Proceedings of Workshop on Sri Lanka National Water Development Report, eds. Wijesekera, N. T. S.; Imbulana, K. A. U. S.; Neupane, B. Paris, France: World Water Assessment Programme. Paris, France.

Santoso, H.; Idinoba, M.; Imbach, P. 2008. *Climate scenarios: what we need to know and how to generate them.* Bogor, Indonesia: Centre for International Forestry Research (CIFOR). Working Paper No. 45.

Seneviratne, L. W.; Gunatilaka, M. 2005. Surface and ground water quality monitoring and assessment – Sri Lanka. Transactions of the 19th International Congress on Irrigation and Drainage, Beijing, China.

Seo, S. N.; Mendelsohn, R.; Munasinghe, M. 2005. Climate change and agriculture in Sri Lanka: a Ricardian valuation. *Environment and Development Economics* 10: 581-596.

Shantha, W. W. A.; Jayasundara J. M. S. B. 2005. Study on changes of rainfall in the Mahaweli upper watershed in Sri Lanka due to climatic changes and develop a correction model for global warming. Paper presented at the International Symposium on the Stabilisation of Greenhouse Gas Concentrations. Hadley Centre, Met Office, Exeter, UK.

Somaratne, S.; Dhanapala, A. H. 1996. Potential impact of global climate change on forest distribution in Sri Lanka. *Water, Air and Soil Pollution* 92(1-2): 129-135.

Suppiah, R. 1996. Spatial and temporal variations in the relationships between the Southern Oscillation phenomenon and the rainfall of Sri Lanka. *International Journal of Climatology* 16(12): 1391-1407.

Thornton, P. K.; Jones, P. G.; Owiyo, T.; M., Kruska, R. L.; Herrero, M.; Kristjanson, P.; Notenbaert, A.; Bekele, N. Omolo, A.; Orindi, V.; Otiende, B.; Ochieng, A.; Bhadwal, S.; Anantram, K.; Nair, S.; Kumar, V.; Kulkar, U. 2006. *Mapping climate vulnerability and poverty in Africa*. Report to the Department for International Development, ILRI.

UNDP (United Nations Development Programme). 2006. Calculating the Human Development Indices, Technical Note 1 in *Human Development Report, 2006*.

Vidanage, S. P.; Abeygunawardane, P. 1994. An economic assessment of global warming on agriculture: the case of paddy production in Sri Lanka. *Marga* 13(1): 33-44.

Vincent, K. 2004. *Creating an index of social vulnerability to climate change for Africa*. Working Paper 56. Tyndall Centre for Climate Change Research.

Weerakkody, U. 1996. Impact of sea level rise on beach erosion and inundation of wetlands in the South-West coast of Sri Lanka. Paper presented at the Regional Workshop on Climate Change Vulnerability and Adaptation in Asia and the Pacific, Manila, Philippines.

Weerakoon, S. B.; De Silva, A. P. K. 2006. Wind pumping based water supply schemes for remote villages in Sri Lanka. 32nd WEDC International Conference, Colombo, Sri Lanka.

Weerasinghe, K. D. N.; Leelamanie, D. A. L.; Pushpitha, N. P. G. 2001. Construction of an adjustable roof shelter house and hydroponics system to grow lettuce in hot humid climate in Matara. *Proceedings of the 57th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. pp. 100.

Wickramagamage, P. 1998. Large-scale deforestation for plantation agriculture in the hill country of Sri Lanka and its impacts. *Hydrological Processes* 12(13-14): 2015-2028.

Wickramarachchi, B. n.d. *Risk profiling for sea level rise in South-West coast, Sri Lanka*. Coast Conservation Department, Sri Lanka.

Wijeratne, M. A. 1996. Vulnerability of Sri Lanka tea production to global climate change. *Water, Air and Soil Pollution* 92(1-2): 87-94.

Wijeratne, M. A.; Anandacoomaraswamy, A.; Amaratunge, M. K. S. L. D.; Ratnasiri, J.; Basnayake, B. R. S. B.; Kalra, N. 2007. Assessment of impact of climate change on productivity of tea (camellia sinensis L.) plantations in Sri Lanka. *Journal of the National Science Foundation of Sri Lanka* 35(2): 119-126.

World Bank. 2009. *South Asia: Shared views on development and climate change*. Washington, DC, USA: South Asia Region Sustainable Department of the World Bank.

Yusuf, A. A.; Francisco, H. A. 2009. *Climate change vulnerability mapping for Southeast Asia*. IDRC, CRDI, Sida, Economy and Environment Program for Southeast Asia, Canadian International Development Agency.

Zubair, L. 2003. El Nino-southern oscillation influences on the Mahaweli streamflow in Sri Lanka. *International Journal of Climatology* 23(1): 91-102.

Zubair, L.; Ropelewski, C. F. 2006. The strengthening relationship between ENSO and North-East monsoon rainfall over Sri Lanka and Southern India. *Journal of Climate* 19(8): 1567-1575.

Zubair, L.; Siriwardhana, M.; Chandimala, J.; Yahiya, Z. 2008. Predictability of Sri Lankan rainfall based on ENSO. *International Journal of Climatology* 28(1): 91-101.

Zubair, L.; Hansen, J.; Chandimala, J.; Siraj, M. R. A.; Siriwardhana, M.; Ariyaratne, K.; Bandara, I.; Bulathsinghala, H.; Abeyratne, T.; Samuel, T. D. M. A. 2005. *Current climate and climate change assessments for coconut and tea plantations in Sri Lanka*. IRI, FECT, NRMS and UoP Contribution to AS12 Project Report to be submitted to START, Washington, DC., USA.

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www.iwmi.org/Publications/Water_Policy_Briefs/PDF/WPB31.pdf

IWMI (International Water Management Institute). 2009. ***Water storage and climate change.*** Water Figures: quarterly newsletter of the International Water Management Institute (IWMI). 2. 8p.

www.iwmi.org/News_Room/Newsletters/Water_Figures/PDFs/WF_Issue2_2009.pdf

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www.iwmi.org/Publications/Other/PDF/Summary-Rethinking_Agriculture_in_the_Greater_Mekong_Subregion.pdf

Kim, U.; Kaluarachchi, Jagath J.; Smakhtin, Vladimir U. 2008. ***Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin, Ethiopia.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 21p. (IWMI Research Report 126)

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