HOW PREPARED ARE WATER AND AGRICULTURAL SECTORS IN SRI LANKA FOR CLIMATE CHANGE? A REVIEW

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Abstract

Climate is changing world wide, and the science community in Sri Lanka have come up with ample evidence to suggest that the country's climate has already changed. During 1961- 1990 it's mean air temperature has increased by 0.016 ^{0}C per year (higher than the global average of 0.013 ^{0}C), and mean annual rainfall- decreased by 144 mm (7%) compared to the period 1931-1960. In addition, mean annual daytime maximum and mean annual night-time minimum air temperatures increased. However, the bigger question of national importance is what Sri Lanka's climate will look like in 50 or 100 years and how prepared is the country to face it. Apart from the IPCC projections at the coarse global scale, few studies attempted to project future climate scenarios for Sri Lanka and to identify climate change impacts on agriculture, water resources, the sea level, the plantation sector, the economy and health. Vulnerability and adaptation to climate change are the least studied areas. The paper reviews the status of climate change research/activities in Sri Lanka with respect to future climate predictions, impacts, mitigation and adaptation, and identifies existing knowledge gaps. Messages emerging from this review suggest that Sri Lanka's mean temperature during the North-East (December-February) and South-West (May-September) monsoon seasons will increase by about 2.9 ^{0}C and 2.5 ^{0}C respectively, over the baseline (1961-1990), by the year 2100 with accompanying changes in the quantity and spatial distribution of rainfall. Extreme climate events are expected to increase in frequency. These changes will bring about widespread impacts on the country's agriculture and economy. For example, a 0.5 ^{0}C increase in temperature can reduce rice yield by approximately 5.9%; extended dry spells and excessive cloudiness during the wet season can reduce coconut yield so that annual losses can range between $32 and $73 million. Pilot studies in the Galle District suggest that sea level rise could inundate about 20% of the land area of coastal district secretariat divisions. Adaptation measures already undertaken in the agricultural sector include development of low water consuming rice varieties and use of micro-irrigation technologies. Tools have been developed for predicting seasonal water availability within the Mahaweli Scheme and for predicting annual national coconut production. However, Sri Lanka is yet to undertake a

comprehensive national study on the vulnerability of its water resources and agriculture to climate change. Formulation of detailed and reliable future climate scenarios for the country is and urgent need in this regard.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2007) defines climate change 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". IPCC definition refers to changes in climate over time due to both natural variability as well as anthropogenic activities, as opposed to the usage of the United Nations Framework Convention on Climate Change (UNFCC), where climate change 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 review the IPCC definition is adopted since generally climate change research / activities that have been carried out in Sri Lanka do not differentiate between natural and human induced variability. However, be it due to natural variability or human activity, a pronounced change in the country's climate is observed as evidenced by a number of recent studies presented in section 2.0. Many of these studies fed into IPCC's third and fourth assessment reports. After IPCC's Fourth Assessment Report (AR4) in 2007, which projected an alarming global average temperature increase in the range of 0.3 – 6.4 ^{0}C at the end of the 21st century (IPCC, 2007), 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 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 ^{0}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 realised unless stringent GHG emission reductions are agreed and adhered to. Such global changes are apt to impact Sri Lanka's climate yet further. Sri Lanka being an island state is especially vulnerable to all identified impacts of climate change including rise in land and sea surface temperature, changes in precipitation amount and pattern, 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 paper attempts to review the progress already made in this direction, especially with regard to water resources and agriculture, and to identify key knowledge gaps and future research needs.

2. Present Climate, Observed Changes and Future Projections

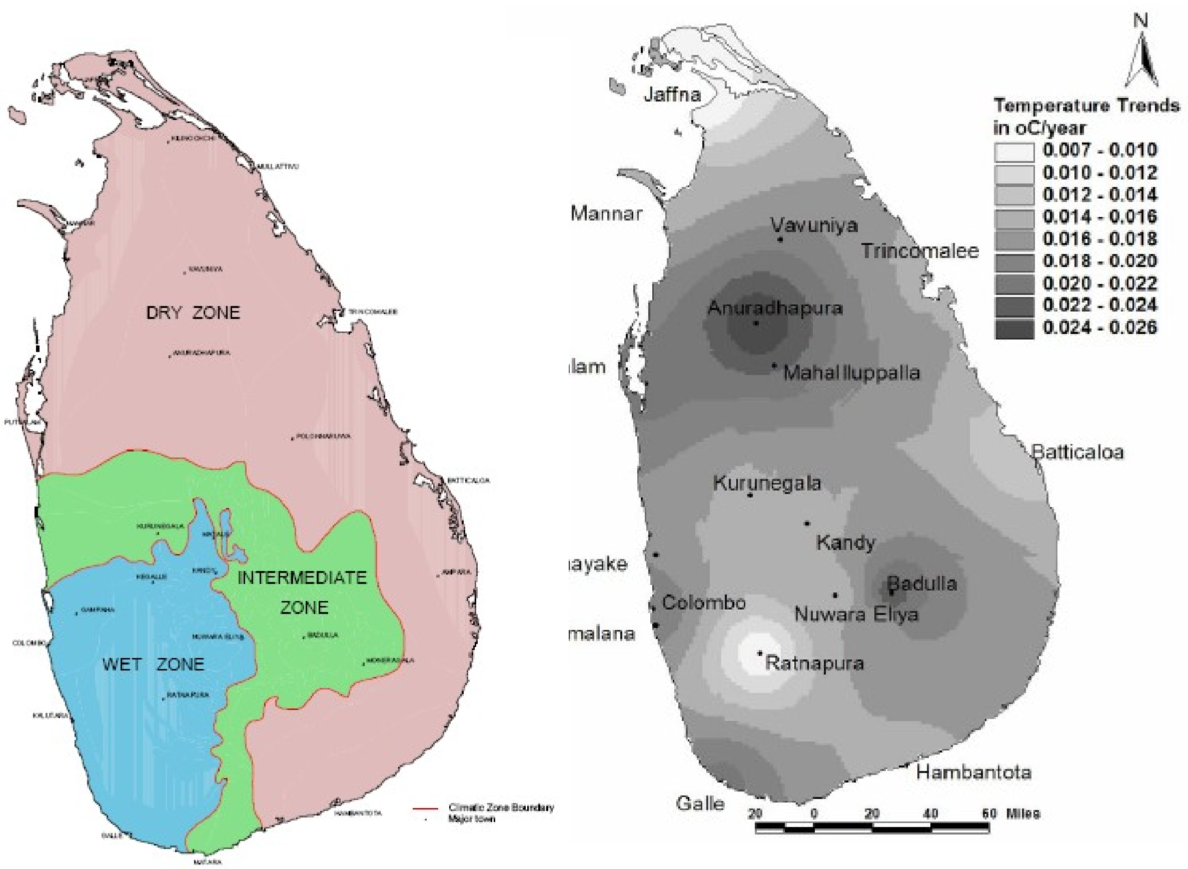
2.1 Present Climate

Sri Lanka is an island in the Indian Ocean just to the North of the Equator. Its topography consists of a central highland (altitudes of 300 m amsl) surrounded by an extensive lowland area. The long-term mean annual temperature in the lowlands is 27 ^{0}C while it is 15 ^{0}C in the highlands (Nuwara-Eliya at altitude 1895 m amsl; - Chandrapala, 1996). Mean annual rainfall ranges from under 1000 mm in the north-western and south-western coastal areas to over 5000 mm in the western slopes of the central highlands. The spatial pattern of precipitation is strongly influenced by topography and two seasonal wind regimes (Chandrapala, 1996). The South-West monsoon (SWM) is from May to September and the North-East 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). Sri Lanka consists mainly of three climatic zones: The Wet Zone, Dry Zone and the Intermediate Zone (Figure 1). The El Nino-Southern Oscillation (ENSO) is a primary mode of climate variability in the South Asian region as a whole (Zubair et. al., 2008).

2.2 Observed Changes in Climate

Filtered time series of annual mean temperature anomalies from1871-1990 show a significant warming trend throughout the country during the latter half of this period (Chandrapala, 1996; Fernando and Chandrapala, 1992). The rate of increase in temperature from 1961 to 1990 is 0.016 ^{0}C per year (Chandrapala, 1996) which is higher than the global average rate of 0.013 ^{0}C per year for a comparable period - 1956 to 2005 (IPCC, 2007). Sri Lanka's 100 year warming trend from 1896 to 1996 is 0.003 ^{0}C per year (IPCC, 2001), while it is 0.025 ^{0}C per year for the 10 year period 1987-1996 (Fernando, 1997), indicating faster warming in more recent years. Seasonal mean temperatures for Yala (April – September) and Maha

(October – March) agricultural seasons also display similar warming (Basnayake et. al., 2002). Mean (annual and seasonal) daytime maximum and mean (annual and seasonal) night-time minimum air temperatures have both increased during 1960-2001 (Basnayake et. al., 2002; Zubair et. Al., 2005) with trends of 2.6 ^{0}C/100 years and 1.7 ^{0}C/100 years respectively (Zubair et. Al., 2005). Scientists attribute this warming trend seen throughout the country to both enhanced greenhouse effect as well as the ‘local heat island effect’ caused by rapid urbanization (Basnayake, undated; Basnayake et. al, 2003; Fernando and Basnayake 2002; Emmanuel, 2001).



Figures 1 and 2. Climatic Zones of Sri Lanka (left) and observed warming trends in mean annual temperature (right; source: Zubair et. al., 2005)

There is no significant trend in Sri Lanka’s mean annual rainfall (MAR) during the last century although higher variability is evident (Jayatillake et. al., 2005; L. Chandrapala, NDMC, pers. comm.). However, more recent data records reveal a decreasing trend: MAR during 1961-1990 has decreased by 144 mm (7%) compared to that during 1931-1960 (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).

However, 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 in the SWM and IM2, rainfall in the NEM (the Maha season when the majority of agricultural areas in the country receive rainfall) and IM1 has reduced with NEM showing increased variability (Jayatillake et. al., 2005; Basnayake et. al., 2002, L. Chandrapala, NDMC, pers. comm.).

The north eastern and western regions experience increasing rainfall and the rest of the country – decreasing rainfall (Ratnayake and Herath, 2005). A few authors have made observations on rainfall in the central region: An analysis of inter-annual as well as intra-annual rainfall trends of the central region from 1964-1993 suggests that there is a decrease in MAR, with IM1 showing the highest decrease (Herath and Ratnayake, 2004); Shantha and Jayasundara (2005) observe a 39.12% decrease in MAR in the Mahaweli upper watershed from 1880 to 1974; Bandara and Wickramagamage (2004) also reveal that rainfall on the western slopes of the central highlands has declined significantly from 1900 – 2002 due to reduction in SWM rainfall in this region (which has the highest MAR in the country often exceeding 5000 mm). The reduction in observed rainfall in the central region is attributed to both global climate change as well as local land use changes such as large-scale deforestation for plantation agriculture (Wickramagamage, 1998). In the country as a whole, the number of consecutive dry days have increased while the number of consecutive wet days have reduced (Ratnayake and Herath, 2005; Premalal, 2009). Recent analysis of the spatial pattern of rainfall indicates an expansion of the dry zone (MAR<2000 mm) as well (Figure 3 - Imbulana et. al., 2006).

In addition to the above, the intensity and frequency of extreme climate events (floods, droughts and cyclones) have increased in recent times triggering an increase in natural disasters (Imbulana et. al., 2006, Herath and Ratnayake, 2004, L. Chandrapala, NDMC, pers. comm.): The country has already experienced two years of serious drought and one major flood event within the first five years of the 21st century (Imbulana et. al., 2006); The districts of Ratnapura and Kalutara which are generally flooded once or twice a year experienced floods four times during 2008 along with one severe event (L. Chandrapala, NDMC, pers. comm.). 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 triggering an increase in landslides. Although Sri Lanka is outside the cyclone belt, the few cyclones it experienced were the reasons for extreme rainfall events (Ratnayake and Herath, 2005). Upwards trends in the occurrence of thunder activity as well as increased lightening hazards have also been observed (Fernando and Chandrapala, 1994; Jayaratne, 1997).

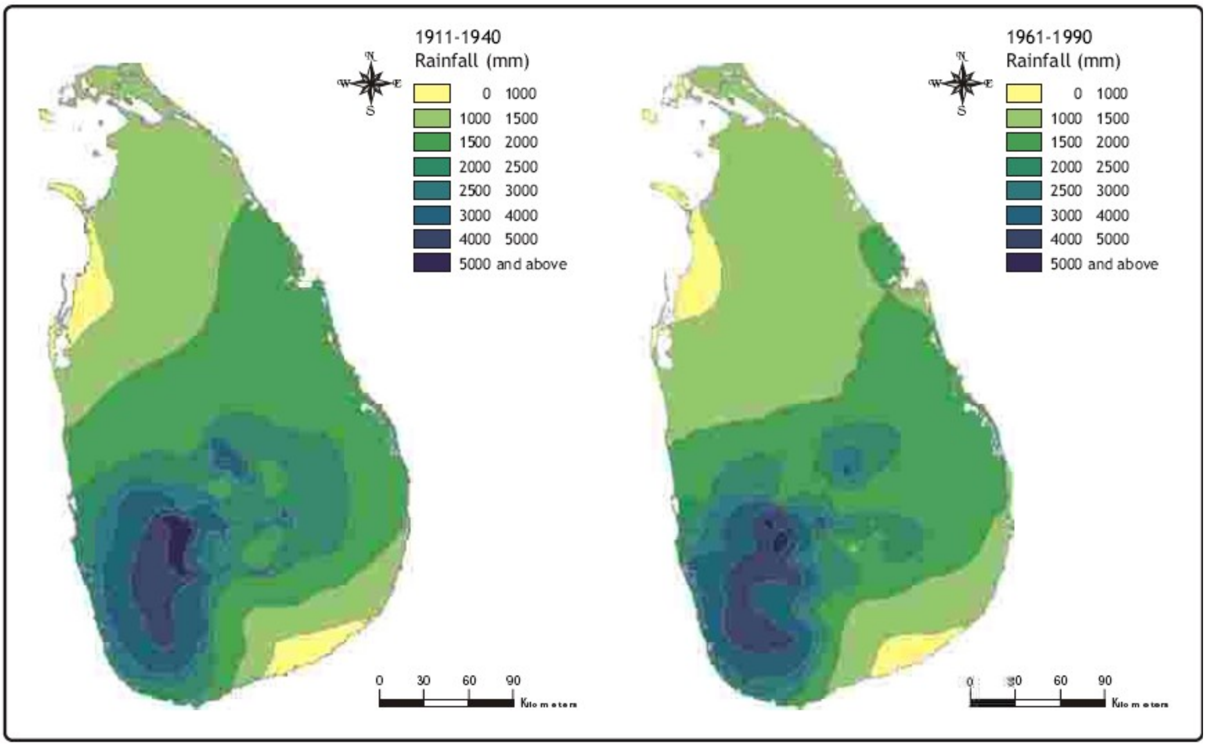


Figure 3. A comparison of average rainfall 1911-1940 and 1961-1990 indicating expansion of the dry zone (AAR < 2000 mm).

Source: Imbulana et. al., 2006

The current rate of sea level rise in coastal areas of Asia is reported to be 1-3 mm/year which is marginally greater than the global average (Cruz et. al., 2007). Evidence also suggests an *accelerated rate of sea level rise over the past decade* (3.1 mm/year) compared to that over the 20th century as a whole (1.7 to 2.4 mm/year) (Cruz et. al., 2007).

2.3 Future Climate Projections

Studies which spell out future climate scenarios for Sri Lanka are scarce and even the ones that exist appear to project contradictory results, especially with respect to future rainfall. However, there is general consensus among them that Sri Lanka will become increasingly warmer during the 21st century, although the projected magnitude of temperature increase differs from study to study mainly due to differences in projection method and assumed future GHG emission scenarios. IPCC regional projections based on AR4 atmospheric ocean general circulation models (AOGCMs or simply - GCMs) suggest a significant acceleration of warming in Asia over that observed in the 20th 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). A temperature increase of 5.44 ^{0}C and 2.93 ^{0}C respectively with respect to 1961-1990 is projected over South Asia in the summer of 2070-2099 for the two IPCC emission trajectories A1F1 (highest future emissions) and B1 (lowest future emissions) (Cruz et. al., 2007; IPCC, 2002). Other regional climate models for South Asia also project widespread warming in the region including in Sri Lanka (rise in annual mean temperature in the range 2.5 – 4 ^{0}C for IPCC scenario A2 and 2 – 3 ^{0}C for B2) towards the end of the 21st century (eg: Kumar, 2006; Islam and Rehman, undated). Both Kumar (2006) and Islam and Rehman (undated) confirm IPCC's projections 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. They project mean temperature increments of varying magnitudes by 2100: Basnayake et. al. (2004) – 2-3 ^{0}C under scenario A1F1 and 0.9-1.4 ^{0}C under B1; De Silva (2006) - 1.6 ^{0}C under A2 and 1.2 ^{0}C under B2 with increases mainly in the north, north eastern and north western regions (all within the dry zone); Basnayake (undated) - 2.9 ^{0}C in NEM season and 2.5 ^{0}C in SWM season. Meanwhile, Jayatillake and Droogers (2006) suggest a 0.5 ^{0}C increase in 2010-2039 and a 2-3 ^{0}C increase in 2070-2099 within the Walawe basin in southern Sri Lanka. Zubair et. al., (2005) constructed 1 km resolution present climatology fields (i.e. minimum, mean and maximum temperatures, rainfall and solar radiation) and projected future temperature climatology fields for 2025 and 2050 by assuming that present trends (1960-2001) will continue.

Rainfall projections for Sri Lanka within this century appear to be confusing and sometimes contradictory. While the majority of them project higher MAR, some project lower MAR: AR4 models (Cruz et. al., 2007), regional climate models by Kumar et. al. (2006) and Islam and Rehman (undated) and statistically downscaled projections from the HadCM3 model by De Silva (2006) all show increases in MAR under a range of IPCC scenarios (A1F1, B1, A2, B2). De Silva (2006) further elaborates that these increases will be 14% for A2 and 5% for B2 by 2050 with reference to 1961-1990. While statistical downscaling of projections from HadCM3 and CSIRO models by Basnayake et. al. (2004) show an increase in MAR, the

CGCM model shows a decrease in MAR for scenarios A1F1, A2 and B1. Seasonally, AR4 models (Cruz et. al., 2007), De Silva (2006) and Basnayake and Vithanage (2004) project an increase in SWM rainfall (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). De Silva (2006) envisages a 26-34% decrease in the NEM rainfall and a 16-38% increase in the SWM rainfall compared to 1961-1990 for scenarios B2-A2; this will result in enhanced rainfall in the wet zone, northern, north-western and south-western dry zones and reduced rainfall in other dry zone areas such as Anuradhapura, Batticaloa and Trincomalee (Figure 1). A 2% increase in rainfall is projected in the intermediate zone by 2050 (De Silva, 2006).

The two regional climate models (Kumar et. al., 2006 and Islam and Rehman, undated), and downscaled projections from HadCM3 and CSIRO models by Basnayake et. al. (2004) suggest increases in both SWM and NEM rainfall (for a range of IPCC scenarios from A1 to B2), with Basnayake et. al. (2004) suggesting higher increases in SWM than in NEM. They also envisage much higher increments of rainfall on the windward side of the central hills in each monsoon season and lesser increments on the leeward side by 2100. In contrast, downscaled CGCM model projections (Basnayake et. al. 2004) indicate decreases in both SWM and NEM. A recent study by the Purdue University (Ashfaq et. al., 2009) especially on the South Asian Summer Monsoon also projects a weakened and delayed (by 5-15 days by the end of the 21st century) SWM over the majority of South Asia. However, image results of future projections suggest increased SWM rainfall 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 (2006) and Basnayake and Vithanage (2004). Meanwhile, Jayatillake and Droogers (2004) project a somewhat wetter situation with simultaneously more variation in annual precipitation in the Walawe basin. Shantha and Jayasundeara (2005) envisage a 16.6% reduction in rainfall in the upper Mahaweli watershed by 2025.

The IPCC envisages an increase in the occurrence of extreme weather events including heatwave and intense precipitation events in South Asia within this century; Inter-annual variability of daily precipitation in the SWM is also projected to increase (Cruz et. al., 2007). An increase of 10-20 % in tropical cyclone intensities (for a rise in sea surface temperature of 2-4 ^{0}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. Scientist are of the view that since South Asia in general is unique from the rest of the world with very complex topography, global models like the ones featured in the IPCC reports have difficulty capturing some of the more subtle atmospheric processes; understanding the potential impacts of future climate change in this region requires improved understanding of a host of climate processes (Ashfaq et. al., 2009). Therefore, it is of utmost importance that projections from detailed high-resolution regional climate models (RCM)are employed to obtain reliable climate scenarios for Sri Lanka. Accurate quantification of impacts and identification of adaptation strategies both depend on it. Climate model simulations with RegCM3 by the Purdue University, which accurately recreates the monsoon season of past years (Ashfaq et. al., 2009), is believed to be the most detailed to date for the South Asian Region.

3. Impacts of Climate Change

3.1 Impacts on Water Resources

There are 103 distinct radial draining river basins in Sri Lanka 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 (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 the main source of power is hydro-electricity. However, groundwater use is also rapidly increasing in the country (IWMI, 2005). In this context, accurate quantification of climate change 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 climate change while meeting rising demands on water resources due to growing population and increased allocations to sectors other than agriculture. One school of thought is that while Sri Lanka will actually gain in terms of mean annual water availability due to climate change, its increased variability and inequitable spatial distribution (wet areas getting wetter and dry areas getting drier: Basnayake, undated; Basnayake et. al., 2004 ;Basnayake and Vithanage, 2004; De Silva, 2006)) will negatively impact agriculture and food security. The brunt of the impact of climate change on water resources is expected to be born by the north-eastern and eastern dry zone of the country. The changes in rainfall and temperature, together with other climatic factors, would increase the maximum annual soil moisture deficit (MASD) significantly 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, 2006). The areas with the highest MASD (1961-1990) are located in the North and the East, notably in Jaffna, Mannar, Vavuniya, Trincomalee, Anuradhapura and Baticaloa, while Colombo, Galle, Ratnapura and Nuwara Eliya have the lowest. By 2050, Jaffna will experience a 12% increase (from 1162 mm to 1305 mm) in MASD; In general, northern, eastern and south-eastern areas (covering the whole of the dry and intermediate zones) will see substantial increases in MASD. However, among the dry zone areas, Hambantota in the southern tip of the island is expected to see a decrease in MASD, while also gaining in MAR (De Silva, 2006; Jayatillake and Droogers, 2004).

As stated earlier, reduction in rainfall in the central highlands have been observed and projected by several authors. Since the central highlands contribute the largest volume of water for hydro-power generation and subsequently for irrigation (eg: through multipurpose reservoirs in the Mahaweli System), negative climatic changes in this region will very likely result in significant negative ecological and economic impacts. The Kotmale, Victoria, Randenigala and Rantembe reservoirs constructed in the heart of the upper Mahaweli watershed supply nearly one third (29.11%) of the national power generation and 23% of irrigation water supplied by major irrigation schemes (Shantha and Jayasundara, 2005). Since the Mahaweli is a multi-purpose water supply scheme, hydro-electricity generation by associated power stations is governed by downstream irrigation requirements. In the event of low runoff, water allocation between the two sectors will be problematic. This emphasizes even more the need for reliable climate projections for the country so that appropriate adaptation strategies on hydropower generation and irrigation water allocation are formulated based on them.

Notably absent are research on climate change impacts on groundwater resources in Sri Lanka both in terms of quantity and quality except perhaps in the Walawe Basin (eg: Ranjan et. al., 2007). The country's dry zone area suffers from excess fluorine (Seneviratne and Gunatilaka, 2005) while sea level rise due to climate change 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 salt water intrusion due to global warming (Ranjan et. al., 2008). 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 21st century amid increased warming.

3.2 Impacts on Agriculture

Impact of Climate Change on Agriculture maybe broadly categorized in to two areas as impact of Carbon Dioxide (CO_2) on crop growth and impact of temperature on crop growth. Two effects of temperature have been distinguished (Jayatillake and Droogers, 2004): physiological effects (at the level of plants and plant organs) and the crop ecosystem effects (at the level of the field or at the region including changes in hydrology). 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 Centre for the Study of Carbon Dioxide and Global change in Tempe, Arizona (**http://www.co2science.org**), increases in potential crop growth (Table 1) are indicated for rice, Sri Lanka's staple food, and other vegetables (Jayatillake and Droogers, 2004). Meanwhile other studies show that a 0.1-0.5 ^{0}C increase in temperature can reduce rice yield by approximately 1.2-5.9% (Vidanage and Abeygunawardena, 1994). However, more recent experiments carried out in Sri Lanka suggest that rice yields respond positively (increases of 24% and 39% in the two seasons) to elevated CO_2 even at higher growing temperatures (>30 ^{0}C) in sub-humid tropical environments (De Costa et. al., 2006).

Table 1. Increases of potential crop growth as a result of enhanced CO2 levels in percentages

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

Tomato	2010-2030 2070-2100	15 30	8 15

Source: Jayatillake and Droogers, 2004

The real threat to rice cultivation might be changes in hydrology and ecosystems due to growing temperatures in the form of altered rainfall regimes and length of growing periods. Nearly 72% of paddy production is grown during the wet (Maha) season in dry areas where water resources are already stressed (De Silva et. al. 2007). De Silva et. al. (2007) suggests that by 2050, average paddy irrigation water requirement during the wet (Maha) season will increase by 23% and 13% respectively in A2 and B2 scenarios due to reductions in average rainfall, increase in potential evapotranspiration and early ending of rainfall. Irrigation water requirements for other field crops cultivated in the dry and intermediate zones during the dry (Yala) season will also significantly increase (De Silva, 2006). However, positive impacts are shown in the extreme south (De Silva et. al., 2007; Jayatilleke and Droogers, 2004). 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.

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 generating income to the majority of unskilled labourers in the country. Several studies have been undertaken to assess the impact of Climate change on plantation crops. Wijeratne, et. al. (2007) have found that tea cultivations at low and mid elevations are more vulnerable to adverse impacts of climate change than those at high elevations. They also found that reduction of monthly rainfall by 100 mm could reduce productivity by 30-80 kg of 'made' tea/ha while increase in ambient CO_2 concentration from the present level (around 370 ppm) to 600 ppm may increase tea yield by 33-37% depending on elevation. Yield projections also showed that rising temperatures and diminishing rainfall reduce tea yield in many tea growing regions except in the up country wet zone.

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 et. al., 1996). Future yields in coconut production under six different climate scenarios using integrated crop models 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). Extended dry spells and excessive cloudiness during the wet season can reduce coconut yield so that annual losses can range between \$32 and \$73 million (Fernando et. al., 2007). Among the different stakeholders in the coconut industry, the coconut oil industry will be most vulnerable to climate change: increasing air temperatures will increase the future pest and disease problems on coconut and therefore increased investment in pest control would be required (Peiris et. al., 2004).

Climate Change 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 due to global warming poses another threat to coastal agricultural areas due to inundation and salinity intrusion of coastal wetlands and aquifers (inundation of 41 km2 for a rise of 0.3 m and 91.25 km2 for a rise of 1 m: Weerakkody, 1996). Pilot studies in the Galle District suggest that sea level rise could inundate about 20% of the land area of coastal district secretariat divisions (Wickramarachchi, undated). The damage caused could be of higher magnitude if the combined effects of beach erosion, 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 Centre, Malaysia, which compared the vulnerability of 132 national economies to potential climate change impacts on fisheries under IPCC scenario B2 finds that Sri Lanka's vulnerability is low in this respect (Allison et. al., 2009).

Climate change impacts on agriculture invariably impacts the country's economy. Seo et. al. (2005) finds that nationally, the impact on agriculture (rice, tea, rubber and coconut) will result in economic impacts in the range -11 billion rupees (\$96.4 million: -20%) to +39 billion rupees (\$342 million: +72%) depending on the climate scenarios. They reconfirm that climate change damages could be large in tropical developing countries, but highly dependent on the actual climate scenario.

4. Mitigation and adaptation to Climate Change

Climate change mitigation

Sri Lanka is a signatory to UNFCC and has ratified the Kyoto Protocol on climate change. Therefore, under its obligation to contribute to efforts to mitigate climate change, 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 33630.22 Gg CO_2, 1098.38 Gg 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 in a small scale through 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, development of sustainable energy 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 Ariyaratne, 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 climate change impacts are planting of 73,000 trees to offset carbon emissions generated by the tourism industry as part of a 'carbon clean Sri Lanka' campaign and installation of ten trial base stations using solar and wind power by Dialog Telekom, a mobile telecommunications provider (Anderson, T., 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 program of the Global Environmental 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 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 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

Adaptation to climate change 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 in reducing or mitigating the effects of climate change, the subject of climate change has not been directly addressed in them (Ministry of Forestry and Environment, 2000). Therefore, the Initial National Communication recommends incorporation of climate change considerations into existing policies. Munasinghe (2008) proposes adoption of the 'sustainomics' framework (developed by the World Bank) and its tools to integrate climate change policies into Sri Lanka's development strategy, to help make the transition from the risky 'business as usual' scenario to a safer and more sustainable future. Using one such tool called the 'Action Impact matrix,' he identifies vulnerability of Sri Lanka's water resources and agricultural output as the key challenge to national food security in the wake of climate change. Hence the island's successful adaptation depends on accurate projections of climate change 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 paragraph. However, a more comprehensive national study on river basin or district scale covering vulnerability of water resources and agriculture, which makes use of findings already made, is an urgent need for the country.

Understanding present climate is imperative in projecting future climate. 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 (eg. Zubair et. al., 2008; Pathirana et. al., 2007 ; Zubair and Ropelewski, 2006; Suppiah, 1996). Some of them (eg. 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. Studies on crop adaptation are performed mainly by six research institutes in the country conducting research on Rice, Field crops, Horticultural Crops, Tea, Rubber and Coconut. The Rice Research and Development Institute (RRDI) is involved in developing technologies and appropriate rice varieties which 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.com.; Piyadasa et. al., 1993). Short term (low water consuming) rice varieties, suitable for shorter growing seasons, have already been developed and tested (eg: Harris and Satheeswaran, 2005). Other adaptation options recommended for rice (especially in the dry zone) include partial shift of present locations to areas projected to receive more beneficial rainfall and changing planting time to suit altered rainfall onset times (De Silva, 2007). 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), crop diversification (Nanthakumaran, 2004), investigating the impact of increased temperatures, humidity and moisture stress on crops (e.g.: Inpadevy and Mahendran, 2003; Weerasinghe et. Al., 2001, Peiris et. al., 1993) are other adaptation strategies under consideration. Adaptation measures proposed in the tea sector are: use of hardy tea clones resistant to drought, pests and diseases; improvement and implementation of soil conservation measures; proper shade management, and expansion of multicropping systems (Wijeratne, 1996). Coconut farmers have already adopted moisture conservation methods such as cover crops, organic manure, burying coconut husks and contour drains to minimise the effects of less rainfall (Mathes, 1996). Adaptation strategies focussed on two alternative development approaches (sustaining food security and enhancing environmental quality) have been proposed for rice farmers in the Walawe basin by Jayatillake and Droogers (2004).

Rain water 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 (2006) suggests provision of a rain water harvesting system to all households in drought prone areas, making it a prerequisite to receive drought relief. Renovating the existing tanks in the dry and intermediate zones to store excess rainfall during the SWM season 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, 2006). A greater shift towards alternative energy sources from hydropower and fossil fuels is advocated in the energy sector (Shantha and Jayasundera, 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.

5. Research Priorities

First and foremost among research priorities is the need for reliable and detailed climate scenarios for the country, without which any country cannot even begin to understand what its vulnerabilities are. While there is consensus among available projections that gradual warming will be experienced throughout the country within this century, there is no such consensus regarding rainfall. Therefore, resolving the existing ambiguity regarding rainfall projections especially for the dry zone and NEM (through which much of the dry zone receives a major portion of its annual rainfall) is of utmost importance. A comprehensive national study on river basin or district scale on vulnerability of Sri Lanka's water resources and agricultural sectors to climate change should follow. This study should include not only surface water but also groundwater covering both water quality as well as water quantity issues. Only if the combined impact on agriculture, of increased temperature, increased CO2 in atmosphere and increased / decreased rainfall is quantified, a true picture of the benefits or costs of climate change on agriculture, food security and the economy can be projected. Appropriate adaptation measures may be implemented based on such a study. The Walawe basin research by Jayatillake and Droogers (2004) is a good example of a comprehensive basin scale study. Central to any research on climate change 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.

5. Conclusion

It is evident that Sri Lanka's climate has already changed. This review suggests that although a few attempts have been made to project Sri Lanka's climate during the 21st century, they lack consensus and are even contradictory. However, many available projections indicate that climate change impacts can be large in the dry zone, especially in the North-East and the East. A decline in rainfall in the dry zone, combined with an increase in temperature, evapotranspiration and soil moisture deficit will have serious impacts o the country's food production, livelihoods and 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 (Nelleman, 2009). Apart from food insecurity, the predicted adverse impacts on the Dry and Intermediate Zones will worsen the existing economic and social inequities and widen the gap between the developed core (Colombo Metropolitan Region) and less developed areas. Therefore, reliable and detailed climate scenarios and a comprehensive national study on the vulnerability of Sri Lanka's water resources and agriculture to climate change are urgently needed so that timely action is initiated towards adaptation.

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Reference:

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

2. 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

3. 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. Fish and Fisheries. DOI: 10.1111/j.1467-2979.2008.00310.x

4. Amarasinghe, U. A., Mutuwatta, L., Sakthivadivel, R., 1999. Water Scarcity Variations within a Country: A Case Study of Sri Lanka. Research Report 32. IWMI, Colombo, Sri Lanka

5. 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.

6. 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.

7. Anderson, T., 2009. Green Mobile Network for Rural Sri Lanka under Trial. Science and Development Network (SciDev.Net) News, March 18, 2009

8. Arumugam, S., 1969. Water Resources of Ceylon. Water Resources Board, Colombo

9. Asian Development Bank, 2006. Country Synthesis Report on Urban Air Quality Management: Sri Lanka. Discussion Draft, December, 2006. Asian Development Bank.

10. Bandara, C. M. M., Wickremagamage, 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. Colombo, Sri Lanka

11. Basnayake, B. R. S. B., undated. 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 (May 05, 2009)

12. Basnayake, B. R. S. B., Vithanage, J. C., 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

13. 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

14. Basnayake, B. R. S. B., Punyawardena, Vithanage, J. C., 2003. An investigation of ambient air temperature trends at Hambanthota – 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

15. 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, Phillipines

16. Chandrapala, L., 1996: Long term trends of rainfall and temperature in Sri Lanka. *Climate Variability and Agriculture*, Y.P. Abrol, S. Gadgil and G.B. Pant, Eds., Narosa Publishing House, New Delhi, 153-162.

17. 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

18. 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. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 469-506

19. 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

20. De Silva, C. S., 2006. Impacts of Climate Change on Potential Soil Moisture Defecit 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.

21. De Silva, C. S., 2006. Impacts of Climate Change on Water Resources in Sri Lanka. Paper presented at the 32nd WEDC International Conference, Colombo, Sri Lanka

22. 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.

23. 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

24. 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, Phillipines.

25. 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 Srilanka. AIACC Working Paper No. 45.

26. 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

27. 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

28. 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

29. 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

30. 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

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

32. Imbulana, K.A.U.S., Wijesekara, N.T.S. and 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

33. 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

34. IPCC, 2002. Emission Scenarios. N. Nakicenovic and R. Swart (Eds.). A Special Report of IPCC Working Group III

35. IPCC, 2007, Climate Change 2007: Synthesis Report

36. 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 (April 30, 2009)

37. Islam, S. U., Rehman, N., Undated. 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 (May 11, 2009)

38 International Water Management Institute (IWMI). 2005. Planning Groundwater Use for Sustainable Rural Development. IWMI, Colombo, Sri Lanka

39. Jayaratne, K. P. S. C.,1997. Some features of thunderstorm activity in Sri Lanka. Proceedings of the 52nd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).Section E1. pp 264-265

40. 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. CABI, UK.

41. Jayatillake, H.M., Chandrapala, L., Basnayake, B.R.S.B. and 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, and Neupane, B. Eds. World Water Assessment Programme (WWAP): Paris, France

42. 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

43. Mathes, D. T., Kularatne, J. D. J. S., 1996. Uncertainities 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, Phillipines.

44. Ministry of Forestry and Environment, 2000. Initial National Communication under the United Nations Framework Convention on Climate Change – Sri Lanka. Final Draft.

45. Munasinghe, M., 2008. Rising Temperatures, Rising Risks. Finance and Development, 45(1)

46. 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

47. National Oceanic and Atmospheric Administration (NOAA). 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 (April 30, 2009)

48. 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, www.grida.no

49. 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, Phillipines.

50. Pathirana, A, Herath, S., Yamada, T., Swain, D., 2007. Impacts of Absorbing Aerosols on South Asian Rainfall. Climatic Change, 85(1-2): 103-118

51. 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

52. 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

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

54. 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.

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

56. Piyadasa, C., Sumanasinghe, V. A., Abesiriwardhena, D. S. de Z., 1993. Varietal Screening of Rice for Tolerance to Salinity at Early Growth Stages. Proceedings of the 48th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).Section B. pp 95

57. Prasad, R., 2006. Green Power to the Sri Lankan People. The Guardian, December 21, 2006.

58. 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

59. Ranjan, P., Gupta, A. D, KIazama, 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.

60. 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. Wijesekera, N.T.S., Imbulana, K.A.U.S, and Neupane, B. Eds. World Water Assessment Programme. Paris, France.

61. 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.

62. 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

63. 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

64. 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

65. 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

66. United Nations Economic and Social Comission for Asia and the Pacific (ESCAP), 2009. Sustainable agriculture and food security in asia and the pacific

67. 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

68. Weerakkody, U., 1996. Impact of Sea Level Rise on Beach Erosion and Inundation of Wetands in the Sout-West Coast of Sri Lanka. Paper presented at the Regional Workshop on Cimate Change Vulnerability and Adaptation in Asia and the Pacific, Manila, Phillipines.

69. 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.

70. 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

71. 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

72. Wickramarachchi, B., undated. Risk Profiling for Sea Level Rise in South-West Coast, Sri Lanka, Coast Conservation Drpartment, Sri Lanka.

73. Wijeratne, M. A., 1996. Vulnerability of Sri Lanka Tea Production to Global Climate Change. Water, Air and Soil Pollution, 92(1-2): 87-94

74. 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

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

76. 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

77. 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

78. 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, D.C., USA