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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Impacts of Climate Change on Water Resources in Sri Lanka

C. Shanthi De Silva, Sri Lanka

Anthropogenically induced climate change is expected to influence rainfall and temperature. Therefore this study focuses on the climate change impacts on soil moisture deficits which will have serious impacts on the water resources. Climate change datasets for Sri Lanka were derived using outputs from the UK Hadley Centre for Climate Prediction and Research model (HadCM3) for selected IPCC SRES scenarios for the 2050s and compared with the baseline data from IWMI.Under the scenarios tested, there will be a slight increase in annual average rainfall because of an increase in rainfall during the south west monsoon. But the north east monsoon rains decrease. Similarly the annual average temperature increases. These changes in rainfall and temperature, together with other climatic factors, would increase the maximum annual soil moisture deficit significantly in the dry zone areas, demanding higher irrigation need. The major food production activities in these zones would then be at risk.

Introduction

Future atmospheric behaviour not only depends on increases in greenhouse gas concentrations and earth orbital changes but also depends heavily on changes in the sea surface temperature (SST), global ocean circulation, and the increased atmospheric turbidity. It is worth noting that the SST increase is predominant in the tropical ocean, but the SST in the Atlantic Ocean north of 30°N was markedly decreased, probably owing to an increased cloud amount caused by water vapour transported from the low-latitude zone. The effect of global warming on the SST and the air temperature does not appear to follow the same trend: the temperature decreases in some regions and increases in others owing to global warming. This is also true for precipitation changes.

According to Kayane et al (1995) the SST in the Indian Ocean increased by 0.5-1.0°C during 1930-1989. As a result of increased ocean evaporation due to the SST increase, the rainfall during the SW monsoon season from May to September at Colombo increased by about 30 per cent during 1869-1993. However, the rainfall at Nuwara Eliya, a station at an elevation of 1,895 m in the central high mountains in Sri Lanka, has decreased by about 40 per cent during the same period. An almost linear increase in rainfall during 1870-1970 was also observed at Calicut (Lengerke 1976), a coastal station in south-west India located to the west of the Western Ghats Mountains, where the same orographic effect on rainfall pattern is expected as on the Sri Lankan south-west coast. Such long-term changes in rainfall in Sri Lanka and southwest India can be interpreted as the result of intensified Indian monsoon circulation caused by global warming (Kayane et al. 1995). Changes in local rainfall may take opposite trends within a relatively small island like Sri Lanka, owing to global warming.

If the Hadley (north-south) circulation was intensified by global warming, the subtropical high would also be intensified, resulting in a decrease in precipitation in arid lands in the middle latitudes. Kayane (1996) has concluded that the SST has increased markedly in the low latitude ocean during the past 60 years. The global energy and water cycle has intensified in response to the increase in SST, resulting in an increase in precipitation in some regions and a decrease in other regions. Generally speaking, the precipitation in arid lands seems to be on a decreasing trend.

As discussed earlier, global climate change will have varying impacts and within a small island like Sri Lanka the impacts of climate change will be variable from region to region. Therefore this paper is intended to study the spatial impacts of climate change on climatic factors and the consequences on potential evapotranspiration and soil moisture deficits. It also highlights the implications of climate change and the possible adaptation measures.

Background

Sri Lanka is an island in the Indian Ocean and located south of the Indian subcontinent (65,610 sq.km in extent) with a central hill country surrounded by coastal lowlands. Nearly 75% of the land is flat or undulating. Sri Lanka has a warm climate, moderated by ocean winds and considerable moisture. However this island has highly varying climatic conditions within it based on the rainfall patterns and the monsoonal rains which bring rains to the island. Based on the rainfall the country is demarcated mainly into three zones namely: dry, intermediate and wet zones (Figure 1).

Rainfall

The rainfall pattern is influenced by the monsoon winds of the Indian Ocean and Bay of Bengal and is marked by four seasons that consist two monsoonal seasons and two inter monsoonal seasons. The first monsoonal season (South west monsoon season) starts from mid-May to September, when winds originate in the south west, bringing moisture from the Indian Ocean. The second monsoonal season (North east monsoon) starts from December to February, and the monsoon winds come from the north east, bringing moisture from the Bay of Bengal. The first inter monsoonal season occurs from March until mid-May, with light, variable winds and evening thundershowers. The second inter monsoonal season occurs in October and November. During this season, periodic squalls occur and sometimes tropical cyclones bring overcast skies and rains to the south west, north east, and eastern parts of the island.

Temperature

The mean temperature ranges from a low of 15.8° C in Nuwara Eliya in the Central Highlands (where frost may occur for several days in the winter) to a high of 29°C in Trincomalee on the northeast coast (where temperatures may reach 37°C). The average yearly temperature for the country as a whole ranges from 26° C to 28° C. Day and night temperatures may vary by 4° C to 7° C.

Water resources

The amount of water obtained from rainfall, ranges between 127-130 billion m^3 of which approximately 35% is estimated as surface water which flows along 4500km of rivers and streams. Another 20% seeps underground and 45% is lost through transpiration and evaporation (Madduma Bandara, 2000). Water resources in Sri Lanka are utilized for agriculture, domestic and industrial uses and for the generation of electricity. The surface water potential is highest in the wet zone and lowest in the Northern and Eastern parts of the dry zone. The dry zone is highly vulnerable to water shortages.

Signs for climate change

According to the studies by (Deheragoda and Karunanayake, 2004) during the last two decades of the 20th century, Sri Lanka had witnessed a number of extreme rainfall events. In 1986, daily rainfall ranged between 90 mm to 299 mm in 24 hour period caused land slides in the hill country. In the city of Colombo, 419.8 mm of rain had occurred within 7 hours and 15 minutes in June 1992 during south west monsoon. Then the most recent extreme rainfall event occurred in May 2003 (16th to the 18th), when 820 mm recorded at Deniyaya had triggered landslides and floods in 6 districts.

Chandrapala (1996) reveals that long term temperature trends are rising by 0.016^o C per year in 14 Meteorological stations during the recent 30 year period. The highest rate of increase of 0.36^o C occurred at Anuradhapura, in the North Central Dry Zone.

Methodology

Climate change scenarios

In this work the HadCM3 which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre for Climate Prediction and Research (United Kingdom) has been used (Gordon et al., 2000; Pope et al, 2000) and considered as significantly more sophisticated than earlier versions (Hulme *et al*, 1998). This model has a spatial resolution of 2.5 x 3.75 (latitude by longitude). HadCM3 provide information about climate change all over the world during the 21st century and provide information about three time slices: 2020s, 2050s, and 2080s. In order to provide information on possible changes in the world climate, the climate change models are forced to consider future scenarios. The IPCC (Nakicenvic et al., 2000) has developed emission scenarios known as SRES (Special Report on Emission Scenarios). The SRES scenarios are summarised in Table 1.

The four SRES scenarios combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (IPCC-TGCIA, 1999). In this work the two scenarios have been considered: A2 and B2. The percentages of change predicted by the HadCM3 model must by applied to a baseline. As the resolution of the model is too big, using simple interpolation techniques these percentages have been applied to the baseline developed by the International Water Management Institute (IWMI). It is 10 latitude/ longitude data set of mean monthly surface climate over global land areas, excluding Antarctica and the period from 1961 to 1990 has been considered (New *et al*, 2002).

Since the HadCM3 projections are based on grid cells of 2.5 x 3.75 arc degrees (250 km x 375 km) which is larger than the base line data grid cells, downscaling is essential. Different statistical transformation exists for this downscaling. In this study the one generally accepted within global change research community by Alcamo et al., 1997 is used. According to it the approach for temperature is not the same as for precipitation. For temperature, absolute changes between historical and future GCM time slices are added to historical values. For precipitation, relative changes between historical and future GCM output are applied to measured historical values.

Estimating reference evapotranspiration (ETo)

The FAO Penman-Monteith equation is the international standard in both humid and arid environment for estimating the reference evapotranspiration (ETo) (Smith, 2000). None of the baseline or the future scenario datasets contains ETo estimates. However, an adequate set of climatic variables were available in the baseline dataset to derive ETo using the Penman-Monteith formula. For each monthly baseline dataset, the mean monthly temperature, radiation, wind speed and humidity were extracted and the mean monthly ETo was estimated for each 50km x 50km pixel. The procedure was repeated using the corresponding future climate data to produce ETo datasets for each SRES scenario using a procedure developed by Hess and Knox (2003).

Estimation of maximum annual soil moisture deficit (PSMD)

The potential soil moisture deficit (PSMD) for each month is calculated using the simple water balance equation (Knox et al, 2005) which is summarised as follows:

$$PSMD_i = PSMD_{i-1} + ET_i - P_i$$

Where:
$PSMD_i$ = potential soil moisture deficit in month i, mm
ET_i = potential evapotranspiration of short grass in month i, mm
P_i = rainfall in month i, mm

In months where $P_i > (PSMD_{i-1} + ET_i)$, no soil moisture deficit is assumed to occur and $PSMD_i = 0$. In Sri Lanka wet season rains starts in October and by January each year the soil moisture deficit is usually zero. Therefore in Sri Lanka, the estimation of PSMD can start with January as month i = 1. The maximum PSMD of the 12 months of the year is the maximum annual PSMD ($PSMD_{max}$) for that grid pixel. The procedure was repeated using the corresponding rainfall and ETo datasets to calculate the maximum annual PSMD for each SRES scenarios A2, B2 2050s.

Mapping regional changes

A geographical information system (GIS) has been used to integrate the climate data (mean monthly) to generate maps showing the spatial changes in predicted rainfall, reference evapotransppiration and maximum annual potential soil moisture deficit ($PSMD_{max}$) for the baseline and SRES scenarios A2, B2 for 2050s. The data set (rainfall, temperature and maximum annual soil moisture deficit) were imported into a geographical information system (GIS) and converted from grid pixel to point (centriod) format. The attribute value of each data set of each grid pixel was appended to each centriod. A contouring function was used to generate the point data set into a surface, by applying an ordinary Kringing method in geo statistical analysis.

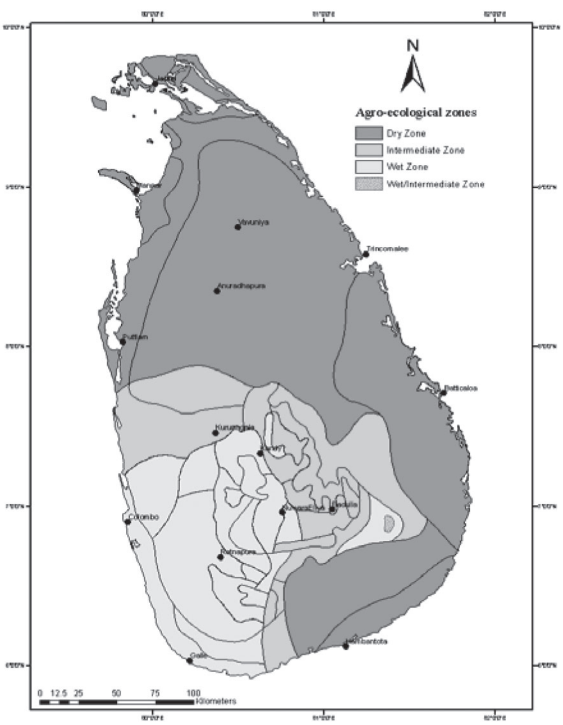

Figure 1. Agro ecological zones of Sri Lanka

Results and discussion

Impact of Climate Change on Rainfall and Temperature

The average annual rainfall for the baseline (1961-1990) and the SRES scenarios A2 and B2 for 2050s are presented in Figure 2. The average annual rainfall is predicted to increase by 14% (A2) and 5 % (B2). Among the wet zone areas the average annual rainfall in Colombo and Galle is predicted to increase by 32% (A2) and 24% (B2). In Kandy, Nuwara Eliya and Ratnapura the average annual rainfall is predicted to increase by 12% (A2) 5 % (B2). Among the dry zone areas the average annual rainfall is predicted to increase in Jaffna, Mannar, Puttlam and Hambantota. The highest increase is in Hambantota 4% (A2) and 3% (B2). However the rainfall is predicted to decrease in other dry zone areas such as Anuradhapura, Batticaloa and Trincomalee. Among the dry zone areas the highest decrease is predicted in Batticaloa 14% (A2) and 12% (B2). Average annual rainfall in intermediate zones also predicted to increase by 2% in A2 and B2 scenarios.

The north east monsoon (December to February) is predicted to decrease 34% (A2) and 26 % (B2). The north east monsoon rainfall in dry zone areas such as Jaffna, Mannar, Vavuniya, Anuradhapura, Batticaloa, Trincomalee and Hambantota is predicted to decrease. The highest decrease is predicted in Trincomalee and Batticaloa 27% (A2) 29 %(B2). It will create more drought problems in these zones and require higher irrigation need for paddy and other field crop cultivation. This significant decrease in rainfall during the period from December to February is mainly due to the significant decrease in rainfall during January and February months according to the A2 and B2 scenarios for 2050s compared to the baseline (1961-1990) scenario (De Silva et al, 2006).

The impact of climate change on the south west monsoon (May to September) rainfall across the country is predicted to increase by 38% (A2) and 16% (B2). The south western regions of the country will be experiencing significant increase in rainfall. The highest increase is predicted in Puttalam by 69 %(A2) and 40% (B2). Rainfall in all the wet zone areas is predicted to increase. In Colombo, Ratnapura, Galle and Nuwara Eliya the rainfall during May to September is predicted to increase by 43%-57% (A2) and 19%-27% (B2). This increase in rainfall will have serious impacts on the country's infrastructure to cope with floods. Extreme rainfall events will also affect the urban squatters who live close to marshes that are liable to flooding. The increased rainfall in Colombo, the capital of the country will have serious flooding problems in lowland areas due to poor drainage facilities which will cause severe traffic and road accidents. Other impacts of high intensity of rainfall on transport are inundation of low lying road sections; erosion of road sides; removal of railway tracks, and track bed materials such as ballast: voids created under railway sleepers: scouring and erosion of bridge abutments, piers and culverts (Bandara et al, 1998). Even at present, heavy rains cause floods and land slides in the hill country (wet zone). The predicted higher rainfall in Nuwara Eliya, and Ratnapura areas will cause flood and land slides.

Impact of climate change on annual average temperature

The impact of climate change on annual average temperature is presented in Figure 3. The temperature increase is mainly in north, north eastern and north western regions of the country. The average annual temperature is predicted to increase by 1.6° C (A2) and 1.2° C (B2). The highest increase in temperature is predicted in Anuradhapura by 2.1° C (A2) and 1.6° C (B2). The lowest annual average temperature increase is predicted in Nuwara Eliya by 1.1° C (A2) and 1° C (B2). During the north east monsoon period (December - February) the overall increase in mean annual air temperature across the island is predicted to increase by 1.6° C (A2) and 1.3°C (B2). The highest increase in temperature compared to the baseline (1961-1990) is predicted in Jaffna and Kurunagala by 1.8° C (A2) and 1.4° C (B2). The lowest increase in temperature is predicted in Nuwara Eliya and Badulla by 0.9° C (A2) and 0.7° C (B2).

During the south west monsoon period (May –September) the overall increase in mean annual air temperature across the island is predicted to increase by 1.6° C (A2) and 1.2° C (B2). The highest increase in temperature compared to the baseline (1961-1990) is predicted in Galle by 2.1° C (A2) and 1.1° C (B2). The lowest increase in temperature is predicted in Nuwara Eliya by 1.3° C (A2) and 0.7° C (B2). Predicted temperature increases with decrease in rainfall in dry zone areas will create more drought problems.

The average reference evapotranspiration (ETo) is predicted for SRES A2 and B2 scenarios for 2050s. Even though the ETo across the country is predicted to increase by 2% in A2 scenario, the increase is mainly in the north and north eastern regions of Sri Lanka. There is no predicted change in potential evapotranspiration in other regions of Sri Lanka. It reflects that the impact of climate change is severe in the north eastern areas where the agricultural activities are concentrated.

Impact of climate change on maximum annual potential soil moisture deficit ($PSMD_{max}$)

Figure 4 represents the maximum annual potential soil moisture deficit (PSMDmax) across Sri Lanka for baseline, A2 and B2 scenarios in 2050s scenario. According to the baseline (1961-1990), the areas with highest $PSMD_{max}$ are located in the northern and eastern parts notably in Jaffna, Mannar, Vavuniya, Trincomalee, Anuradhapura and Batticaloa. These correspond to parts of the country where agricultural activities are intensive and where the reliability and availability of water resources are under severe pressure. In contrast the areas with the lowest $PSMD_{max}$ extend across as much as Colombo, Galle, Ratnapura and Nuwara Eliya, have a corresponding low demand for irrigation.

In A2 2050s scenario, the northern part of the country becomes drier than at present due to the significantly higher $PSMD_{max}$. At Jaffna, the baseline $PSMD_{max}$ is 1162 mm and the predicted PSMDmax for the SRES A2, 2050s will be 1305 mm; 12% increase to the baseline (1961-1990). The maximum average $PSMD_{max}$ has increased substantially in the northern, eastern and south-eastern areas covering the whole of the dry and intermediate zones of the country.

However among the dry zone areas only in Hambantota the $PSMD_{max}$ is predicted to decrease than the baseline (1961-1990) scenario which indicates the beneficial effect of climate change. Earlier studies by Droogers (2005) and De Silva et al (2006) also confirm that the southern tip of the island will have beneficial effects due to climate change.

Implications of climate change

A decline in rainfall, particularly in the Dry Zone, combined with an increase in temperature and evapotranspiration and soil moisture deficit will have serious impacts on the country's food production. It will have serious impacts on country's water resources and could undermine the poverty alleviation strategies.

Unless timely remedial action is taken, it is evident that adverse impacts would worsen the existing economic and social inequities, widen the gap between the developed core (Colombo Metropolitan Region) and the less developed areas in the dry and intermediate zones and create new problems for the future generations.

Possible adaptation measures

Adaptation to climate change means any "adjustments in ecological, social and economic systems in response to actual or expected climate changes and their impacts" (IPCC, 2001). Adaptive capacity is the potential or ability of a system, region or a community to adapt to the effects or impacts of climate change. Enhancement of adaptive capacity reduces vulnerabilities and promotes sustainable development" (IPCC, 2001).

This study could be used as a tool to identify the impacts of climate change at different agro ecological zones as they vary significantly. The adaptation measures must be planned carefully. Considering the impacts on the dry and intermediate zones, encouraging rain water harvesting would be advantageous as it is predicted to receive increase in rainfall during the south west monsoon. A National Rain Water Harvesting Policy and providing a rainwater harvesting system to all households in drought prone areas would increase water security in these zones and it must be the prerequisite to receive drought relief. Rain water harvesting is an effective low cost adaptation strategy to overcome the anticipated decline of rainfall in the dry zone areas.

Renovating the existing tanks in the dry and intermediate zones will help to store the excess rainfall during the south west monsoon. Methods should be devised to store the excess water during the south west monsoon in the wet zone areas to compensate for the decrease in rainfall during the north east monsoon in drier areas. Similarly water saving methods such as drip irrigation will be more useful to continue agricultural activities during the water shortage period. As the southern part of the country is having some beneficial effect due to climate change cropping areas could be increased (Droogers, 2004). Adapting short term varieties to avoid the low rainfall periods also could be considered.

Awareness about the implications of climate change is very important among the vulnerable individuals and communities. It is also important to educate them on adaptation measures such as integrated water resource management, watershed management, and waste management to make necessary adjustments to the predicted climate change.

Conclusions

Under the scenarios tested, there will be a slight increase in the annual average rainfall because of an increase in rainfall during the south west monsoon. But the north east monsoon rain will decrease. Similarly the annual average temperature will increase. These changes in rainfall and temperature, together with other climatic factors, would increase the maximum annual soil moisture deficit significantly in the dry zone areas, demanding higher irrigation need. The major food production activities in these zones would then be at risk. Adaptation measures could be focused on changing the crops, varieties, timing of cultivation and adopting water saving methods.

However this study has used only one global circulation model among the seven models available at present. In addition only one time slice of 2050s representing 2035 -2065 was considered in this study. There is a need to study other model predictions for different time slices and scenarios to confirm that all the models predict the same trend in climate change impacts.

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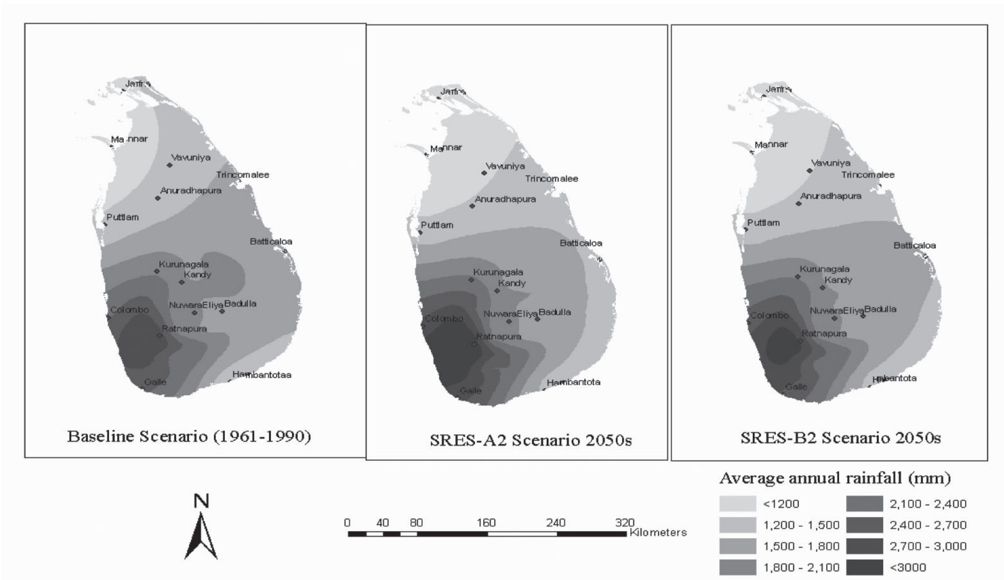

Figure 2. Spatial variation in average annual rainfall for the baseline (1961-1990) and SRES A2 and B2 scenarios for 2050s

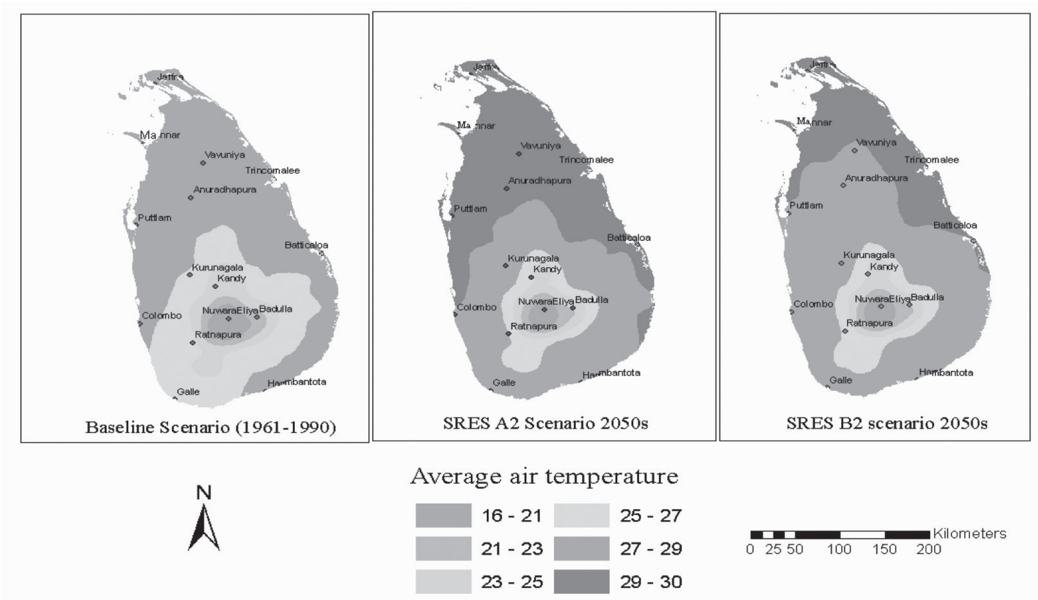

Figure 3. Spatial variation in average air temperature for the baseline (1961-1990) and SRES A2 and B2 scenarios for 2050s

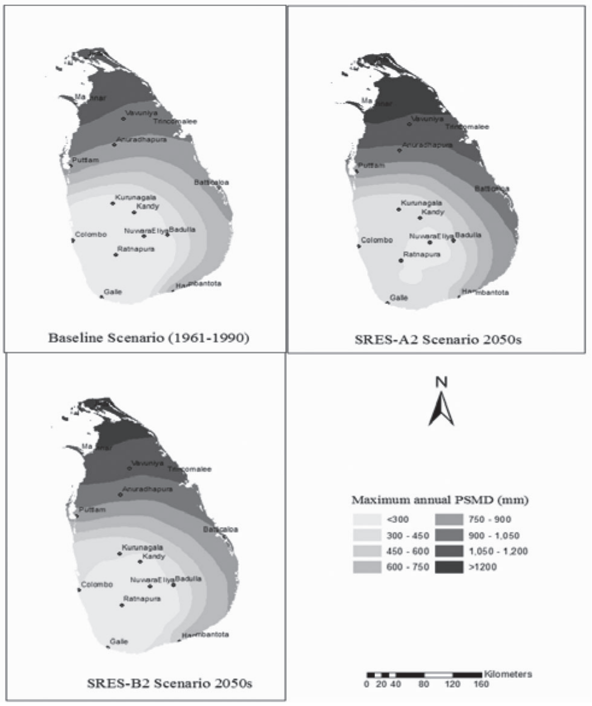

Figure 4. Spatial variation in maximum annual potential soil moisture deficit (PSMDmax) for the baseline (1961-1990) and SRES A2 and B2 scenarios for 2050s

Table 1. Summary of the SRES marker scenarios and their estimated environmental consequences (IPCC-TGCIA, 1999)

Scenario estimates	1990	A1	A2	B1	B2
Population (billion)	5.252	7.1	15.1	7.2	10.4
CO_2 concentration (ppmv)	354	680	834	547	601
Global annual-mean temp. change (°C)	-	2.52	3.09	2.04	2.16
Range (°C)	-	1.7-3.7	2.1-4.4	1.4-3	1.4-3.1
Global mean sea-level rise (cm)	-	58	62	50	52
Range (cm)	-	23-101	27-107	19-90	20-93

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Contact address

Dr C.Shanthi de Silva
Senior Lecturer in Agricultural Engineering
Faculty of Engineering Technology
The Open University of Sri Lanka
Nawala, Nugegoda
Sri Lanka