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Spatial Impacts of Climate Change on Major Climatic Factors in Sri Lanka

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Abstract

This study focuses on the climate change impacts on major climatic factors; rainfall, temperature and other factors (relative humidity, wind speed and solar radiation) contributes to evapotranspiration and soil moisture deficits. Climate change datasets for Sri Lanka were derived from the outputs of the Hadley Centre for Climate Prediction and Research model (HadCM3), UK for selected Intergovernmental Panel of Climate Change emission scenarios A2 and B2 for 2050s and compared with the baseline data of 1961-1990. Under the scenarios tested, there will be an inconsiderable increase in annual average rainfall with a significant increase in the south west monsoon rainfall. But the north east monsoon rains is predicted to decrease. Similarly the annual average temperature is predicted to increase. These changes will increase evapotranspiration and the potential soil moisture deficit significantly in the dry zone areas, demanding additional irrigation water to compensate the crop water requirement. In contrast there will more flood and landslides in wet zone areas. Therefore in order to cope up with climate change impacts proper planning of adaptation measures is important.

Key word: Rainfall, Temperature, Reference Evapotranspiration, Potential soil moisture deficit, Irrigation water

Introduction

The future evolution of the global environment is depending on the total heat stored in the hydrological systems. Therefore, the atmosphere acts as the source of future dynamic changes in the global climate. It can only respond to changes in forcing, such as changes in solar irradiation or heat supply from the ocean. According to Kayane (1996) 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. Further he found that the SST in the Indian Ocean has increased by 0.5-1.0°C during 1930-1989. As a result, the rainfall during the Southwest monsoon season from May to September at Colombo has increased by about 30 per cent during 1869-1993. However, the rainfall at Nuwara Eliya, has decreased by about 40 per cent during the same period (Kayane, 1996). Similar linear increase in rainfall during 1870-1970 was also observed at Calicut (Lengerke, 1976), a coastal station in south-west India, where the same orographic effect on rainfall pattern is expected as on the Sri Lankan south-west coast. According to Kayane et al., (1995), such long-term changes in rainfall in Sri Lanka and southwest India could be the result of intensified Indian monsoon circulation caused by global warming. He also says that the changes in local rainfall may take opposite trends within a relatively small island like Sri Lanka, owing to global warming.

As discussed earlier, global climate change will have varying impact even within a small island like Sri Lanka and the impacts of climate change will be variable from region to region. Future climatic changes will not be able to predicted by studying past climate data only. In predicting future general circulation and weather forecasting models are very much useful. Therefore this paper is intended to study the spatial impacts of climate change on evapotranspiration and potential soil moisture deficits using a general circulation model outputs on climatic factors. Therefore systematic planning of adaptation measures could be done to enhance the resilience of the people in different agro-ecological regions (Figure 1) to cope with longer term climate change and its associated insecurities.

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). HadCM3 provide information about climate change in all over the world during 21st century in three time slices: 2020s, 2050s, and 2080s.

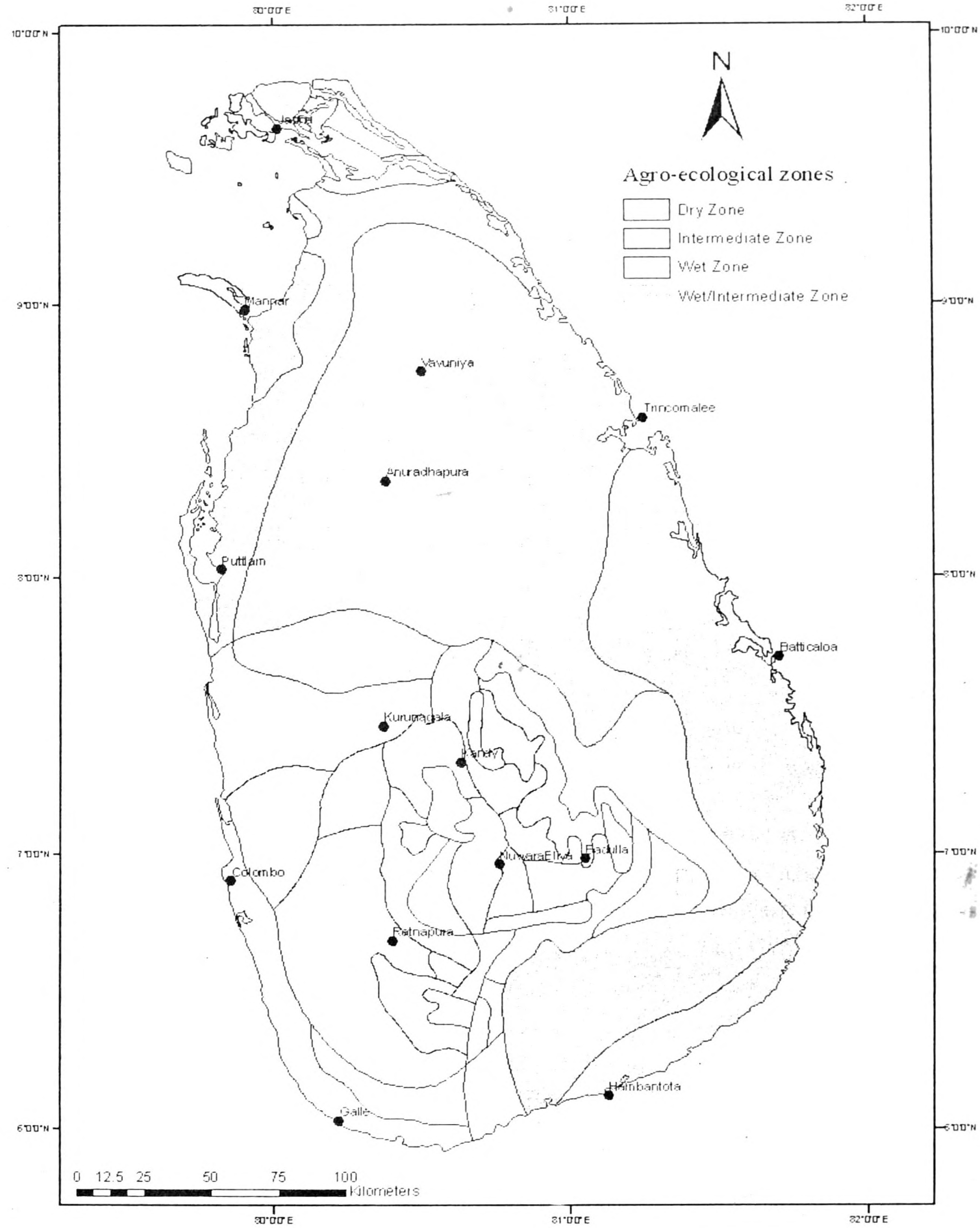

Figure 1: Agro ecological zones of Sri Lanka

In order to provide information on possible changes in the world climate, the climate change models are forced to consider future scenarios. Intergovernmental Panel of Climate change (IPCC-TGCIA, 1999) introduced Special Report Emission (SRE) Scenario is considered for this study and their conditions are summarised in Table 1.

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

A1: A future world of very rapid economic growth, relatively low population growthand rapid introduction of new and more efficient technology.

A2: A differentiated world. The underlying theme is that of strengthening regional and cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

B1: A convergent world with rapid change in economic structures, dematerialization" and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity.

B2: A world in which is emphasis is on local solutions to economic, social and environmental sustainability. It is a heterogeneous world with less rapid, and more diverse technologies change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.

The four SRE scenarios (A1, B1, A2 and B2) 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 scenarios A2 and B2 have been considered. Accordingly scenario A2 is the worst impact scenario with highest population increase, temperature etc. Scenario B2 is considered as the second worst impact scenario. These scenarios were selected in this study to the represent the possible impact due to climate change. The percentages of change predicted by the HadCM3 model for the climatic variables (mean monthly rainfall, temperature, radiation, wind speed and humidity) must be applied to a baseline. As the resolution of the model is too big (300km x 300km), generally accepted within global change research community and scientific statistical downscaling by Alcamo et al., (1997b) was used to apply these percentages changes to the baseline data which is 10 latitude/ longitude data (16km x 16km) set for the period from 1961 to 1990 of mean monthly surface climate over global land areas (New et al., 2002). Accordingly 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 16km x 16km pixel. The procedure was repeated using the corresponding future climate data to produce ETo datasets for each SRE scenario using a procedure developed by Hess and Knox (2003).

Estimation of maximum annual potential soil moisture deficit (PSMD)

The potential soil moisture deficit (PSMD) for each month is calculated using simple water balance equation (Knox et al., 2005) 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 prevails till January each year in the dry zone area which extends upto two third of the country. Therefore the soil moisture deficit is assumed to be zero in January based on random soil moisture testing in the dry zone and in rest of the country. 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 SRE scenarios A2, B2 for 2050s.

Mapping regional changes

The Geographical Information System (GIS) has been used to integrate the climate data (mean monthly) to generate maps showing the spatial changes in predicted rainfall, temperature and reference evapotranspiration for the baseline and SRE scenarios A2, B2 in 2050s.

The data set (rainfall, reference evapotranspiration and maximum annual potential soil moisture deficit) were imported into a geographical information system (GIS) and converted from grid pixel to point (centroit) format. The attribute value of each data set of each grid pixel was appended to each centroit. A contouring function was used to generate the point data set into a surface, by applying an ordinary Kringing method (Alcamo et al., 1997a) in geo statistical analysis.

Results and discussion

Impact of Climate Change on Rainfall

Average Annual Rainfall

The average annual rainfall for the baseline (1961-1990) and the HadCM3 model prediction for SRE scenarios A2 and B2 for 2050s are presented in Figure 2. According to the Figure 2, the dark contours of higher rainfall contours increases in wet zone areas and light shade contours of low rainfall spread over more to dry zone areas in A2 scenario compared to the baseline data of 1961-1990. It shows that wet zone areas get more rainfall while the dry zone areas get less rainfall due to climate change. Therefore the average annual rainfall is predicted to increase by 14% (A2) and 5 % (B2) across the country. About 15 stations in Sri Lanka are analyzed to study the impact of climate change. Selected stations and locations are given in Table 2. 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). In the dry zone areas the average annual rainfall is predicted to increase only in Jaffna, Mannar, Puttlam and Hambantota by very small percentages. The highest increase in Hambantota is 4% (A2) and 3% (B2). This result agrees with Drooger (2004) as he has found that increase in annual average rainfall has reduced the demand for irrigation water for paddy cultivation in Hambantota area. Therefore he suggests that paddy cultivation could be increased by 20% with this irrigation water in Hambantota. However the rainfall is predicted to decrease in other dry zones areas such as Anuradhapura, Batticaloa and Trincomalle. 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.

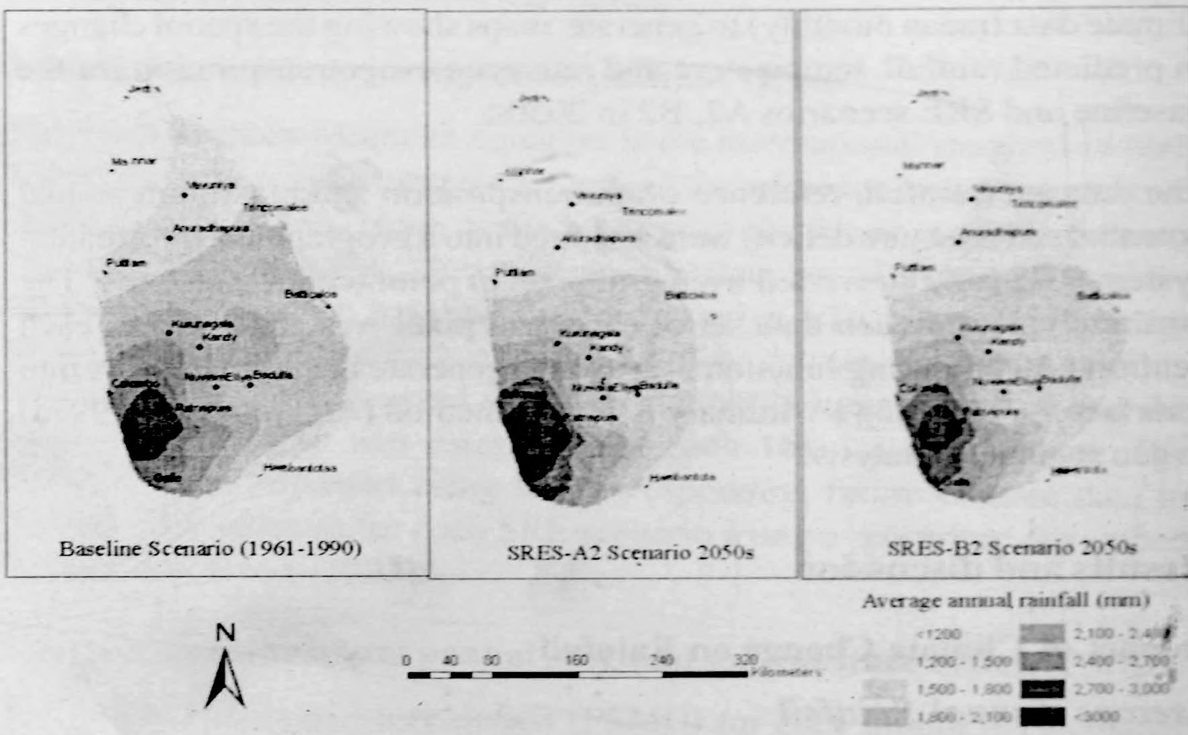

Figure 2: Spatial variation in average annual rainfall for the baseline (1961-1990) and HadCM3 model prediction for SRE A2 and B2 scenarios for 2050s.

Table 2: Selected weather stations and their location used in this study

Weather station	Latitude	Longitude
Anuradhapura	8.35°N	80.38°E
Batticaloa	7.71°N	81.7°E
Badulla	6.98°N	81.05°E
Colombo	6.9°N	79.86°E
Galle	6.03°N	80.22°E
Hambantota	6.12°N	81.13°E
Jaffna	9.65°N	80.02°E
Kandy	7.33°N	80.63°E
Kurunagala	7.46°N	80.37°E
Mannar	8.98°N	79.91°E
Nuwara Eliya	6.96°N	80.76°E
Puttlam	8.03°N	79.83°E
Ratnapura	6.68°N	80.4°E
Trincomalee	8.58°N	81.25°E
Vavuniya	8.75°N	80.5°E

Northeast monsoon Rainfall

Figure 3 shows the impacts of climate change on northeast monsoon rainfall in Sri Lanka predicted by HadCM3 model for 2050s A2 and B2 scenarios and for the baseline (1961-1990). According to the Figure 3 darker shades in Northeast region of baseline becomes lighter in A2 and B2 scenarios which show the predicted decrease in rainfall in northeast regions due to climate change. Therefore the north east monsoon (December to February) is predicted to decrease by 34% (A2) and 26 %(B2) compared to the baseline (1961-1990). Decrease in north east monsoon rainfall is predicted in wet zone areas such as Nuwara Eliya and Ratnapura by 30-35% in A2 and B2 scenarios. It will have serous impact on foreign exchange earning cash crops such as tea, rubber and minor export crops in Sri Lanka.

Especially decrease in rainfall will decrease the tea yield and the dry weather would increase the outbreaks of pests and increases the susceptibility of tea plants to diseases such as canker (Wijeratne, 1996).

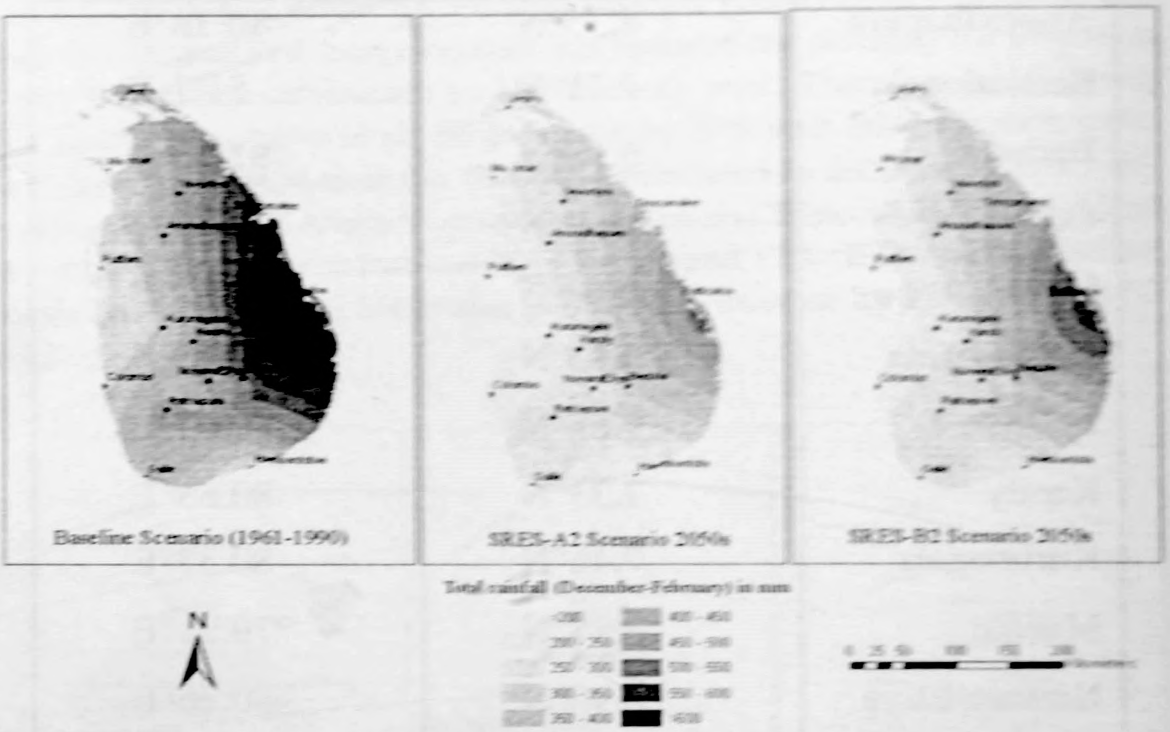

Figure 3: Spatial variation in northeast monsoon rainfall for the baseline (1961-1990) and HadCM3 model prediction for SRE A2 and B2 scenarios for 2050s.

The north east monsoon rainfall in dry zone areas such as Jaffna, Mannar, Vavuniya,

Anuradhapura, Batticaloa, Tricomalee and Hambantota are predicted to decrease too. The highest decrease is predicted in Batticaloa 37% (A2), 27% (B2) and lowest decrease is predicted in Hambantota 11% (A2 and B2). Dry zone areas which receive significant amount of rainfall during northeast monsoon is predicted to decrease in 2050s. Therefore paddy cultivation in these zones will require more water resources. This significant decrease in rainfall during the northeast monsoon period is mainly due to the significant decrease in rainfall predicted during January and February months in the A2 and B2 scenarios for 2050s compared to the baseline. This result also agrees with Fourth Assessment Report of the IPCC. According to the Fourth Assessment Report (FAR) of Intergovernmental Panel of Climate Change (IPCC), there is seasonal variability in precipitation for South Asia, an increase of 11% in June, July August months and a decline of 5% in December, January and February months (IPCC, 2007).

Southwest Monsoon Rainfall

Impacts of climate change on southwest monsoon (May to September) is predicted by HadCM3 model and Baseline is presented in Figure 4. Accordingly the lighter shade in southwest region in the baseline becomes darker in A2 and B2 scenarios of 2050s. It shows that the rainfall across the country is predicted to increase by 38% (A2) and 16% (B2) during southwest monsoon. This result is very close to the findings of Kayane in1996 as the rainfall during the southwest monsoon season from May to September at Colombo has increased by about 30 per cent during 1869-1993.

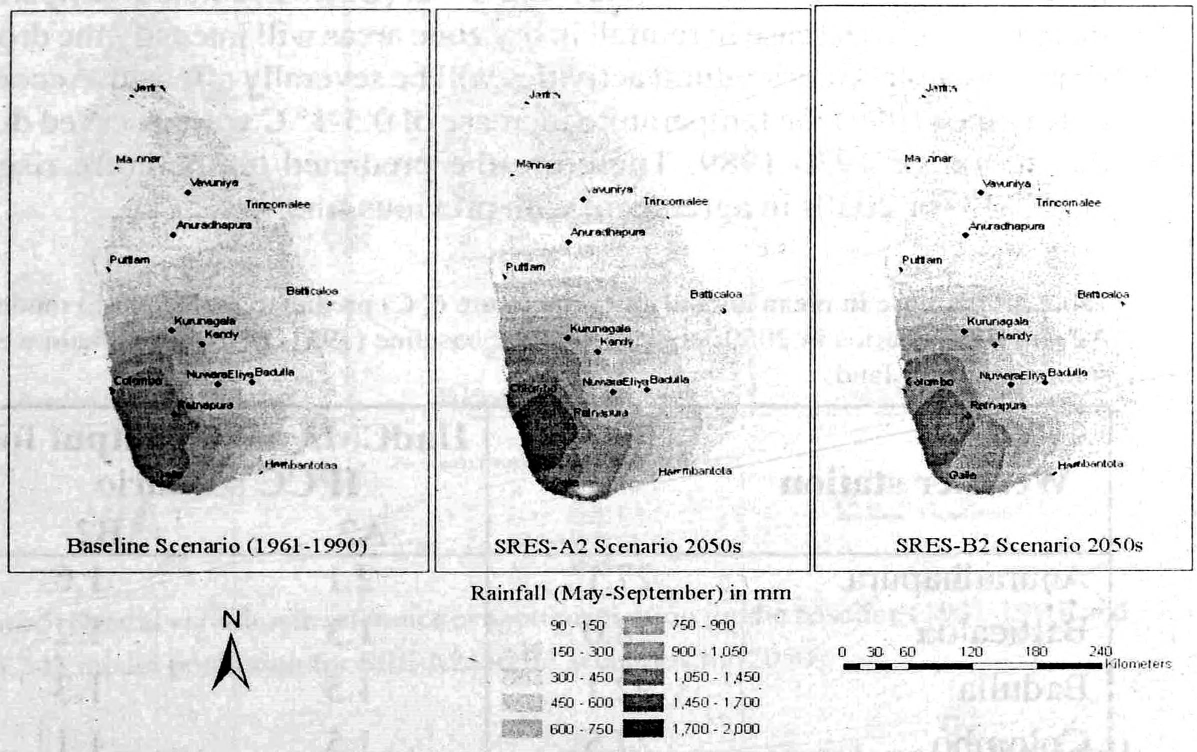

Figure 4: Spatial variation in southwest monsoon rainfall for the baseline (1961-1990) and SRE A2and B2 scenarios for 2050s.

Rainfall in all the wet zone areas is predicted to increase. In Colombo, Ratnapura, Galle, 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. Even at present, heavy rains caused floods and land slides in the hill country (wet zone). The predicted higher rainfall in Nuwara Eliya, Ratnapura areas will cause flood and land slides. These increasing frequency and intensity of extreme weather events in future could bring about illness and deaths as well as injuries, collapse of health infrastructure and displacement of affected persons, as well as physical and psychological trauma.

Impact of Climate Change on Temperature

Impact of climate change on annual average temperature predicted by HadCM3 model and Baseline is presented in Table 3. The average annual temperature is predicted to increase by 1.6° C (A2) and 1.2° C (B2). 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). Predicted temperature increases with decrease in rainfall in dry zone areas will intensify the drought problems and the agricultural activities will be severally affected. According to Kayane (1996) the temperature increase of 0.5-1° C was observed during the period of 1930-1989. Therefore the predicted temperature rises by HadCM3 for 2050s in agreement with previous findings.

Table 3: Increase in mean annual air temperature (° C) predicted by HadCM3 model for A2 and B2 scenarios in 2050s compared to the baseline (1961-1990) at the main weather stations in the island.

Weather station	Baseline	HadCM3 model output for IPCC scenario	
		A2	B2
Anuradhapura	27.1	2.1	1.6
Batticaloa	28.0	1.3	1.2
Badulla	22.1	1.5	1.3
Colombo	27.5	1.5	1.1
Galle	26.5	1.7	1.4
Hambantota	27.1	1.5	1.3
Jaffna	28.0	1.9	1.5
Kandy	22.1	1.5	1.3
Kurunagala	26.9	1.7	1.0
Mannar	28.0	1.5	1.2
Nuwara Eliya	18.8	1.1	1.0
Puttlam	27.7	1.6	1.3
Ratnapura	25.7	1.7	1.4
Trincomalee	28.5	1.4	1.0
Vavuniya	27.7	1.6	1.5

Impact of Climate change on reference evapotranspiration

Figure 5 presents the average reference evapotranspiration (ETo) predicted by HadCM3 model for SRE A2 and B2 scenarios for 2050s and the Baseline data set. It shows that lighter shade in the baseline becomes darker in north eastern region which reveals that ETo is predicted to increase in north and north eastern regions of Sri Lanka. It reflects that the impact of climate change is more in north eastern areas where the agricultural activities are intensive and higher evapotanspiration leads to higher irrigation need.

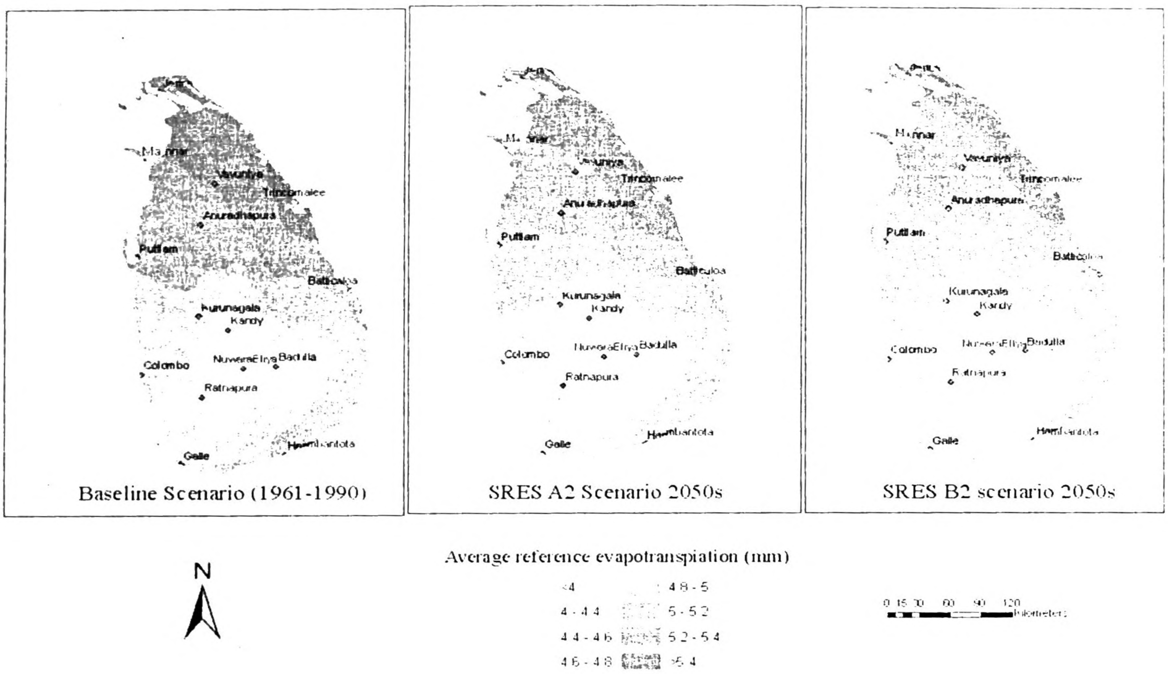

Figure 5: Spatial variation in reference evapotranspiration for the baseline (1961-1990) and HadCM3 model prediction for SRE A2and B2 scenarios for 2050s.

Impact of Climate Change on maximum annual potential soil moisture Deficit ($PSMD_{max}$)

Table 4 represents the maximum annual PSMD across Sri Lanka for baseline, HadCM3 model prediction for A2 and B2 -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, Trincamalee, 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 lowest $PSMD_{max}$ extend across much as Colombo, Galle, Ratnapura 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 $PSMD_{max}$ (Table 4). At Jaffna, the baseline $PSMD_{max}$ is 1162 mm. The HadCM3 predicted $PSMD_{max}$ for the SRES A2, 2050s will be 1305 mm; will be 12% increase to the baseline (1961-1990). The maximum average $PSMD_{max}$ has predicted to increase substantially in northern, eastern and south-eastern areas covering major areas of dry zone 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 the Droogers (2004) and De Silva et al., (2007) too confirm that the southern tip of the island will have beneficial effect due to climate change because this is predicted to receive higher rainfall which will reduced the demand for irrigation water and therefore the extend of cultivation under paddy could be increased by 20%.

Table 4: Maximum annual soil moisture deficit (PSMDmax) for baseline and HadCM3 prediction for A2 and B2 scenarios in 2050s at selected sites.

Weather station	Baseline (1961-1990)	HadCM3 model prediction for IPCC scenario -2050s	
		A2	B2
Anuradhapura	905	981	944
Badulla	253	387	304
Batticaloa	782	981	885
Colombo	190	387	304
Galle	190	273	304
Hambantota	663	627	527
Jaffna	1162	1305	1225
Kandy	190	387	304
Kurunagala	190	387	304
Mannar	1162	1305	1225
Nuwara Eliya	128	273	197
Puttlam	782	866	885
Ratnapura	64	273	197
Trincomalee	905	1200	1115
Vavuniya	1032	1200	1115

Conclusions and recommendations

Conclusions

HadCM3 predicts decline in rainfall, particularly in the Dry Zone, combined with an increase in temperature and evapotranspiration and soil moisture deficit, which will have serious impacts on the country's food production in dry and intermediate zone. In contrast the model predicts increase in rainfall in south-western region which will create more floods and landslides.

Recommendations for 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"

This study could be used as a tool to identify the impacts of climate at different agroecological zones as they are varying significantly and the adaptation measures must be planned carefully.

- Considering the impacts on dry and intermediate zone, more irrigation water must be allocated for dry zone and it could be done by augment and /or restore the existing reservoirs to store more water.
- Encouraging rain water harvesting, introducing water saving irrigation methods such as drip irrigation with agro wells could be beneficial in dry zone.
- Encouraging farmers to cultivate short duration paddy varieties to cope with predicted decrease in rainfall during northeast monsoon.
- Improving the drainage system in Colombo and the surrounding areas will help to cope with increase events of rainfall.
- Predicted excess rainfall in wet zone could be stored safely and diverted to the zones where water is scarce.
- 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.

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