Simulation of the Impact of Deforestation on the Rainfall in Lake Victoria Basin

DAVID F. MUHATI, JOSEPH M. ININDA AND FRANKLIN J. OPIJAH

Department of Meteorology, University of Nairobi

CORRESPONDING AUTHOR
JOSEPH M. ININDA
Department of Meteorology
University of Nairobi
P.O. Box 30197-00100
Nairobi- Kenya
Email jininda@uonbi.ac.ke

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ABSTRACT

Over the past four decades, Lake Victoria basin has experienced drastic environmental changes on account of both natural and anthropogenic factors. The natural factors include prolonged droughts and the recent emergence of water hyacinth in the Lake, while anthropogenic factors include the deforestation rates, poor agricultural practices, and destruction of critical wetlands. This study examines the potential impact of deforestation on the rainfall over the lake Victoria basin.

To assess the potential impact of deforestation on rainfall over the region, the General Circulation Model (GCM) ECHAM5 was applied. ECHAM5 was used to predict the possible impact of land cover and land use changes on rainfall using land cover and land use scenarios based on the Integrated Model to Assess Global Environment (IMAGE). The projected vegetation cover for 2050 was used to model the impact of deforestation, which indicated a general decrease in the canopy.

The results from the model indicate a decrease in rainfall over many parts, although some areas showed increased rainfall. From the study we conclude that while deforestation has an impact on climate, there seem to be a complex interaction between forest and the rainfall generation mechanism.

1.0 INTRODUCTION

Observational studies have shown that the extent and type of vegetation covering the earth, the lake Victoria basin being no exception, has changed dramatically in the recent past due to both natural causes and human activity (Overpeck, 1993; Otterman, 1997). Vegetation plays an important role in the climate system because plants are a primary component for the exchange of water, energy, and momentum between the land and atmosphere. Deforestation therefore, may lead to a disruption of the climatic regime over an area.

Terrestrial ecosystems such as forests mitigate global warming by absorbing and storing carbon, ensure clean water supplies, clean air, abundant fish stocks and wildlife; the diversity of species on which life depends. They also regulate regional and global hydrological cycles, preserve soil fertility and prevent floods and landslides. Hence deforestation may have a considerable effect on both the climatic regime as well as the socio-economic activities of the lake basin.

Approximately 13 per cent of the total land area of Eastern Africa is covered by forests and woodlands, and this constitutes approximately 5 per cent of the total forest cover in the African continent (FAO 2001, Wass 1995). The major issue in this sub-region is conversion of natural forest to alternative land uses, predominantly cultivation and grazing; urban encroachment is also a contributing factor to forest destruction. According to the United Nations Food and Agriculture Organization, Africa lost large tracts of rainforests of many biogeographical realm during the 1980s, a trend that continued during 1990-1995, FAO (2003).

The Lake Victoria Basin has potential in many areas, which include fisheries and tourism; transport and communications, water and energy, agriculture, trade and industry. The basin has potential in the abundant natural resources like wildlife, forestry, minerals and fertile soils.

The crucial significance of Lake Victoria to the region and globally arises from the fact that it is; the largest inland water fishing sanctuary, major inland water transport linkage for the three East Africa countries, a source of water for domestic, industrial and commercial purposes, major reservoir for hydroelectric power generation, major climate modulator in the region, and rich in biodiversity.

More than 80% of the population in the Lake basin are engaged in agricultural production, the majority are small scale farmers and livestock owners producing maize and cash crops such as sugar, tea, coffee, cotton and meat. The fish resources of the lake sustain – directly or indirectly – livelihood for about 3 million people engaged in subsistence, artisanal and commercial fishing. The fisheries are very important as a source for foreign exchange earnings.

Various studies have demonstrated the relationship between environmental degradation and poverty. While the East African countries have increasingly recognised, the importance of the Lake and its basin as a resource that can be exploited, the realisation of this potential is hampered by the threat to the environment over the lake basin.

Over the past four decades, Lake Victoria has experienced drastic environmental changes on account of both natural and anthropogenic factors. The natural factors include prolonged droughts and the recent emergence of water hyacinth in the Lake.

Anthropogenic factors include massive deforestation, poor agricultural practices, and destruction of critical wetlands. This study examines the potential impact of deforestation on the rainfall over the lake Victoria basin.

1.1 Study Area

The area of study is enclosed by latitude 4°S to 2°N and longitude 30°E to 36°E. This area was then subdivided in smaller regions for further analysis namely; Region I (lat. 1°S to lat. 2°N and long. 30°E to 33°E), Region II (lat. 1°S to lat. 2°N and long. 33°E to 36°E), Region III (lat. 4°S to lat. 1°S and long. 30°E to 33°E), Region IV (lat. 4°S to lat. 1°S and long. 33°E to 36°E).

2.0 DATA AND METHODOLOGY

Studies of climate change are based on information derived from some parameters that quantify the state of the climate. The two parameters (indicators) which have been widely used to study climatic fluctuations and change are temperature and precipitation.

2.1 The Data Used

The rainfall data was obtained from the NCEP web site. The rainfall data used in the study consisted of monthly grid rainfall records for the period 1949 - 2005 over the area. Deforestation scenarios for the region surrounding lake Victoria were developed by the Integrated Model to Assess Global Environment (IMAGE) program of the National Institute of Public Health and the Environment, Netherlands. These scenarios were used to simulate the associated possible changes in climate over the region.

2.2 Methodology

The methods used included the analysis and development of scenarios using ECHAM model.

2.2.1 Trend Analysis

One of the indication of climate change is the trends in the meteorological parameters. The trend in the seasonal and annual rainfall over the four regions in the study area were examined. The significance of the trends was tested using the t-test. The data was divided into two equal or almost equal sample size. The means **and variance of the sub-groups were used to compute the value of t statistic which was compared with the tabulated.**

The t- value was computed using the

expression given by

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)} \quad \text{.........................} \quad (1)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the means of the two samples of size n_1 and n_2 and variances σ_1^2 and σ_2^2 respectively.

2.2.2 The European Centre GCM, ECHAM

The potential impact of deforestation on rainfall over the study area was carried out using a General Circulation Model (GCM). The General Circulation Model used in this study is the ECHAM model (version 5.2) which evolved from the numerical weather prediction model developed at the European Centre for Medium Range Weather Forecasting, ECMWF (hence the first part of its name: EC) and a comprehensive parameterization package developed at Hamburg (hence the abbreviation HAM). This model has been described in detail by Roeckner et al. (2003).

It was essential to assess the ability of the climate model to reproduce specific features of the present-day climate in order to ascertain the validity of its application to predict future climate change. The simulated rainfall was therefore validated against rainfall observations over the region.

In its standard configuration, the climate model uses a pressure based terrain-following vertical coordinate with 19 layers spaced unevenly in the vertical with the top level at 10 hPa. The horizontal representation is configured using spectral transform techniques at triangular 42 spectral truncation (T42), which is equivalent to a spatial resolution of about 2.8^o longitude by 2.8^o latitude grids (128 by 64 points in the horizontal and vertical respectively). A semi-implicit time scheme (a scheme in which the unknown or future time level is only applied to terms in the primitive equations that generate fast gravity waves, and the remaining terms handled explicitly) is used for equations of divergence, temperature and surface pressure, based on the work of Robert *et al*. (1972). The growth of spurious computational modes is inhibited by a time filter, with the time step for the T42 resolution taken as 24 minutes (Asselin, 1972). The model is forced using the Alexander and Mobley (1976).

2.2.2.1 IMAGE description

The Integrated Model to Assess the Global Environment (IMAGE) is an integrated assessment-modelling framework for global change whose main goal is to contribute to the scientific understanding and support decision-making by quantifying the relative importance of the main processes and interactions in the society-biosphere-climate system. Details of the model can be obtained from Leemans *et al.,* (1998). IMAGE provides dynamic and long-term perspectives of the systematic consequences of global change, insights into the impacts of global change and a quantitative basis of analyzing the relative effectiveness of various policy options to address global change.

IMAGE version 2.2 consists of three subsystems of models; Energy-Industry component, Terrestrial Environment component, and Atmospheric-Ocean component. Reference is made to the Terrestrial Environment System (TES) of the model, which simulates the grid scale changes in global land cover based on climatic and socio-economic factors. Data for the period 1970-1995 was used to calibrate the TES, which reasonably reproduced the observed trends of transformation of land cover. Olson *et al.,* (1985) datasets of the world's major ecosystem complexes were used to initialize the model in 1970. The time horizons of the model calculations extend from 1970 to 2100, although the land cover and land use scenarios for this study were available for only 1995 and 2050. The calculations of deforestation scenarios were performed on a grid mesh of 0.5 by 0.5-degrees.

The deforestation scenarios produced for the years 1995 and 2050 using IMAGE were used to constrain the ECHAM5 model and assess the changes in climatic parameters as a result of changes in the vegetation cover between the two years. These scenarios were based on the *I*ntergovernmental *P*anel for *C*limate *C*hange report in which the A2 storyline was used (IPCC, 2000). This storyline assumes a heterogeneous, market-led world, with more rapid population growth but less rapid economic growth. The underlying theme in the storyline is self-reliance and preservation of local identities. Economic growth is regionally oriented, and hence both income growth and technological change are regionally diverse. Fertility patterns across the world regions converge slowly, resulting in high population growth (Alcamo, 1994 *et al.).*

The IMAGE scenarios provide data of the

distribution of biogeophysical parameters such as leaf area index (ratio of leaf area to land surface area in a vertical column) which does express the changes in the distribution of the IMAGE land cover classes and the leaf biomass estimates. Other parameters such as forest fraction, leaf area density, canopy height and displacement height are assigned to the IMAGE vegetation classes and used to infer the 1995 and 2050 changes in vegetation characteristics. These parameters are then used in ECHAM5 as described below.

2.2.2.2 Experimental Design

` Four sets of experiments were carried out to assess the influence of forests on the climate over the lake basin. ECHAM5 was used to simulate the present and future state of the atmosphere basing on the land cover and land use scenarios for the years 1995 and 2050.

The first two experiments, were run for a duration of one-and-a-half years each using, respectively, the initial data for 1995 and 1997. The purpose of these two experiments was to determine how well the model captures the space-time characteristics of rainfall over the study domain. The performance of the model in these two experiments was validated by comparing the model outputs with the observed data.

The next two sets of experiments, were performed to assess the potential impact of deforestation on the climate of East Africa using the ECHAM5 dynamical model. In both of these experiments, the model was integrated to ten-and-a-half years using the initial and boundary data for June 1990 to December 2000. In these experiments, as in the previous two, the first six months were discarded as spin-up time. In Experiment 3, the deforestation scenario for 1995 was used. This scenario was obtained using the IMAGE model. In Experiment 4 the deforestation scenario for the year 2050 as projected by IMAGE was used. The initial six months were used as spin-up time, before the model run attained stability.

3.0 RESULTS AND DISCUSSION

The results from the time series analysis are shown in Figure 1 while the summary of the trend are given in Table 1. From Figure 1a it is apparent that there has been a decreasing trend in the March to May (MAM) season rainfall in region I to III while region IV indicate an upward trend. From 1980 to 2005, severe droughts over all the regions occurred during MAM season in 1983, 1984, 1992, 2000 and 2004. Over the same period, above normal rainfall during the MAM season occurred in 1981, 1985, 1990, 1991 and 2001. It was evident from the analyses that the rainfall deficit outweighed the surplus leading to a decreasing trend. Okoola (1999) has also identified the years 1981 and 1984 as wet and dry respectively.

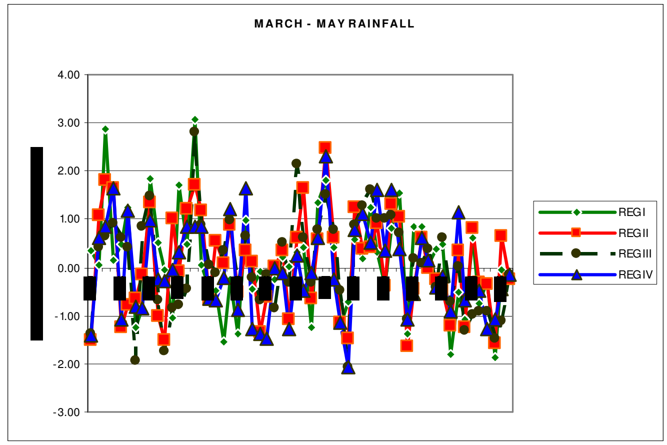


Figure 1 (a)

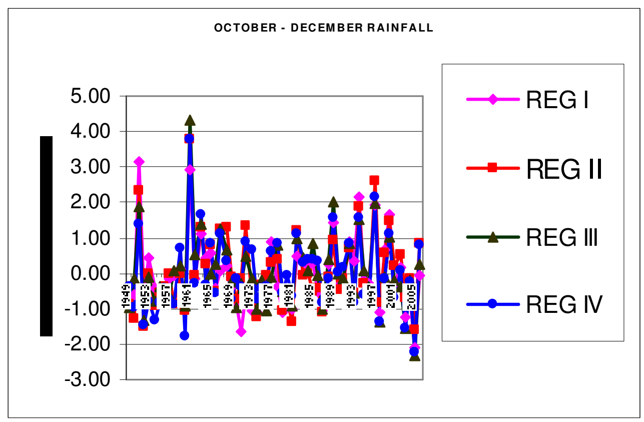


Figure 1 (b)

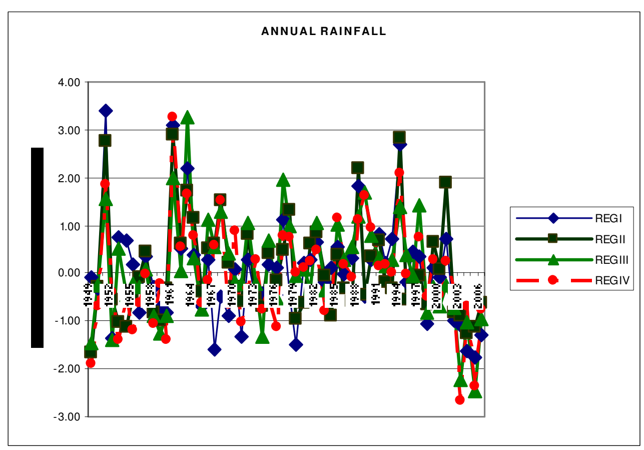


Figure 1 (c)

Figure 1 The time series of standardized rainfall anomaly (a) March to May (b) October to December (c) Annual

Table 1: The annual and seasonal rainfall t-test statistic. The bolds indicate statistically significant values at 90% confidence level.

Region	Season	Trend	The computed t
I	Annual	Negative	**-1.49**
	MAM	Negative	**-2.38**
	OND	Positive	0.70
II	Annual	Negative	**-1.27**
	MAM	Negative	-0.59
	OND	Negative	-0.28
III	Annual	Negative	**-1.50**
	MAM	Negative	**-1.25**
	OND	Negative	-0.07
IV	Annual	Positive	**1.29**
	MAM	Positive	0.46
	OND	Positive	0.99

Figure 1b shows the time series of the October to December (OND) season. The driest years over all the regions during the OND season for the period from 1980 to 2005 were 1981, 1987 and 2005 and the wettest years were 1982, 1994 and 1997. Unlike the MAM season, the rainfall surplus during OND season over most of the regions outweighed the deficit leading to an increasing trend.

The annual rainfall time series (Figure 1c) indicate the driest years during the period 1980 to 2005 as 1984, 2002, 2003, 2004 and 2005, while the wet years were 1988, 1994 and 2001. While, on average, the MAM season contributes a large proportion of the annual rainfall, in some years significant rainfall occur during the dry seasons and offsets the deficit of the main rainfall season. Moreover during most of the El-Nino years excessive rainfall occur during the OND season which influence the annual totals. El-Nino episodes have been frequent in the recent years. This is evident from the fact that significant positive trends were observed in the annual rainfall.

Results from climate modeling using ECHAM5 showed that the climate model simulates the temporal and spatial variation of the rainfall fairly well over the region of study. Figure 2a and 2b show the model simulated and observed rainfall over Region I for 1995 and 1997 respectively. Similar results were obtained for the other three regions considered in the study over the lake basin. However, in most cases the model underestimates the observed rainfall. This may be due to the fact that the model does not replicate well the fine details associated with the mesoscale features.

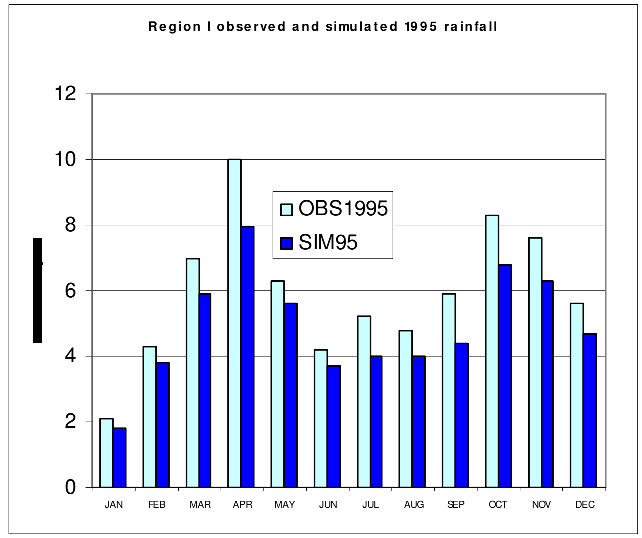


Figure 2a: The observed and simulated rainfall for 1995 over region I

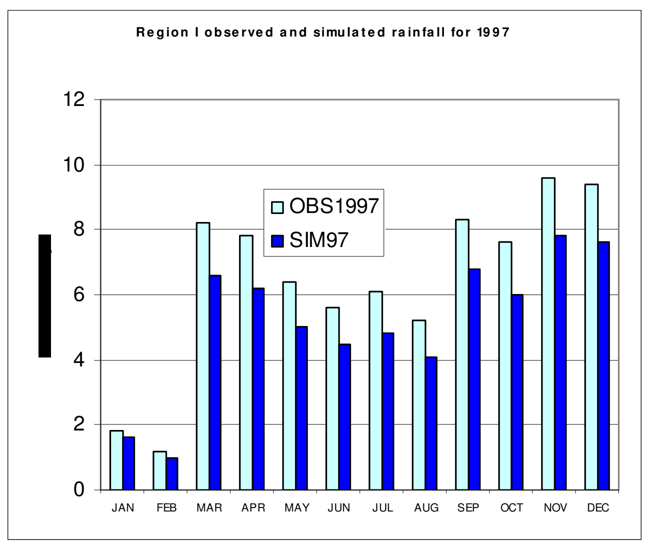
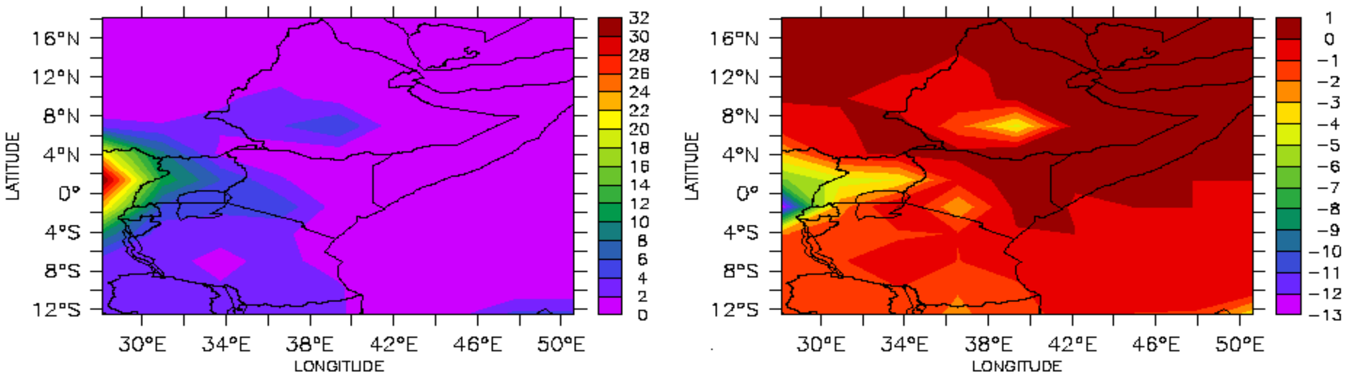


Figure 2b. The observed and simulated rainfall for 1997 over region I

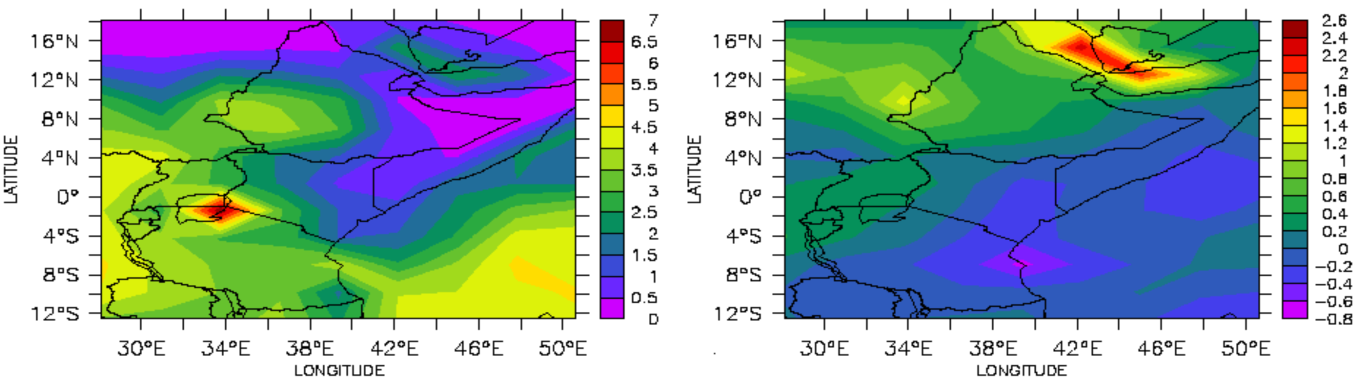
Figure 3a shows the canopy height 9height of vegetation top) for 1995 while figure 3b shows the difference between the projected canopy height of 2050 and 1995. It can be seen that there is a general decrease in the canopy for the future. Figure 4 shows the spatial distribution of the simulated rainfall using the 1995 vegetation cover and the projected 2050 vegetation cover. Figure 4a shows that for the reference scenario (1995) higher amount of rainfall occur in the western parts of the study area, which is consistent with the observation. Figure 4a indicate an increase in rainfall evident over the western parts of the study region for the projected 2050 vegetation scenario with reductions in rainfall to the east. This result suggests a non linear relationship between the canopy height (extent of vegetation from surface) and rainfall.

Figure 5 shows that the simulated rainfall is below the mean. However, it is noted that during the first half of the year the simulated rainfall using the projected 2050 vegetation scenario is higher compared to that simulated with the 1995 vegetation while during second half year the simulated rainfall using the projected 2050 vegetation scenario is lower than that simulated with the 1995 vegetation. This suggests that there is a complex interaction between forest and the rainfall generation mechanism. Further more the effect of deforestation may have local, regional and global effects.



3(a). 3(b)

Figure 3: The distribution of the averaged canopy height fields (in metres) (a) canopy height for 1995 (b)) the difference between the projected 2050 projected canopy and the canopy for 1995



4(a) 4(b)

Figure 4: The spatial distribution of the simulated rainfall (mm day^{-1}) (a) the simulated rainfall for the 1995 canopy (b) the difference between the rainfall simulated using the 2050 projected canopy and that simulated for 1995

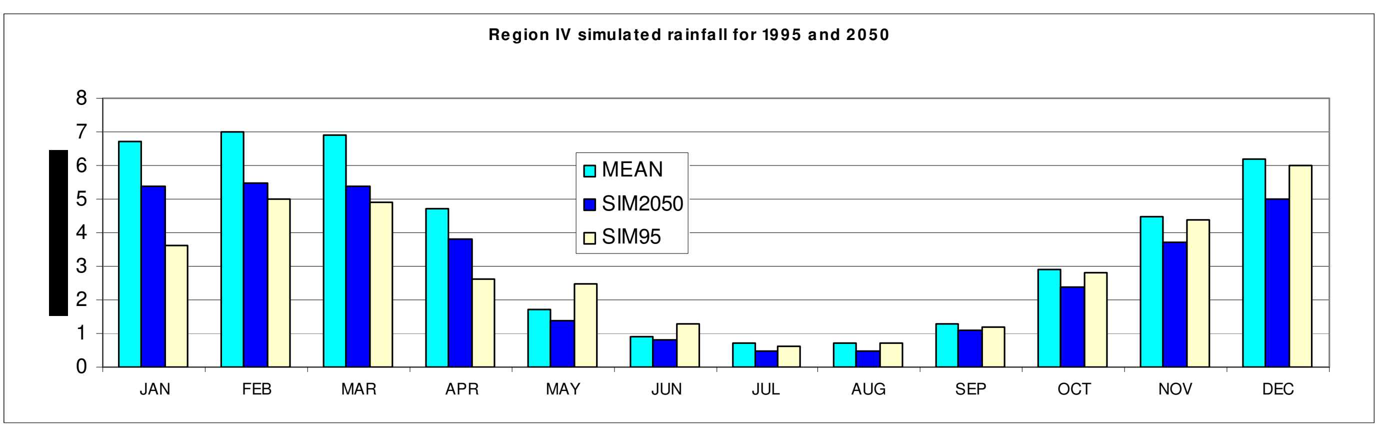


Figure 5: The simulated rainfall over region IV for the 1995 and 2050 vegetation and land use scenario and the mean rainfall.

4.0 CONCLUSIONS

This study examined the possibility of regional climate change and the impact of deforestation on the rainfall over the lake basin. The results from time series analysis showed a general decreasing trend in the MAM rainfall. The OND indicated increasing trends over some regions while the annual rainfall indicted increasing trend over most of the region. These results suggest that the observed decrease in the Lake Victoria levels may be attributed to factors other than rainfall. Such factors may include evaporation, increased outflow from the lake and evapo-transpiration associated with the lake hyacinth. The simulated rainfall using the ECHAM5 climate model suggest that deforestation may not have the same affect on rainfall over various regions. For instance, the 2050 vegetation scenarios increased the rainfall over the western region and decreased rainfall over the eastern regions.

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