Impacts of climate change on precipitation in the Cuvelai-Etosha basin

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Abstract

This research paper presents an assessment of climate change and its impact on precipitation in the Cuvelai-Etosha basin. The Cuvelai-Etosha basin (CEB) is an ephemeral river system, a system of shallow pans, locally known as 'Iishana' situated in northern central Namibia. Research on climate change theory, the use of General Circulation Model's (GCM's) and historical precipitation observations were the basic inputs for the study. Using R, annual and seasonal precipitation from observations and simulated data were plotted to represent the trends. The data used for the analysis included precipitation records from Okaukuejo (1934-2007), Oshikuku (1931-1997) and Ombalantu (1930-1996). Model simulations were forced by the SRES A1B emission scenario and all simulations span the period 1951-2099. From observed precipitation data records; annual totals, averages, frequencies, relative and absolute changes were calculated and plotted. Simulated data were also treated in the same way. Results from simulations were used for compilation with observed data and to present future precipitation trends. Changes in precipitation were noticed in all analysed observations and simulated precipitation. Generally both results show a decrease in annual and seasonal precipitation, which is strongly linked to climate change. Large biases were also found in all three GCM simulations with respect to observed data.

Introduction

The study Impacts of climate change on precipitation in the Cuvelai Etosha-Basin is aimed to assess the changes in precipitation of the CEB basin that might be caused by climate change. The Cuvelai-Etosha basin is an ephemeral river system, a system of shallow pans, locally known as 'Iishana' situated in northern central Namibia. Formed by flood water flowing from Angolan highlands formed and shaped the 'Iishana' river system that drains into the Etosha lake. As the most arid country in Southern Africa, Namibia is one of the driest countries in the world with increasing aridity and high variability in precipitation.

The CEB is of major importance to the Namibian people because:

- it is home to 40% of the country population (Korberg et al., 1996, Cunnigham et al., 1992),
- It’s agricultural potential in the dry Namibian conditions, which is seasonally fed by rain and flood water
- Its unique hydrological and landscape characteristics

Whether climate change affects precipitation, is a question that has been discussed and answered in many past research papers such as (Christensen et al, 2007). The relevant question is how big the changes are. There are several reasons, why climate change cause changes to precipitation. One of the most important changes has to do with the general physics of water, when water heats up, it expands. However, it is hard to notice the change on a small scale, but in large reservoirs or in the case of the

Cuvelai-Etosha basin, the effect is quite large. Increase in global and regional temperatures leads to changes in the hydrological cycle which directly affects precipitation.

The country has an annual precipitation of 25-700 mm (Amakali, 2008) which show high variability of Namibian rainfalls. Precipitation occurs mostly in areas with conditions that favor condensation and high water vapor in the atmosphere. The CEB is located in a dry area with relatively small evaporation of water from the surface, thus there is less water vapor in the atmosphere that favor precipitation conditions.

There are different ways in which precipitation may change due to change in climate as listed bellow (Thomas et.al, 2007):

1) Changes in the frequency of precipitation events
2) Changes in the intensity of precipitation events
3) Combination of the first 2
4) Changes in type of precipitation
5) Changes in duration of precipitation events

In this study, Annual precipitation frequency will be analysed to determine any change in annual precipitation distributions.

Defining the Study area

The Namibian part of the Cuvelai-Etosha basin (CEB) is situated in the north-central part of Namibia and covers an area between the Okavango and Kunene Rivers and ends up in the Etosha pan. It lies within the Omusati, Ohangwena, Oshikoto and Oshana region. The Cuvelai is an endoric river of about 430 Km in length, a total area of up to 25 053.60 Km² (Kolberg, 2007), and has no discharge to the sea.

The basin is made up of shallow pans known as Iishana, which form a shallow ephemeral river system draining up south in the Etosha pan. The area between Iishana watercourses is mostly used for crop and livestock farming. The CEB basin is sub divided into four sub-basins by the Ministry of Agriculture, Water and Forestry (MAWF): Tsumeb, Cuvelai-Iishana, Niipele-Odila and Olushandja sub-basin. The Etosha pan is the center point for drainage with an elevation that ranges from 1,071 m to 1,086 m and has an area of 6,133 Km² (McGinley, 2007).

Methodology

For analysis, monthly observed precipitation records and GCM data for compilation were used. Long term observed data records from 3 stations within the CEB (Ombalantu, Oshikuku and Okaukuejo) were carefully chosen for analysis. The datasets were selected based on their homogeneity i.e. less errors and missing values. Data records for the study was supplied on request by the Namibian Meteorological Service (METEONA). The data used for the analysis included records from Okaukuejo (1934-2007), Oshikuku (1931-1997) and Ombalantu (1930-1996). Historical data were mostly measured from old SADF (South African Defense Force) army bases and/or airports, however more details on how the measurements were carried out were not provided.

GCM data were obtained from the database of the ENSEMBLES project (http://ensemblesrt3.dmi.dk/). For the analysis, three simulations of the HadCM3 global climate model produced by the Met Office

Hadley Center (UK) were selected. These simulations were forced by the SRES A1B emission scenario and all simulations span the period 1951-2099. The resolution of this version of the model was 3.75° longitude by 2.5° latitude. The simulations resulted from the perturbed physics ensemble experiment (Collins et al., 2006). The HadCM3Q0 uses the standard parameter settings, while the HadCM3Q3 and HadCM3Q16 include parameter perturbations giving the lowest and largest response to external forcing (from the perturbed physics ensemble), respectively. From the archive we extracted monthly precipitation sums for a grid box covering the study area (coordinates of the grid box center are 15° E 20° S)

The process of data analysis was intended to provide the following from observed and modeled data;

- Annual precipitation amounts
- Annual precipitation averages
- Annual precipitation frequencies from observed precipitations
- Seasonal averages of precipitation
- Annual and seasonal relative and absolute changes

To analyse how precipitation is changing, it is necessary to evaluate proportion of precipitation falling in a specific period/time interval, and evaluate or compare results to a control period of precipitation. In this research, observed and modelled precipitation were divided into 3 groups and 6 periods. Group 1 in the study represent observed and simulated precipitation during the year 1935 to 1996 which is further sub-divided into 3 periods that describe past observed precipitation. Group 2 of the study represent current observations in climate, which is described for the period between the years1997 to 2020. Group 2 has only 1 period to it. Group 3, is intended to address future simulated precipitation from the GCM's and is sub divided into 2 periods as shown in table 1.

Group	**Period**	**Time**	**Observed Precipitation dataset**			**Modelled Precipitation dataset**		
			Ombalantu	Oshikuku	Okaukuejo	HadCM3Q0	HadCM3Q3	HadCM3Q16
OBS. P.	**1**	1935-1950	A	A	A			
	2	1951-1975	A	A	A	A	A	A
	3	1976-1996	A	A	A	A	A	A
Future P.	**4**	2021-2050				A	A	A
	5	2075-2099				A	A	A

table 1. Summary of study groups and study periods used in data analysis [A]- analysed data.

The time series of the annual and the seasonal precipitations are analysed with the R project for statistical computing software, which is part of the General Public License (GNU) project and it is freely available under the GNU(R, 2008).

Using R, summer and winter averages were calculated from monthly total precipitation. Observed total monthly precipitations were provided in the data sets. Total monthly precipitations data sets were used to:

1. Define summer seasons (October to March) and winter (April-September) used in data analysis.

2. Calculate annual, summer and winter totals.
3. Calculate means and moving averages for summer and winter precipitations.
4. Calculate summer relative changes and winter absolute changes.

Because there is mostly little or no (0 mm) precipitation in winter months, absolute changes were calculated to analyse changes in winter seasons instead of relative changes, which are used to study changes in summer precipitation and annual periodical changes.

Results and Discussions

Computing Total annual precipitation for observed precipitation was the first step in the study. Total annual precipitation were calculated from available observed monthly data, by adding observed monthly values for whole year periods i.e. yearly sums. Calculated observed total annual values were then used to plot total annual precipitation, annual precipitation frequency and to find differences in observed and modelled precipitation from GCM's.

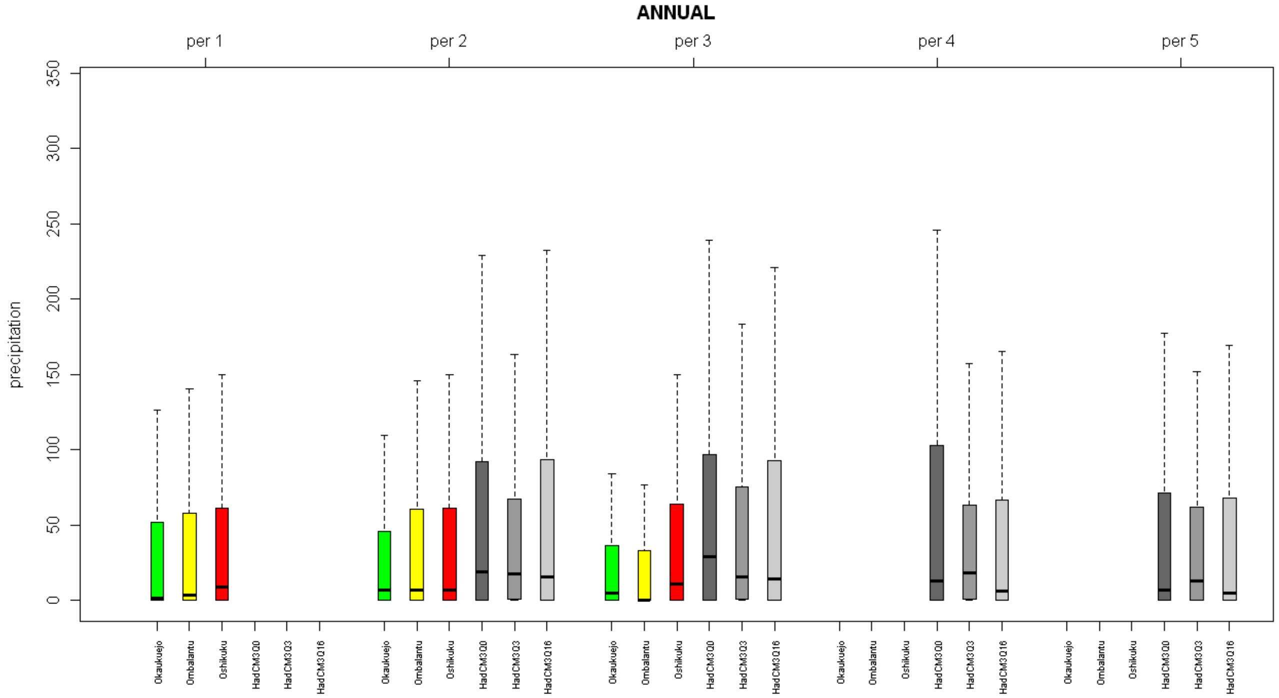


Fig 1. Summary of observed and simulated annual precipitation Observed: Okaukuejo (green), Ombalantu (yellow), Oshikuku (red)

From the plots, summer precipitation dominates in all observed precipitations (see also Annex 1, for trend plots). This is caused by different seasonal conditions such as atmospheric circulation, temperature, evaporation and water content in the atmosphere over the basin.

Results for Okaukuejo shows that there has been a slight decrease in summer precipitation and almost a constant trend in winter precipitation. Overall there has been a decrease in mean summer precipitation with a difference of 99.02 mm between period 1 and period 3. Summer precipitation totals has also decreased, with the lowest total observed precipitation in period 3. On the other hand, winter precipitation has increased but annual winter precipitation totals remained constant with only slight changes.

Ombalantu experienced a decrease in total and mean summer precipitation from period 1 to period 3. There is a mean precipitation difference of up to 163.22 mm between period 1 and period 3. Lowest summer observed total and mean precipitation has also been recorded in period 3. Ombalantu winter precipitation plot shows a contradicting precipitation distribution comparing to the other observation plots.

Oshikuku station did not experience many changes, it showed almost constant trend in summer and winter average precipitation. Both annual precipitation totals and precipitation mean experienced little decrease from period 1 to period 3. Difference in summer precipitation means between period 1 and period 3 was only 2.86 mm, however the difference was bigger (11.08 mm) between period 2 and period 3.

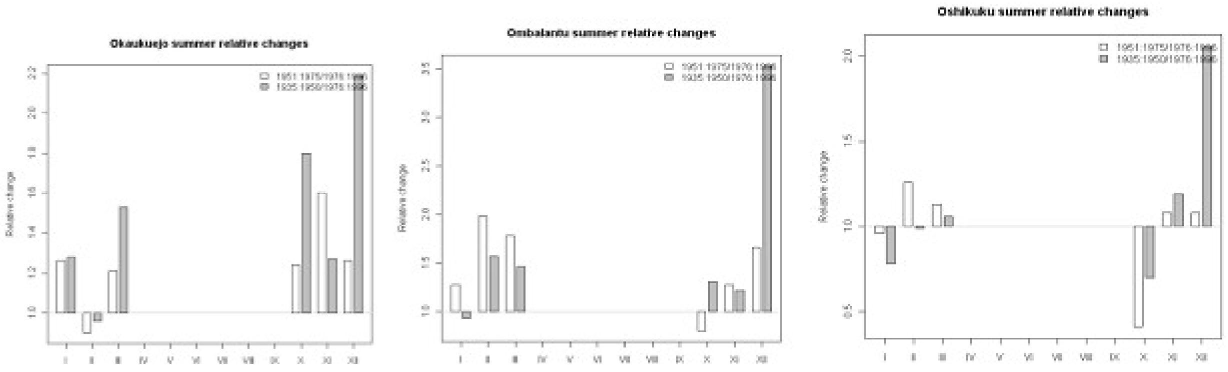


Fig. 2 Summer relative changes for observed precipitation (from left to right: Okaukuejo, Ombalantu and Oshikuku) for 1935-1950/1976-1996 (grey) and 1950-1975/1976-1996 (white)

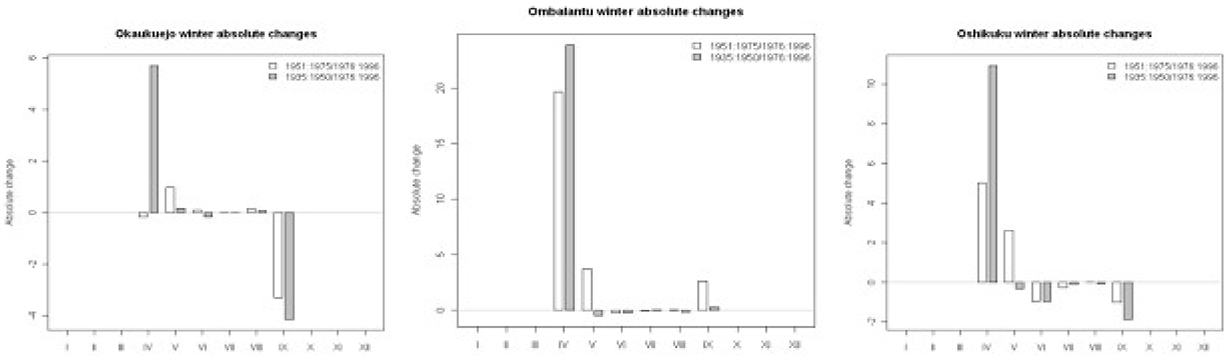
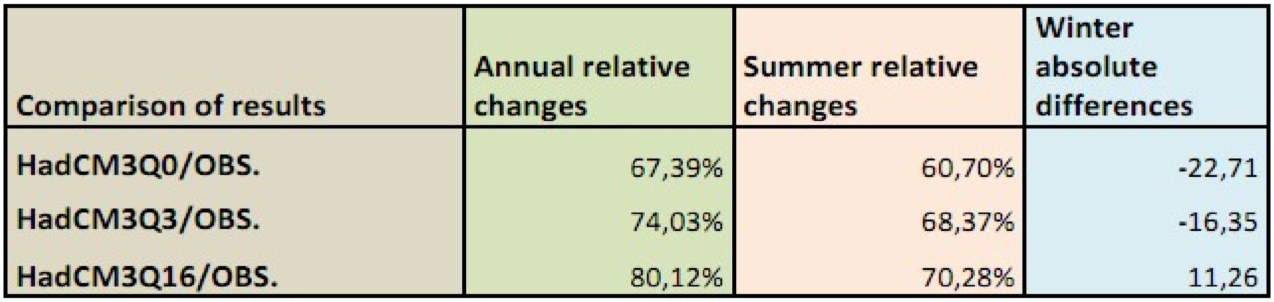


Fig 3. winter absolute changes for observed precipitation (from left to right: Okaukuejo, Ombalantu and Oshikuku) for 1935-1950/1976-1996 (grey) and 1950-1975/1976-1996 (white).

Precipitation data from GCM's were treated in the same way as those of observed precipitation. Plots and all statistical calculations were also done with R. Like with observed precipitations, total annual precipitations for the whole time series were calculated from monthly precipitation and plotted (Annex 2). Results from GCM's data analysis showed a lot of similarities and differences. Similarly, summer precipitation dominates comparing to winter precipitation in all studied periods.

HadCM3Q0, the first model to be analysed showed a decline in mean annual precipitation of up to 96,62 mm between period 2 and period 3, although extreme annual values (minimum and maximum precipitation) show stability or less variability, comparing to differences in mean annual precipitation (Table 6). The highest simulated precipitation by HadCM3Q0 were within this decade 2000-2010 with the highest annual precipitation recorded of 1234.32 mm. Of all analysed models, HadCM3Q3 simulated the lowest mean annual precipitation for both period 1 and 2. Similarly like HadCM3Q0, the highest recorded annual precipitation for HadCM3Q3 was again in the decade 2000-2010 (Annex 2.). Variation in mean annual precipitation between period 1 and period 2 is smaller (24,02 mm), comparing to variations in HadCM3Q0 for the same periods. HadCM3Q16, the last model analysed, contrary to the previous discussed models had a decrease in both total annual precipitation and mean precipitations between period 2 and period3 (Table 6). This increase is better represented in plots by moving average lines (Annex 2.). Annual mean precipitations has also decrease a lot from period 2 to period 4 by 133.46 mm in precipitation. The highest recorded annual precipitation of 998.1 mm and highest mean precipitation, 677.11 mm were all recorded in period 2, and lowest annual precipitation (913.41 mm) and lowest mean precipitation were recorded in period 4.

From the plots (Fig. 2), we can judge that comparing to period 3 (control/reference period) precipitations, Okaukuejo monthly observation were higher in period 1 and period 2 comparing to period 3, with the only increment in the months of February. Overall, Okaukuejo experienced the most changes between period 1 and period 3. Monthly precipitation were at least twice as much during period 1 than in period 3 in the months of October and December. Notable changes have also been experienced in the month of March for period 1 to period 3. There has been also visible relative changes between period 2 and period 3 in March monthly precipitation, where precipitation in period 2 were almost 1,5 times higher than those of period 3. Similarly, Ombalantu also had smaller monthly precipitation in period 3 comparing to period 1 and 2, for all months, except October of period 2, and January of period 1, where monthly precipitation where slightly higher in period 3. Bigger changes were again in December precipitation from period 1 to period 3, where precipitation were almost 3,5 times higher in period 1 comparing to period 3. Contrary to Okaukuejo observations, where period 3 had higher precipitations in February for both period 1 and 2, Ombalantu February precipitation for period 3 were almost 2 times lower than those of period 1 and 2. Again, bigger changes can be seen in the month of December, where similar to Okaukuejo and Ombalantu observations, precipitation has dropped from period, 1 to period 3 by almost a half. Similarly, Ombalantu has notable increase in October precipitation from period 1 to period 3, with a bigger change between period 2 and period 3, unlike to Okaukuejo.



Comparison of results	Annual relative changes	Summer relative changes	Winter absolute differences
HadCM3Q0/OBS.	67,39%	60,70%	-22,71
HadCM3Q3/OBS.	74,03%	68,37%	-16,35
HadCM3Q16/OBS.	80,12%	70,28%	11,26

Table 2. Datasets evaluation for model data and Observed (OBS.) data.

From the table above that shows evaluations of model data and observations, it can be clearly seen that models simulations are by far not corresponding to observed precipitation, especially in the seasonal distribution of precipitation. Winter precipitation where winter values are given in absolute changes and a minus (-) sign indicate that observed average precipitation were higher than those of model data.

Conclusions

Changes in precipitation have been noticed in all analysed observations and in simulated precipitation. Generally both results show a decrease in annual and seasonal precipitation. Different conclusions can be concluded on the findings as listed bellow.

- Overall for all observed precipitation, there has been a 23.54% decrease in annual mean precipitation from study period 1 to period 3.
- Year-to-year variability in precipitation is increasing and this is strongly associated with changes in climate.
- Relatively large biases were found in all three GCM simulations with respect to observed data. This lessens the confidence in their future projections.
- Study results have showed consistency with the results of studies done on similar theme, in similar regions and locations.

With the above mentioned, we can conclude that climate change does have in impact on precipitation, and has a very negative effect to society and the country as a whole. With these increasing changes and variability in precipitation, the region remain very susceptible to events such us flood threats and deforestation that can lead to further change in climate. Modernisation of towns, urban influences and a high population growth in the study area are some of the things that have grown since the early recording days, thus new living standards can also bring fear of more influence on the climate.

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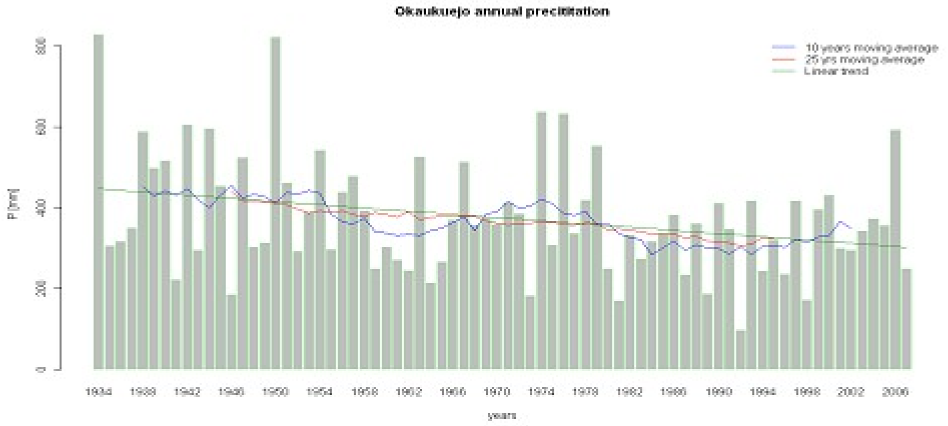
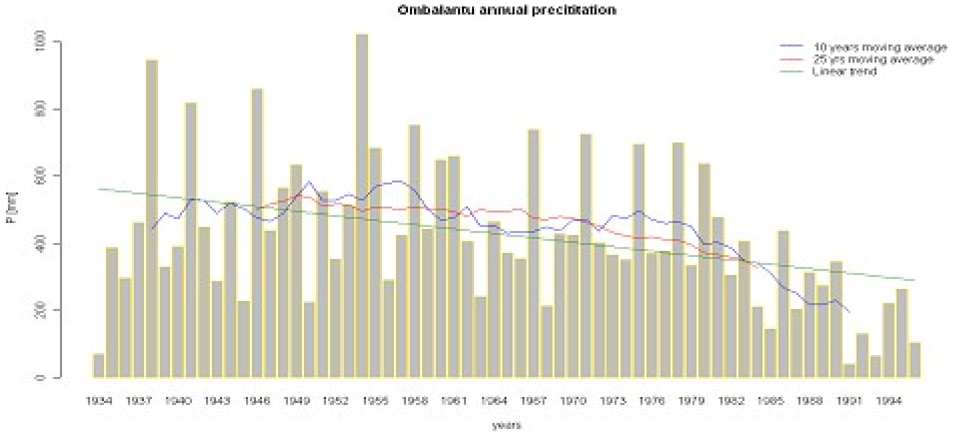
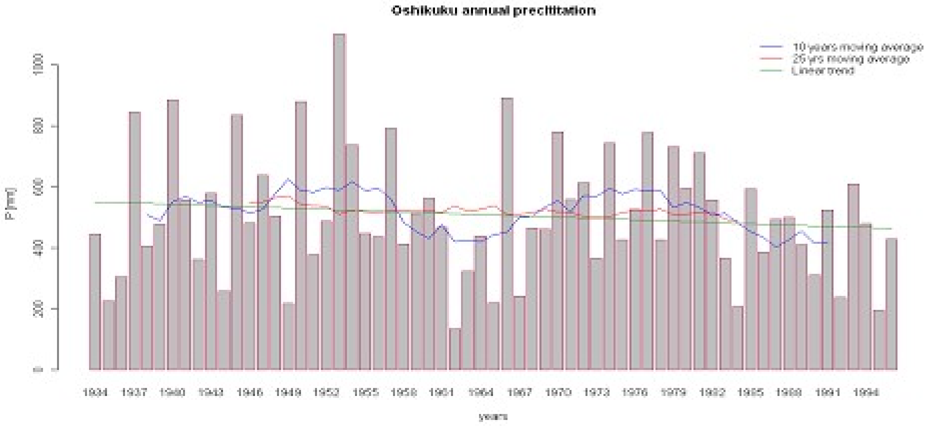
Annexes

Annex 1. Total annual precipitation of Okaukuejo (1934-2007), Oshikuku (1931-1997) and Ombalantu (1930-1996) with moving averages: in blue (10 years moving averages), red (25 years moving averages) and green (linear trends)


Okaukuejo annual precititation


Ombalantu annual precititation


Oshikuku annual precititation

Annex 2. Total annual precipitation plots for GCM (HadCM3Q0, HadCM3Q3 and HadCM3Q16) for 1951-2099.Blue line (10 years moving averages) red line(25 years moving averages)