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A Preliminary Assessment of Characteristics and Long-term Variability of Rainfall in Ethiopia - Basis for Sustainable Land Use and Resource Management

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Abstract
Droughts subjected Ethiopia to recurrent vulnerability. A study was conducted in the country's central highlands, to provide baseline information on summer rainfall variability. Data from 1898-1997 were statistically analysed. Data irregularities were confirmed. Rainfall tends to decrease. Yet, extremely high rainfall events were noted. Positive rainfall deviations from the long-term mean in the first, and negative deviations in the second half of the 20th century dominated. Agro-ecological crises coincided with precipitation lows. Data management and agro-meteorological stations should be enhanced. Water resource management measures and policies should be thoroughly designed and implemented. Agricultural research should incorporate agro-meteorology.

1 Introduction

During the last century, Ethiopia's climate variability and the consequent agricultural as well as socio-economic crises attracted strong global attention. It was reported that shortage of precipitation and its space-time variability in Ethiopia had led to recurrent and substantial shortfalls in agricultural production, which claimed tens of thousands of human and animal lives (see Wolde-Mariam, 1984; Degefu, 1987; Hurni, 1993). During these years, the country suffered significant production deficit of about 20% in the agricultural sector, resulting in a decrease of total annual production by about one million tonnes, mainly involving cereals and pulses. The central highlands of Ethiopia, which play a great role in the country's economy, have suffered most, compared to other parts of the Ethiopian highlands. In spite of these experiences, environmental impacts of the past climate variability in Ethiopia, especially on changes in land use systems and land management practices, and their socio-economic consequences, were not addressed at satisfactory depth and length. Development proposals envisaging resource management as a means to attain sustainable self-reliance failed to consider the investigation of the effect of long-term climate change on this macro objective. The stumbling blocks to and primary reasons for this are: the lack of systematically documented database as well as preliminary studies on long-term rainfall variability. This study aims to make an initial contribution to filling this crucial information gap. The result is expected to significantly enhance future activities in agricultural development planning within the framework of sustainable ecosystems management at national as well as at global scale.

2 Methods and materials

2.1 The study area

The central highlands of Ethiopia, arbitrarily defined for the purpose of this study, lie between latitudes 7°02´-11°46´N and longitudes 36°27´-40°12´ E. The climate of the area is predominantly tropical highland climate, with dry winter season. According to traditional Ethiopian classification, the climate of the area ranges from dry *Kolla* to moist *Dega* (Amharic). The topography of the region is dominated by high mountains dissected by the Great Ethiopian

Rift System. The Shoa Plateau, the Arsi and Bale Mountains constitute the outstanding physiographic features of the area.

2.2 The data set and statistical analysis

The data set

Precipitation data of total monthly rainfall of the period 1898-1997 were obtained from the database of the National Oceanic and Atmospheric Administration (NOAA), the climate CD-ROM of the FAO (FAO, 1995), and the archives of the Ethiopian National Meteorological Service Agency (NMSA). The summer period was chosen for this study because it is the main rainy season in major part of the central highlands of Ethiopia. Tab. 1 illustrates generalised geographic information of the selected weather stations used for this study.

Tab. 1: Selected weather stations in the central highlands of Ethiopia and their general geographic information

Weather stations	Latitude (North)	Longitude (East)	Altitude (m)	Years of observation
Addis Ababa	9°02´	38°42´	2408	1898-1996
Debre Markos	10°20´	37°40´	2515	1954-1991
Debre Zeit	8°44´	38°57´	1900	1951-1984
Ejaji	9°00´	37°19´	1900	1966-1997
Fiche	9°48´	38°42´	2750	1954-1997
Kombolcha	11°07´	39°44´	1916	1952-1991
Majete	10°27´	39°51´	2000	1962-1996
Sheno	9°20´	39°18´	2655	1962-1995
Shola	9°13´	39°27´	2650	1962-1996
Tulu Bolo	8°40´	38°13´	2100	1962-1996
Wonji	8°29´	39°15´	1540	1951-1984

Statistical analysis

An areal average of precipitation at the selected weather stations was used for this study. Statistics on measures of location (mean, minimum, maximum), dispersion (standard deviation) and distribution (skewness, kurtosis and variability coefficient) were calculated for the data. The data series was tested for normality using One-Sample Kolmogorov-Smirnov test (see Janssen and Laatz, 1997). The two dimensional linear Product-Moment correlation coefficient – Pearson's correlation coefficient – was calculated for the series for further comparison with the results of Spearman's coefficient used to test representativity (Rapp and Schönwiese, 1996). For the time series analysis, short-term missing data ranging from one to three consecutive years were substituted by series mean (e.g., Sneyers, 1990). Long-term areal rainfall data series of the selected weather stations was smoothed using 5-years and 11-years simple running means (see Essenwanger, 1986). Linear trend lines were fit to the smoothing curves to investigate the general tendency of the series in the course of the observation period. Systematic trend analyses were performed using Spearman's non-parametric statistics (Mitchell et al., 1966). Auto-correlation analyses were carried out to investigate the persistence of the rainfall data records in the course of observation period (see Brockwell and Davis, 1996).

3 Results and discussion

3.1 Statistical characteristics of long-term rainfall

The central highlands of Ethiopia received a long-term average summer rainfall of 666 mm in the period of observation, with a standard deviation of 162 mm and a variability coefficient of 24% (see Fig. 1).

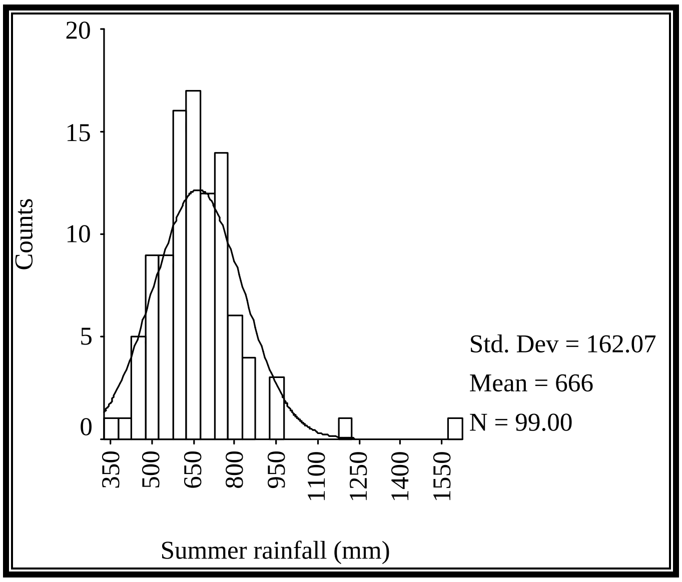

Fig. 1: Long-term summer rainfall distribution in the central highlands of Ethiopia

A minimum rainfall of 355 mm and a maximum of 1594 mm were recorded for the summer period, with an extreme average of 619 mm. A skewness coefficient of 2.30 and a kurtosis coefficient of 11.00 were calculated for the data. The result of normality test for the distribution type indicated that summer rainfall data of the area are approximately normally distributed, at a significance level of 5%. Hence, the applicability of parametric statistical methods to representativeness analysis of long-term areal rainfall data of the study region is justified.

3.2 Representativeness analysis

The representativeness of a regional precipitation data series shows the extent to which the areal data represents records and trends at individual weather stations (Rapp and Schönwiese, 1996). The highest coefficient was obtained for the Addis Ababa weather station, with a correlation coefficient of 0.86. Good correlation was determined for the Debre Zeit, Fiche and Kombolcha weather stations, each with a value of 0.60, and fair correlation was obtained for the Sheno, Tulu Bolo and Wonji weather stations, each with a value of 0.55. The coefficients for the remaining weather stations lie between 0.20 and 0.45. It was confirmed from these results that significant relationship at 5% level was obtained for the Addis Ababa, Debre Zeit, Fiche and Kombolcha weather stations. The remaining weather stations are weakly to fairly represented. Despite the weak representativeness of the areal rainfall time series for some of the selected weather stations, it is the only useful data to investigate rainfall variability at regional scale. Moreover, these data can be used for regional water resource management and development planning exercises for agriculture and ecosystems management.

3.3 Graphical time series analysis

Rainfall in the study area followed a clearly decreasing observed trend in the period of investigation (Fig. 2). The declining trend commenced in the year 1917, and continued with progressive downward trend. However, phenomenal fluctuation was observed in the course of time, while the declining tendency persisted. The individual data points are relatively clustered along the smoothing curves, while still maintaining a general declining trend in the successive years. Long-term summer precipitation records reached their lowest point in the years 1951 and 1987, when the central highlands of Ethiopia suffered extremely serious rainfall deficit (*c.f.* Hurni, 1993). As can be confirmed from the data, the year 1984 coincided with the largest drought disaster Ethiopia has ever seen in the 20th century. Contrary to the general declining trend in rainfall noted from the 5-years and 11-years moving averages and their respective trend lines, of which only the 11-years trend line is statistically significant for the summer period at 95% level of confidence, the central Ethiopian highlands have also seen years of extremely high rainfall events. The year 1922 is an example of a period with summer precipitation surplus in the region. In addition, extreme highs were detected in 1916 and 1946. Despite the overall declining trend in rainfall, it was frequently reported that a series of flooding had inflicted environmental as well as socio-economic damage to the central highlands of Ethiopia (see UNDHA, 1995).

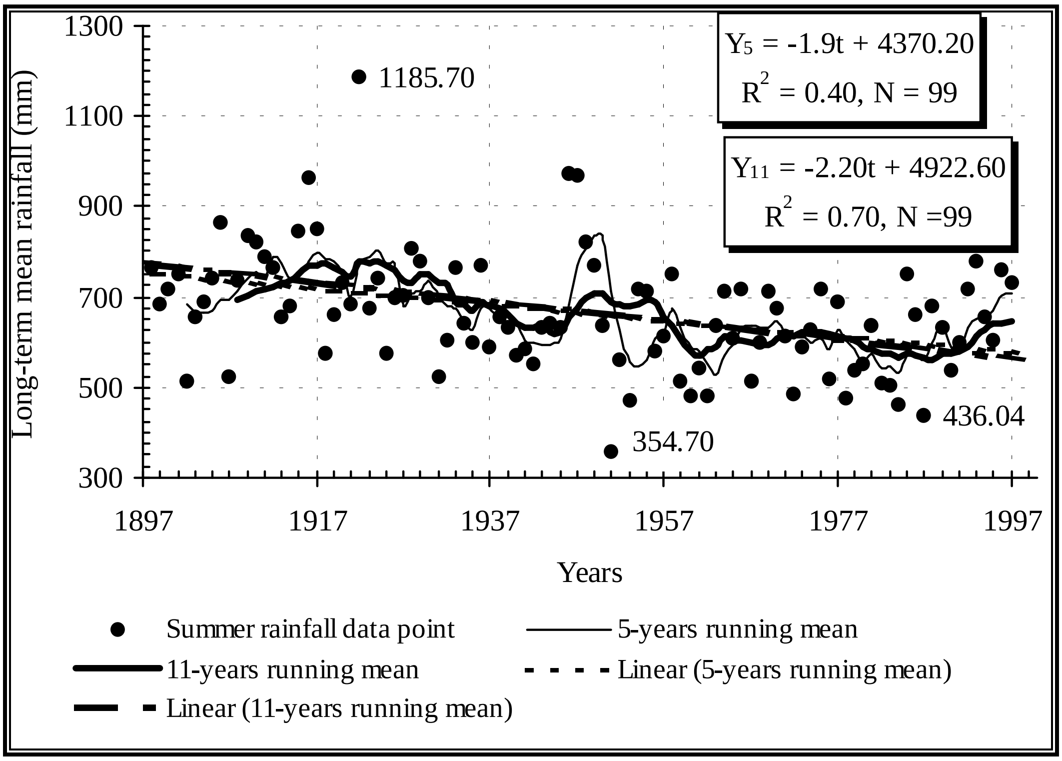

Fig. 2: Long-term summer rainfall time series of the central highlands of Ethiopia (1898-1997)

The observed decline in precipitation in the study area during the investigation period was characterised by precipitation anomalies. These might even have had long-term historical antecedents (see Verschuren et al., 2000). Such anomalies would best be illustrated by the deviation of rainfall records from long-term average, as shown in Fig. 3.

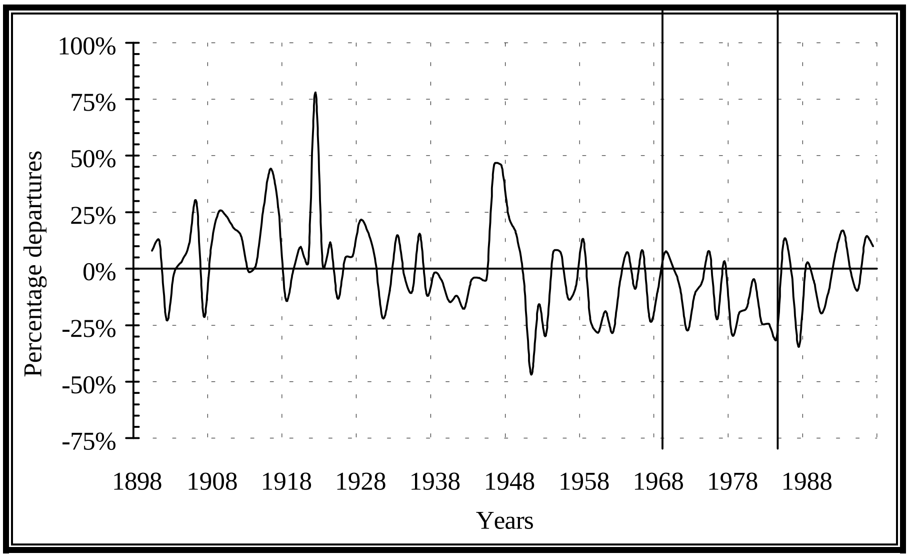

Fig. 3: Departures of long-term summer rainfall from its long-term average in the central Ethiopian highlands (1898-1997)

It is apparent that the deviations of long-term areal summer precipitation from its long-term average were very low at the initial phase of the series records (Fig. 3). While deviations in this period were dominantly positive, pronounced departures were noted in the period between 1915 and 1922, with deviations from the long-term average reaching up to 78% - observed in 1922. This period was succeeded by years of consecutively diminishing rainfall variability which, nevertheless, did not persist over long duration. The years 1925 and 1926 were characterised by rainfall shortage in summer, which is the major rainy season in the central Ethiopian highlands. Accentuated precipitation marked by high positive departure was noted in 1947, with values 46% higher than the corresponding long-term average. Yet, the year 1951 saw the highest negative deviation from the long-term average ever recorded for the study area. The occurrence of such high discrepancy between the positive and negative departures within a short interval of time has a negative implication on the reliability of expected variability. However, the data show that persistent recurrence of precipitation shortfalls in the central highlands of Ethiopia has prevailed since 1951, with major positive departures observed only in 1958, 1985, 1993 and 1996. Generally, the central Ethiopian highlands were predominantly characterised by positive rainfall deviations from the long-term mean in the first, and negative deviations in the second half of the 20^{th} century. The positive departures observed in the first half of the 20^{th} century are highly pronounced in the first three decades. It was noted that the second half of the century suffered predominantly negative rainfall deviations, with summer values frequently lower than the long-term average. This statement agrees with the results found by Seleshi and Demarée (1995) for North Ethiopian and Eritrean highlands. The authors also reported that there was high concentration of meteorological drought in Addis Ababa in the period from 1948 to 1973. The authors recorded meteorological, hydrological as well as agricultural drought in Ethiopia in the second half of the 20^{th} century. It was revealed that only since the early 1990s have the central Ethiopian highlands experienced successive years with rainfall higher than the long-term average. This might have had considerably influenced the surface flow regimes of major rivers springing from and flowing through the central highlands of Ethiopia, as well as the land use patterns in the area (e.g., Osman and Sauerborn, 2002).

3.4 Systematic trend analysis

Systematic trend analysis of rainfall time series data enhances the knowledge of temporal precipitation behaviour by means of statistical evidence (see Mitchell et al., 1966). The result of statistical time series analysis of long-term areal summer rainfall time series data in the study area is consistent with that of graphical analysis illustrated by Fig. 2. A trend correlation coefficient of -0.41 was determined for the data series, thus showing a decreasing tendency. It was noted that, the declining trend in the long-term summer rainfall in the study area is statistically significant at 1% level, with a probability value of 0.

Generally, it is evident from the analytical results that rainfall has decreased throughout the central highlands of Ethiopia during the 20th century. Therefore, water resource management measures and supporting natural resource management policies should be thoroughly and meticulously designed and strictly implemented to tackle the challenges of rainfall deficit and meet the ever increasing demand of progressively growing population for water for survival.

3.5 Autocorrelation and persistence analysis

The autocorrelation coefficient provides a measure of temporal correlation between rainfall data points with different time lags; namely 1, 2, 3, ..., n years. Thus, autocorrelation provides initial information relevant to the internal organisation of each time series data (Essenwanger, 1986; Brockwell and Davis, 1996). The prevalence of autocorrelation in a data series is also an indication of persistence in the series of observations. The auto-correlation coefficients provide an essential hint whether forecasting models can be developed based on the given data (Janssen and Laatz, 1997). For a purely incidental event, all autocorrelation coefficients are zero, apart from r (0) which is equal to 1. Fig. 4 shows the results of autocorrelation analysis of summer rainfall time series data of the central Ethiopian highlands.

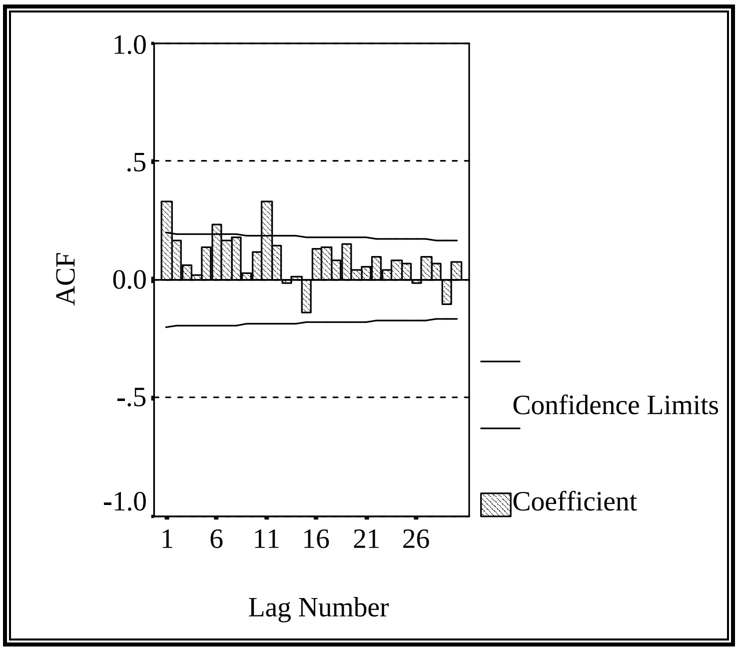

Fig. 4: Autocorrelation of long-term areal summer rainfall in the central highlands of Ethiopia

The autocorrelation coefficients of summer rainfall lie between -0.14 and 0.33, each with standard error of 0.09 (Fig. 4). As shown by the autocorrelogram (Fig. 4); the 1st, 6th and 11th order lag autocorrelation coefficients of the areal rainfall data series were found to be statistically significant at 0.25 confidence limits (see Janssen and Laatz, 1997). The fact that the 1st order lag autocorrelation coefficient significantly deviates from zero confirms the existence of persistence in the series at the respective order lag. At the same time, for the summer rainfall data, the values of second and third order lag autocorrelation coefficients are greater than the square and the cubic values of the first order lag autocorrelation coefficients, respectively, i.e. $r_2 > r_1^2$ and $r_3 > r_1^3$. Hence, there is a clear indication of the persistence of the first order linear Markov process (Mitchell et al., 1966).

In the absence of any reliable physical and empirical base for predicting seasonal and/or annual climatic conditions, as the case most likely holds true for the Ethiopian climate data set, any assumptions about future climatic conditions, especially with relevance to water resources management and sustainable agricultural development, have to rest on the experiences of past occurrences (e.g., Meigh et al., 1999). Mostly, the characteristics of rainfall in the past are the only accessible guide for advanced decision making regarding water resources development and management, particularly for a fragile agrarian economy like that of Ethiopia. Similar procedures were recommended for Scotland (Smith, 1995). The author stressed the use of best normal periods with the least extrapolation variances for statements about precipitation conditions and, hence, water resources management. In spite of the fact that constant persistence in the observed precipitation series data was not found for the central highlands of Ethiopia, the above trend analysis would help practitioners, particularly water resource managers, agricultural development planners and ecosystems managers, with their strategic planning and decision making processes (c.f. Mikelsen et al., 1998).

4 Conclusions and recommendations

The study of precipitation time series of selected weather stations in the central Ethiopian highlands using various graphical and statistical methods enabled to characterise and analyse the long-term temporal behaviour of rainfall in the study area.

Some irregular characteristics were noted in the original data due to, presumably, recording errors and database drawbacks. Despite the weak representativeness of the areal rainfall time series for some of the selected weather stations across the region, it is the only available and useful data to investigate long-term temporal rainfall variability at regional scale. The data can be used in water resource management and sustainable agriculture development planning, to improve agricultural production and integrated ecosystems management at regional level and meso scale. The general tendency is that summer rainfall in the study area is decreasing. However, extremely high rainfall events were noted, causing significant ecological and socio-economic damage.

It is highly recommended that data recording and management be improved, to facilitate further water resource management research and development, based on reliable information. Modern and reliable weather and climate observation facilities with reasonable spatial distribution need to be established, to enhance resource management research in the country. In the light of decreasing precipitation during the main rainy season of the research area, water resource management measures and supporting policies should be thoroughly designed and strictly implemented in the central highlands of Ethiopia. This would enable to tackle the challenges of rainfall deficit, and meet the ever increasing demand of progressively growing population for water for survival. Future climate research in Ethiopia should focus on integrated climate and agro-ecosystems research, to ensure efficient resource development and its effective management at national level, and to contribute to the global climate and environmental research and management.

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