DEVELOPMENT WORKSHOP
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ANALYSIS OF HISTORIC RAINFALL DATA FOR ANGOLA

TO IMPROVE UNDERSTANDING OF RAINFALL VARIABILITY AND ITS IMPLICATIONS FOR FLOODING AND EROSION

A WORKING PAPER OF THE PROJECT ON "WATER RESOURCE MANAGEMENT UNDER CHANGING CLIMATE IN ANGOLA'S COASTAL SETTLEMENTS"

DEVELOPMENT WORKSHOP ANGOLA

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Summary

This paper reports on a component of Development Workshops' research project "Water resource management under a changing climate in Angola's coastal settlements". It sets out why recovery and analysis of historic rainfall data is important, as well as the challenges of using rainfall data in Africa. It shows why these difficulties are greater in the case of Angola, where there are significant gaps in the records before 1940 and after 1975. It lists the sources of data and the analyses carried out in this component of the research. It discusses the mean annual rainfall in different regions of Angola and then goes on to discuss the issue of rainfall variability, which is particularly important in the context of Angola. It presents two measures of variability and demonstrates that rainfall variability is high along the Atlantic coast of Angola and some adjacent areas inland. Rains in this area tend to fall as very heavy, isolated storms late in the rainy season and a high percentage of the mean annual rainfall can fall in one day. This creates the conditions for flooding in the rapidly growing cities of the coastal regions of Angola. Heavy rainfall splashes fine particles on bare soil surfaces in coastal river basins and deposits them as a water-repellent crust. This increases run-off and water level in rivers rises quickly. Cities can also be affected by rainstorms in the urban area itself. Flooding and erosion are common in coastal urban areas in Angola. The high variability of rainfall makes it difficult to judge whether the climate is changing. However under future climate regimes it is unlikely that variability will be less, and adaptation to the current variability will be a useful step in step to adaptation to climate change.

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1 Introduction

This paper reports on a component of Development Workshops' research project "Water resource management under a changing climate in Angola's coastal settlements", which includes devising new approaches to filling gaps in knowledge about rainfall patterns in Angola. It reports on the first part of this work, which involved collating historical rainfall data for Angola and carrying out a preliminary analysis of some of these data to examine mean rainfall and its variability in different areas of Angola.

The paper begins by discussing why the achievement of development goals in Africa requires better requires better knowledge about the climate, not just of average conditions but also information about variability and change. It discusses why this requires analysis of long-term historical data, and why this can be difficult in the case of Africa (particularly so for Angola). It describes what rainfall data have been collected for Angola since records began, what data are presently available, where they are available, the quality of those data and the issues with the data and its availability.

It goes on to describe the methods used to bring together rainfall data for Angola and to the analyses carried out on these data. The paper presents a preliminary description of annual rainfall patterns in Angola based on the available historic rainfall data from about 50 stations, with a focus on measures of rainfall variability (which are higher in coastal and adjacent regions of Angola). Finally the paper discusses the rainfall patterns in areas of high rainfall variability and the implications of the flooding and erosion risk for urban planning, as well as the risk of climate change.

2 Why analyse historic rainfall data?

Livelihoods in Africa's least developed countries are dependent on a climate that is not only highly variable and unreliable in the short term but is also expected to change in the longer-term. Achievement of development goals will be possible only if African countries are better equipped to manage the impacts of both natural climate variability and human-induced climate change. Effective management of climate variability and change requires that climate information be used effectively in planning and that climate risk be incorporated routinely into development decisions in areas such as agriculture development, urban planning and disaster management.

Studies of actual change of climate around the world, and of climate variability, rely on past observations, and they require deeper study and longer records than the examination of average conditions, which may not be the most important factor in development planning. Levees, dams, and reservoirs engineered on the basis of short-term climate records could result in inadequate flood protection, as they may not take account of infrequently occurring heavy rainfall events. Agricultural calendars designed on the basis of short-term climate records could result in inadequate protection against drought, because they may not take into account of infrequently occurring low rainfall events. On the other hand planning on the basis of old climate data may not take into account trends since the data were collected.

Thus historical climate data are important for placing current observations into a historical context. They are also used in assessing climate-related baseline risks, climate modelling, improving predictions and calibrating observation systems. Historic climate data are important because, without them, it is impossible to examine what values of rainfall above the mean can be considered to be normal variations and whether a year of high rainfall is an indication of climate change. However in many African countries an adequate inventory of historical climate data has not been made, the data is sometimes inaccessible and unavailable in a digital form. Rescuing historical climatological and hydrological data is therefore necessary (GCOS/UNECA/AUC, 2006).

3 The challenge of historic rainfall data in Angola

3.1 Issues with historic rainfall data in Africa

It is obvious that, as one goes further back in time in any part of the world, the number of stations, making meteorological measurements decreases. Climate and weather recording in Africa started about a hundred years ago, during the colonial period, with a small number of meteorological stations (Griffiths and Peterson, 1997), though the development of the network came later than in other continents. Due to the importance of weather and climate information for various socio-economic sectors, the number of meteorological stations increased with time. However Africa has continued to have a less dense meteorological observation network than other continents. In much of Africa the number of stations is less than that required for determining a real change of climatic elements, and less than that required to address important issues related to variability and extremes of climate (GCOS/UCECA/AU, 2006).

In Africa the spatial distribution of climate observation stations is still poor. Climate observation networks which should generate the climate information needed for climate risk assessments and quantifying trends in climate are weak and deteriorating. In Africa, there are about 1,152 weather stations reporting to WMO and one weather station covers an area of 7,347 km², while in Germany there are 287 operating WMO weather stations and the area covered by one WMO weather station is 1,244 km². Hydrological stations in Africa (excluding the area of Sahara) also have low density. There are 888 gauging stations in an area of 21,300,000 km², while there are 1150 gauges per 357, 114 km² area of Germany.
There are 1152 WWW (WMO World Weather Watch) stations in Africa giving a station density of one per 26,000 km2, 8 times lower than the WMO minimum recommended level (UNECA, 2011). The stations are unevenly spread, leaving parts of central Africa unmonitored. Most stations which are not recording or are recording less 50 % of the time are located in Africa.

According to the Secretary General of the World Meteorological Organisation, Africa's weather and climate monitoring system is deteriorating and needs major improvements to meet the challenges of climate change. “Overall it is estimated that Africa needs 200 additional automatic weather stations, a major effort to rescue historical data and improved training and capacity building on climate and weather reporting" (Jarraud M., 2006).

Continuous records of climate data for 30 years are found in only a few stations in Africa. Many stations do not operate and data from some of the operating stations is not fed into the international system. There continue to be issues of quality with the data, with gaps of missing data. In some cases there are inefficient quality control systems. The continuity and the distribution of meteorological stations in Africa are insufficient for applications such as weather and climate forecasting, climate studies and climate projections (Griffiths and Peterson, 1997). The gaps in historic climate data for Africa are particularly apparent when one looks at the currently digitized data (Griffiths and Peterson, 1997). Many observations have also not been digitized or they are stored on older electronic media that are now difficult to use (Tan et al., 2004). These data risk being lost due to rapid deterioration of the medium. Data on papers may even get discarded as paper-based records take up office space.

However there are data collected by the colonial powers, even if the data have not been digitized or even adequately collated. Some of these data are to be found in the archives or publications of the colonial powers while others are to be found in the now independent countries in Africa, though the publications or the archives may be not well-known and difficult to access. Attempts to obtain some of these data from countries now independent make it appear that most have not been retained, or their whereabouts in the country are unknown. Fortunately much can be discovered in the archives or publications of the colonial powers (Griffiths and Peterson, 1997).

3.2 The need for data recovery for historic rainfall data in Africa

Data rescue involves preserving data at risk of being lost due to deterioration of the medium and converting past and current data into computer compatible digital formats for easy access and use (WMO, 2004).

There are two types of data gaps. Spatial gaps are a result of sparse station distribution while temporal gaps are due to interrupted observations or lost data due for example to communication problems. Both gaps need to be filled to have spatially continuous and temporally complete climate time series. One approach to do this is combining observations from all available meteorological stations with global products such as satellite proxies and climate model reanalysis data.

Thus, the undigitalised data need to be rescued and digitalised, while steps should also be taken to fill spatial and temporal gaps in climate observations. New approaches may need to be devised.

3.3 The challenge of historic rainfall data in Angola

Detailed data for the Observatório João Capelo meteorological station in Luanda go back to 1875. Apart from this station, and a few months of records in the late 19th century for Mbanza Congo, there are no meteorological records for Angola until 1913. Efforts appear to have been made by the Portuguese colonial authorities to set up meteorological stations in other cities of Angola from 1913 onwards, but the number of stations opened was very limited, there were immediately gaps in the records of these stations and they ceased functioning after a few years. In the records for the years 1910-1915 for the Portuguese colonies the following statement is made about the meteorological services at the time in Angola.

> "In this province much has been done lately in favour of meteorology, with the creation of new meteorology posts due to the unceasing attention of the governor Norton de Matos. The pity is that information from few of these posts can be used due to the lack of continuity in the observations and little confidence that many of them can inspire. This can be attributed to the absence of instructions, constant changes in personnel, with responsibility falling on individuals who do not understand the usefulness of such observations." (Direcção Geral das Colonias, 1915)

Other stations were opened in the 1920s but, once again, it proved difficult to keep them functioning and to obtain continuous and reliable data. There appear to have been no regular inspections and supervision of the stations created outside Luanda. Thus in the rainfall records for 1929 for Angola the following comment appears.

> "Colony Angola - The results from meteorological posts continue to be nil or almost nil. These problems will only cease to exist when there are regular inspections of the posts, such as occur in Mozambique, which would require the actual appointment of a sub-Director (which is already a legal requirement) who could carry out such inspections." (Direcção Geral das Colonias, 1929)

Similar comments appear in each annual meteorological bulletin during the 1920s and 1930s. For example the records for 1934 for the Portuguese colonies, the following statement appears.

> "Colony Angola - the observations from João Capelo Observatory in Luanda have been were received regularly The other meteorological services of this Colony may be considered weak, and the outputs nil from most posts. This is despite the suggestions of the Cartography Commission and the recommendations of the Economic Conference in Luanda, which stated that there is a compelling, need to create meteorological services in the Province and that the lack of budget allocations has prevented the study of meteorological regime of this vast colony." (Direcção Geral das Colonias, 1934)

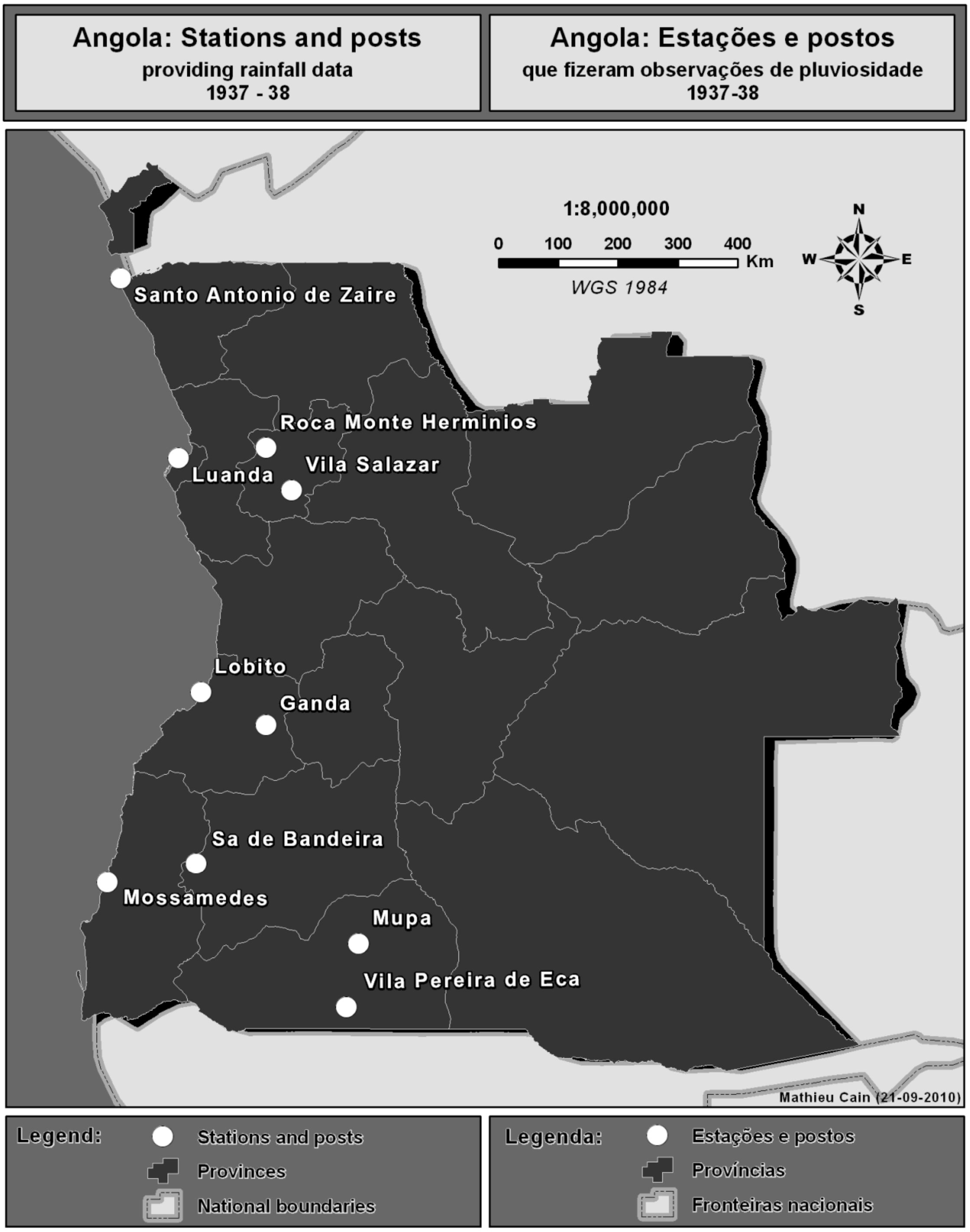
In 1934, eight stations were listed for Angola in the records for the Portuguese colonies compared to 60 stations listed for Mozambique (which in turn was less than the number of stations in similar British or French colonies in Africa at the time). These eight stations were not the same as those for which data were collected between 1910 and 1920. As well as the lack of a budget for management of a network of meteorological stations there was no staff that could travel to inspect and supervise the collection of data outside Luanda.

The number of stations listed as providing meteorological data increased markedly in 1940 as the Portuguese colonial administration devoted a larger budget to his activity and appointed staff to monitor and supervise stations throughout the country. Some of these stations were directly managed by the Meteorological Services while others were run in collaboration with agricultural companies, the railways and local government. In the next three years there was a notable increase in the number of functioning stations and there were about 250 stations of various types by the late 1940s.

The number of stations remained stable throughout the 1950 and 1960s. In the few months leading up to independence in 1975, however, the number of rainfall observation stations fell to about 20 as the Portuguese technicians and engineers who had managed the observation network, and the companies that were collaborating with the meteorological services, abandoned the country.

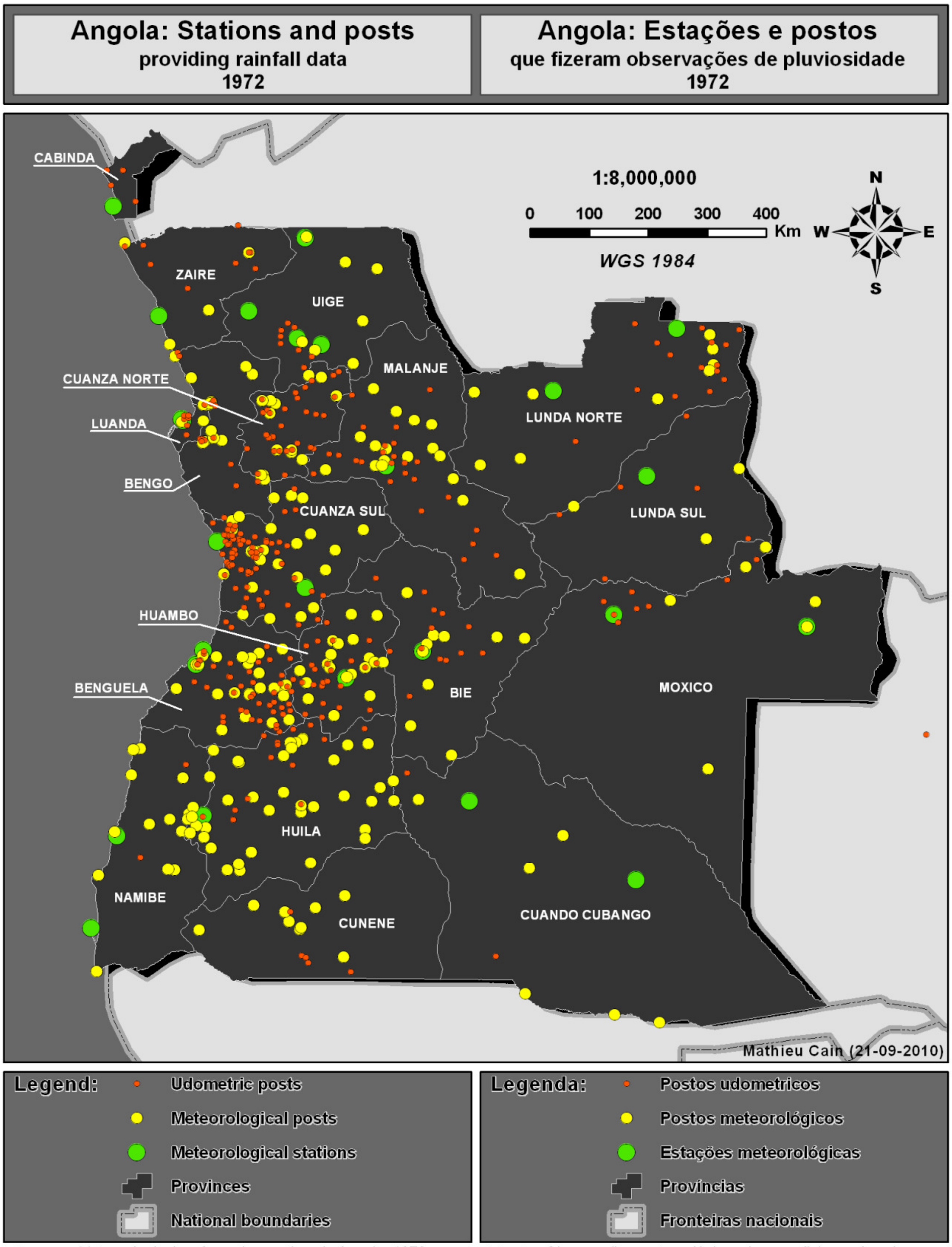
Attempts to redevelop the network since then have no success as the country was engulfed in civil conflict. Some stations were re-opened with support from the United Nations but were destroyed or sabotaged. By the late 1990s there were only eight stations operational in some years.

Since peace was achieved in 2002 the Angolan Meteorological Services (INAMET) have gradually re-opened stations throughout the country. There is at least one station operational in each of the 18 provinces. This is still a small number of stations, compared to the area of the country, however. The map on page 6 of the working paper of the African Climate Policy Centre of the United Nations Economic Commission for Africa (UNECA, 2011) indicates that the region of Africa including Angola (including the Democratic Republic of Congo to the north) is one of the most significant gaps in meteorological data with a large number of stations that are not sending data or incomplete data to international reference centres.



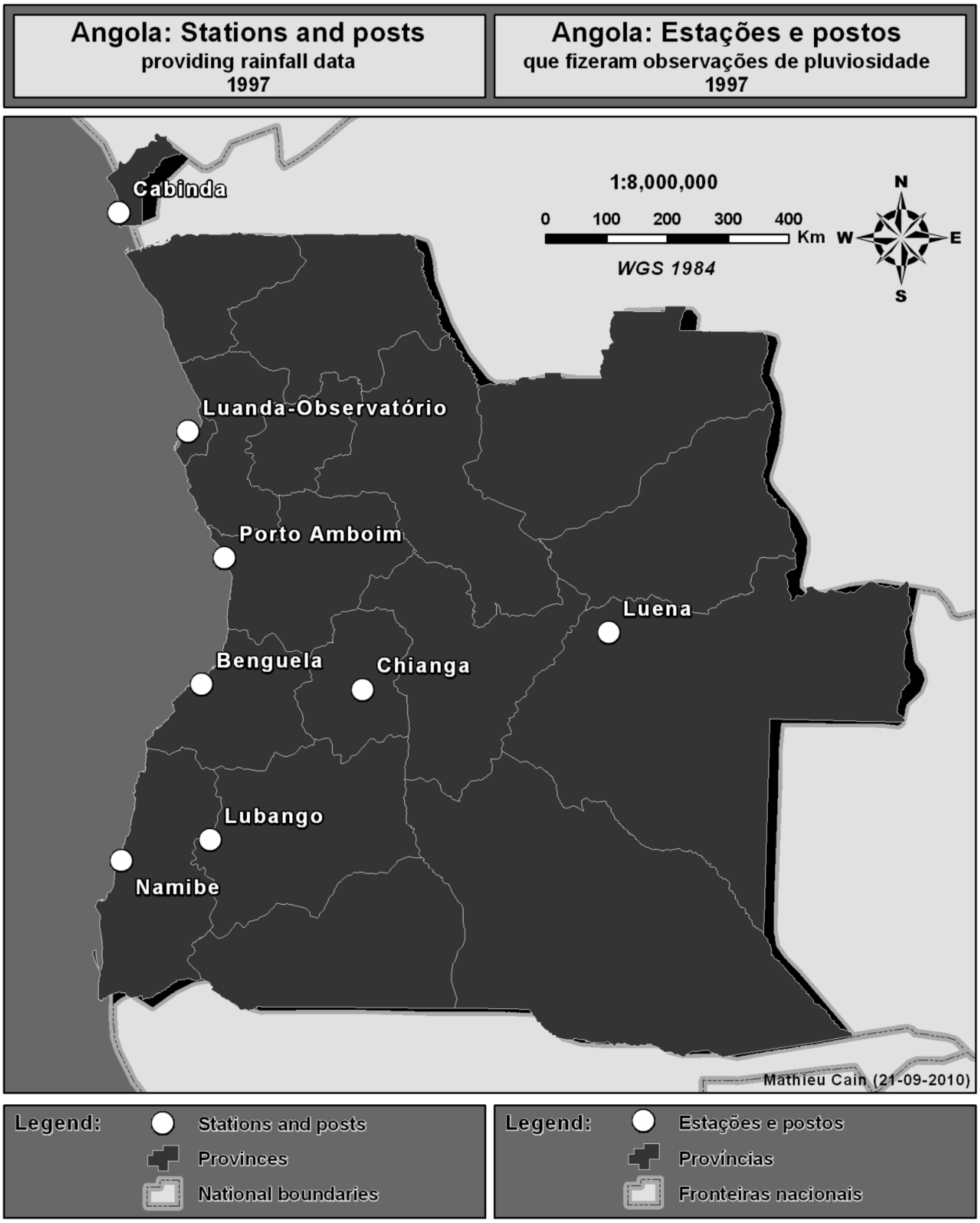
Author: Colonia de Angola, Reparticao tecnica de Estatistica Geral. Elementos meteorolgicos e climatologicos. Luanda, Imprensa Nacional, 1940. Accessed through archive of NOAA, US Department of Commerce.

Fonte: Colónia de Angola, Repartição técnica de Estatistica Geral. Elementos meteorológicos e climatológicos. Luanda, Imprensa Nacional, 1940. Aceso através do arquivo do NOAA, Departamento do Comercio dos Estados Unidos



Source: Meteorological surface observations in Angola: 1972. Meteorological Service of Angola. Angola's national press, 1977

Fonte: Observações meteorológicas de superficie em Angola: ano de 1972. Serviço meteorológico de Angola. Imprensa nacional de Angola, 1977.



Source: From data supplied by INAMET

Fonte: Dados fornecidos pelo INAMET

Thus there are significant challenges in creating a rainfall record for Angola that will allow systematic investigation of rainfall patterns. The gaps in the records before 1940 and after 1975 present a particular challenge. Observation in Angola was sporadic until the 1940s (except for the Luanda observatory for which there is a complete rainfall record going back more than 100 years). There were few stations pre-1940 and observations at all expect Luanda were sporadic. Historic climate data for Angola are even scarcer than in the rest of Africa in this period, and the quantity and quality of information for Angola pre-1940 even compares unfavourably with the other Portuguese colonies. The period of reliable records last only about 30 years. The most significant analysis in the colonial period was carried out in the 1950s using only 10 years of records for some stations.

4 Recovery of lost data

4.1 Overview of recovery of lost data

One component of Development Workshop Angola's programme on "Water resource management under changing climate in Angola's coastal settlements" involves devising new approaches to filling gaps in knowledge about rainfall patterns in Angola, and part of this work involves an examination of the historical rainfall data, particularly for coastal areas of Angola. This has involved collating historical rainfall data for Angola and carrying out a preliminary analysis of some of these data to examine mean rainfall and its variability in different areas of Angola.

4.2 Data sources for Angola

Griffiths and Peterson have identified paper sources of monthly weather data for Africa, and their locations as guidance to future researchers (Griffiths and Peterson, 1997). They list publications that may not be well-known or may never have made available to the general public. Some of the publications may be difficult to obtain. The publications relevant to Angola are the following.

1) Servicio Meteorologico Nacional, Coimbra/Lisbon, Anais Meteorologicos das Colonias, 1910-1946. This covers all Portuguese territories, with increasing numbers of stations as the years progress. Many stations have missing years. Although records for the years 1921 – 1926 were produced these do not appear to be available anywhere now.

   Location: NCDC, NML

2) Anuario Climatologico de Portugal, Servicio Meteorologico Nacional, Lisbon, Part II - Territorios Ultramarinos, 1947-1974. This is the overseas section of the Portuguese Climatological Annual Bulletin. This publication ceased in 1974 after most territories became independent.

   Location: NOAA, TAMU, NML

3) Boletim Oficial Angola, Loanda, 1910 – This was the Official Bulletin of the Province of Angola, publishing a wide range of administrative information. Some meteorological data was published here mixed among other information.

   Location: NOAA

4) Resumo Mensal das Observacoes Meteorologicos, Loanda, 1913 -1936 These were printed together with data for Observatorio Meteorologico e Magnetico Joao Capelo

   Location: NML

5) Elementos Meteorologicos e Climatologicos, Servicio Meteorologico de Angola, Luanda, 1937-53

   Location: NOAA (1950-1951); NCDC (1937-1949); NML

6) Observacoes Meteorologicos de Superficie em Angola, Servicio Meteorologico de Angola, Luanda, 1953-1970

   Location: NOAA; NML

7) Resultados das Observacoes Meteorologicos, Servicio Meteorologico de Angola, Luanda, 1952-74; Monthly summaries

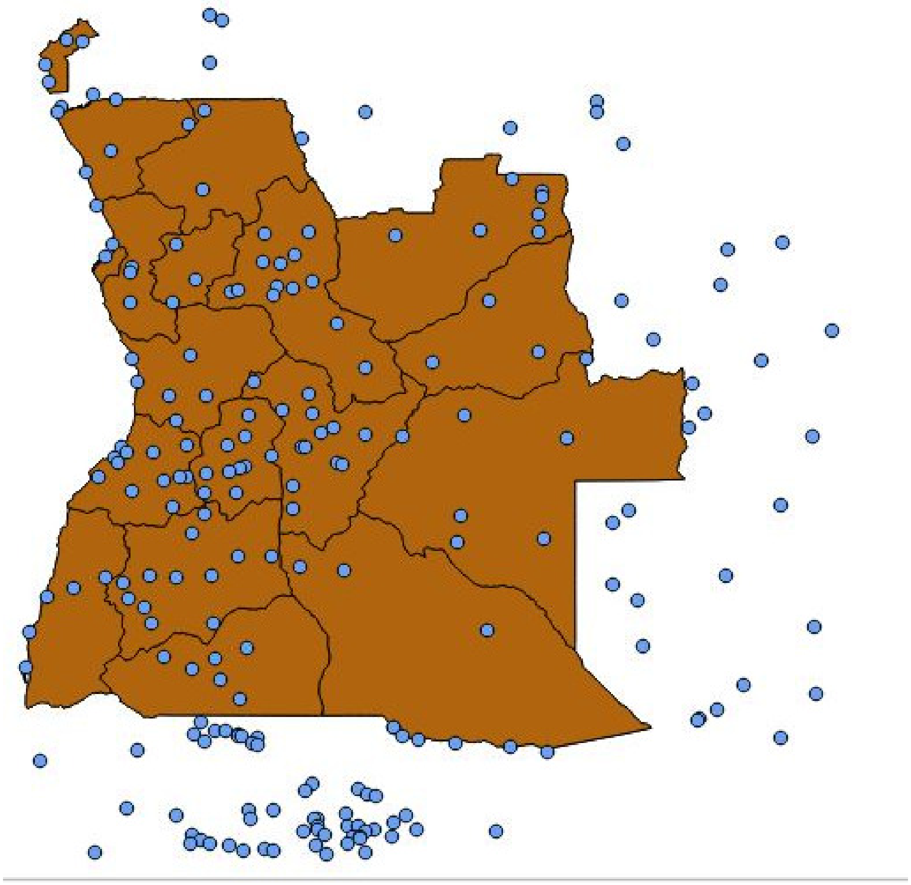
   Location: NCDC (1952-1957); NML (1953-1974)

NCDC – National Climate Data Center of NOAA

NOAA – National Oceanic and Atmospheric Administration (USA)

NML - National Meteorological Library and Archives (UK)

TAMU – Texas A & M University



Map of Met Stations in this study

4.3 Data used in this research

Paper and digitalised sources of monthly rainfall data for Angola were identified. The paper sources were used to c heck, expand and fill the gaps in the digitalised sources.

Scans of the "Anais Meteorologicos das Colonias" (source 1 above) are available on the internet site of NCDC and these were used as a source of information. Scans of "Elementos Meteorologicos e Climatologicos" (source 5 above) are also available on the internet site of NCDC and were also used. For the period from 1921 to 1926, which are (as noted above) missing from the series of the "Anais Meteorológicos das Colonias," the paper copies of "Resumo Mensal das Observações Meteorológicos 1913 -1936" were consulted at NML (Exeter UK). NML also provided scans of the rainfall summaries for 1953 to 1974 of the "Resultados das Observações Meteorológicos". Monthly rainfall summaries, on paper, for western Zambia and southern DRC were also consulted at NML.

INAMET provided monthly rainfall data, in digitalised form, of the few meteorological stations that are operating at present for the years 1960 onwards. A digitalised dataset was provided by EIS Namibia covering some areas of Angola (though not the north) plus some stations in western Zambia and southern DRC. However it was found, after cross-checking with paper and scanned sources, that there are some errors on the existing digital databases. At some stations the database obtained from EIS has data for months for which no data appear on the paper and scanned records. There are also cases where the geographical coordinates have been rounded to the nearest 0.10 of a degree. These errors also appear in the rainfall data available on the internet site "Climate Explorer", which suggests that they have a common source.

The databases were therefore used as a basis for the purpose of the present project but the geographical coordinates were corrected, using the paper records and scanned sources, and the monthly rainfall data itself checked and corrected against the same sources.

4.4 Methodology

A database was created containing monthly rainfall records for 119 meteorological stations in Angola and 33 stations in neighbouring areas of the DRC and Zambia. This appears to be the most extensive database of monthly rainfall data for Angola.

The choice of stations was made so as to have a reasonable representation of different areas of Angola, and including those stations that have long records of monthly rainfall data. Stations were also included if they are included in other publications such as Queiroz (1955) and Todorov & Steyaert (1983) (for comparative purposes).

Database functions were used to calculate a variety of monthly, seasonal and annual parameters. The seasonal calculations only included three month periods where complete data are available for all three months. Annual calculations only included calendar years where complete data are available for the calendar year.

The results have been used to examine normal rainfall plus, more importantly, variability and change. Some of the results have been mapped. Data from stations close to Angola, in Zambia and the DRC have also been used in preparing these maps, as have results from a Namibia report on rainfall and its variability.

5 Mean annual rainfall in Angola

Mean annual rainfall is the best known measure of rainfall. It is a measure that is widely quoted and depicted on maps. Mean annual rainfall has been calculated in this report by summing all the rain measured in calendar years for which there is a complete record and dividing that total by the total number of calendar years for which there is a complete record. Where there is a gap of one or more months in the rainfall record for a particular calendar year at a station, this year has been omitted from the calculations.

These data have been used to produce a map of mean annual rainfall of Angola, which can be seen on the following page. This map is not very different from maps that have been produced previously showing mean annual rainfall in Angola. It shows that coastal areas of Angola have a lower rainfall than the interior of the country, and that the southern coastal areas are drier than northern coastal areas. Rainfall decreases from south to north in Angola while the Atlantic coast is drier than the interior.

The main reason for the differences in rainfall between inland and coastal areas are the effects of ocean currents. Coastal areas of Angola are affected by warm Guinea sea current, flowing from the north, and the cool Benguela current flowing from the south. Sea temperatures depend on the relative influence of the two currents at any particular time. The cold Benguela Current, flowing north from Cape Agulhas and Cape of Good Hope towards the Equator has a cooling and drying influence on the coastal areas of Namibia and Angola, which inhibits rainfall in coastal areas.. It is similar to the Humboldt Current flowing north along the west coast of South America, which has a cooling influence on the climates of Chile, Peru and Ecuador and which is responsible for the aridity of the coasts of those countries. In both cases marine air is cooled by the currents and thus is not conducive to generating precipitation (although clouds and fog are produced). Rainfall on the western coast of Africa is less than rainfall inland as far north as Gabon because of the cold current inhibiting rainfall in coastal areas. (See for example Figure 3.1 of Todorov & Steyaert, 1983). Thus while certain sources show the Benguela Current as flowing only as far north as the centre of the Angolan coast, the effect of cool maritime air is felt further north.

The Inter-tropical Convergence Zone (ITCZ), when it moves south across Africa in the southern summer, does not form a straight east-west line as it does across northern Africa in the northern summer. It travels much further south across the continent than it does across the ocean and the coastal areas. The ITCZ, an area of intense convection that is the source of most rainfall in Africa, travels about as far south as 15.00 degrees south in January in inland areas of southern Angola but lies much further north in coastal areas. The extreme south of Angola and the coastal areas are thus dry while northern and central inland areas are humid.

It should be noted that rainfall increases rapidly from the coast inland. However the lack of meteorological stations with reasonable records in areas a short distance inland from the coast means that little is known about the gradient of rainfall increase going inland from the coast. Rainfall increases rapidly inland from Benguela (217 mm) to Catengue (930 mm), Cubal (1259 mm) and Ganda (1503 mm) before then declining further inland to Caala (1235 mm). Catengue is only 60 km inland from Benguela but has a significantly higher rainfall. This confirms the findings of dos Santos (1961).

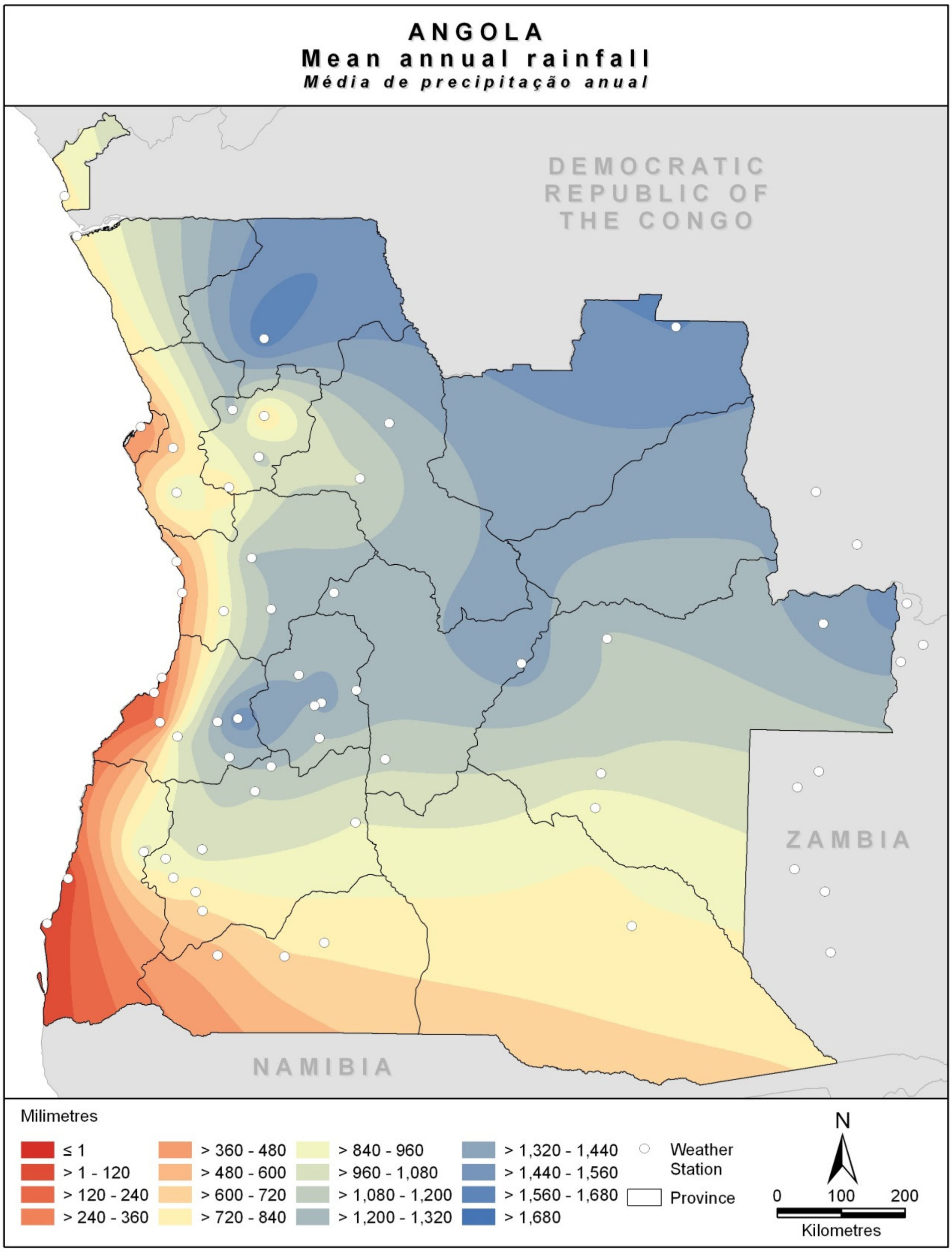
The graphs on the following pages show the monthly distribution of rainfall in different areas of Angola. Of the coastal areas of Angola, only Cabinda (in the extreme north) has significant rainfall in the first half of the rainy season. Further south, the effects of the cold Benguela Current inhibit rainfall until late in the rainy season when SST are higher. The peak month for rainfall in Luanda is April while further south on the coast it is March: this corresponds with the return northward of the Inter-Tropical Convergence Zone at the end of the rainy season. Rainfall is markedly higher on the north coast than in the south.

In the central north-south strip of Angola, away from the influence of the cold Benguela Current, rainfall totals are highest. In the north, which are closer to equatorial regions (Mbanza Congo, Uige, Ndalatando, Wako Kungo) there is a noticeable mid-season dip in rainfall as the Inter-Tropical Convergence Zone moves southwards away from those areas in January and then returns northwards later in the rainy season. In the most northerly of these places (Mbanza Congo, Uige), however, there is no month with less than 100 mm of rainfall in the middle of the rainy season and the weather calendar cannot be divided into two rainy seasons. Counterintuitively it is in the area further south (around Ndalatando and Wako Kungo) that there are months with less than 100 mm of rain in the middle of the rainy season.

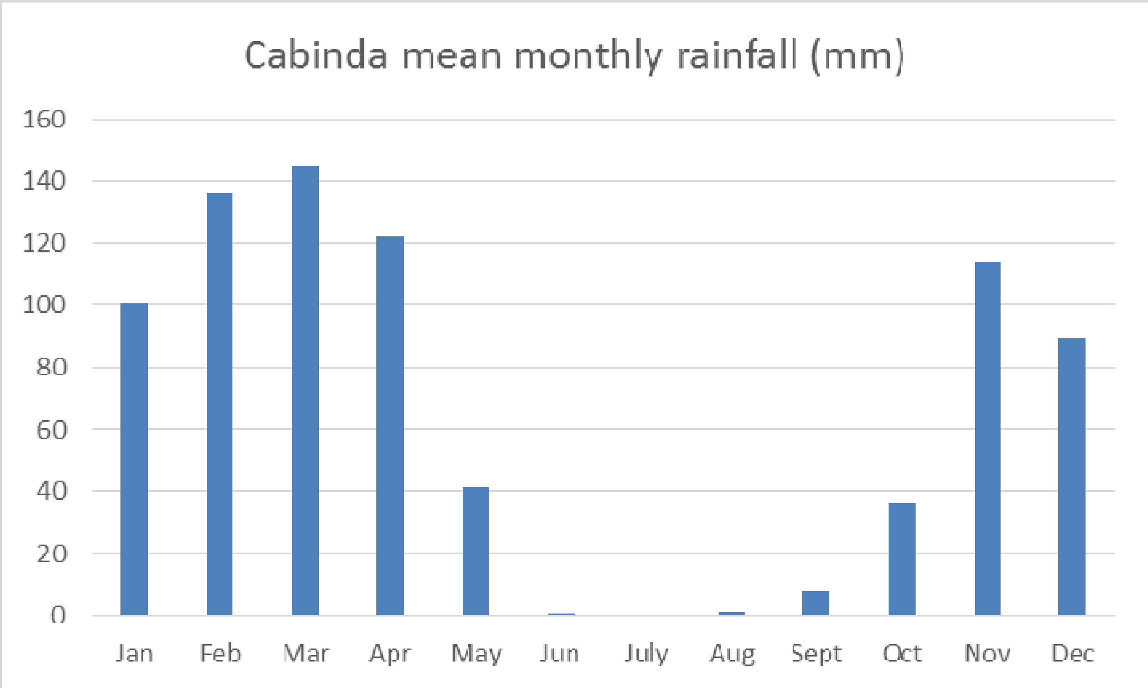
Dondo is an intermediate case, between the coastal climate of Luanda and the central areas around Ndalatando: there is 100 mm of rainfall in November, and a significant dry period in December to February, then the end of the rainy season sees the significant rainfall.

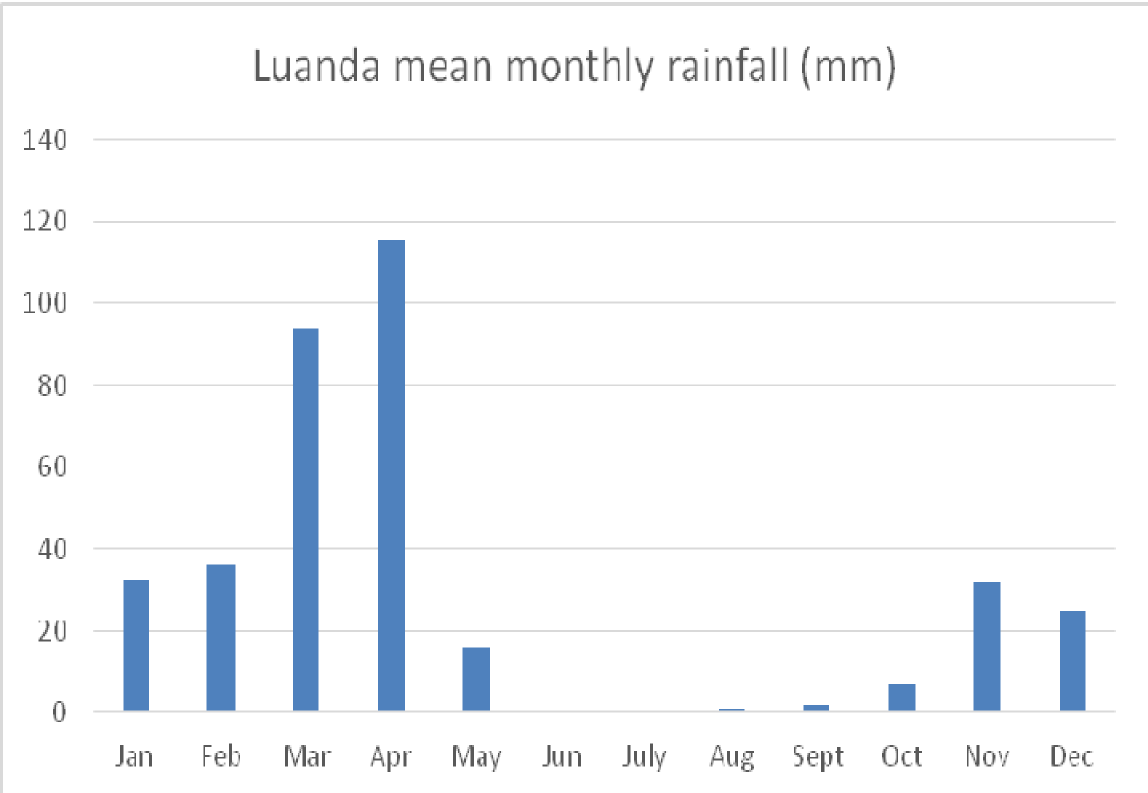
In the central strip, the importance of the mid-season dry period declines going southwards to Rio Chipa in the central plateau and then again to Lubango in the Huila Highlands (where rainfall increases throughout the rainy season from November to March and then declines rapidly). The dry period in mid-season is agriculturally significant in the central plateau, however, because the important local crop is maize and because in some years there is a period of more than 10 days without rain which can significantly reduce yields.

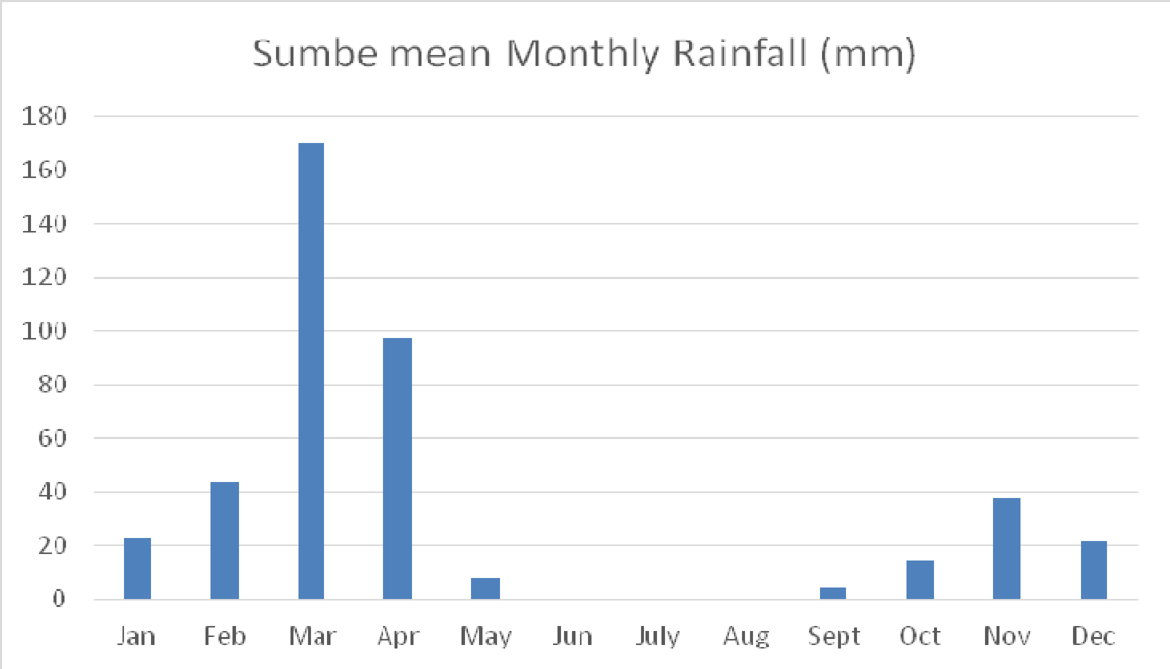
In eastern areas of Angola total rainfall declines from north to south. The importance of the mid-season dip in rainfall declines from north to south but even in the north (Dundo) all months from October to April have more than 150 mm of rain.

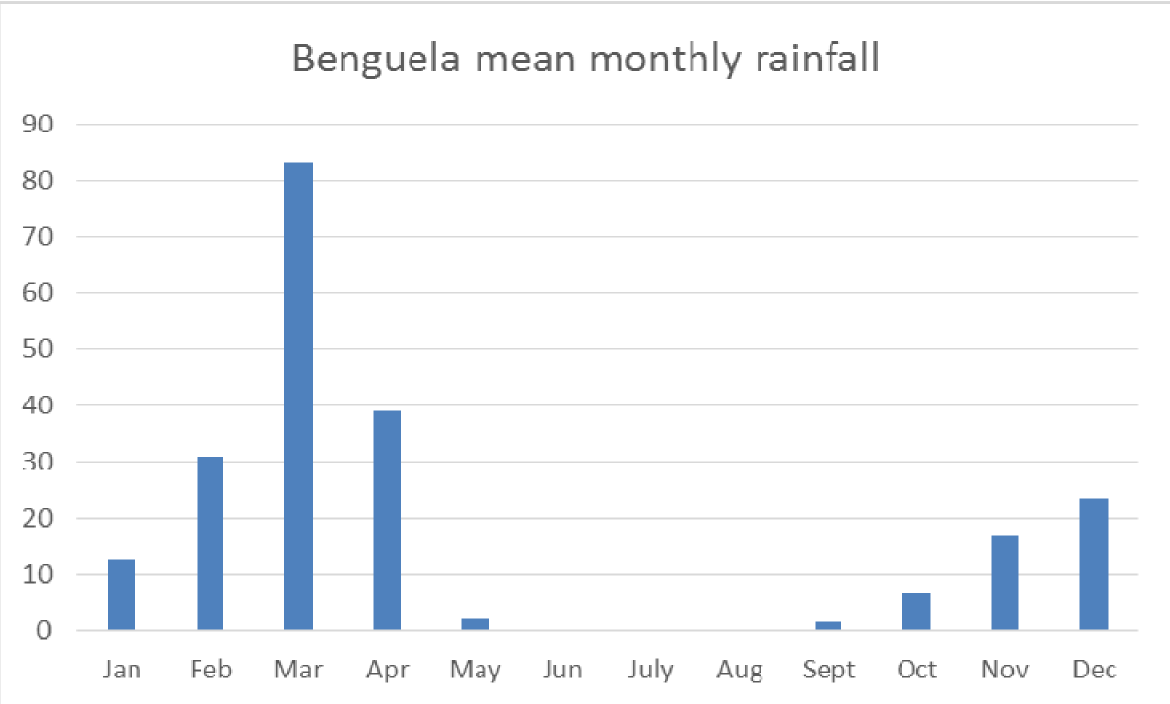

ANGOLA
Mean annual rainfall
Média de precipitação anual
DEMOCRATIC REPUBLIC OF THE CONGO
ZAMBIA
NAMIBIA
Milimetres
≤ 1
> 1 - 120
> 120 - 240
> 240 - 360
> 360 - 480
> 480 - 600
> 600 - 720
> 720 - 840
> 840 - 960
> 960 - 1,080
> 1,080 - 1,200
> 1,200 - 1,320
> 1,320 - 1,440
> 1,440 - 1,560
> 1,560 - 1,680
> 1,680
Weather Station
Province
N
0 100 200
Kilometres

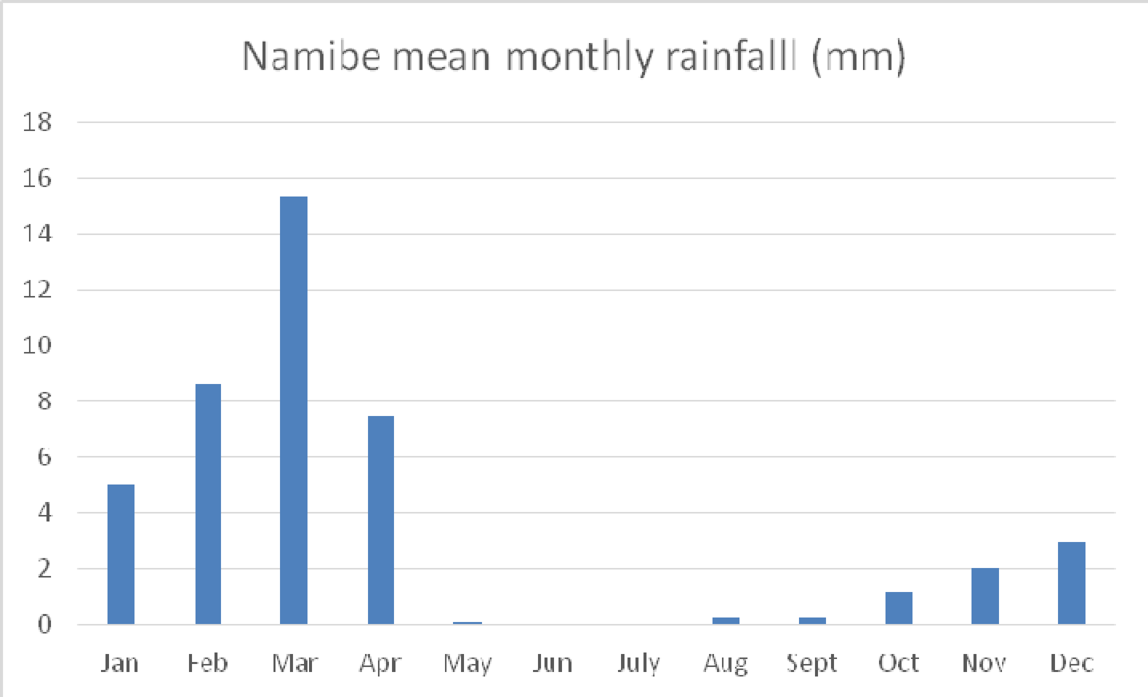
COASTAL AREAS



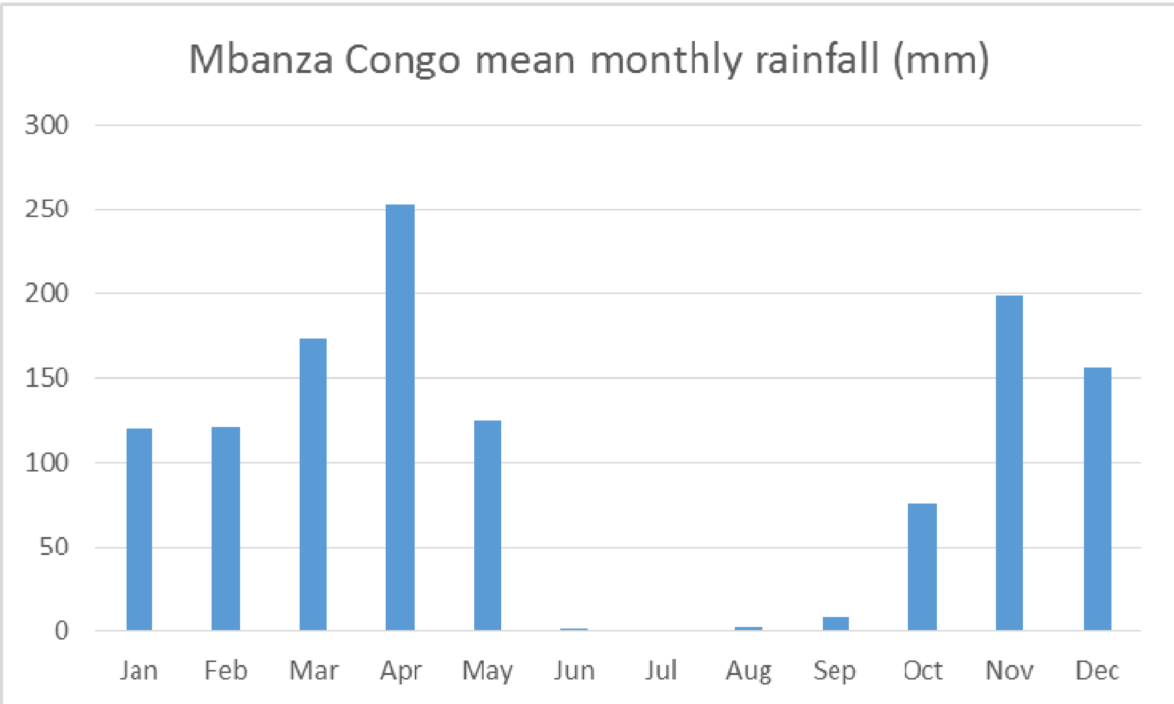


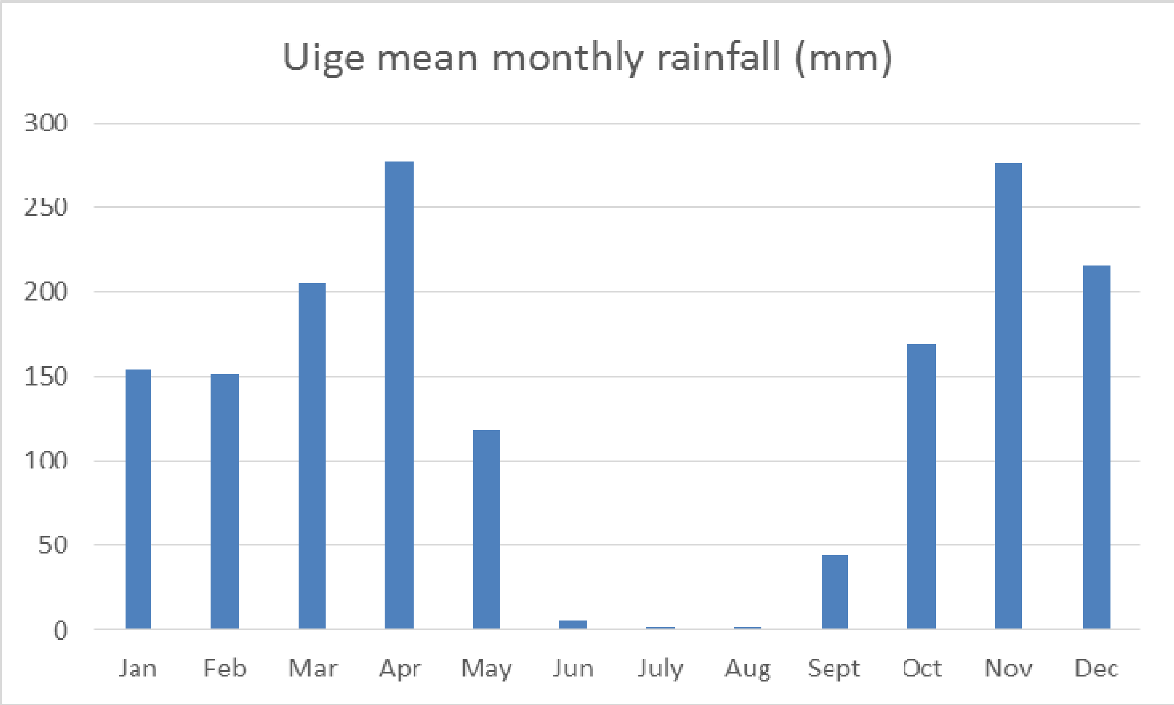

Sumbe mean Monthly Rainfall (mm)
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

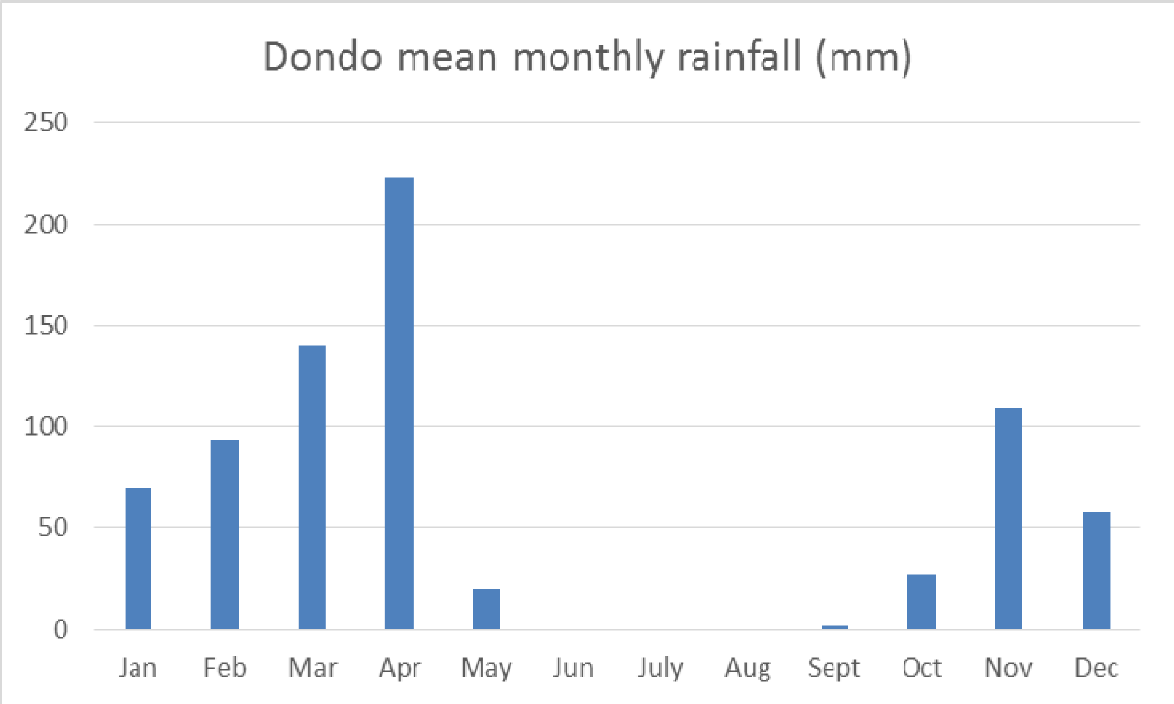

Benguela mean monthly rainfall
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

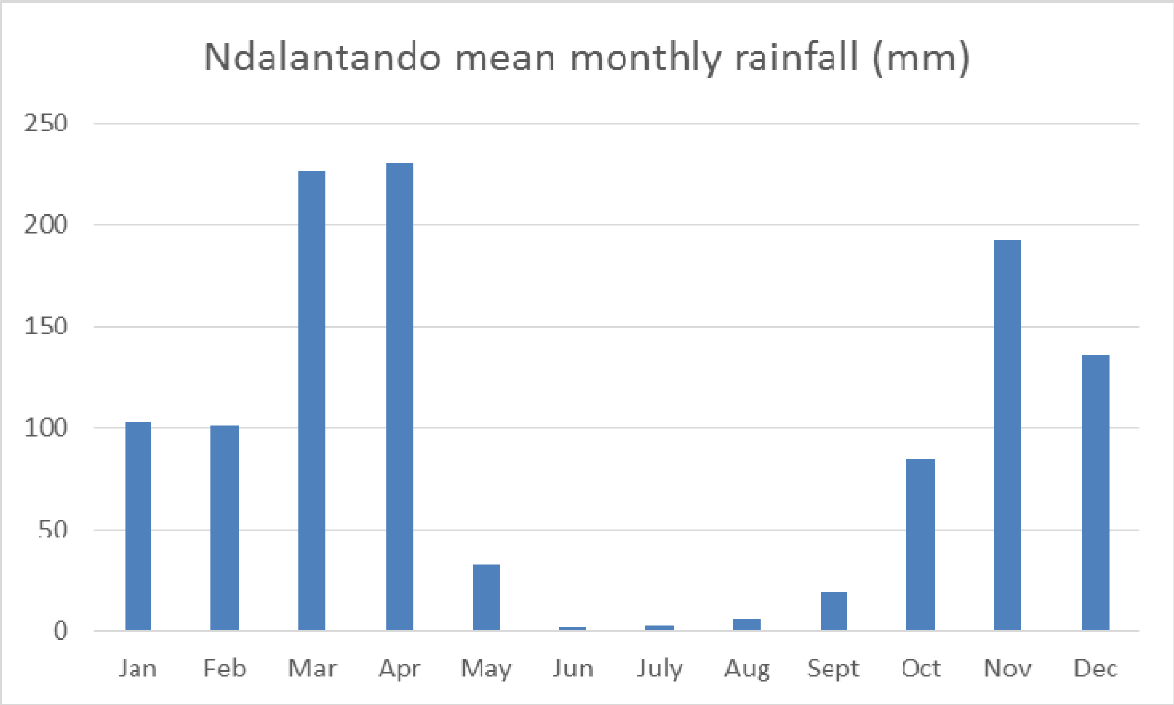


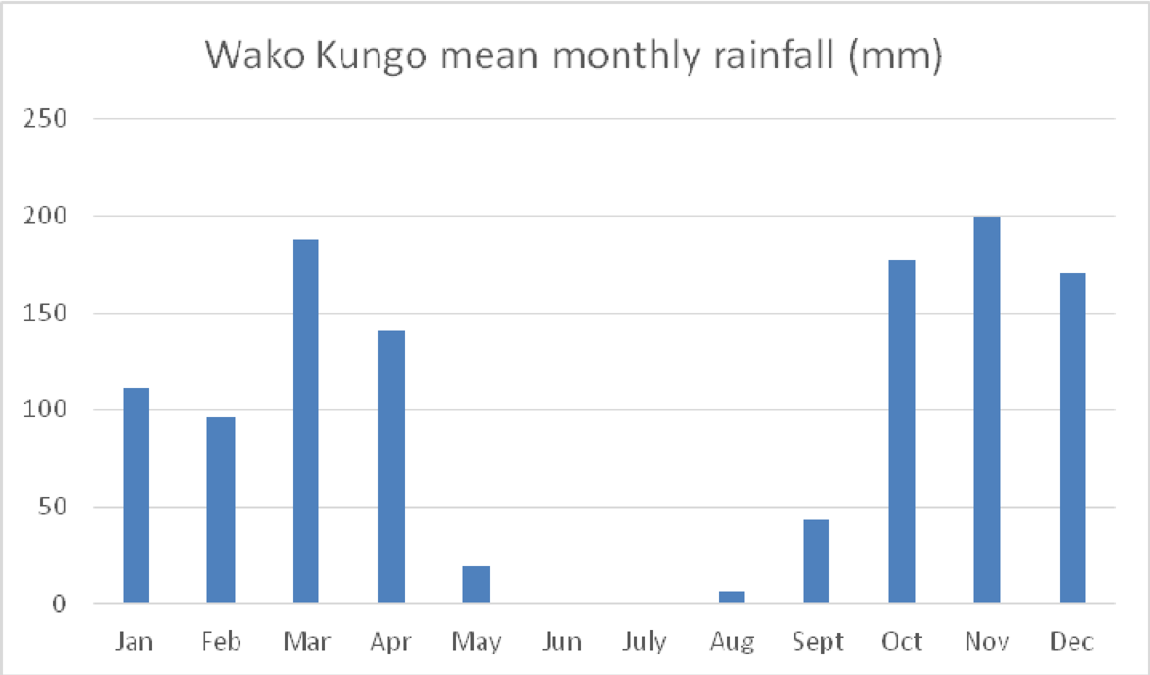
CENTRAL AREAS

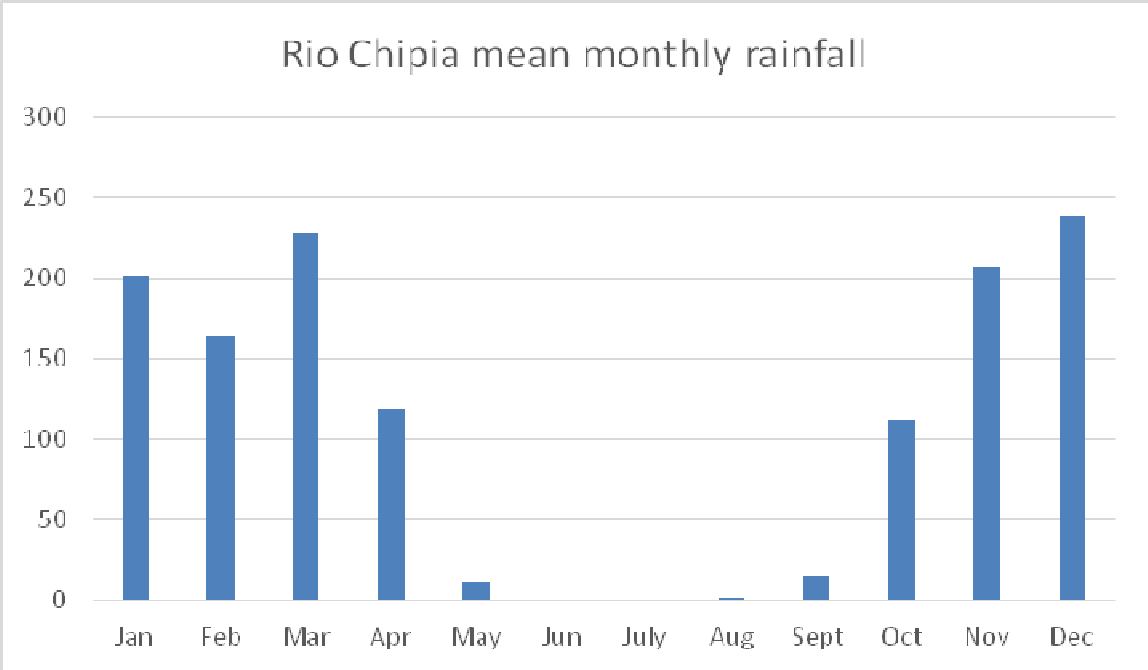


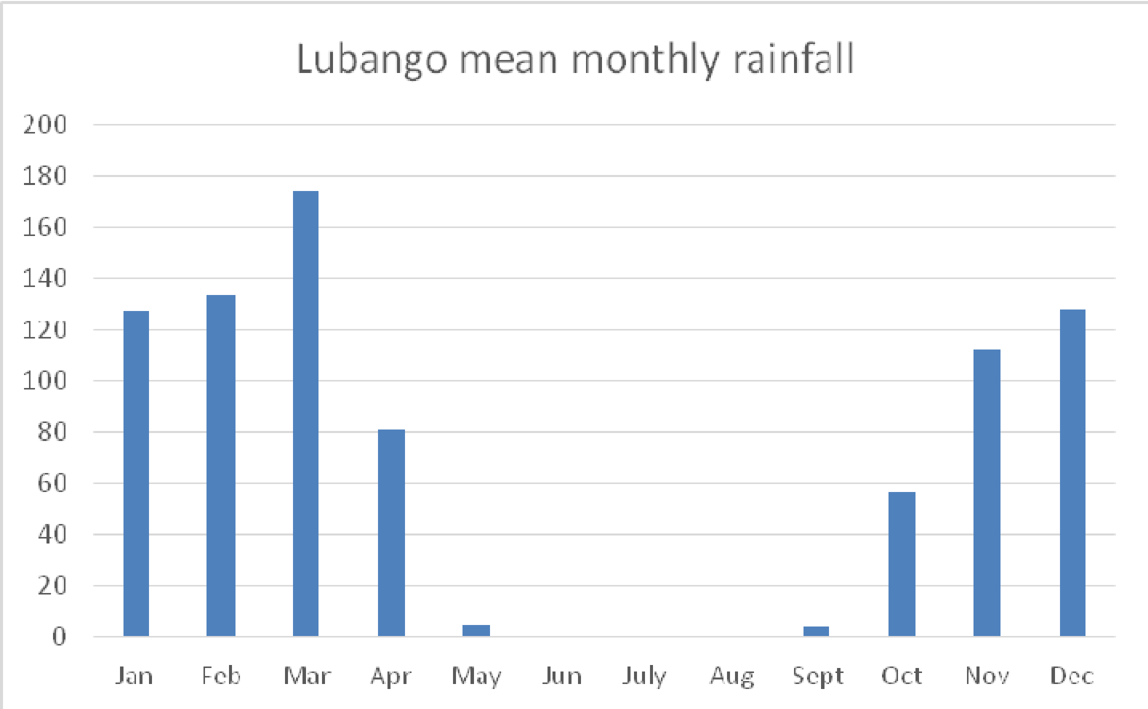

Uige mean monthly rainfall (mm)
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec


Dondo mean monthly rainfall (mm)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

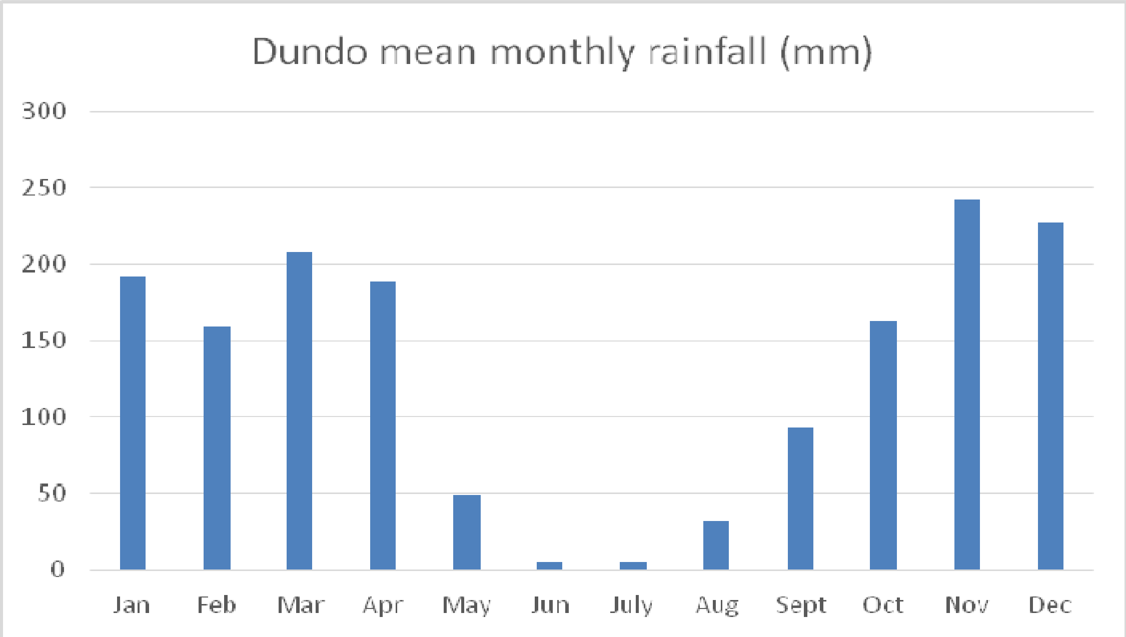

Ndalantando mean monthly rainfall (mm)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

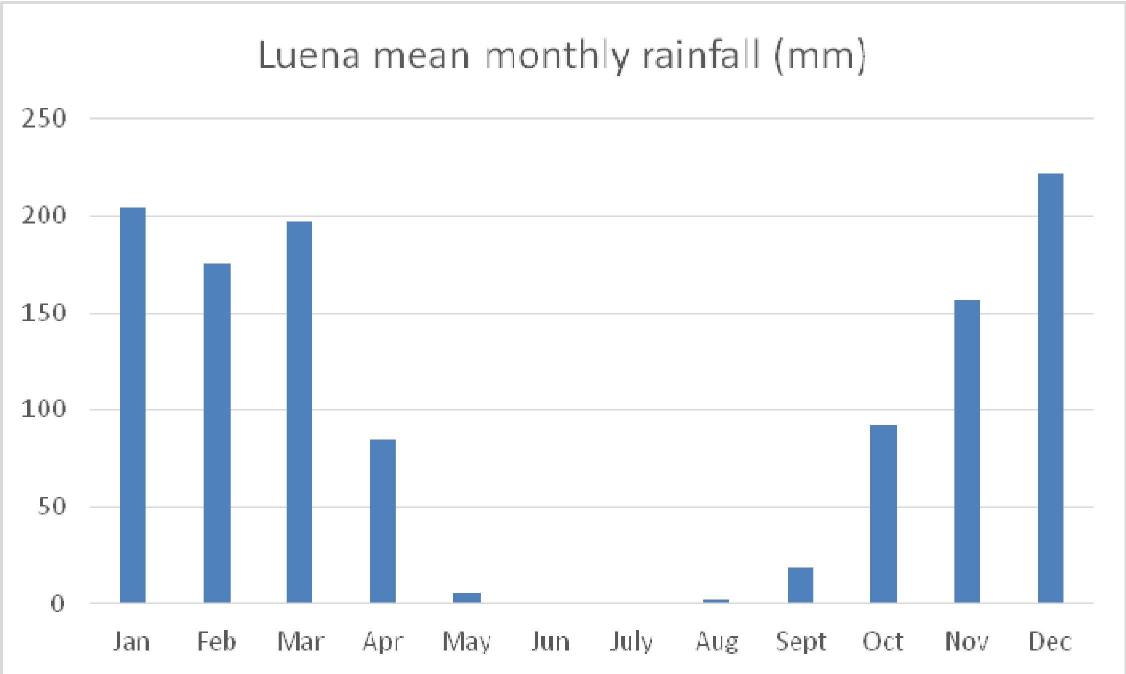

Wako Kungo mean monthly rainfall (mm)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

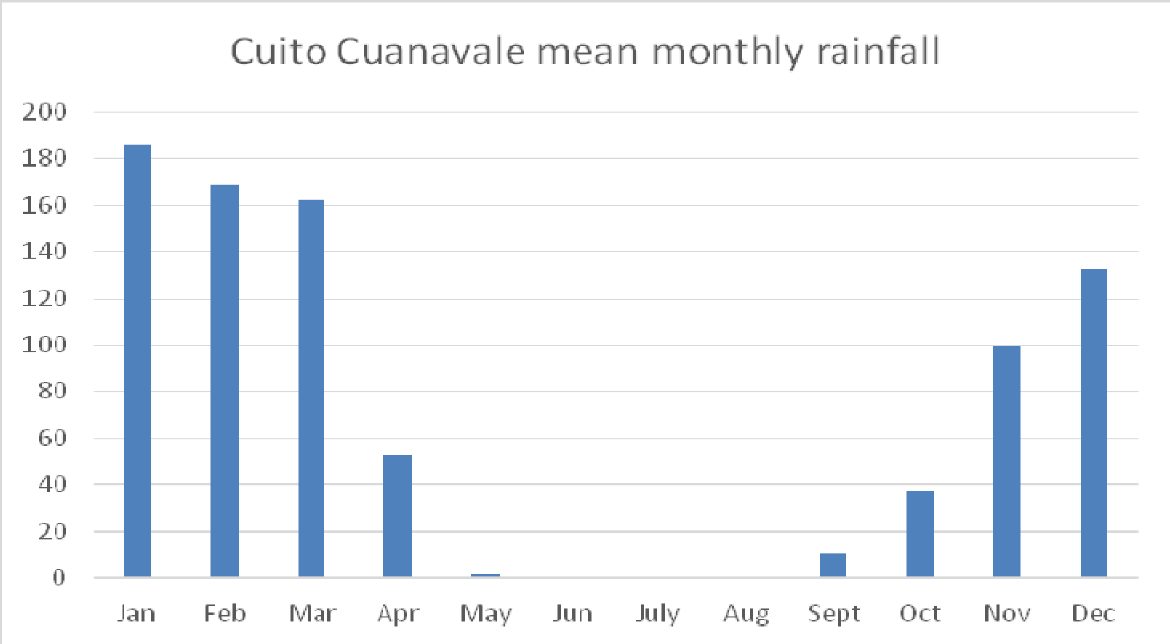

Rio Chipia mean monthly rainfall
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec


Lubango mean monthly rainfall
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

EASTERN AREAS







6 Rainfall variability in Angola

A high degree of variability is a feature of rainfall in some areas of Angola. In these areas the mean value is an unreliable measure of rainfall because in many years rainfall varies significantly from the mean. Knowledge about rainfall in these areas requires information about how much rainfall in a particular year is likely to deviate from the mean as well as information about the mean itself. Variability is, though, a difficult concept to portray.

The variability of rainfall in Angola has been little studied. A study by Queiróz (1955) calculated the coefficient of variation for 22 stations but in some cases this was based on rainfall records for just over 10 years.

In this report two measures of variability are used. The first is the coefficient of variation and the second is anomalies of mean relative variability.

6.1 Coefficient of variation

One measure of variability is the coefficient of variation. It shows the extent of variability in relation to the mean of a data set, and is defined as the standard deviation divided by the mean of that data set. This was the measure used by Queiróz (1995)

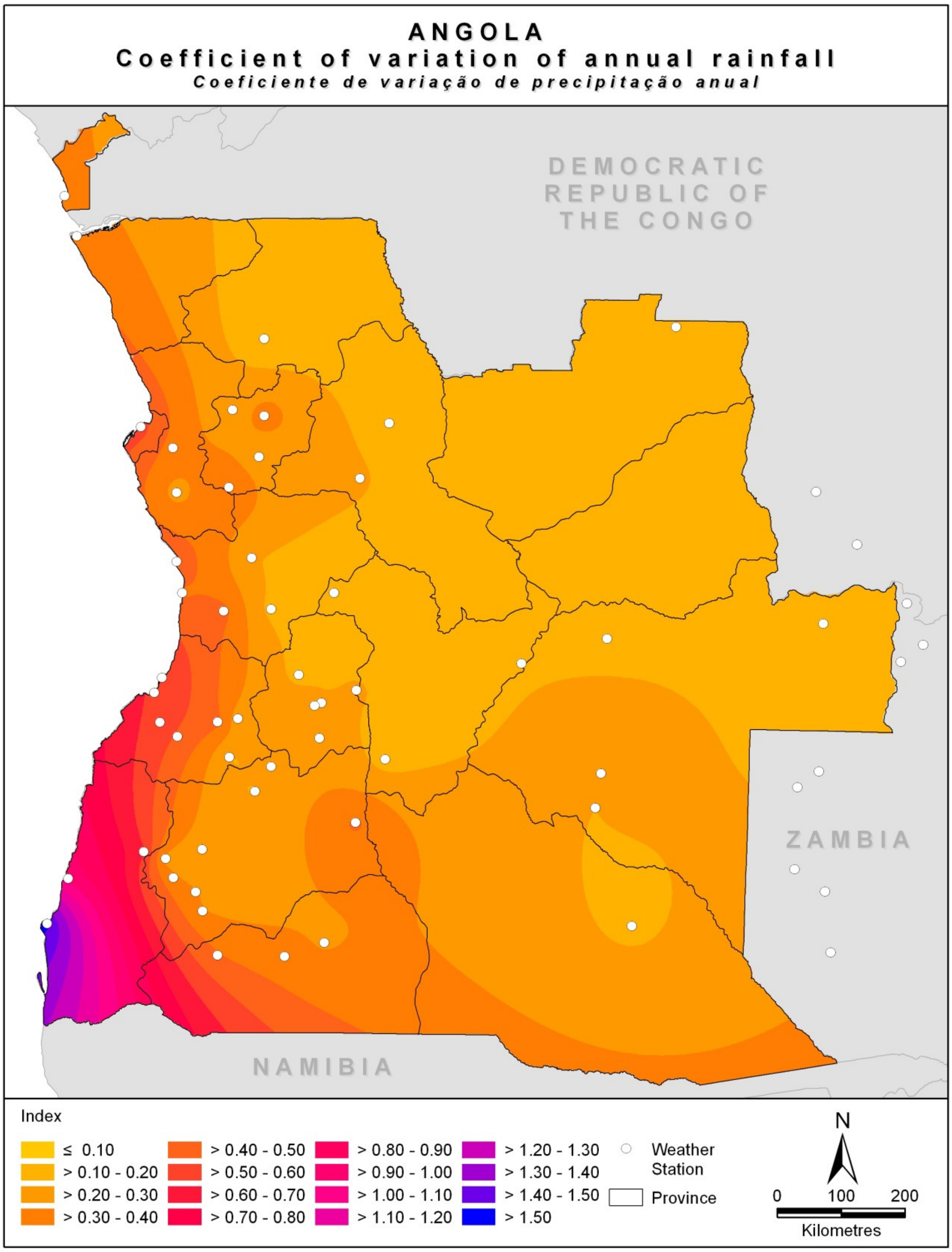
Standard deviation shows how much variation exists from the mean. A low standard deviation indicates that the data points tend to be very close to the mean; high standard deviation indicates that the data points are spread out over a large range of values.

The coefficient of variation of precipitation serves as a measure of dispersion of the observed values from the average, or in other words, as a measure of regularity of rainfall in the regions for which they are calculated. Where the coefficient of variation is low, the mean value is quite representative of the rainfall in that area: rainfall in any one year is not going to be very different from the mean. Where the coefficient of variation is high, the mean value does not adequately represent the rainfall in that area and in any particular year the rainfall may be much higher or lower than the mean value.

Mean values and the coefficient of variability are complimentary. They should be used together. If a region is an area of low coefficients of variability, the annual averages are representative, or in other words annual rainfall does not deviate greatly from the annual average. Otherwise, if the coefficients of variability are high in the region considered, the annual averages are not representative and we can expect, in some future years, values different from the annual average.

The results are similar to those obtained by Queiróz. Coefficients of variation are high in coastal regions of Angola and some parts of the south. Along the coast they increase from north to south. In the most southerly coastal areas of Angola (the coast of Namibe Province) the value of the coefficient is greater than 1. As with mean rainfall, the coefficient of variation declines rapidly with distance from the coast. In most areas if Angola away from the coast the coefficient of variation is less than 0.30, which is similar to most areas of sub-Saharan Africa (though it is high by European standards: the coefficient of variation of annual rainfall in the United Kingdom is 0.13).

It should be noted, though, that some areas of the south of Angola have a high variability of annual rainfall and also that there is an area inland from Luanda (near Dondo and Ndalatando) with a high variability of annual rainfall. This is an area where the transition from the coastal plain to inland plateau is further from the coast than the areas to the north and to the south.


ANGOLA
Coefficient of variation of annual rainfall
Coeficiente de variação de precipitação anual
DEMOCRATIC REPUBLIC OF THE CONGO
ZAMBIA
NAMIBIA
Index
≤ 0.10
> 0.10 - 0.20
> 0.20 - 0.30
> 0.30 - 0.40
> 0.40 - 0.50
> 0.50 - 0.60
> 0.60 - 0.70
> 0.70 - 0.80
> 0.80 - 0.90
> 0.90 - 1.00
> 1.00 - 1.10
> 1.10 - 1.20
> 1.20 - 1.30
> 1.30 - 1.40
> 1.40 - 1.50
> 1.50
Weather Station
Province
N
0
100
200
Kilometres

6.2 Anomalies of mean relative variability.

Conrad (1941) investigated the variability of precipitation globally. He noted that there are some places in the world where rainfall varies little from one to the next, while there are others (the Malden Islands) where precipitation can be 100 mm one year and 2000 mm the next. Places where rainfall is very variable are spatially contiguous: the variability of rainfall is not a random attribute but is due to climatological factors in a particular region. Conrad found that variable rainfall occurs particularly on continental coasts where there is low rainfall deficit and where the weather is affected by ocean currents (such as the California Current, the Chile-Peru Current and the Benguela Current). The normal behaviour of these cold currents causes the low rainfall that is typical of these regions. A small deviation of the ocean allows the intrusion of warmer water between the current and the coast, which brings more abundant rain. Globally the areas of highest variability are the Sertões region at the north-east tip of Brazil (where occasional cooling of the ocean currents causes drought years), the coasts of Peru and north Chile, and a region of southern Saudi Arabia with an adjacent part of Africa (north of the Horn of Africa) and part of India. (An exceptional area of high variability found in the centre of a continent is the semi-arid region to the east of the Rocky Mountains in the USA, where the annual variation of the Chinook Winds leads to variable annual rainfall).

Conrad's methodology involved defining areas where the variation in annual rainfall is higher than would be expected for a place with that mean annual rainfall. The absolute value of the difference between the annual rainfall in a particular year and the mean annual rainfall is calculated. The average of these deviations from the mean is then calculated, and this is divided by the mean to give the relative variability. This is then compared with the expected value of the relative variability for a place with that value of mean rainfall. Conrad calculated this expected value (the Normal Relative Variability) using data from stations worldwide

The anomalies of relative variability are the difference between the Observed Relative Variability at a particular place and the Normal Relative Variability, the expected variance for a place with that mean annual precipitation. Where this anomaly is positive (Observed Relative Variability is higher than Normal Relative Variability) rainfall variability is high.

Globally Conrad found that positive anomalies are less frequent but more intense than negative anomalies. High positive anomalies are frequent in dry regions. The advantage of this measure of variability, compared to the Coefficient of Variation, is that it defines areas of high variability and also that it is less skewed to areas with very low rainfall. The Coefficient of Variation is very high in areas with very low rainfall but is less useful in distinguishing, in areas of medium rainfall, between those with high variability and those with low variability.

For the purposes of this report, the anomalies of relative variability of annual rainfall were calculated for a selection of stations in Angola, and the results were mapped. The map of this measure shows that the variability of rainfall is highest along the coast and declines with distance inland. It also shows that rainfall variability is higher than expected in some areas of southern Angola and, as with the Coefficient of Variation, there is an area inland from Luanda (around Dondo and Ndalatando) where variability is high. The area of high variability in Angola is similar to that mapped by Conrad, though the results of the present analysis suggest that rainfall is more variable in inland southern Angola than suggested by Conrad's mapping (which, as he states, is based on data from relatively few stations).

It should be noted that, although the highest variability is along the coast where rainfall is low, there are stations with 1000 mm or more mean annual rainfall that are within the area of high rainfall. Ndalatando, Ganda and Cubal have a mean annual rainfall of more than 1000 mm but are within that area of high variability. Rainfall in 1960 was over 2000 mm in Ganda and Cubal and over 1800 mm in Ndalatando.

7 Rainfall patterns in areas of high variability in Angola

7.1 Coastal rainfall index

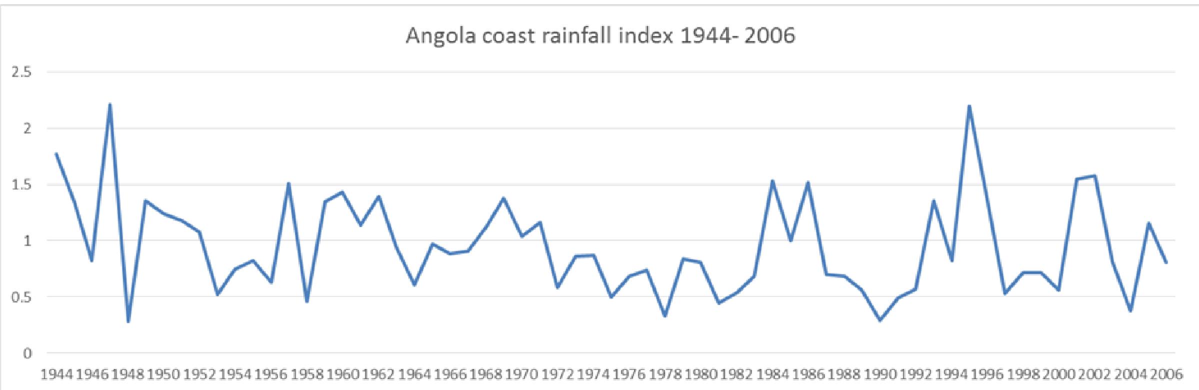
The variability of rainfall along the coast of Angola raises the question of whether the pattern of variation is similar throughout this area and, if so, whether there is one underlying driver of year to year variations. If there is, it opens up the possibility of forecasting years of high and low rainfall and incorporating this in early warning systems.

Hirst and Hastenrath (1983) reported that local meteorologists in Angola have long been aware of the tendency for years of abundant rainfall along the coast to coincide with years of warm coastal waters. They showed that in years of low rainfall, Sea Surface Temperatures (SST) were low along the coast of Angola; in wet years SSTs were high. SST affects the moisture in the atmosphere in coastal areas and also affects convective stability. They used an index derived from the annual totals for 1940 to 1975 for three coastal stations (Luanda, Lobito and Namibe) as an index of rainfall activity in coastal areas of Angola, and demonstrated that annual rainfall totals show a pronounced inter-annual variability, which in turn show a strong spatial correlation. Rainfall in these stations is concentrated in the months of March and April. Years with high rainfall (notably in the months of March and April) were 1944, 1947, 1957, 1962, 1963, 1969, 1971. Years with low rainfall were 1948, 1953, 1954, 1958, 1964, 1972 (figure 2 of Hirst and Hastenrath, 1983).

For the purpose of this research, a similar index was constructed using annual rainfall totals from seventeen stations in the coastal area of Angola, covering the years 1944 to 2006. The stations were Cabinda, Soyo, Luanda, Onga Zanga, Catete, Porto Amboim, Sumbe, Uku Seles, Lobito, Benguela, Cubal, Cassequel , Catengue, Ganda, Bibala, Namibe and Tombwe. For each station the annual total rainfall for each year was divided by the mean annual rainfall over the period 1944 to 2006: if the value of this parameter is 1 the annual rainfall was the mean for this station; if it was above 1 it was higher, if it was below 1 it was lower. An overall index for each year was created by calculating the mean for that year across all the stations with a valid annual rainfall total for that year.

The values of this coast rainfall index for Angola are shown in the following graph and table.

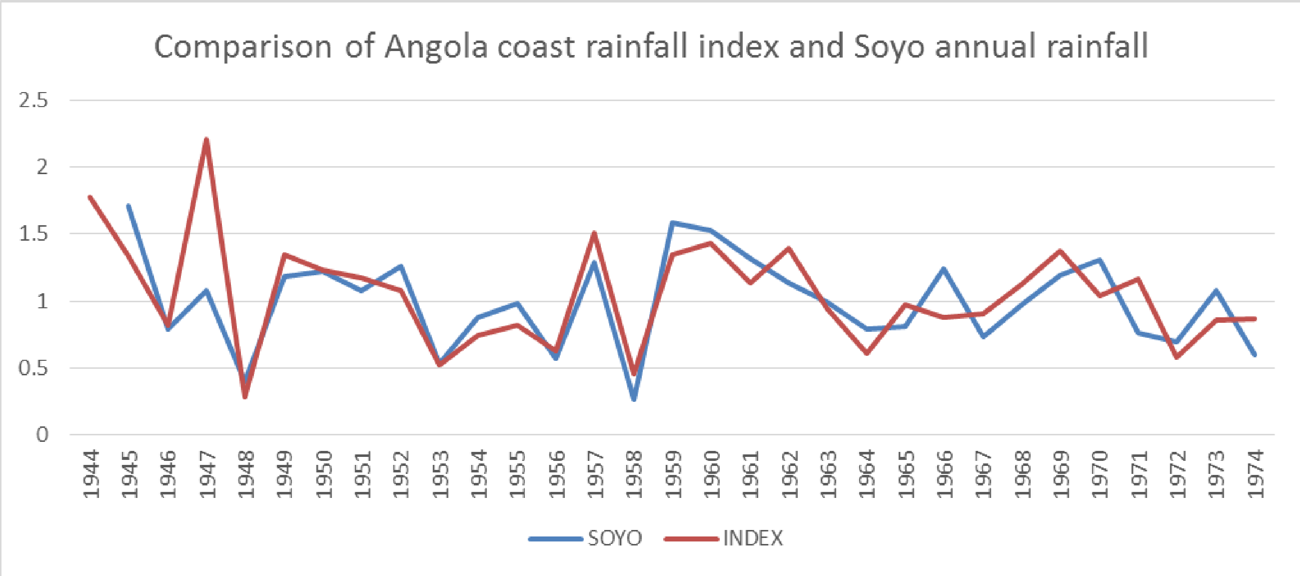
Years of high rainfall (when the index is 1.40 or higher) are 1944, 1947, 1957, 1960, 1962, 1984, 1986, 1995, 2001 and 2002. Years of low rainfall (when the index is 0.60 or lower) are 1948, 1953, 1958, 1972, 1975, 1978, 1981, 1982, 1990, 1997 and 2000. This corresponds closely with the years indicated by Hirst and Hastenrath as wet and dry years along the coast of Angola, though their analysis included only years up to 1975.

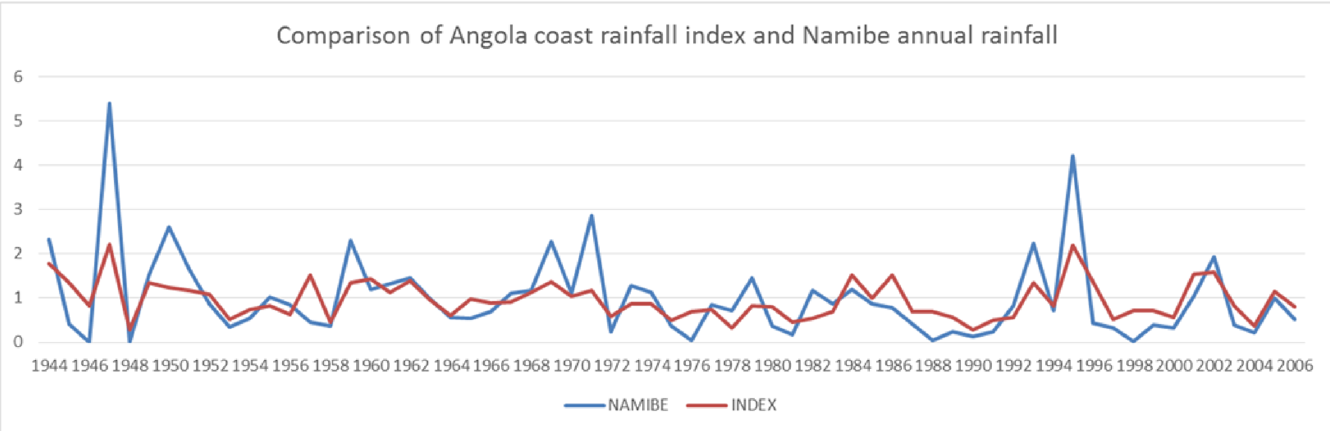


1944	1.77		1976	0.68
1945	1.34		1977	0.74
1946	0.82		1978	0.33
1947	2.21		1979	0.83
1948	0.29		1980	0.81
1949	1.35		1981	0.45
1950	1.24		1982	0.54
1951	1.17		1983	0.68
1952	1.08		1984	1.53
1953	0.52		1985	1.00
1954	0.75		1986	1.52
1955	0.82		1987	0.70
1956	0.63		1988	0.68
1957	1.51		1989	0.56
1958	0.46		1990	0.29
1959	1.34		1991	0.49
1960	1.43		1992	0.57
1961	1.14		1993	1.35
1962	1.40		1994	0.83
1963	0.95		1995	2.19
1964	0.61		1996	1.36
1965	0.97		1997	0.53
1966	0.88		1998	0.71
1967	0.90		1999	0.71
1968	1.13		2000	0.56
1969	1.37		2001	1.55
1970	1.04		2002	1.58
1971	1.16		2003	0.82
1972	0.58		2004	0.37
1973	0.86		2005	1.15
1974	0.87		2006	0.81
1975	0.49			

To what extent do years of high rainfall (and low rainfall) coincide at stations along the coast of Angola? As the following graphs indicate, the year-to-year variation in rainfall at Soyo (on the coast in northern Angola) and at Namibe (on the coast in southern Angola) both show similarities to the coastal index. There are similarities in the pattern of high and low rainfall right along the coast of Angola. This suggests that there is a similar underlying driver along the whole of the coast of Angola.

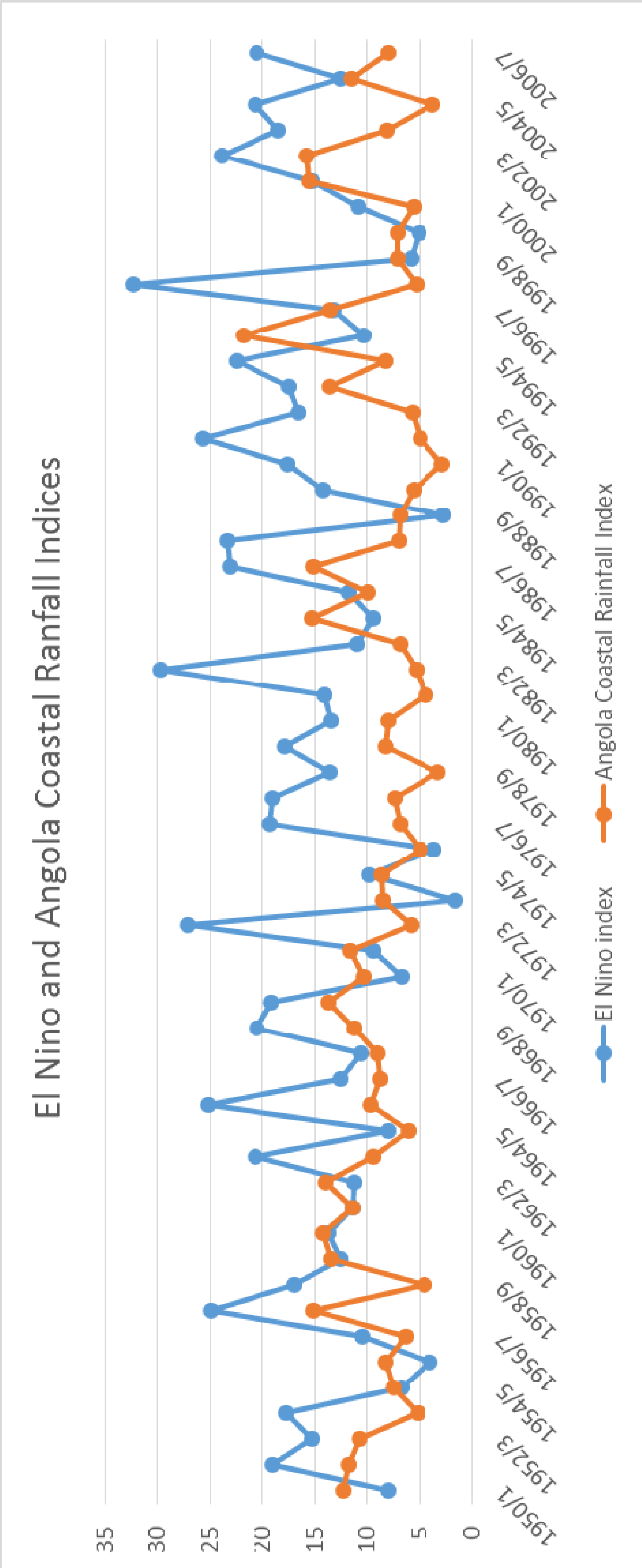
There are, however exceptions. Although 1947 was a year of very high rainfall in most stations along the coast of Angola, the rainfall in Luanda was 395 mm, only slightly above the mean of 359 mm. Although factors such as SST may make a year favourable to high rainfall it does not necessarily mean that it will occur in all places.





The strong spatial correlation for rainfall along the coast of Angola is shown by the way in which the annual totals follow the pattern of the coastal index along the length of the coast. The above two graphs illustrate this for Soyo in the north and Namibe in the south.

It is important to note that this pattern of variation is different from the El Niño – Southern Oscillation pattern of variation that is found in the eastern part of the Southern Africa Region. In the eastern part of the Southern Africa Region (eastern South Africa, Zimbabwe, Mozambique) El Niño years are warm and dry (and can have devastating droughts). La Niña years are cool and wet (and can lead to serious flooding). The years 1997/98 were El Niño drought years in eastern Southern Africa, while 1999/2000 were La Niña flood years in eastern Southern Africa. In Angola these effects were only felt in the extreme south-east of the country. As the following graph shows, there is no correspondence between the index of coastal rainfall in Angola and the El Niño index. Although the variations in SST in the Atlantic are sometimes called the Benguela Niño, and although many areas of the Southern Africa Region are influenced by El Niño, these are unrelated phenomena.


El Nino and Angola Coastal Ranfall Indices
35
30
25
20
15
10
5
0
1950/1
1952/3
1954/5
1956/7
1958/9
1960/1
1962/3
1964/5
1966/7
1968/9
1970/1
1972/3
1974/5
1976/7
1978/9
1980/1
1982/3
1984/5
1986/7
1988/9
1990/1
1992/3
1994/5
1996/7
1998/9
2000/1
2002/3
2004/5
2006/7
El Nino index
Angola Coastal Rainfall Index

A number of researchers have looked at annual variations in sea surface temperatures in the Benguela Current in recent years. Years when SST were significantly above average have been called "warm events" or sometimes Benguela Niños (in reference to the well-known warming in areas of the Pacific Ocean in certain years). Fidel and O'Toole, in a presentation made at the 2nd Global Conference on Large marine Ecosystems in Qingdao, distinguished a number of major Benguela Niños over the last 50 years. Warm events occurred in 1973, 1984 and 1995, and alternated with cold events of 1958, 1982 and 1992. There is some coincidence of these years with the high rainfall and low rainfall years shown in the coastal index (above) though it should be noted that 1973 was not a high rainfall year in coastal areas of Angola. These differences require further investigation and may be due to differences in conditions between SST off Angola, on the one hand, and off Namibia and South Africa (where more research has been carried out) on the other.

Hirst and Hastenrath suggest that extreme rainfall on the Angola coast coincides with anomalous atmosphere – ocean conditions in much of the tropical Atlantic Ocean, in particular with higher SST of the coast of Angola. SST affects rainfall through variations of atmospheric moisture and stability. Six months prior to a wet rainy season on the Angola coast, easterly winds over much of the Atlantic tend to be stronger, but are not strong during a wet rainy season. This suggests that the seasonal relaxation of zonal wind stress along the Atlantic Equator leads to higher SST off the Angola coast which tends to lead to higher rainfall.

7.2 Twenty-four hour maxima of rainfall

As has been shown above most years in coastal areas of Angola are quite but there are occasional years of much higher rainfall, depending on the strength of the warm counter-current from the north. As in many areas of Angola, rainfall usually falls as very heavy, but irregular, showers. Along the coast, most precipitation occurs in a short period in March (in the south) and April (in the north) when Sea Surface Temperatures are high enough to create the conditions for rainfall: it is usually only late in the rainy season that the intrusion of warmer waters between the cold oceanic current and the coast brings more abundant rains.

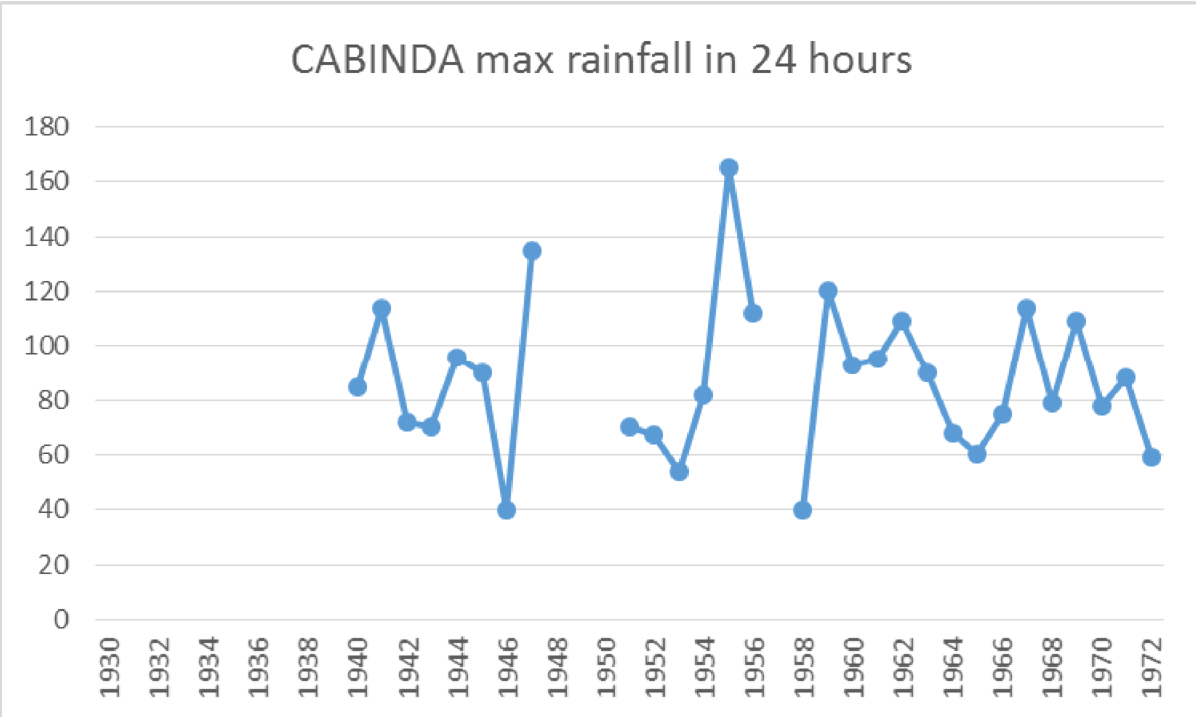
One of the pieces of data that has been collected for some stations is the maximum amount that falls in a 24 hour period during each year. The following pages show graphs of the maximum 24-hour rainfall at a number of coastal stations in Angola. Given the nature of rainfall in these areas these figures probably show the amount of rain that can fall in one storm of less than 30 minutes.

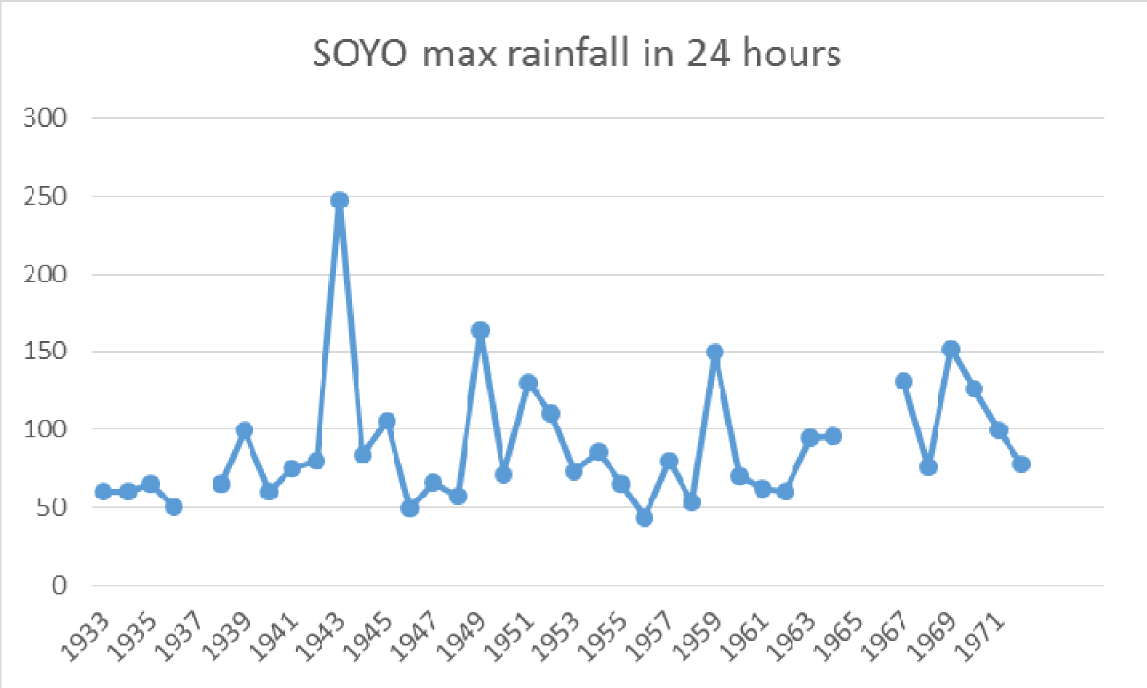
These graphs show that, at all coastal stations, more than 100 mm of rain can occur in 24 hours and on some occasions substantially more than this can occur. The amount that can fall in one storm is a high proportion of a year's rainfall. In Luanda, where the mean annual rainfall is 361 mm, more than 150 mm of rain can occur in 24 hours. In Namibe, where the mean annual rainfall is 45 mm, there have been 24 hour periods with 75 mm of rain and there are a number of years with 30 mm or more of rainfall in 24 hours. Thus even though the mean rainfall is relatively low in coastal Angola, large amounts can fall in a short period and drainage systems need to be capable of dealing with this. It should be noted that the 24-hour maximum rainfall, as a fraction of the mean, is higher in low rainfall areas than in high rainfall areas and the 24-hour maximum rainfall is as high (or higher) along some parts of the relatively dry coast than in the wetter interior.

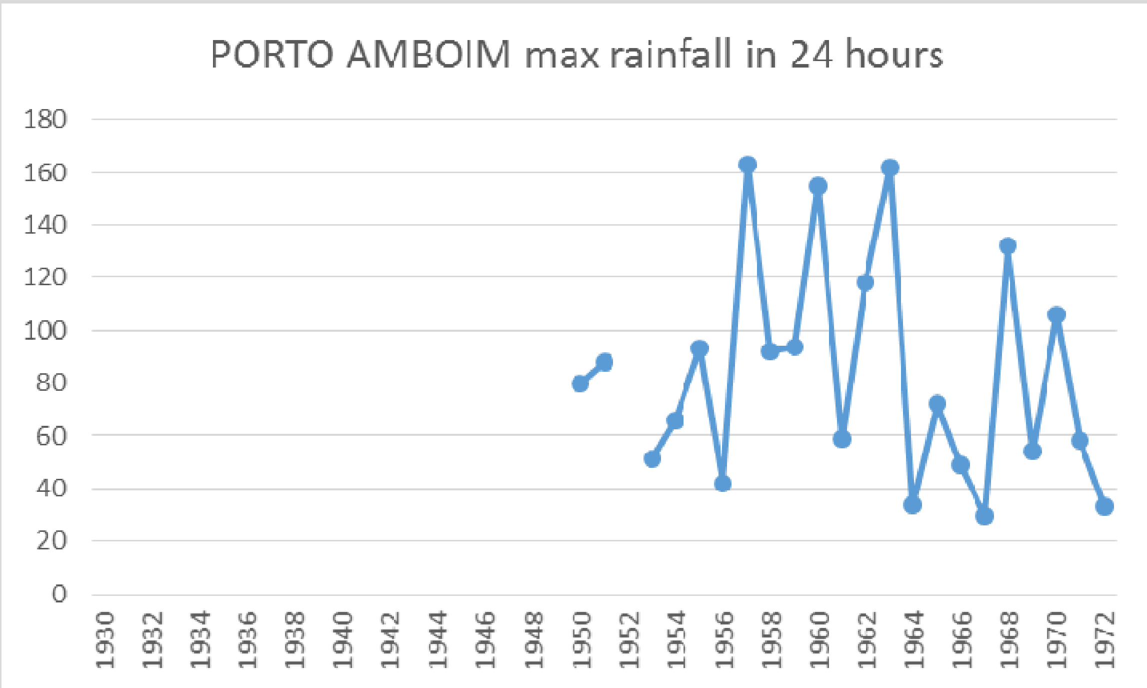
The 24-hour maximum rainfall in one year varies significantly from one year to the next. The years with a high 24-hour maximum rainfall are years with a high total rainfall.

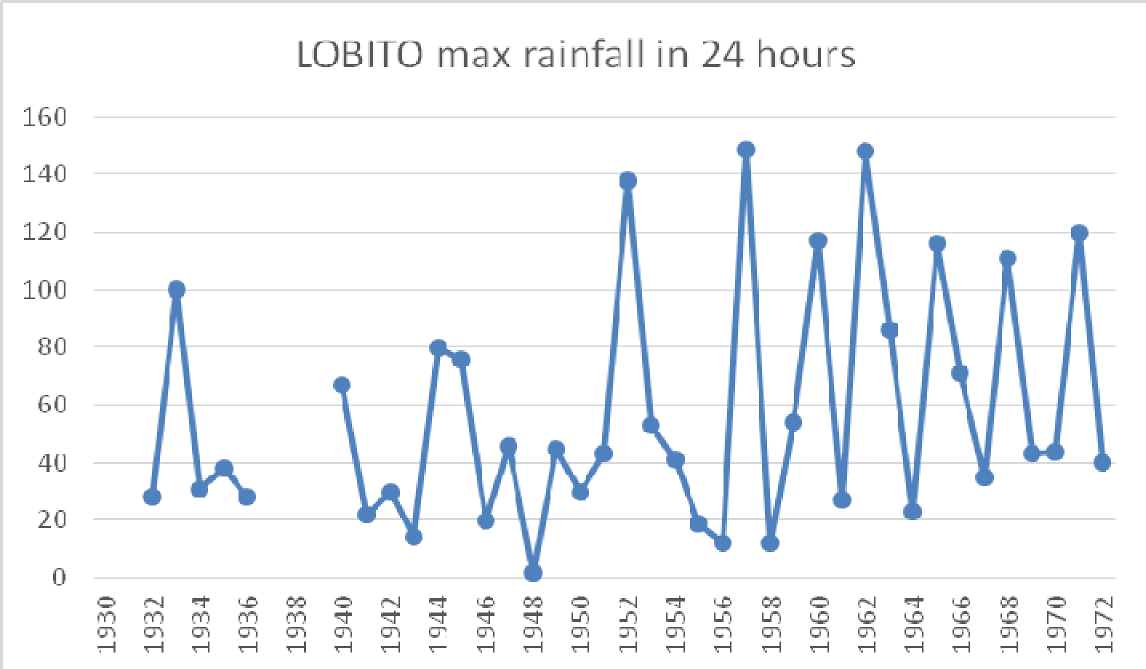
The fact that rainfall occurs in short, heavy and isolated storms implies that, in a region where there are few meteorological stations, some rain storms will not be on the rainfall records. In Angola, where for many years, there has been a very thin network of stations, large numbers of storms that have not been recorded and there may be difficulty in linking flooding events to rainfall. There was flooding in Namibe in March/April 2001 but there is little rainfall recorded at Namibe in this period: the rain probably occurred at some place inland from Namibe as a heavy isolated storm that has not been recorded.

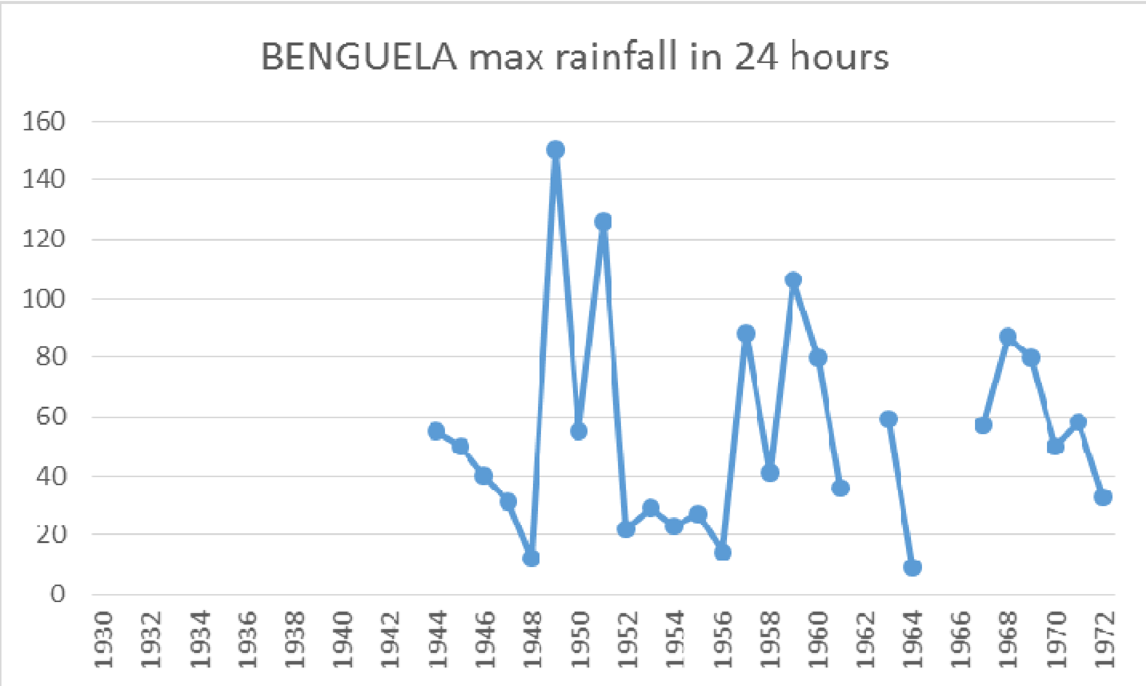
The fact that rainfall occurs in short, heavy and isolated storms also creates difficulty for analysis because it can be difficult to judge whether some high rainfall amounts are a mistake or are real, though exceptional, rainfall. Queiroz (1955) excluded Bibala from his analysis of rainfall variability because, he judged, some of the high rainfall amounts were mistakes. They have been included in the present analysis but it is impossible to know whether they are mistakes or not: the possibility of really exceptional storms in this context is a question that requires further exploration.

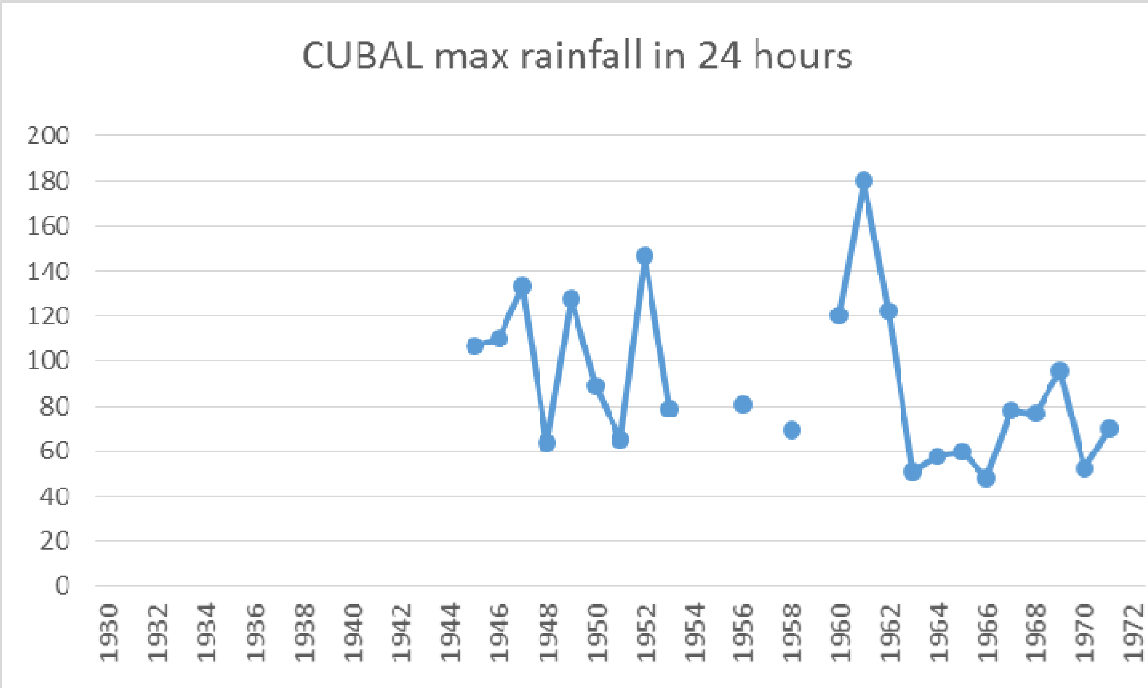


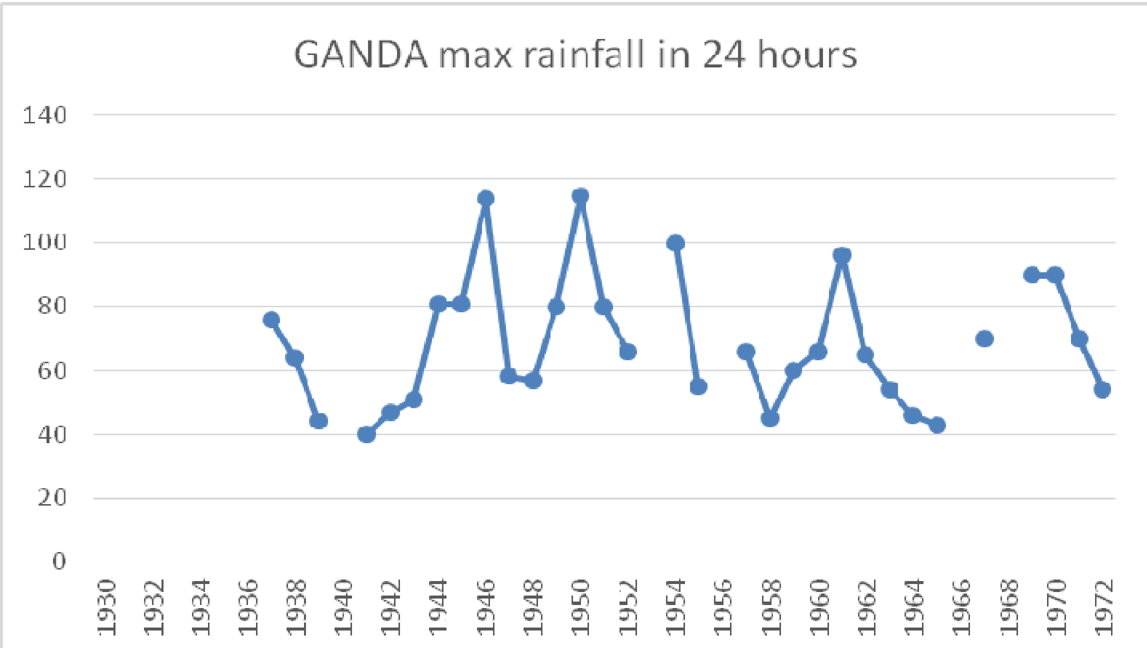

SOYO max rainfall in 24 hours
300
250
200
150
100
50
0
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971

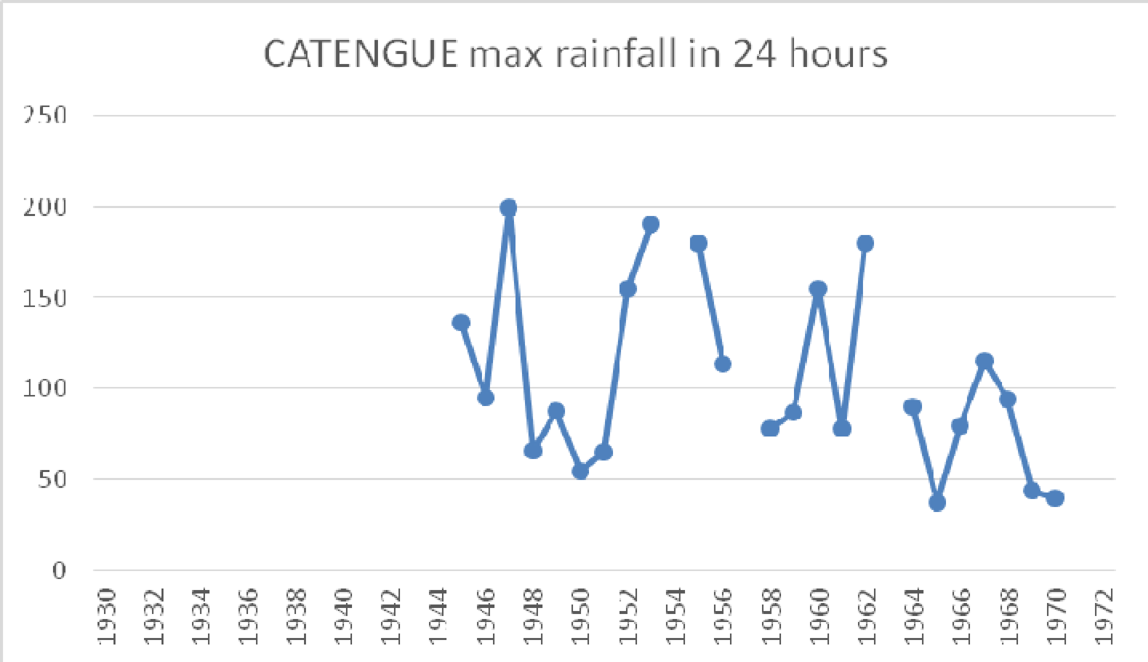

PORTO AMBOIM max rainfall in 24 hours
180
160
140
120
100
80
60
40
20
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972

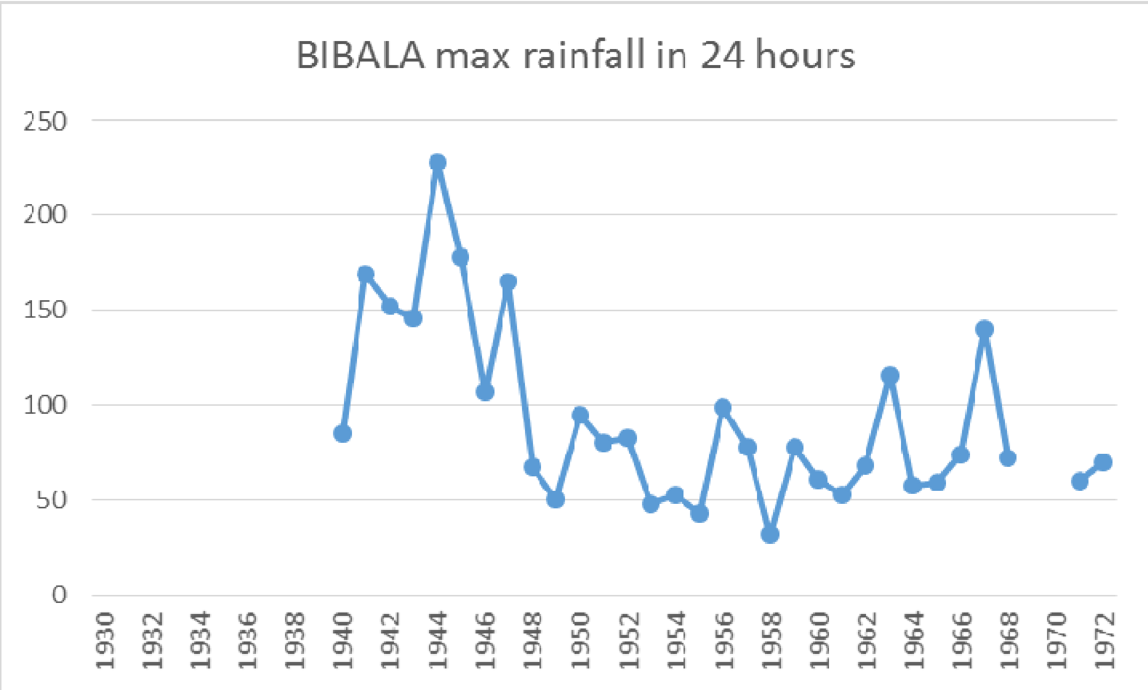

LOBITO max rainfall in 24 hours
160
140
120
100
80
60
40
20
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972

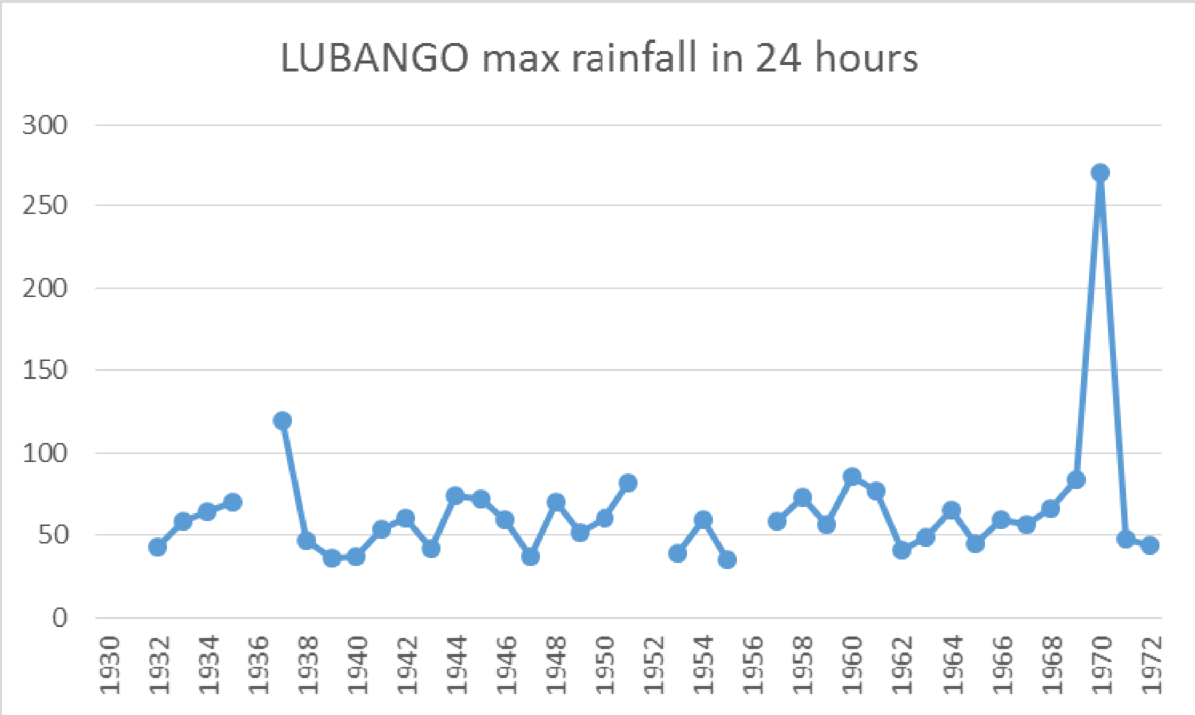

BENGUELA max rainfall in 24 hours
160
140
120
100
80
60
40
20
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972

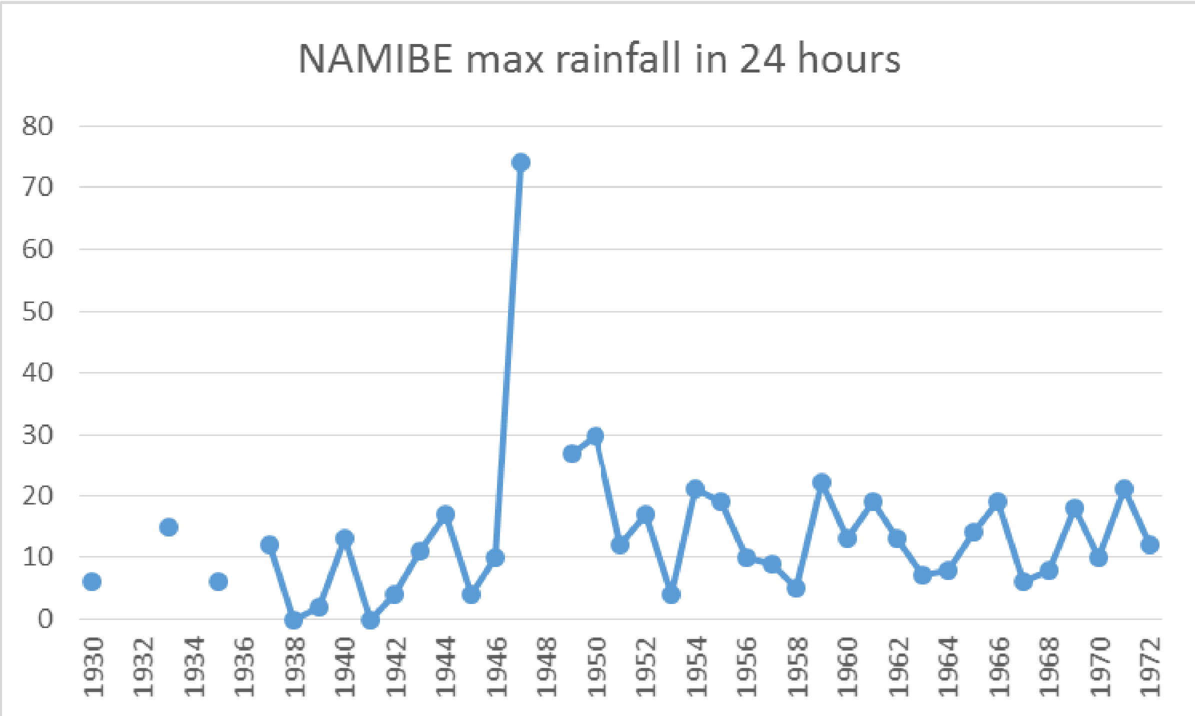

CUBAL max rainfall in 24 hours
200
180
160
140
120
100
80
60
40
20
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972

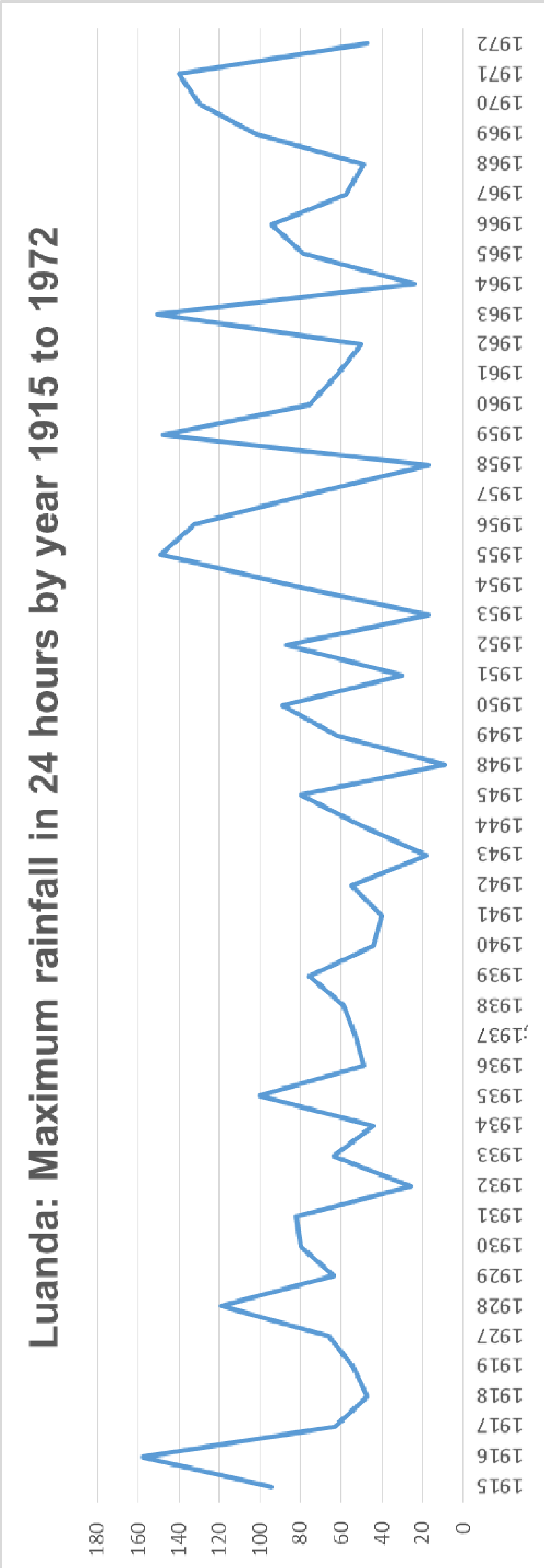

GANDA max rainfall in 24 hours
140
120
100
80
60
40
20
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972


CATENGUE max rainfall in 24 hours
250
200
150
100
50
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972


BIBALA max rainfall in 24 hours
250
200
150
100
50
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972


LUBANGO max rainfall in 24 hours
300
250
200
150
100
50
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972


NAMIBE max rainfall in 24 hours
80
70
60
50
40
30
20
10
0
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972


Luanda: Maximum rainfall in 24 hours by year 1915 to 1972
180
160
140
120
100
80
60
40
20
0
1915
1916
1917
1918
1919
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
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1971
1972

8 Flooding and erosion

The main Angolan urban areas are in relatively low rainfall areas. The cold current that flows from south to north along the coast usually inhibits rainfall, but with the risk in some years of very heavy isolated storms that have a high impact (especially in March and April). Thus even though the mean rainfall is relatively low in coastal Angola, large amounts can fall in a short period and drainage systems need to be capable of dealing with this. Twenty-four hour periods with 100 mm of rain are common and 24-hour periods with more than 200 mm of rain are not unknown. The amount of rain that can fall in 24 hours (which is probably accounted for by one short storm in that day) are as high as at inland stations that have a much higher total rainfall. Given that rain falls in short, heavy and isolated storms, and given the small number of stations in Angola, it is likely that rainfall occurs that is not recorded. The nature of rainfall just inland from the coast is difficult to study because it is difficult to assess how much rainfall increases moving away from the inhibiting effect of the ocean current; such rainfall may feed rivers that can cause flooding in the coastal cities.

There are conditions for flooding in the rapidly growing cities of the coastal regions of Angola. Heavy rainfall in very short periods splashes fine particles of the soil, and deposits them as a water-repellent crust. This increases run-off, and so surface water flow and water levels in rivers can increase rapidly. Cities can also be affected by rainstorms in the urban area itself.

Significant numbers of households in Development Workshop's household surveys say that they have been affected by flooding and erosion (20% of households in Luanda and 6.4% of households in Cabinda). It should be noted that more households in Luanda are affected by flooding and erosion than in Cabinda even though rainfall in Luanda is lower. Flood and erosion risks are not necessarily higher where rainfall is higher and the variability of rainfall is an important factors. Observation in Cabinda suggests that individuals and the Municipal and Provincial government take more mitigation measures because the risks are clearer.

9 Climate change

The high variability of rainfall in coastal and southern areas of Angola makes it difficult to judge whether the climate is changing. A year with high rainfall raises the question of whether it is part of the normal variability or is something abnormal. However under future climate regimes it is unlikely that rainfall variability will be less. Adapting to current rainfall variability will be a big step in adapting to climate change.

Hirabayashi et al (2012) have carried out a global flood risk assessment to the end of the 21st century based on the outputs of 11 climate models. A state-of-the-art global river routing model was employed to compute river discharge and inundation areas. Global exposure to floods would increase, depending on the degree of warming, but inter-annual variability of the exposure may imply the necessity of adaptation before significant warming (as isolated occurrences of rainfall leading to flooding could occur sooner). Most of central Africa (including all of Angola except the extreme southern strip) is predicted to have increased flood risk. In some areas the 100 year flood (for the 20th century) will occur every 75 – 95 years in 2100, but in some areas it might occur every 25 to 50 years.

Drainage systems will need to be designed for exceptional, short-duration storms. Drainage systems in cities will need to be kept clear and clean throughout dry years in readiness for an unexpected, violent storm. Rubbish collection will need to be designed for exceptional, short-duration storms.

10 Conclusions

It has been possible to recover and digitalise monthly rainfall data for 199 stations in Angola and further stations in DRC and Zambia close to the Angola borders. This has allowed some analysis of rainfall patterns in Angola, and in particular rainfall variability in coastal areas.

The pattern of mean annual rainfall derived from this data is not significantly different from that available in previous publications. The issue of rainfall variability is particularly important in the context of Angola, however. The calculation of two measures of rainfall variability demonstrates that rainfall variability is high along the Atlantic coast of Angola and some adjacent areas inland, particularly in the south of the country. It also shows that the area of high rainfall variability extends inland to the western areas of the Malange Plateau around Ndalatando.

Rains in this area tend to fall as very heavy, isolated storms late in the rainy season and a high percentage of the mean annual rainfall can fall in one day. This creates the conditions for flooding in the rapidly growing cities of the coastal regions of Angola. This increases run-off and water level in rivers rises quickly. Cities can also be affected by rainstorms in the urban area itself. Flooding and erosion are common in coastal urban areas in Angola.

Heavy rainfall splashes fine particles on bare soil surfaces in coastal river basins and deposits them as a water-repellent crust. Deforestation in river basins can contribute to this. Reforestation and other measures of vegetation improvement, will reduce surface run-off and decrease peaks in river flows (as well as silting in dams).

The high variability of rainfall makes it difficult to judge whether the climate is changing. However under future climate regimes it is unlikely that variability will be less, and adaptation to the current variability will be a useful step in step to adaptation to climate change. Measures to reduce the impact of heavy rain need to take into account the fact that heavy rainfall events may be rare but the impact can be very severe.

The years in which heavy rainfall occurs tend to be those in which there are higher ocean temperatures off Angola. Understanding the mechanisms that lead to higher ocean temperatures in some years may help to improve warning systems, and to better predictions of whether the climate is likely to change. In the longer term it may be possible to forecast years that are high risk for heavy rains along the coast if have a better understanding of why some years have higher sea temperatures. Work is ongoing, particularly by the Benguela Current Commission, to study these inter-annual changes in the Benguela Current and to explore whether changes can be predicted, and these could contribute to better warning of years in which flood risks are higher in coastal Angola.

It should be noted that ENSO (the El Niño Southern Oscillation), a better known pattern of weather variability, will only be a direct factor in south-east Angola (though El Niño directly affects most of the rest of southern Africa). Weather variation in Angola is not related to ENSO. In the centre-south of Angola, rainfall variability may be linked to the variability of how far south the Inter-tropical Convergence Zone I(TCZ) penetrates southwards and the strength of high pressure over southern Africa preventing the southward movement of the ITCZ.

Potential areas for further study are as follows.

1 Whether the number of years with heavy rain, or the intensity of rain, is tending to increase. There is not enough gauge rainfall data for Angola for recent years to assess this, though the use of satellite-based estimates might allow the study of this question. High variability makes it difficult to detect whether the climate is changing. However improved adaptation to variability will prepare for climate change.

2 Rainfall patterns a few kilometres inland from the coast. There was not a heavy rainfall recorded at Namibe at the time of the March/April 2001 floods. The floods seem to have been caused by heavy rainfall inland but the lack of meteorological stations in such areas makes it difficult to research this. Again the use of satellite-based estimates might allow the study of this question, as in theory they should indicate whether there are areas with heavy rainfall inland from the main meteorological station on the coast.

3 A better understanding of the drivers of variability of rainfall in this region and the linkages with weather systems in the Atlantic. This could allow better forecasting of rain and floods in coastal Angola as well as an indication of possible changes in rainfall intensity and variability patterns.

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