Inventory of Hydro -Meteorological Data of Somalia

Technical Report No. W-03
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1. BACKGROUND

1.1 Introduction

Developing countries; especially in Africa, face great challenges in data and information management. While it is known that centralised database management is a good practice in the field of research, not many countries have managed to achieve this, even with the growing rate of knowledge of information and communication technology. Somalia faces even greater challenges than these countries due to the prolonged civil war. One and a half decade of the civil war in the country have resulted in loss and damage of most water & land related information collected in the previous half century. On the other hand, great numbers of agencies are working in Somalia with different objectives and activities, which have led to disintegration of information. Having realised this, land and water data management and exchange have become important components within the SWALIM project. SWALIM is trying to recover lost information from different sources all over the world and at the same time re-establish data collection networks in collaboration with partner agencies. One area of interest is information and data on hydro-meteorology. A lot of resources and efforts have been put into place by SWALIM in an effort to recover these lost data.

The Food and Agriculture Organisation, Somalia Water and Land Information Management (FAO SWALIM) started working in 2002, when some of the major objectives of the project were, firstly to provide access to information products on land and water for Somalia; and secondly, to provide baseline information on land and water to all stakeholders. As part of the activities to meet these objectives, SWALIM have been mandated to build national streamflow and climate archives, using all available data. The search for river flow and climate data began at that time and has never ceased.

This report presents an inventory of the historical hydro-meteorological data that have been accumulated from various sources, and the hydrometeorological data that are currently being collected by SWALIM in collaboration with partner agencies.

Copies of books, documents, reports and journals have been collected during this recovery exercise. Appendix 1 is a bibliography providing a preliminary list of documents associated with projects and studies in weather observation in the pre-war era. It is not exhaustive as other reports are unknown to SWALIM may yet exist.

Locating hydro-meteorological datasets proved difficult, may be due to the fact that, apart from the then central government, many other agencies were also involved in similar activities. It is apparent that no centralised hydrometeorological database existed previously. SWALIM has, however, located many of these datasets and efforts have been made to standardise them following international standards. The data were consolidated and archived in a common national climate archive.

This document contains inventories of both river flow and climate data of Somalia before and after the civil war. It must be borne in mind that not all the historical data may have been captured in this inventory, but SWALIM continues to collect all related information and therefore the inventory may be updated if and when further data is collected.

1.2 Objectives of the Inventory

Since the end of the foreign-aided hydrometric project in 1989 there has been no inventory of hydro-meteorological data in the country. The main objective of this inventory report is to provide to users the status of the current available hydrometeorological data for Somalia that is also in SWALIM archive.

The report is meant for all such data stakeholders in the country and how they can access this data from SWALIM.

1.3 Structure of the Report

This report is made of three chapters and Appendices. Chapter one is a general overview of the hydrometeorological data and its historical development and recovery by SWALIM. Chapter two presents the temporal hydrometeorological data and its current status with amount of gaps in the data, while chapter three presents the spatial hydrometeorological data obtained through partner agencies and that are available at SWALIM.

2. INVENTORY OF TEMPORAL HYDRO-METEOROLOGICAL TIME SERIES DATA

2.1 Climate Data

The Somalia climate archive held within SWALIM has data dating back to 1894 (in Kismayo) and 1904 (in Mogadishu) recording stations. However, the data is characterised by huge gaps. Figure 1 shows some of the pre-war monitoring stations and whose data has been used in this technical report. Some stations have been left out deliberately because they have very large gaps of missing data while others have very little data that is almost inadequate for climate analysis and does not add any significant value to the database.

Weather monitoring ceased as soon as the civil war erupted in 1991. This saw the loss of all the monitoring systems through vandalism and lack of maintenance. The collapse of the monitoring system was then followed by a period of many years of missing data when the FAO Food Security Analysis Unit (FAO-FSAU) in collaboration with some NGOs and UN agencies re-established few rainfall stations in Somalia in 1997 with the hope of reviving the network of weather observations. Unfortunately this network did not last long due to lack of maintenance and prevailing insecurity.

Though SWALIM have made an effort to re-establish the monitoring network, it has not been achieved fully. Currently rainfall is the only parameter being monitored. The rainfall monitoring network rehabilitated by SWALIM has been re-established to match with the pre-war network; Figure 2 shows a map of the current operational observational network in Somalia.

Efforts to reconcile the climate data have been made, and only those with substantial meaningful details have been considered in this report. Only the rainfall data has significant time series data. Other weather parameters only indicate mean monthly values, with no indication of the time period.

2.1.1 Rainfall data

Through out the period of data recovery by SWALIM, this set of data has been the hardest to get. Many datasets with contradicting information exist, some to unacceptable levels. This is attributed to the fact that, many agencies were involved in climate observations then and it is apparent that there was no standardised methodology applied to data collection and archiving. Most of the agencies collecting data had different objectives and precision may have not been a requirement for them. Some of the agencies or institutions involved in weather observations included;

- Somalia Government “Food Early Warning System”, FEWS
- Fantoli, “Contributo alla Climatologia della Somalia”, Rome 1965
- Large-scale agricultural projects, e.g. the Juba. Sugar .Project
- Civil Aviation Service
- Short periods of data collection by various consultants
- Current data collection by FAO SWALIM and partner agencies

Other secondary sources of climate data included the following:

- Hutchinson and Polishchouk, “Agroclimatology of Somalia”, FEWS, 1989
- FAO Global Climate dataset (FAOCLIM and LOCCLIM)
- University of East Anglia, Climate Research Unit (CRU)
- Australian National University (ANU)
- British Meteorological Office

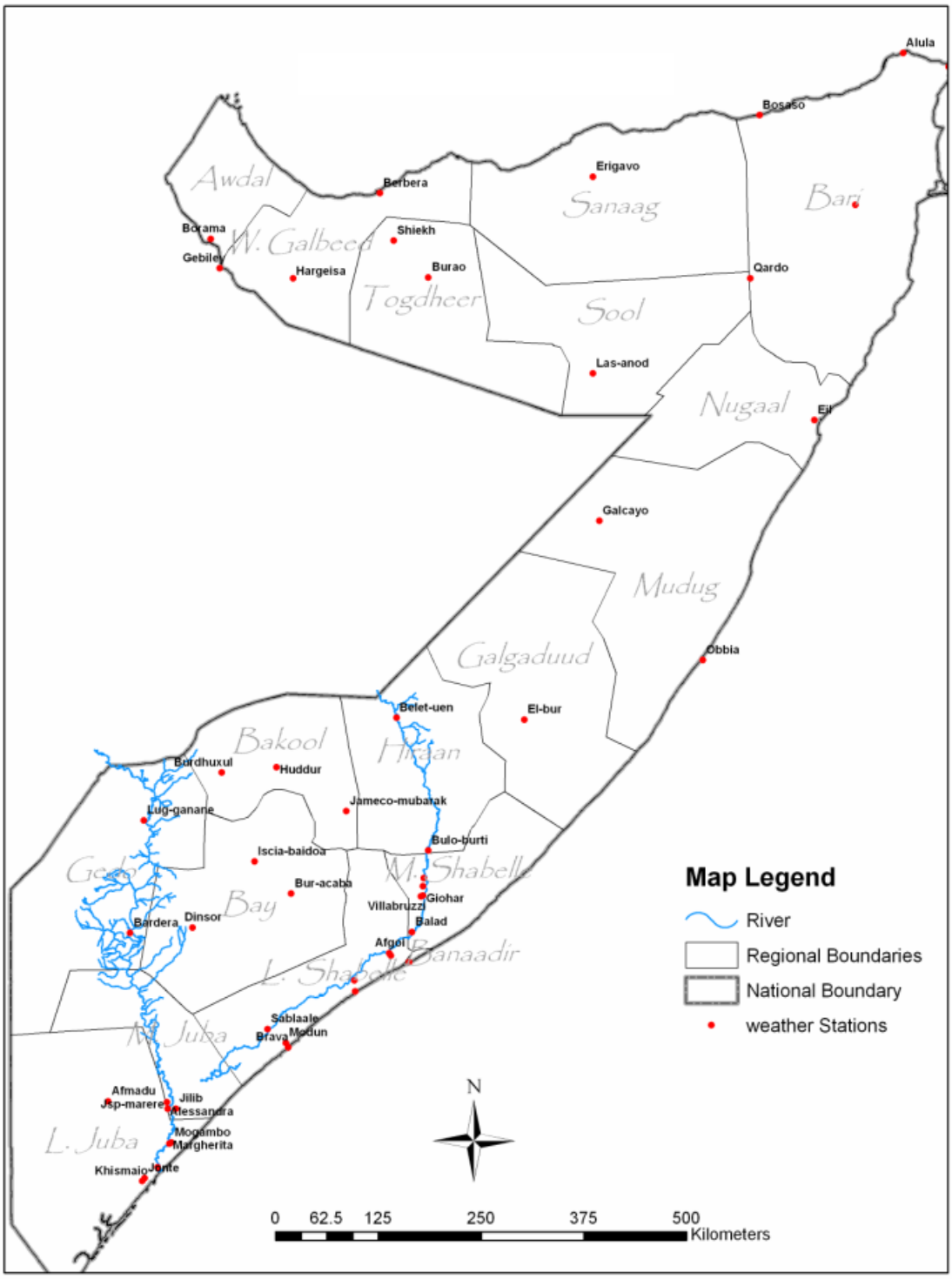


Figure 1: Historical weather monitoring network

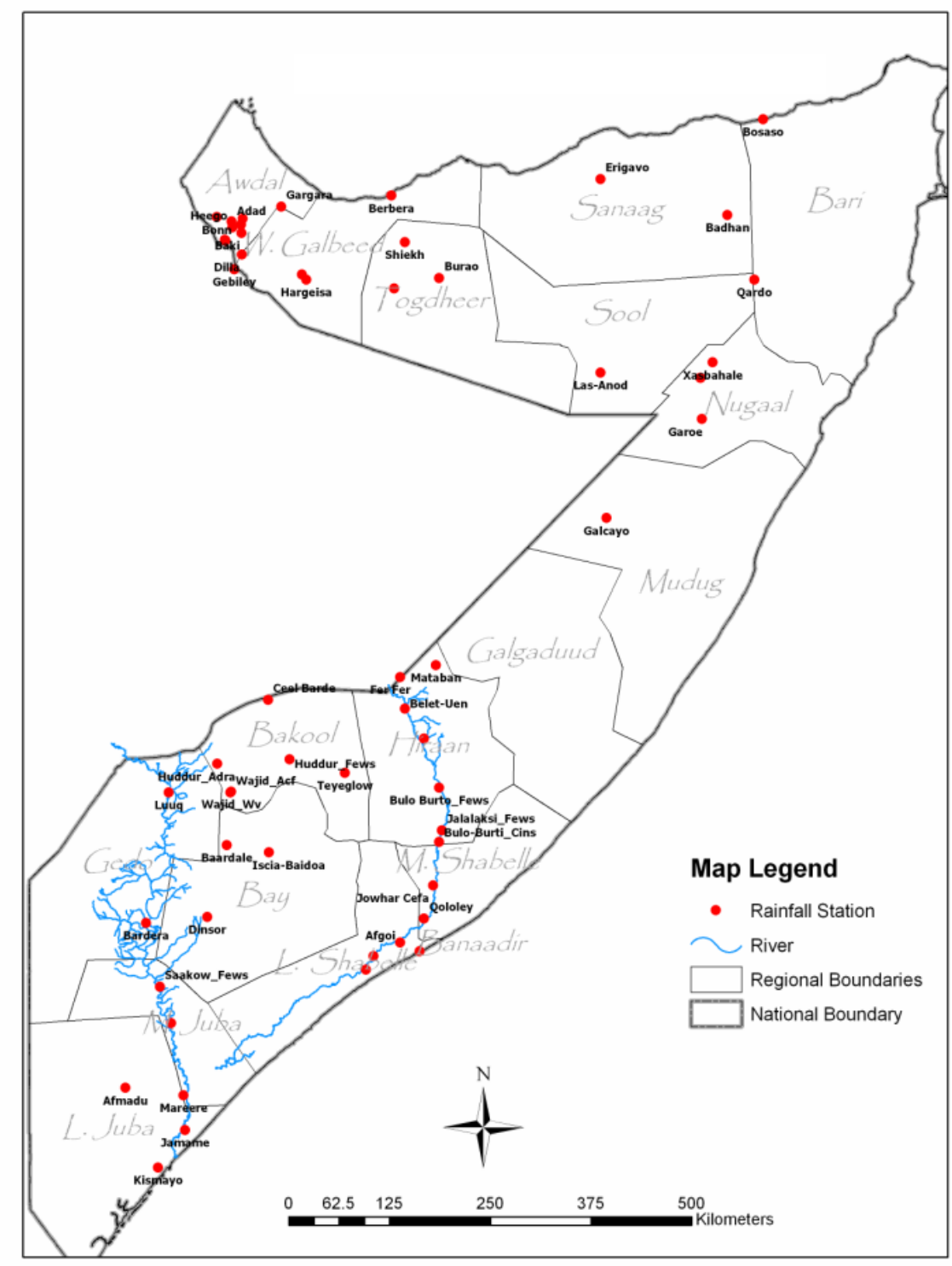


Figure 2: Current rainfall monitoring network in Somalia

Appendix 4 shows the mean monthly time series rainfall data inventory for 42 pre-war rainfall stations. While mean monthly rainfall is available for these 42 stations, the same does not apply to the daily rainfall data, as only few stations have daily rainfall time series records. There are only 12 rainfall stations with daily time serried data as in Appendix 2a.

SWALIM have rehabilitated and installed over 60 rain gauges. The data coming out of this network of 60 stations is transmitted to SWALIM office on a monthly basis. Appendix 3 presents a list of the current functional stations where rainfall data is recorded on daily basis. The appendix also gives the partner agencies responsible for rainfall data collection in Somalia. The distribution of these stations is given in Figure 2.

2.1.2 Agro-meteorological data

Daily time series data for other meteorological parameters does not exist, and if it does the location was unknown by the time this document was written. There are numerous reports that show pieces of datasets regarding the climate of Somalia, but no two reports have similar datasets for a given period. Such data has not been considered in this report due to discrepancies encountered.

Monthly means time series data for mean air temperature however exist, but for only five stations across the country as shown in Appendix 4. Long term mean monthly values for a number of parameters exist. These data was obtained from the global FAO climate data base that is believed to be for the period between 1963 to1990. Parameters include Potential Evapotranspiration (PET), minimum temperature, maximum temperature, vapour pressure; global radiation, sunshine fraction, and wind speed are for the stations shown in the Table 1. Stations that have a long term mean weather parameter were indicated as ‘1’ on the table, and where the long term mean data is not available are indicated as‘0’.

Table 1: Available agro-meteorological data

Station Name	Rainfall (mm)	PET (mm/day)	Mean Temp (^{0}C)	Maximum Temp (^{0}C)	Minimum Temp (^{0}C)	Daytime Temp (^{0}C)	Night Temp (^{0}C)	Vapour Pressure (pascals)	Global radiation (w/m^2)	Sunshine Fraction	Wind speed (m/s)
Afgoi	1	1	1	1	1	1	1	1	1	1	1
Afmadow	1	1	1	1	1	1	1	1	1	1	1
Alessandra	1	1	1	1	1	1	1	1	1	1	1
Alula	1	0	0	0	0	0	0	0	0	0	0
Balad	1	0	1	0	0	0	0	0	0	0	0
Bardera	1	1	1	1	1	1	1	1	1	1	1
Barro-uen	1	0	0	0	0	0	0	0	0	0	0
Belet weyne	1	1	1	1	1	1	1	1	1	1	1
Berbera	1	1	1	1	1	1	1	1	1	1	1
Borama	1	0	0	0	0	0	0	0	0	0	0
Bosaso	1	1	1	1	1	1	1	1	1	1	1
Brava	1	1	1	1	1	1	1	1	1	1	1
Bulo-burti	1	1	1	1	1	1	1	1	1	1	1
Bur-acaba	1	0	1	0	0	0	0	0	0	0	0
Burao	1	0	1	1	1	0	0	0	0	0	0
Burdhuxul	1	0	0	0	0	0	0	0	0	0	0
Capo-guardafui	1	0	1	0	0	0	0	0	0	0	0
Dinsor	1	0	0	0	0	0	0	0	0	0	0
Eil	1	0	1	0	0	0	0	0	0	0	0
El-bur	1	1	1	1	1	1	1	1	1	1	1
El-mugne	1	1	1	1	1	1	1	1	1	1	1

Station Name	Rainfall (mm)	PET (mm/day)	Mean Temp (^{0}C)	Maximum Temp (^{0}C)	Minimum Temp (^{0}C)	Daytime Temp (^{0}C)	Night Temp (^{0}C)	Vapour Pressure (pascals)	Global radiation (w/m^2)	Sunshine Fraction	Wind speed (m/s)
Erigavo	1	0	1	1	1	0	0	0	0	0	0
Galcayo	1	1	1	1	1	1	1	1	1	1	1
Gebiley	1	0	0	0	0	0	0	0	0	0	0
Genale	1	1	1	1	1	1	1	1	1	1	1
Jowhar	1	1	1	1	1	1	1	1	1	1	1
Giumbo	1	0	1	0	0	0	0	0	0	0	0
Hargeisa	1	1	1	1	1	1	1	1	1	1	1
Huddur	1	1	1	1	1	1	1	1	1	1	1
Baidoa	1	1	1	1	1	1	1	1	1	1	1
Jameco-mubarak	1	0	0	0	0	0	0	0	0	0	0
Jilib	1	0	0	0	0	0	0	0	0	0	0
Jonte	1	1	1	1	1	1	1	1	1	1	1
Mareere	1	0	0	0	0	0	0	0	0	0	0
Kismayo	1	1	1	1	1	1	1	1	1	1	1
Lafoole	1	0	0	0	0	0	0	0	0	0	0
Las-a0d	1	0	1	0	0	0	0	0	0	0	0
Luuq	1	1	1	1	1	1	1	1	1	1	1
Mahaddei-uen	1	0	1	0	0	0	0	0	0	0	0
jamaame	1	0	1	0	0	0	0	0	0	0	0
Modun	1	0	0	0	0	0	0	0	0	0	0
Mogadishu	1	1	1	1	1	1	1	1	1	1	1
Mogambo	1	0	0	0	0	0	0	0	0	0	0
Obbia	1	1	1	1	1	1	1	1	1	1	1

2.2 Hydrometric Data

The two oldest hydrometric stations are the uppermost stations of Luuq, in Juba, and Belet Weyne in Shabelle, river basins respectively. Records of water level readings for the two stations are dated back to 1951. Other stations were established in 1963 by an FAO funded project. The gauging network deteriorated over the subsequent 20 years until the 1980s when a project led by the Institute of Hydrology of the UK rehabilitated most of the stations, Mc Donald (1989). Due to the civil war in 1990s, the hydrometric network fell into complete disrepair with no monitoring or collection of water level data in either of the two rivers within the Somali territories.

All hydrometric data that have been recovered is archived in HYDATA, which is a dedicated database software that has the capability to store and analyse hydrometric data developed by the Institute of Hydrology. The database contains both historical and current river level data. The parameters of the rating equations for all of the stations are also included in the HYDATA database. Hydrometric data available in SWALIM is discussed in the following subsequent sub topics.

2.2.1 Discharge measurements and ratings

Direct river flow measurements were carried out between 1963 and 1989 by all agencies that were involved in hydrometric activities. Before then, no direct discharge measurements were carried out. Table 2 shows the number of gaugings that were carried out for individual stations on the Juba and Shabelle Rivers. These gaugings (discharge measurements) represents three stages of the flow hydrograph; low, medium and high flows. The stage-discharge relationship from these measurements was the one used to develop the rating equations and curves that have been in use up to date. More information on the rating curves is given in section 2.2.2.

Table 2: River Flow measurement on the Juba and Shabelle

Station name and Code	Latitude	Longitude	Elevation (m)	Area Km^2	No. of Gaugings	No. of Ratings
Luuq (1)	3:47:30 N	42:32:30 E	141.4	166000	121	3
Bardhere (2)	2:20:30 N	42:17: 0 E	89	216730	79	1
Jamaame (3)	0: 1:10 N	42:41: 0 E	0	268800	52	1
Kaitoi (4)	0:47:30 N	42:40: 0 E	25	240000	171	1
Mareere (5)	0:27: 0 N	42:42: 0 E	10	240000	15	1
Mogambo (7)	0: 9: 0 N	42:44: 0 E	0	260000	1	2
Belet Weyne (10)	4:44: 0 N	45:12:20 E	176.1	207000	87	2
Bulo Burti (11)	3:51:20 N	45:34:20 E	133.4	231000	66	3
Mahadey Weyne (12)	2:58:20 N	45:31:50 E	104.6	255300	64	2
Balcad (13)	2:21: 0 N	45:23:30 E	95	272700	56	2
Afgoi (14)	2: 8:40 N	45: 7:30 E	77.4	278000	64	2
Audegle (15)	1:59:10 N	44:50: 0 E	70	280000	40	3

2.2.2 Rating curves and tables

River flow for the Juba and Shebelle Rivers are calculated based on a relationship between the discharge and the gauge height readings established during periods of foreign-aided projects between 1963 -1989. All the river level data have been converted to discharge and therefore the river discharge and stage data are available for the same periods. No further river gauging has been carried out since 1989 and this alone calls for concern given the changing morphology of the two rivers.

For every gauging station a rating table exists as well as the rating curves. Appendix 5 shows the rating equations for all the stations both on the Juba and Shabelle Rivers. The relationship for all stations is given by the following formula:

$$Q = a\ x\ (H + c)^b \quad for \quad H \le H_{\max}$$

Where; Q is the river flow (discharge), a, b and c are constants; H is the measured (observed) stage and H_{max} is the highest river level for which the relationship is valid. H_{max} varies from station to another.

The same rating equations/curves are currently in use at stations where river level readings have been re-established since the collapse of the hydrometric networwk. It is recommended these curves be updated from time to time to reflect changes in river morphologies. SWALIM will update these curves after complete rehabilitation of the hydrometric monitoring network.

2.2.3 Discharge and water level datasets

River flow and water level data exist for the Juba and Shabelle rivers in Somalia. Apart from Belet Weyne and Luuq, which are the two most important stations on the Shabelle and Juba rivers respectively, started recording river levels in 1951, other stations began recording in 1963. However, records for the period 1951-1962 are intermittent and their accuracy is uncertain, as limited and vague information exists about zero-datum during this period.

Although 1963 saw the establishment of other hydrometric stations, maintenance of the network was irregular and there are inevitable gaps of missing data corresponding to periods between foreign-funded projects. Appendix 3 provides the pre-war (historical) river level data that is available in SWALIM archives. All historical river flow and river level data were obtained from the Centre for Ecology and Hydrology (CEH); formerly known as the Institute of Hydrology (IH) in the United Kingdom.

The hydrometric network collapsed in the late 1990 and data collection ceased. In 2001, SWALIM rehabilitated Luuq and Bardheere gauging stations and later in 2002 Belet Weyne and Bulo Burti recording stations were rehabilitated. River level observations have continued since then at these four sites. It was necessary to make two assumptions at the time of re-established of these stations: Firstly that the staff gauges were at the same zero levels as the pre-war stations, and secondly that the stage-discharge relationship was also the same in the per-war era. River level observations are ongoing at these 4 sites. The inventory of the post-war river levels that is held in the flow archive of Somalia within SWALIM is included in Appendix 6 while the daily discharge data available within SWALIM is presented in Appendix 6a for individual river gauging stations and for specific years of data availability.

3. INVENTORY OF SPATIAL HYDRO-METEOROLOGICAL DATA

3.1 Climate maps

This type of data was developed using available data from the FAO global climate database by interpolation using the new FAO Local Climate software (LocClim). The software was developed by FAO to provide an estimate of climatic conditions at locations for which observations are not available or scare. The software utilises the stations available in the FAO global database and was designed to take care of topographic effects into considerations. User specific stations can also be added to the database. The Inverse Distance Weighting method (IDW) was applied at a grid size of 9.5x 9.5 Km. Data from neighbouring countries (Ethiopian and Kenya) were also used during the interpolation process. The following climate maps were produced and are available in SWALIM archives:

- Mean monthly rainfall distribution maps (12 maps for January to December)
- Seasonal rainfall distribution maps (A map for the Gu and one for Deyr seasons)
- Mean annual rainfall (MAR)distribution map
- Mean Monthly air temperature maps (12 maps for January to December)
- Mean annual air temperature map
- Mean annual potential evapotranspiration map
- Mean annual wind speed map
- Mean annual relative humidity map
- FAO Eco-Climate map for Somalia

Figure 3 presents an example climate map for Somalia. More details are available in SWALIM Technical Report N^{o} W-01.

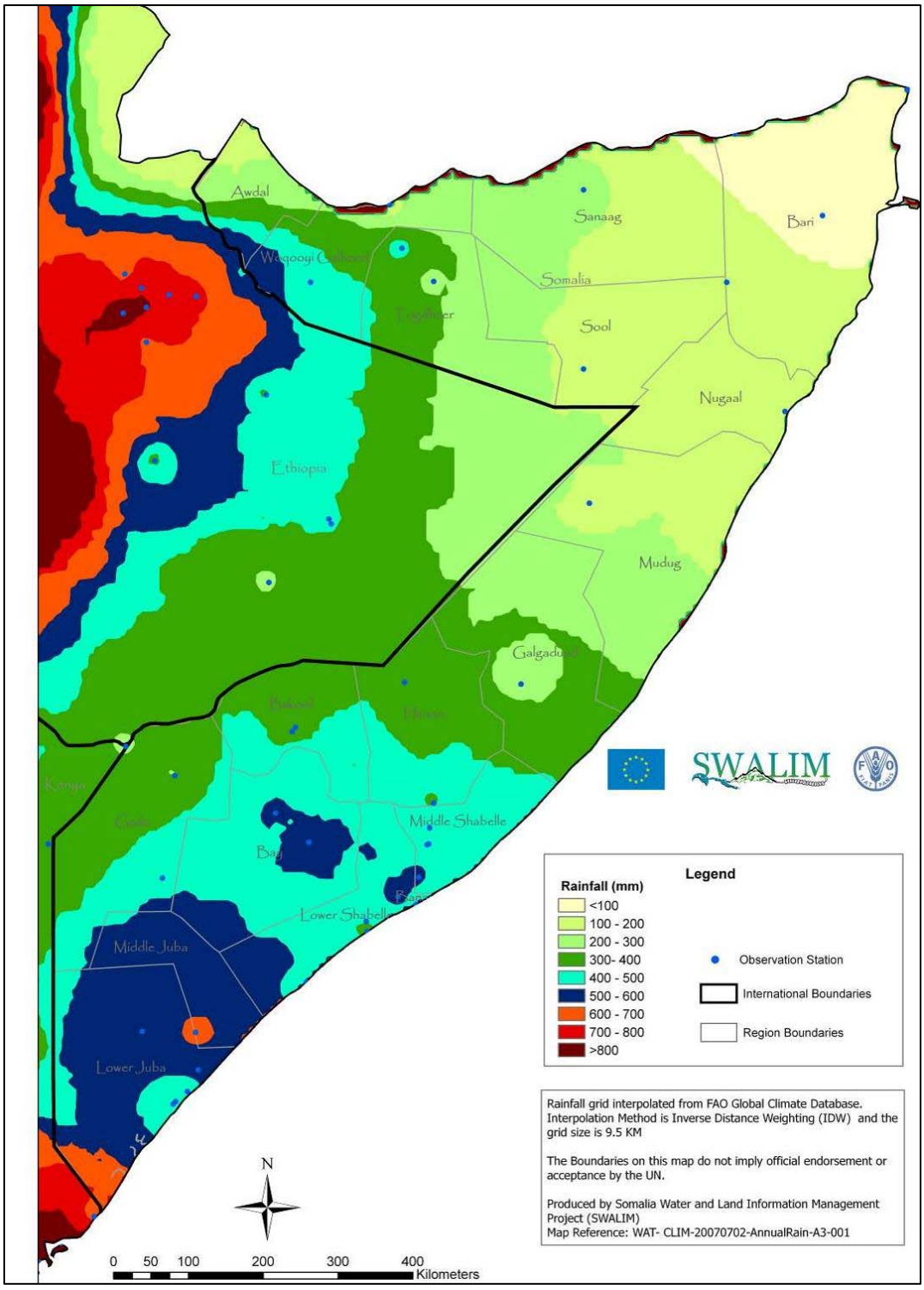


Figure 3: Example climate map – Mean annual rainfall map of Somalia

3.2 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) provides a measure of the amount and vigour of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the vegetation being observed. In general, higher values of NDVI indicate greater vigour and amounts of vegetation. NDVI is derived from data collected by National Oceanic and Atmospheric Administration (NOAA) satellites, and processed by the Global Inventory Monitoring and Modelling Studies group (GIMMS) at the National Aeronautical and Space Administration (NASA).

The NOAA-Advanced Very High Resolution Radiometer (AVHRR) collects the data that are used to produce NDVI. The scanning radiometer (comprised of five channels) is used primarily for weather forecasting; however, there are an increasing number of other applications, e.g., drought monitoring. NDVI is calculated from two channels of the AVHRR sensor, the near-infrared (NIR) and visible (VIS) wavelengths, using the following algorithm:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Where *NIR* is the near infrared channel of the electromagnetic spectrum and *VIS* is the visible channel. NDVI is a nonlinear function that varies between -1 and +1 (undefined when NIR and VIS are zero). Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation.

Since the late 1980's, the Famine Early Warning System Network (FEWS NET) has used NOAA AVHRR satellite data to produce dekadal (10-day) composite NDVI images for Africa, and has built a valuable archive of these data from mid 1981 to present. This data is also available in SWALIM archive. An example of NVDI map is shown in Figure 4.

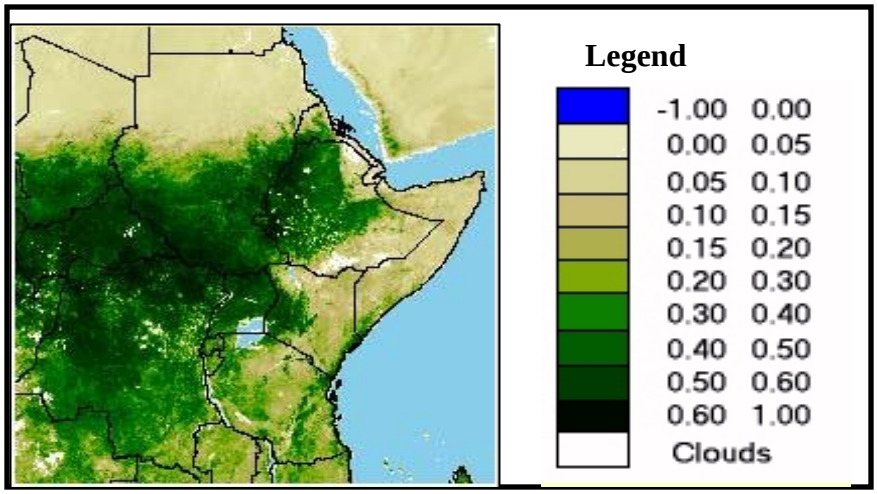


Figure 4: Example NDVI map for the Horn of Africa Region

3.3 Satellite Rainfall Estimates (RFE) Data

Satellite Rainfall Estimates (RFE) was implemented by NOAA's Climate Prediction Centre. Satellite rainfall estimates were operational from 1995 through 2000, Herman et al, (2001). Version 1.0 used an interpolation method to combine METEOSAT satellites and Global Telecommunication System (GTS) data, and included cold cloud information for the dekadal estimates while version 2.0 (RFE 2.0) uses additional techniques to better estimate precipitation while continuing the use of cold cloud duration, or CCD (derived from cloud top temperature), and station rainfall data.

METEOSAT 7 Geostationary satellite infrared data are acquired every 30-minute intervals, and areas depicting cloud top temperatures of less than 235 ^{0}K (- 40 ^{0}C) are used to estimate convective rainfall. The World Meteorological Organization (WMO) GTS data from approximately 1 000 stations provide rainfall totals, and are taken to be the true rainfall within 15-km radii of each station. Two new satellite rainfall estimation instruments are incorporated into RFE 2.0, namely, the Special Sensor Microwave/Imager (SSM/I) on board Defence Meteorological Satellite Program, and the Advanced Microwave Sounding Unit (AMSU) on board NOAA satellites. SSM/I estimate are acquired at 6-hour intervals, while AMSU rainfall estimates are available every 12 hours. RFE 2.0 obtains the final daily rainfall estimation using a two part merging process, then sums daily totals to produce dekadal estimates. All satellite data are first combined using the maximum likelihood estimation method, then GTS station data are used to remove bias.

For many years RFE data have replaced observed rainfall data where it does not exist. Somalia does not have a well represented network of rainfall observation and until such is acquired RFEs will continue to replace it. RFE are currently used by SWALIM in the production of flood watch bulletins. The RFE shows an indication of rainfall activity in the region and at many times the RFEs are qualitative rather than quantitative. As no Global Telecommunication System (GTS) data for Somalia are currently used, the ground calibration is yet to be done and rainfall amounts rely only on remotely sensed measurements.

The daily RFE grids available in SWALIM archives are for the period of 1995 to current. The grids are 8.0 Km spatial resolution grids and are in Albers equal area (conic) projection. An example of an RFE map is as shown on Figure 5.

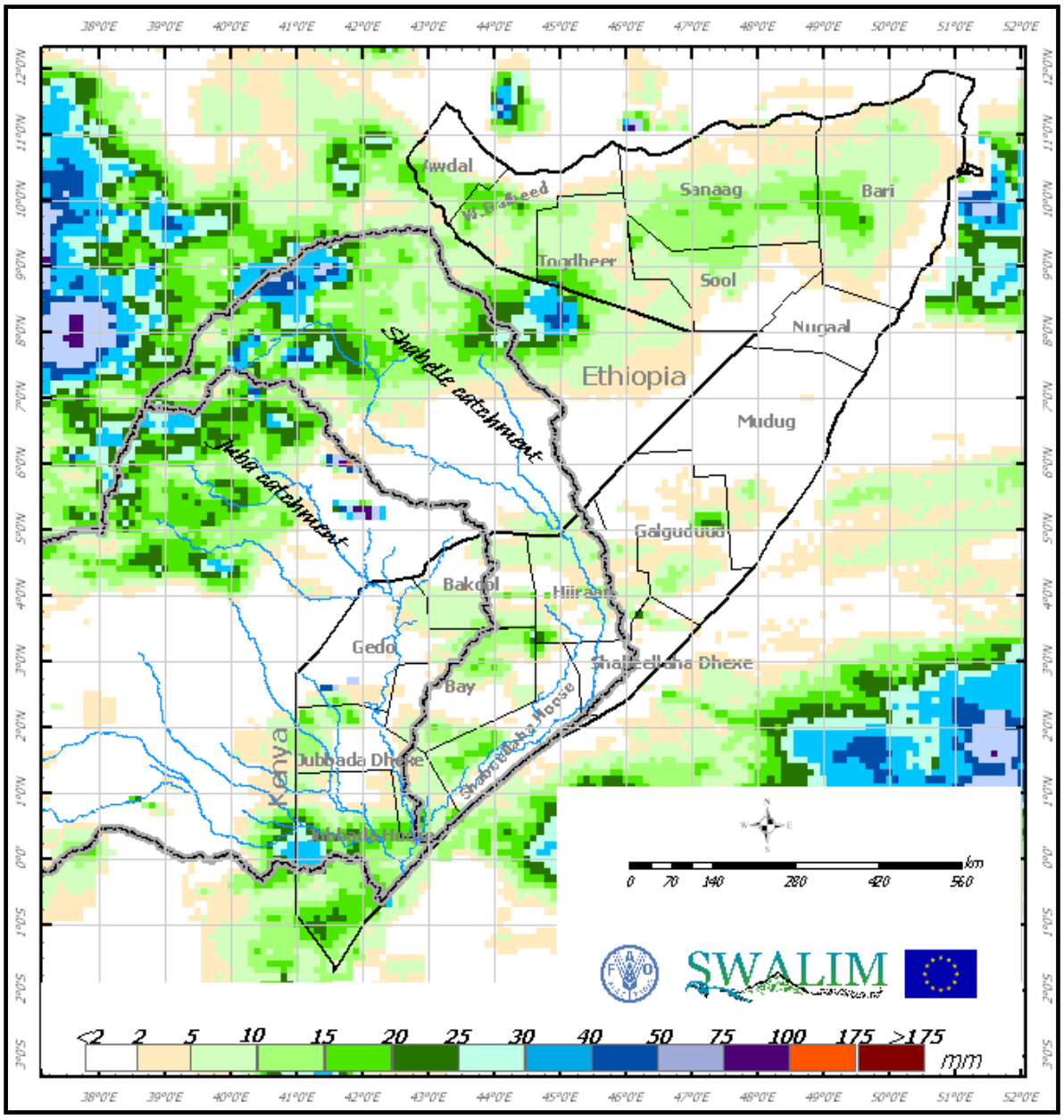


Figure 5: Example rainfall estimate map for Somalia and neighbouring countries

3.4 Potential Evapotranspiration (PET)

Evaporation data are scarce and generally availability is very low over the African continent. NOAA produces daily estimates of precipitation and evaporation for Africa. The Evapotranspiration data is derived by the U. S. Geological Survey, Earth Resources Observation and Science (EROS) by utilizing the Global Data Assimilation System (GDAS) of NOAA using the Penman-Montieth equation, Penmann (1957). The USGS geospatial Stream flow Model (GeoSFM) interface contains procedures for ingesting the resulting PET grids and computing actual daily evapotranspiration based on antecedent soil moisture conditions. Daily PET grids are available within SWALIM archive for the period 2001 to present.

3.5 Juba and Shabelle Catchments

SWALIM in collaboration with the USGS produced high resolution spatial datasets for the Juba and Shabelle catchments covering the three countries, Kenya, Ethiopia and Somalia. The data available for the catchments and that was derived using the recently released 30-m resolution Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) include; slope, drainage network, flow accumulation, flow direction and sub basins processing units.

Appendices

Appendix 1: Bibliography of hydro-meteorological data of Somalia

1 Agrar und Hydrotechnik GMBH (1985)
Hydrology of the Juba River
Keywords: climate general, Climate analyisis, Rainfall data, Evaporation
Location: Unknown

2 Agrar und Hydrotechnik GMBH (1985)
Hydrology and Water management
Keywords: climate general, Climate analyisis, Rainfall ata, Evaporation
Location: Unknown

3 Fantoli A (1962)
Le prime misure della radiazione globale in Somalia
Location: FAO library

4 Fantoli A (1966)
Alcuni elementi relativi alla climatologia della Somalia.
Location: FAO library

5 Fantoli A (1962)
Contributo alla climatologia della Somalia. Riassunto dei risultati e tabelle meteorologiche e pluviometriche
Keywords: Evaporation Data, Rainfall Data, Runoff data
Location: FAO library

6 FAO 1977
Water Use in Irrigated Agriculture
Keywords: Rainfall data, Evaporation, rainwater harvesting, runoff data.
Location: SWALIM

7 FAO (1984)
Agroclimatological data Vol 1
Keywords: Rainfall data, Evaporation Data

8 FEWS – Ministry if Food and Agriculture somalia 1986 - 1988
Daily, Monthly and Annual Rainfall for Somalia Technical Reports
Keywords: Rainfall Data
Description: contains 10 technical reports holding some of the rainfall data for all regions in Somalia from different sources.
Location: SWALIM

9 Griffiths J.F (1972)
Climates of Africa

Keywords: Climate genaral, Evaporation, Rainfall data Climate analysis
Location: SWALIM

10 GTZ, (1984)
Proposal for Programme Implementation in the somali democratic Republic
Location: Unknown

11 Hacrow and partners (1980)
Northern Rangeland development project- hydrology report
Keywords: climate analyisis, Rainfall data, Evaporation
Location: unknown

12 Heather Musgrave (2002)
Drought and Hydrological variability in Southern Somalia
Keywords: Drought , rainfall
Location: SWALIM

13 Hundertmark. W (2001)
Water sectro Assessment in the Lower Juba
Keywords: Rainfall, Water Resources

14 Hunt John A. (1951)
A General Survey of the Somaliland Protectorate 1944-1950
Keywords: climate Genaral, Rainfall data, Evaporation
Location: SWALIM

15 Hunting technical services (1983)
Bay Regional Agricutural development project Vol I - III
Keywords: Climate genaral, Evaporation, Rainfall data Climate analysis

16 Idrotechnico, (1976)
Hydrogeology study in the Bur region
Location: unknown

17 Lahmeyer Int. (1986)
Shabelle Water Strategy(Vol 1-3)
Keywords: climate Genaral, Rainfall data, Evaporation
Location: SWALIM

18 Lockwood Surveyor CR (1968)
Agricultural and water surveys (Vol 1,2 and final report)
Keywords: water Resources, climate of Somalia FAO HQ
Location: SWALIM

19 Macfadyen W. A., (1950)
Water Supply and Geology of Parts of British Somaliland
Keywords: climate general, Climate analyisis, Rainfall data, Evaporation
Location: SWALIM

20 Meteorological service -Somalia (1986)
Climatological data, tables of monthly means 1954-1980
Keywords: Climate gen, Evaporation, Rainfall Data,
Location: SWALIM

21 P.Hutchinson (1992)
The Southern Oscillation and prediction of deyr season rainfall in Somalia
Keywords: Rainfall

22 P.Hutchinson, O. Polishchouk (1989)
The Agroclimatology of Somalia
Keywords: Climate data
Location: SWALIM

24 Pozzi et al.(1984)
Ground water resources in Hoboy(mudug Region - Central Somalia)
Keywords: Climate General, Water Resources
Location: unknown

25 Sir Macdonald & Partners Limited (1969)
Project for Water control and management of Shabelle River Vol II A - The Balad Flood Irrigation Project Feasibility Study Technical Annex
Location: SWALIM

26 Sogreah(1981)
North west region Agricultural development Project
Keywords: climate general, Climate analyisis, Rainfall data, Evaporation
Location: unknown

27 WMO (1990)
Daily Rainfall and Decadal Rainfall of somalia (1980 - 1990)
Location: Regional office WMO (Nairobi)

28 World Bank (1981)
Somalia Agricultural Sector Review climate
Keywords: general,Rainfall data, Evaporation, rainwater harvesting, runoff data.
Location: FAO Rome

29 USGS 1995 -2005
Global decadal RFE data Rainfall Estimates
Location: http://igskmncnwb015.cr.usgs.gov/adds/

30 C.R.Print 1996
Rainfall, Environment and Water Resources Development in Somaliland and Sahel
Location: SWALIM

31 Gifffiths, J.F. 1972
World survey of climatology
Link http://www.ncdc.noaa.gov/oa/climate/ghcn/colonial/africa/africa.html

32 Gommes R and Petrassi (1994)
Rainfall variability and and drought in Sub saharan Africa since 1960
Keywords: rainfall, Drought, Rainfall Variability and Drought in Sub-Saharan Africa
Location: Unknown

33 Morgan M. J (1972)
Surface water resources. -Report to the government of Somalia
Keywords water resources
Location: FAO HQ
Link: http://www4.fao.org/cgi-bin/faobib

34 Martyn D. 1992
Climates of the world
Keywords: continental climate; oceanic climate; solar energy; duration; insolation; atmospheric pressure; winds; temperature; humidity; clouds; precipitation;
http://www4.fao.org/faobib/index.html

35 CLimate Research Unit (CRU)
Precipitaion and Temperature data temperature and rainfall
Location: SWALIM (http://www.cru.uea.ac.uk/cru/data/hrg.htm

36 WeatherBase Monthly rainfall and temperature for some stations in Somalia
Keywords: rainfall, temperature
Location: SWALIM
Link: http://www.weatherbase.com

37 Hutchison P 1990

Frequency distributions of daily, monthly, seasonal and annual rainfalls in Somalia, and their use in the generation of rainfall distributions in data deficient areas
Location: Uk met library

38 Ali F. M 1969
Organization and training in the Somali Meteorological Service.
Keywords: rainfall, temperature
Location: Uk met library

39 EAMD 1949
Summary of the Meteorological Observation in Somalia.
Keywords: Meteorology
Location: Uk met library

40 Hutchnison P. 1989
Climatic Zoning for Agroforestry in Somalia.
Location: Uk met library

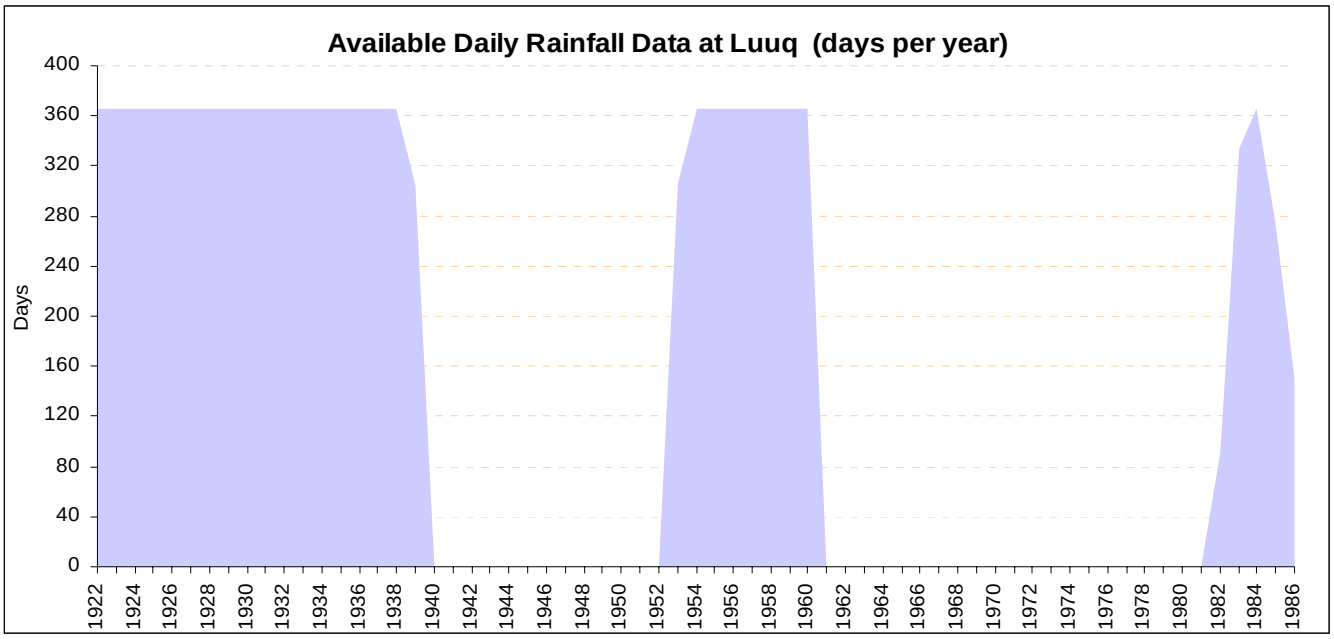
41 Vojtesak, M.J 1990
SWANEA(south Asia- northeast Africa). A climatology study. Vol.1 The Horn of Africa.
Keywords: climatology
Location: Uk met library

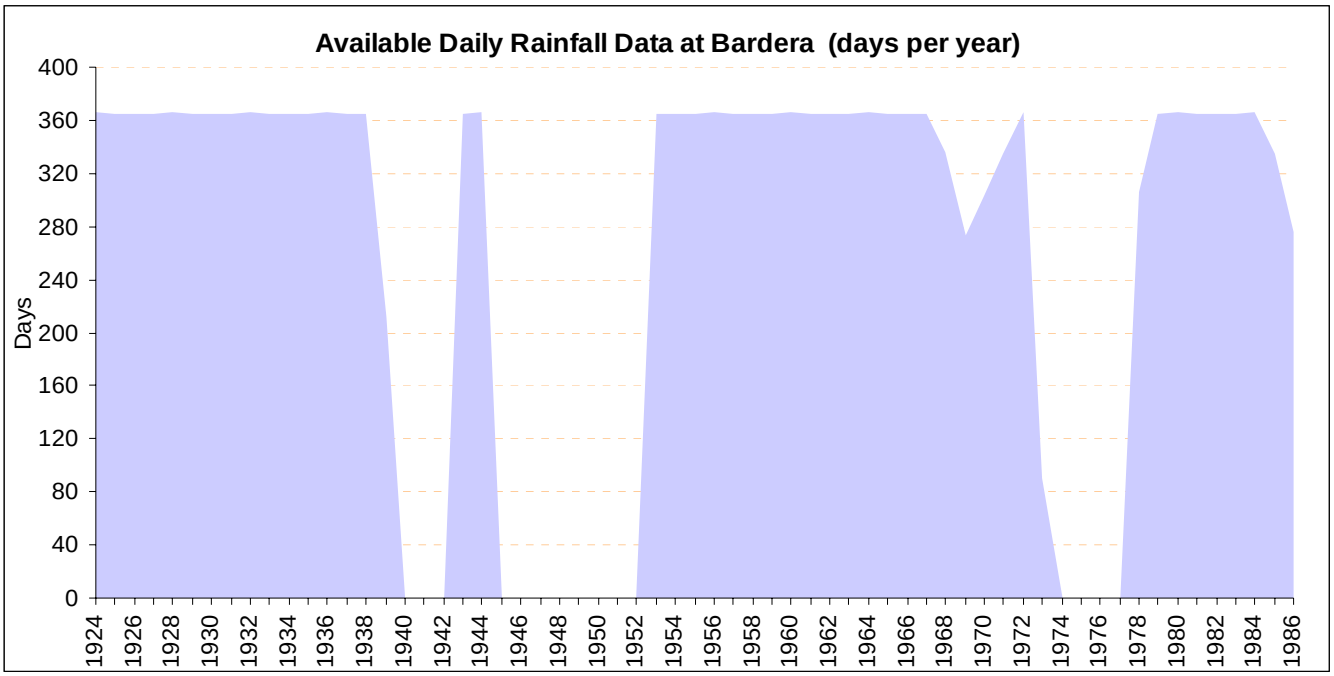
42 Constantini, F. 1970
Le piogge in Somalia e possibiiita' di previsione dei loro quantitativi stagionaii. (The rains in Somalia and the possibility of forecasting their seasonal quantity)
Location: Uk met library

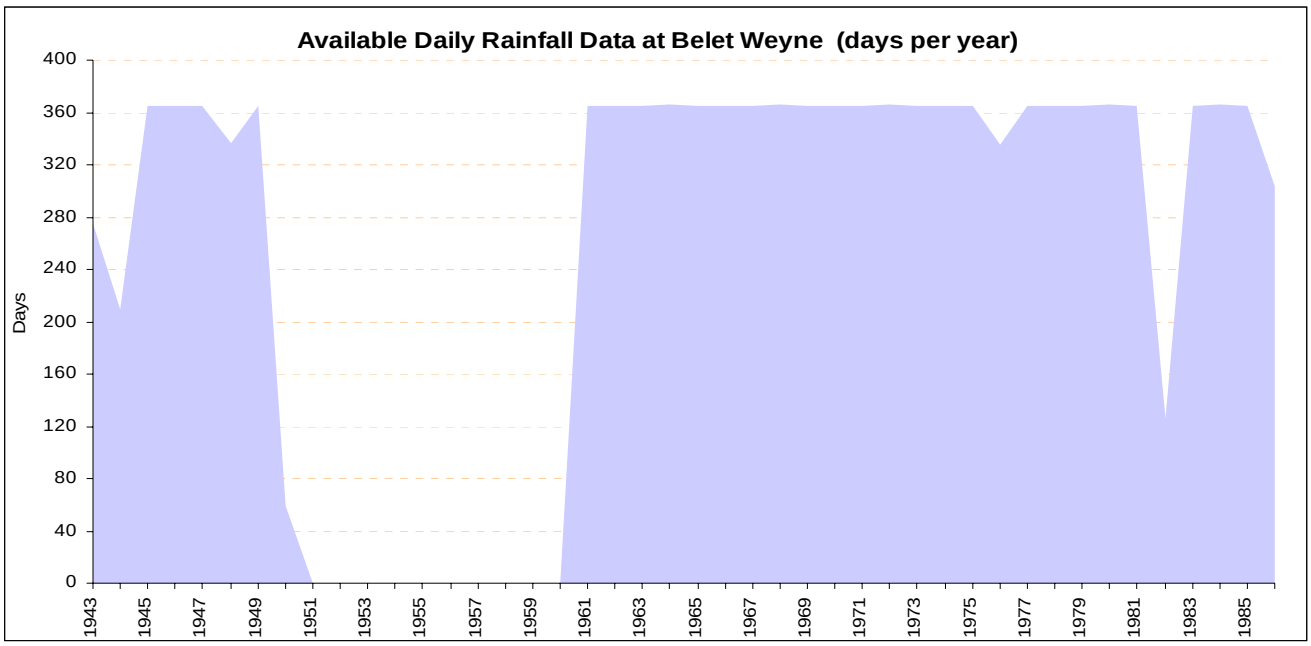
Appendix 2: Mean monthly historical rainfall data

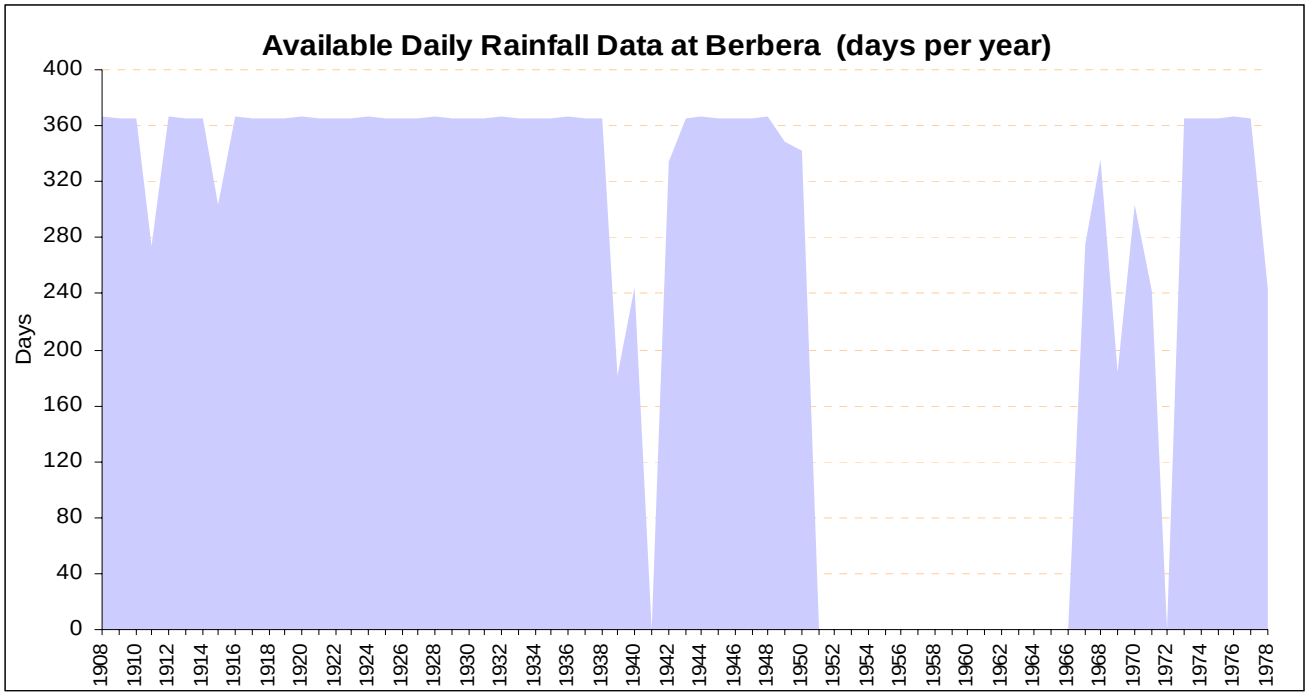
Station Name	Region	Start Year	End Year	No of years	No. of Monthly Records	Fill [%]
Borama	Awdal	1924	1990	67	804	66
Budhuxul	Bakool	1984	1990	7	84	79
Huddur	Bakool	1922	1990	69	828	43
Jameko_Mubarak	Bakool	1984	1990	7	84	79
Mogadishu	Banadir	1911	1990	80	960	99
Qardo	Bari.	1939	1980	42	504	85
Bur-Acaba	Bay	1984	1990	7	84	76
Dinsor	Bay	1939	1990	52	624	26
Baidoa	Bay	1922	1990	69	828	80
Elbur	Galgadud	1930	1974	45	528	60
Bardera	Gedo	1922	1990	69	828	85
Luuq	Gedo	1922	1990	69	828	77
Belet Weyne	Hiraan	1926	1990	65	780	92
Jalalaqsi	Hiraan	1987	1990	4	48	71
Kerialo	Hiraan	1988	1989	2	24	100
Dudunle	L. Shabelle	1987	1990	4	48	66
Barro Weyne	L.Juba	1979	1988	10	120	78
Gololey	L.Juba	1988	1989	2	24	100
Kismayo	L.Juba	1894	1990	97	1164	94
Mogambo	L.Juba	1984	1988	5	60	80
Modu_moden	L.Juba	1987	1988	2	24	100
Caagbashi	L.Shabelle	1987	1990	4	48	69
Genale	L.Shabelle	1929	1990	62	744	60
Lafoole	L.Shabelle	1981	1988	8	96	100
Modun	L.Shabelle	1985	1990	6	72	64
Allesandra	M.Juba	1930	1990	61	708	43
Bualle	M.Juba	1987	1990	4	48	62
Jilib	M.Juba	1923	1990	68	816	45
Mareere	M.Juba	1977	1990	14	168	87
Lambar_Kon	M.Juba	1987	1990	4	48	60
Qalimow	M.Juba	1987	1990	4	48	66
Afgoi	M.Shabelle	1922	1990	69	828	69
Balad	M.Shabelle	1922	1990	69	828	41
Jowhar	M.Shabelle	1922	1990	69	828	51
Galckayo	Mudug	1933	1990	58	696	99
Obbia	Mudug	1924	1982	59	708	63
Allula	Nuugal	1944	1967	24	276	67
Bossaso	Nuugal	1933	1976	44	528	100
Erigavo	Sanaag	1925	1990	66	792	37
Las_Anod	Sool	1944	1969	26	312	46
Burao	Togdheer	1921	1990	70	840	97
Berbera	W.Galbeed	1906	1978	73	864	74
Gebilley	W.Galbeed	1944	1980	37	444	45
Hargeisa	W.Galbeed	1921	1990	70	840	90

Appendix 2a: Available historical daily stream flow data for individual stations






Available Daily Rainfall Data at Belet Weyne (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985


Available Daily Rainfall Data at Berbera (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1908
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
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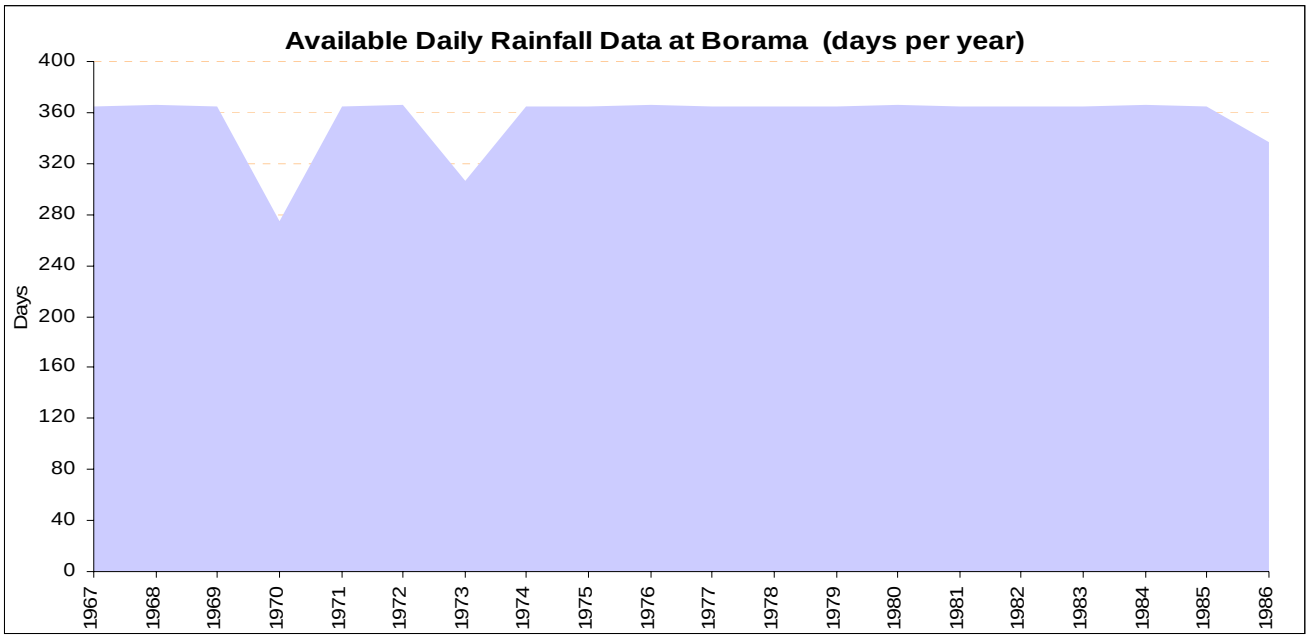
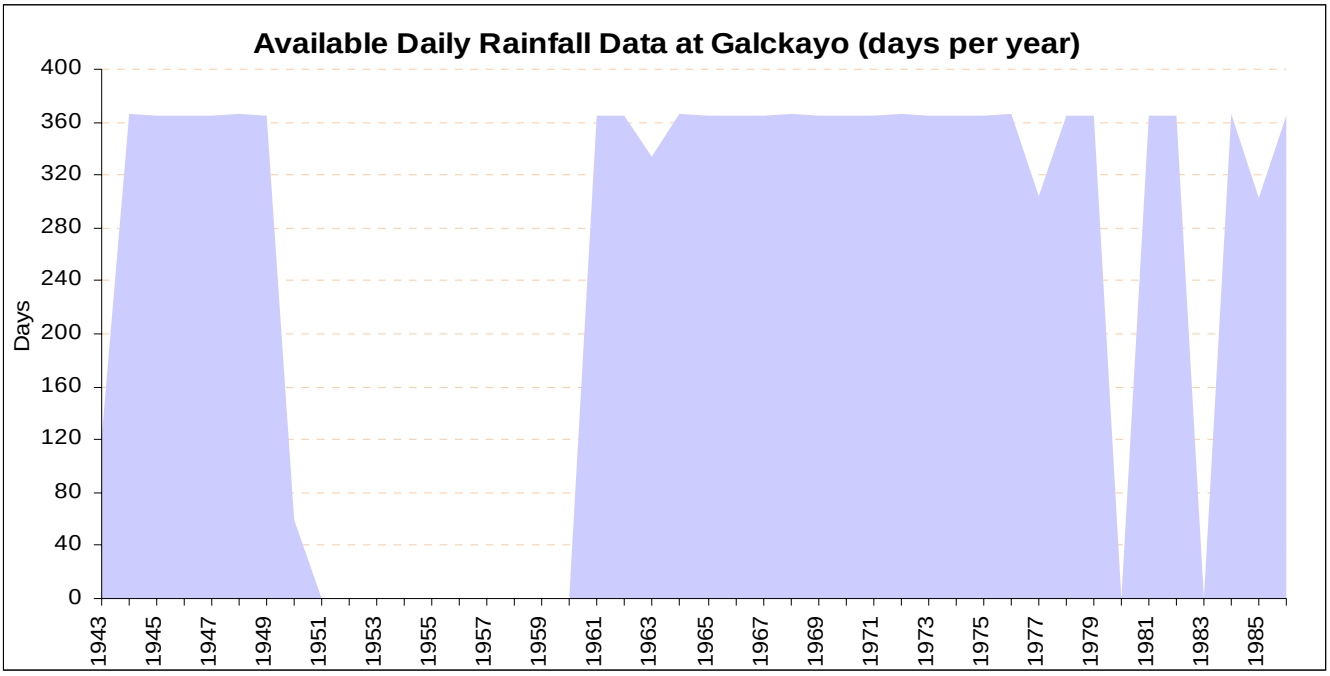
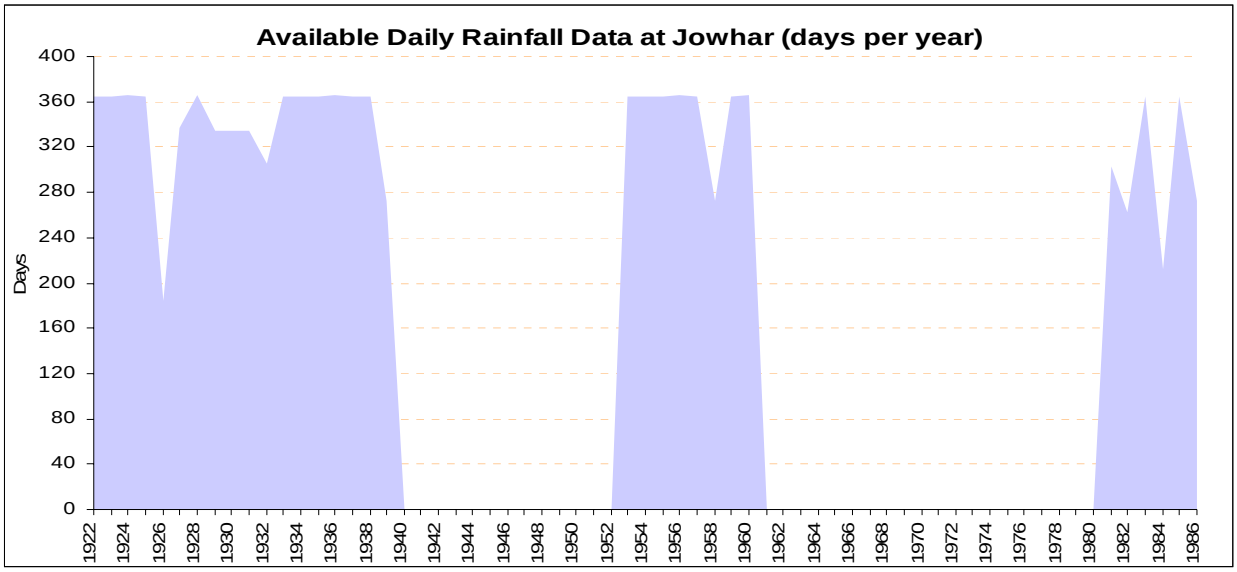
1970
1972
1974
1976
1978


Available Daily Rainfall Data at Borama (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986


Available Daily Rainfall Data at Galckayo (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985


Available Daily Rainfall Data at Jowhar (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1922
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
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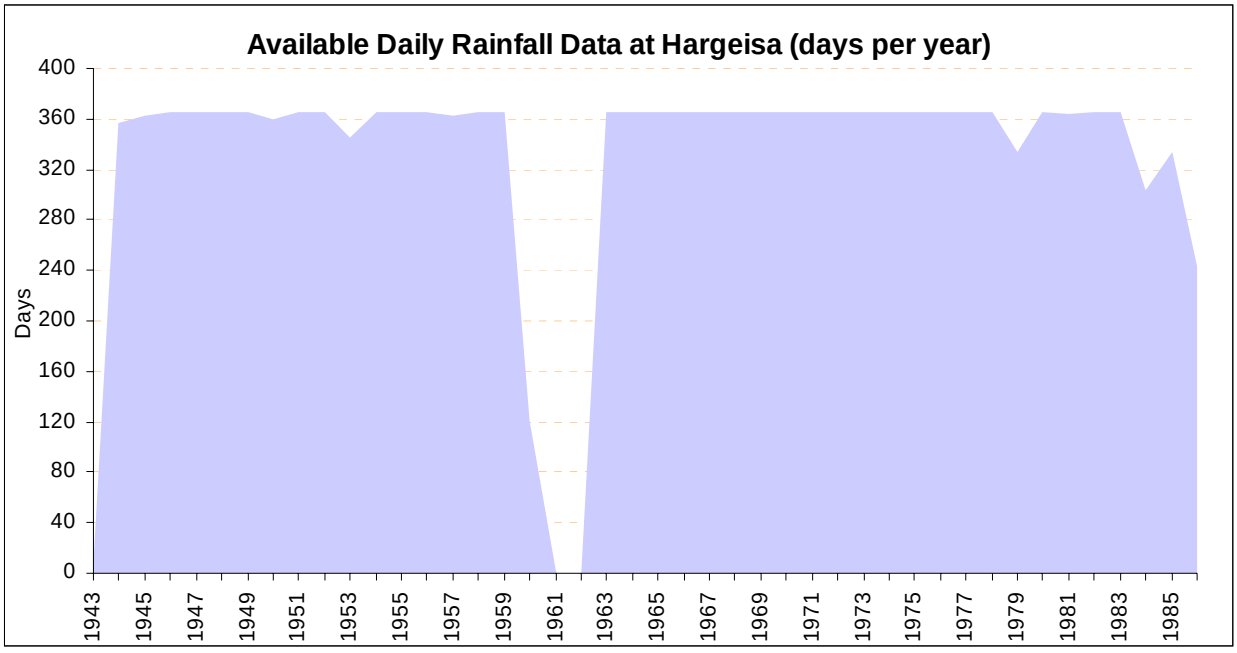
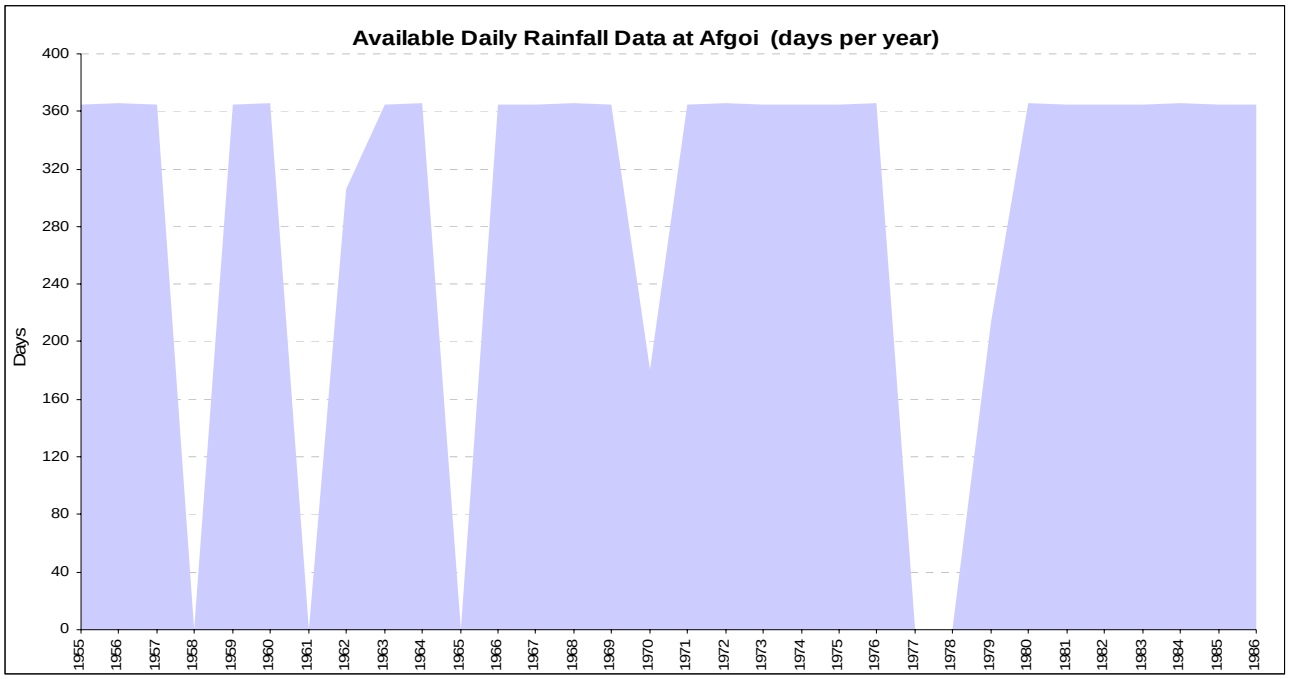
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986


Available Daily Rainfall Data at Hargeisa (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985


Available Daily Rainfall Data at Afgoi (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
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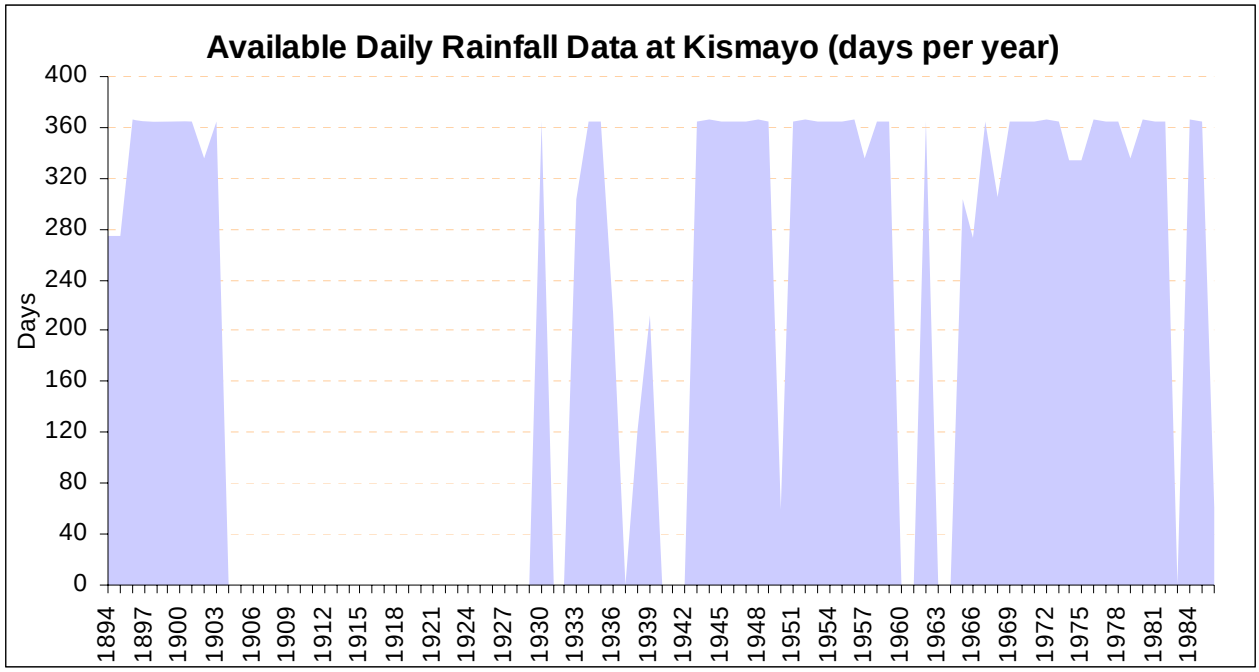
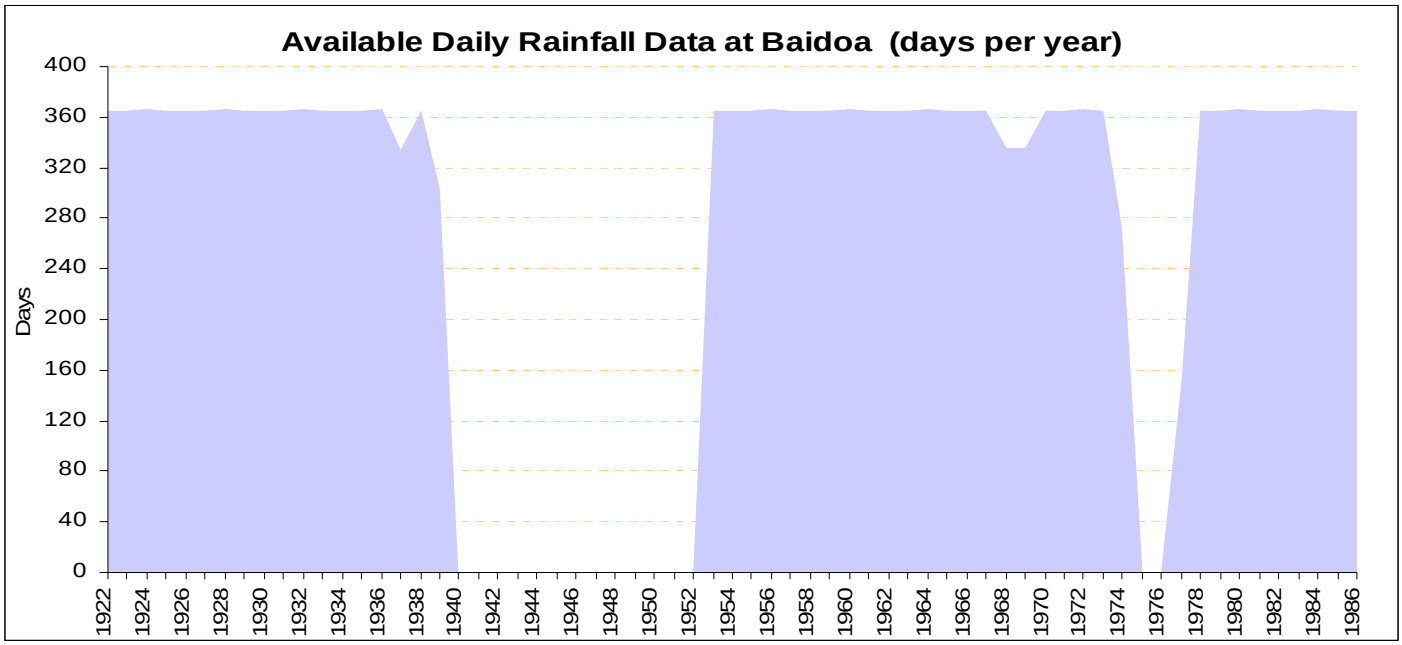
1981
1982
1983
1984
1985
1986


Available Daily Rainfall Data at Kismayo (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1894
1897
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984


Available Daily Rainfall Data at Baidoa (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1922
1924
1926
1928
1930
1932
1934
1936
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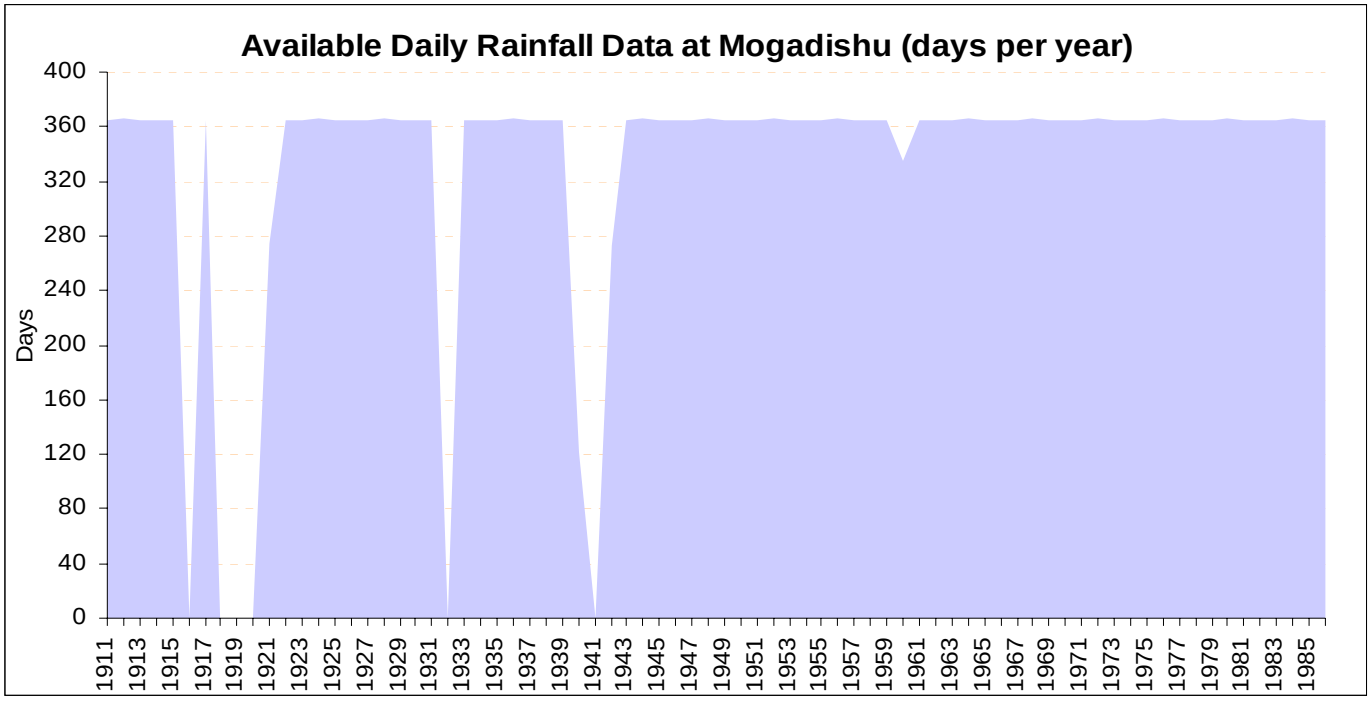
Available Daily Rainfall Data at Mogadishu (days per year)
Days
400
360
320
280
240
200
160
120
80
40
0
1911
1913
1915
1917
1919
1921
1923
1925
1927
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1931
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1981
1983
1985

Appendix 3: List of operational rainfall monitoring station as of August 2007

Rainfall Station	Longitude	Latitude	Date Installed	Region	District	AGENCY RESPONSIBLE	OBSERVING AGENCY
Waajid_ACF	43.24000	3.80000	Jul-06	Bakool	Wajid	ACF	ACF
Garowe_ADRA	48.48024	8.40620	Apr-06	Nugal	Garoowe	ADRA	ADRA
Huddur_ADRA	43.09365	4.11836	Apr-06	bakool	Huddur	ADRA	ADRA
Bardheere	42.30000	2.35000	Apr-06	Gedo	Bardera	CARE	SADO
Luuq	42.45000	3.58333	Apr-06	Gedo	Luuq	CARE	ACA
Jowhar	45.50000	2.76667	Jan-99	M. Juba	Jowhar	CEFA	CEFA
Bananey	45.02685	2.01064	Oct-06	Lower Shabelle	Afgoi	CONCERN	CONCERN
Barrire	44.89766	2.04842	Oct-06	Lower Shabelle	Afgoi	CONCERN	CONCERN
Mubarak	44.77730	1.92045	Oct-06	Lower Shabelle	Awdhegle	CONCERN	CONCERN
Mukidumis	44.43000	1.59850	Oct-06	Lower Shabelle	Kurtnwareey	CONCERN	CONCERN
Wanle Weyne	44.89360	2.61945	Oct-06	Lr. Shabelle	Wanle Weyne	CONCERN	CONCERN
Boroma_coopi	43.00000	10.00000	Apr-06	Awdal	Boroma	COOPI	COOPI
Hargeisa_coopi	44.03651	9.55886	Apr-06	W. Galbeed	Hargeisa	COOPI	COOPI
Baidoa	43.66667	3.13333	Apr-05			FEWSNET	FEWSNET
Afgooye	45.13333	2.13333	Apr-05	Shabelle	Afgooye	FSAU	FEWSNET
Bardaale	43.19809	3.21460	Apr-05	Bay	Dinsor	FSAU	FEWSNET
Ceel Berde	43.65993	4.82821	Apr-05	Bakool	Ceel Berde	FSAU	FEWSNET
Diinsor	42.98333	2.41667	Apr-05	Bay	Bardale	FSAU	FEWSNET
Garoowe_FEWS	48.48270	8.40710	Apr-05	Nugaal	Garoowe	FSAU	FEWSNET
Genale	44.75000	1.83333	Apr-05	L. Shabelle	Marka	FSAU	FEWSNET
Halgan	45.56596	3.85357	Apr-05	Hiran	Bulo Burti	FSAU	FEWSNET
Huduur_FEWS	43.90000	4.16667	Apr-05	Bakool	Hudur	FSAU	FEWSNET
Jalalaqsi	45.59941	3.37951	Apr-05	Hiran	Jalalaqsi	FSAU	FEWSNET
Jamame	42.73333	0.05000	Apr-05	L. Juba	Jamame	FSAU	FEWSNET
Sakow	42.45217	1.63938	Apr-05	Middle Juba	sakow	FSAU	FEWSNET
Xasbahale	48.61611	8.57917	Apr-05	Nugaal	Garoowe	FSAU	FEWSNET

Rainfall Station	Longitude	Latitude	Date Installed	Region	District	AGENCY RESPONSIBLE	OBSERVING AGENCY
Adad	43.25308	10.14475	Apr-04	Awdal	Boroma	GAA	GAA
Baki	43.36222	10.01733	Apr-02	Awdal	Baki	GAA	GAA
Bonn		10.19411	Apr-04	Awdal	Boroma	GAA	GAA
Boroma_GAA	43.18333	9.93333	Apr-02	Awdal	Boroma	GAA	GAA
Dilla_GAA	43.36583	9.77889	Apr-02	Awdal	Baki	GAA	GAA
Garba raho	43.63499	10.23733	Apr-02	Awdal		GAA	GAA
Gargara	43.80567	10.31228	Apr-04	Awdal	Boroma	GAA	GAA
Harmata	43.35719	10.10944	Apr-04	Awdal	Baki	GAA	GAA
Heego	43.25944	10.08194	Apr-04	Awdal	Boroma	GAA	GAA
Horey	43.37806	10.17992	Apr-04	Awdal	Baki	GAA	GAA
Badhan_HR	48.33917	10.71467	Mar-06	Sool	Badhan	Horn Relief	Horn Relief
Agsibiri	44.86975	4.74880	Oct-06	Hiraan	Belet Weyne	SCF	SCF
Belet weyne	45.18450	4.73386	Jan-97	Hiran	Belet Weyne	SCF	SCF
Kerialo	45.39156	4.40555	Oct-06	Hiraan	Belet Weyne	SCF	SCF
Mataban	45.52284	5.19937	Oct-06	Hiraan	Mataban	SCF	SCF
Yibir Suge	45.68286	4.98484	Oct-06	Hiraan	Mataban	SCF	SCF
Abrin	43.80575	9.51743	Apr-07	Galbeed	Hargeisa	SWALIM	SCF
Baran	48.33042	10.71430	Apr-07	Sanag	Baran	SWALIM	MOLAE
Berbera	45.03333	10.43333	Apr-07	Galbeed	Berbera	SWALIM	MOA
Borama	43.17916	9.94007	Nov-06	Awdal	Borama	SWALIM	MOA
Bossasso	49.17605	11.28265	Apr-07	Bari	Bossasso	SWALIM	MOLAE
Bulo burti	45.56667	3.25000	Jan-97	Hiran	Bulo Burti	SWALIM	MOA
Burao	45.56667	9.51667	Apr-07	Togdheer	Burao	SWALIM	MOA
Dilla	43.35675	9.74188	Nov-06	Galbeed	Dilla	SWALIM	MOA
Eeerigavo	47.36667	10.61667	Apr-07	Sanaag	Eeerigavo	SWALIM	MOA

Rainfall Station	Longitude	Latitude	Date Installed	Region	District	AGENCY RESPONSIBLE	OBSERVING AGENCY
Elfweyne	47.21680	9.93027	Apr-07	Sanaag	Elfweyne	SWALIM	MOA
Galkayo	47.42272	6.77719	Apr-07	Mudug	Galkayo	SWALIM	MOLAE
Garowe	48.47754	8.40458	Apr-07	Nugal	Garowe	SWALIM	MOLAE
Gebilley	43.28333	9.61667	Jan-05	Galbeed	Gebilley	SWALIM	MOA
Hargeisa	44.06680	9.55975	Jan-05	Galbeed	Hargeisa	SWALIM	MOA
Las Anod	47.35301	8.47927	Apr-07	Sool	Las Anod	SWALIM	MOLAE
Odweyne	45.06170	9.40858	Apr-07	Togdheer	Odweyne	SWALIM	MOA
Qardo	49.08678	9.50690	Apr-07	Bari	Qardo	SWALIM	MOLAE
Quljeed	43.00190	10.09167	Apr-07	Awdal	zeylac	SWALIM	MOA
Sheikh	45.18333	9.91667	Apr-07	Togdheer	Sheikh	SWALIM	MOA
Bualle	42.57317	1.24477	Jan-02	Bay	Bualle	WVI	WVI
Hargeisa_WV	44.08000	9.50000		W. Galbeed	Hargeisa	WVI	WVI
Sakoow_WV	42.45217	1.63938		Bay	Dinsor	WVI	WVI
Salagle	42.29569	1.81187		L.Juba	jilib	WVI	WVI
Tiaglow	44.51270	4.01820		Bay	Tieglo	WVI	WVI
Wajid_WV	43.24839	3.80948		Bakool	Wajid	WVI	WVI
Afmadow	42.1	0.5	Nov-06	Lr. Juba	afmadow	AFREC	AFREC

Appendix 4: Mean monthly time series temperature

Name	Longitude	Latitude	Altitude (masl)	First Record	Last Record	No. of Monthly Records	Fill [%]
Bossaso	49.18	11.28	6	1934	1960	324	59
Galckayo	47.43	6.85	302	1936	1960	300	66
Kismayo	42.43	-0.37	8	1933	1960	336	73
Mogandishu	45.35	2.03	9	1928	1987	720	90
Qardo	49.08	9.5	810	1954	1978	300	95

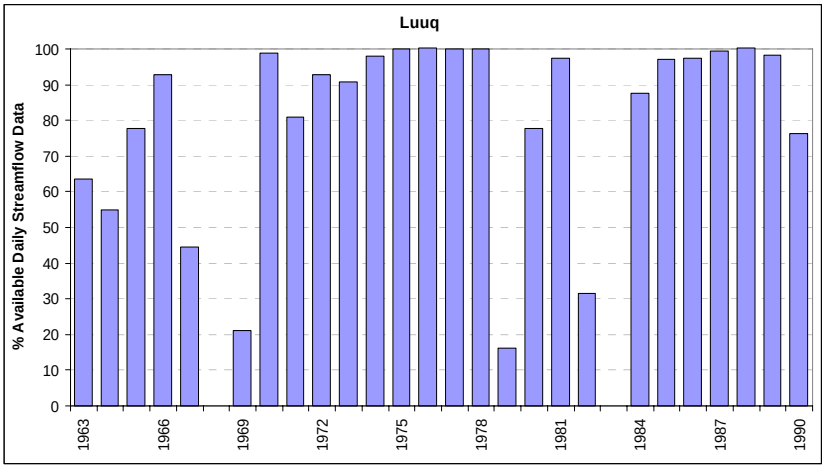
Appendix 5: Rating equations for Juba and Shabelle

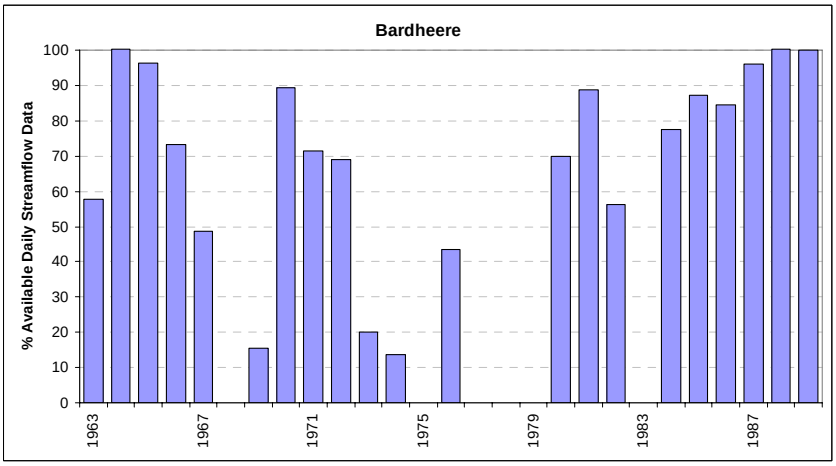
Station	Rating	Type	Period Start	Period End	Constants			Maximum height(m)
					a	b	c	
Luuq	A	Power	01-Jan-1951	31-Dec-1981	60.32	1.87	- 0.66	7.5
	B	Power	01-Jan-1982	31-Dec-1990	58.95	1.87	- 0.752	7.5
Bardheere	A	Power	29-May-1963	31-Dec-1990	47.20	1.90	0.379	7.0
Jamame	A		01-Jan-1963	31-Dec-1990	16.84	1.73	0.09	7.5
Kaitoi	A	Power	01-Jan-1963	31-Dec-1980	35.12	1.61	0.29	7.0
Marere	A	Power	01-Jul-1977	31-Dec-1990	17.87	1.90	- 4.55	12.0
Kamsuma	A	Power	11-Jul-1972	12-Jun-1984	45.76	1.41	- 2.33	9.0
	B		13-Jun-1984	31-Dec-1990	35.02	1.52	- 0.5	9.0
Belet Weyne	A	Power	01-Jan-1951	31-Dec-1978	23.13	1.88	0.27	2.22
	B	Power	01-Jan-1951	31-Dec-1990	39.79	1.29	0.27	7.0
Bulo Burti	A	Power	01-Jan-1963	30-Jun-1978	12.76	1.77	- 0.61	10.0
	B	Power	01-Jul-1978	31-Dec-1990	21.08	1.47	- 0.631	10.0
Mahadey Weyne	A	Power	01-Jan-1963	31-Dec-1979	7.90	1.70	0.28	7.0
	B	Power	01-Jan-1980	31-Dec-1990	4.90	2.07	0.073	6.0
Balcad	A	Power	20-Sep-1962	31-Dec-1979	10.08	1.33	0.1	8.0
Afgoi	A	Power	01-Jan-1963	28-Feb-1985	17.61	1.18	- 0.89	7.0
	B	Power	01-Mar-1985	31-Dec-1990	14.89	1.22	- 0.89	7.0
Awdegle	A		01-Jan-1963	31-Dec-1970	9.81	1.41	- 0.59	6.5
	B		01-Jan-1971	28-Feb-1985	11.86	1.36	- 1.14	6.5
	C		01-Mar-1985	31-Dec-1990	13.74	1.36	- 1.64	6.5

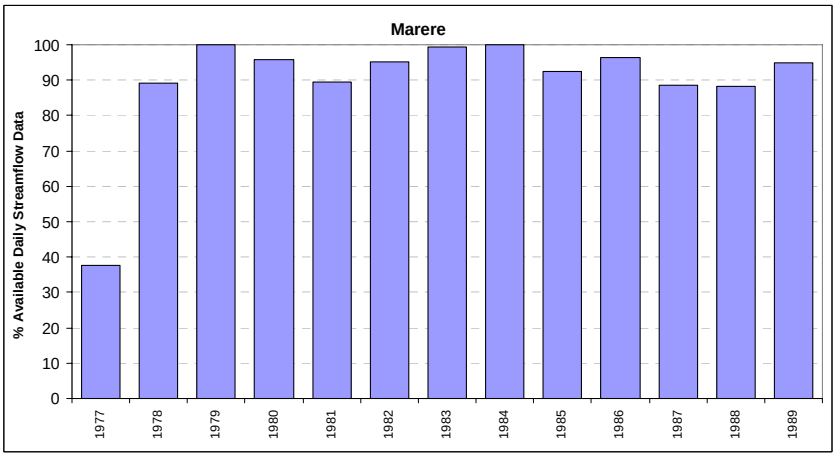
Appendix 6: River level and flow data

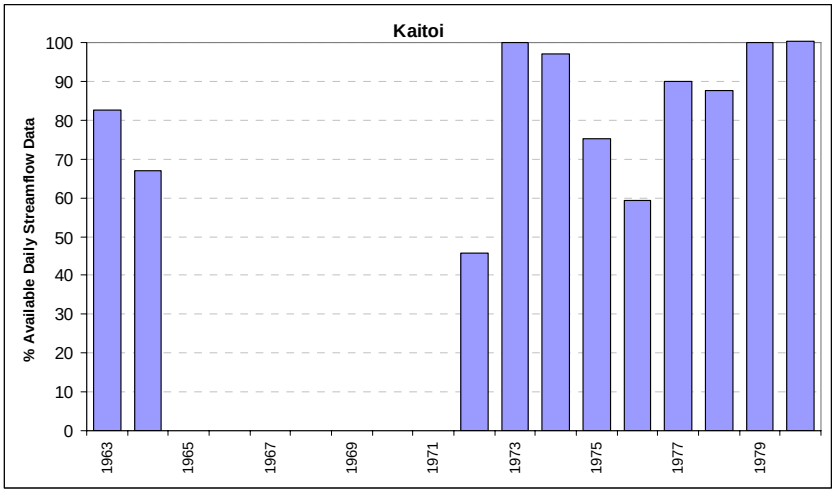
River	Station	Longitude	Latitude	Area Km^2	First Record	Last Record	No. of Records	Fill %
	Historical river levels and flow data)							
Juba	Luuq	03:47:29	42:32:30	166000	25-Mar-1951	11-Oct-1990	14446	74
	Bardheere	02:20:30	42:17:00	216730	04-Jun-1963	11-Oct-1990	9992	57
	Marere	00:27:00	42:42:00	240000	06-Jul-1977	31-Jan-1990	4593	97
	Mogambo	00:09:00	42:44:00	260000	30-May-1983	31-Dec-1989	2408	74
	Kaitoi	00:47	42:40:00	240000	27-Jan-1963	31-Dec-1979	6183	49
	Jamame	00:01:10	42:41:00	268800	01-May-1963	27-Jul-1990	9950	41
Shabelle	Belet Weyne	04:44	45:12:20	207000	15-Apr-1951	11-Oct-1990	14435	80
	Bulo Burti	03:51:20	45;34:20	231000	03-May-1963	31-Aug-1990	9983	63
	M.Weyne	02:58:20	45:31:50	255300	01-Jan-1963	24-Sep-1990	10129	70
	Balcad	02:21:00	45:23:30	272700	20-Apr-1963	29-Nov-1979	6068	65
	Afgoi	02:08:40	45:07:30	278000	03-May-1963	29-Sep-1990	10012	90
	Awdhegle	01:59:10	44:50:00	280000	01-Jan-1963	31-May-1990	10013	54
	Current river levels and flow data							
Juba	Luuq	03:47:29	42:32:30	166000	07-Sep-2001	Ongoing	Ongoing	100
	Bardheere	02:20:30	42:17:00	216730	04-Sep-2001	Ongoing	Ongoing	100
	Bualle	01:24:10	42:32:21		01-Sep-1997	Ongoing	Ongoing	100
Shabelle	Belet Weyne	04:44	45:12:20	207000	25-Apr-2002	Ongoing	Ongoing	100
	Bulo Burti	03:51:20	45:34:20	231000	02-Apr-2002	Ongoing	Ongoing	100
	Jowhar	02:46:11	45:30:00		01-Jan-1999	Ongoing	Ongoing	100

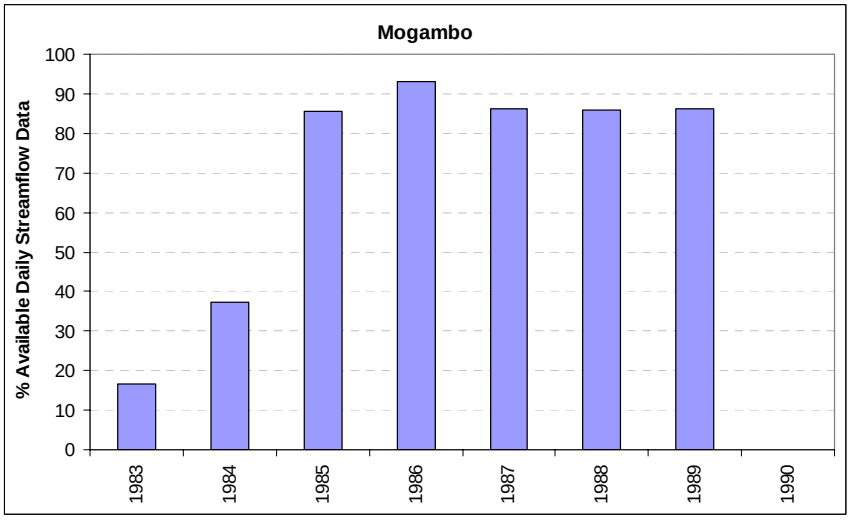
Appendix 6a: Available daily stream flow historical data

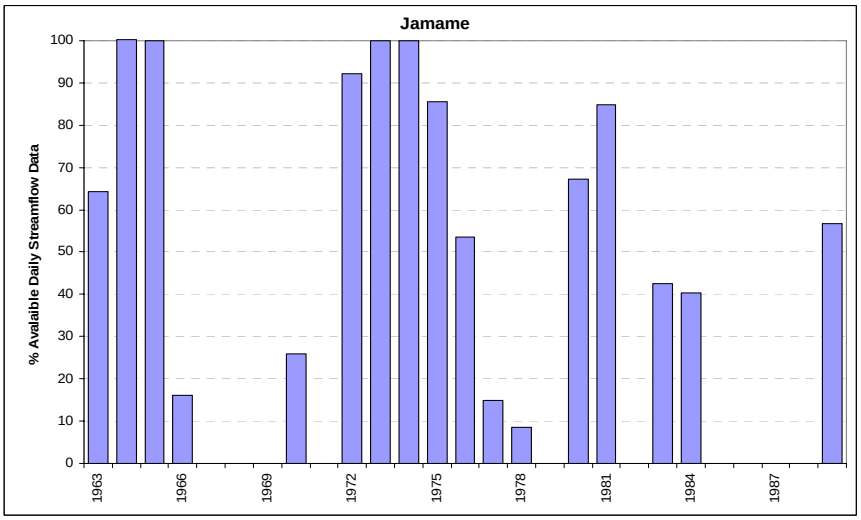


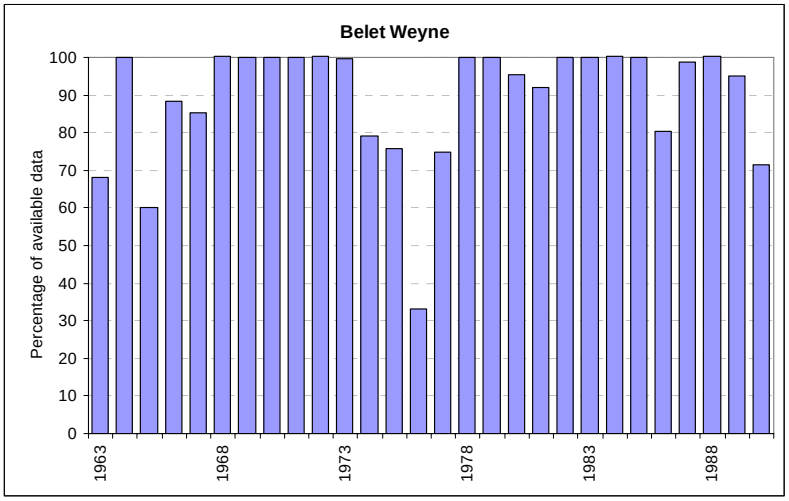


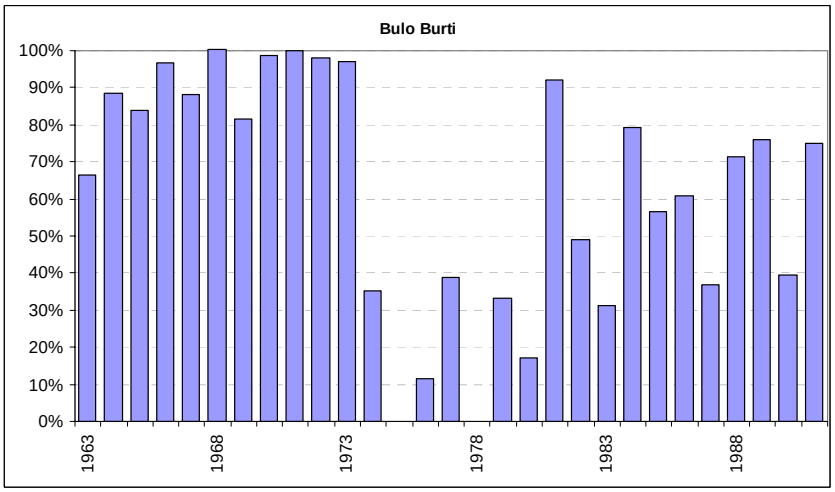


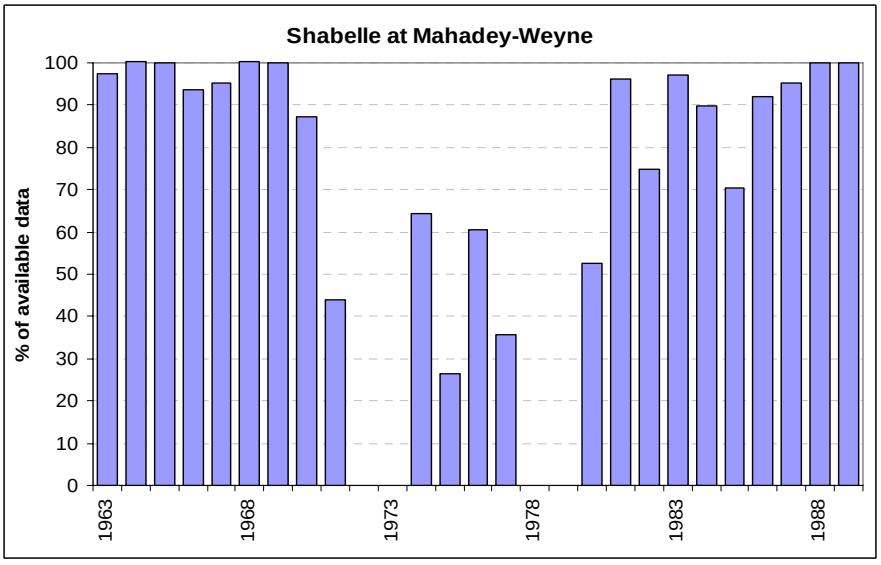

Kaitoi
% Available Daily Streamflow Data
100
90
80
70
60
50
40
30
20
10
0
1963
1965
1967
1969
1971
1973
1975
1977
1979

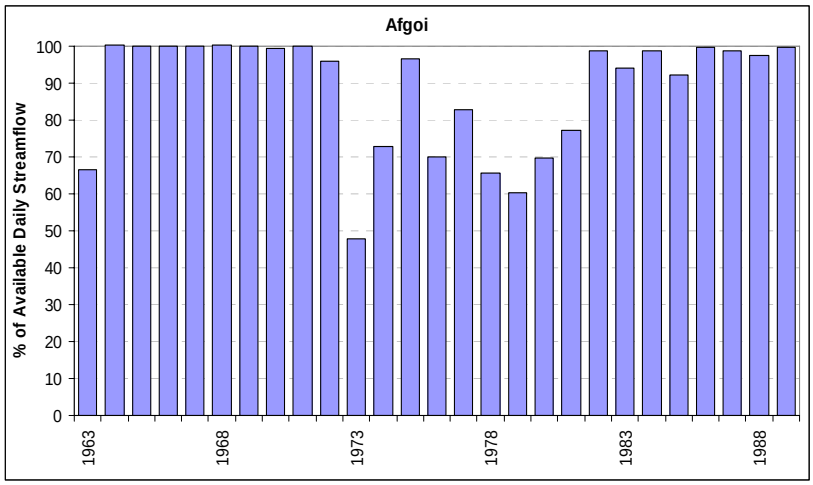

Mogambo
% Available Daily Streamflow Data
100
90
80
70
60
50
40
30
20
10
0
1983
1984
1985
1986
1987
1988
1989
1990

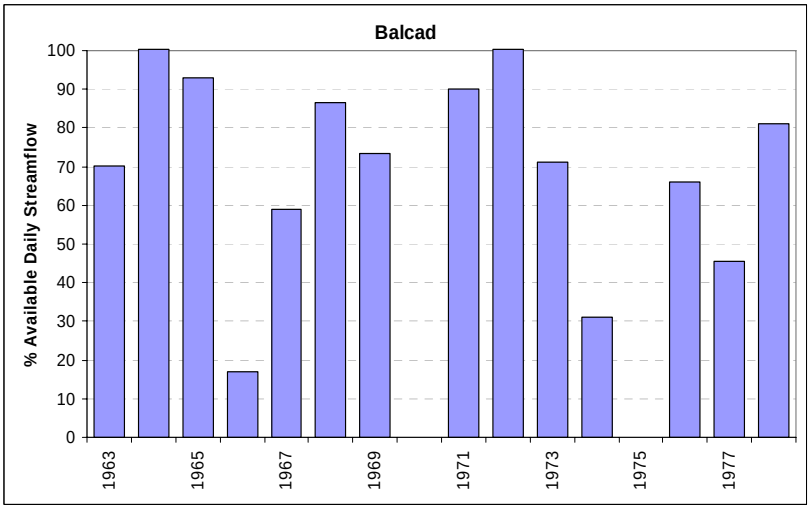

Jamame
% Avalaible Daily Streamflow Data
100
90
80
70
60
50
40
30
20
10
0
1963
1966
1969
1972
1975
1978
1981
1984
1987

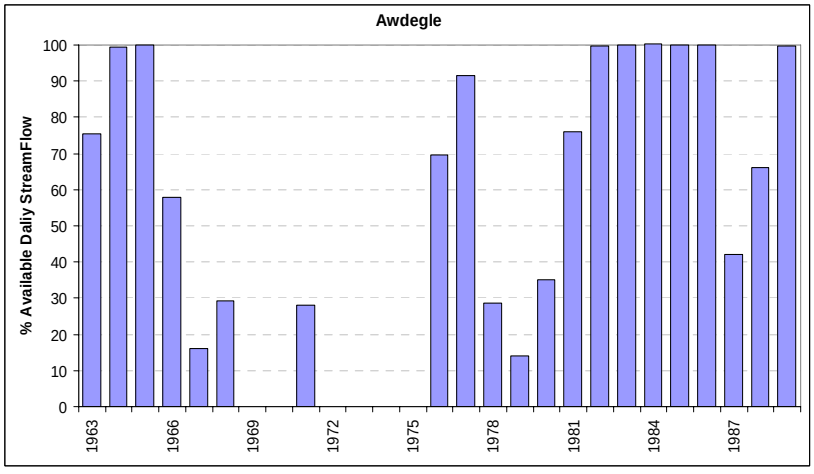

Belet Weyne
Percentage of available data
100
90
80
70
60
50
40
30
20
10
0
1963
1968
1973
1978
1983
1988


Bulo Burti
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1963
1968
1973
1978
1983
1988


Shabelle at Mahadey-Weyne
% of available data
100
90
80
70
60
50
40
30
20
10
0
1963
1968
1973
1978
1983
1988


Afgoi
% of Available Daily Streamflow
100
90
80
70
60
50
40
30
20
10
0
1963
1968
1973
1978
1983
1988


Balcad
% Available Daily Streamflow
100
90
80
70
60
50
40
30
20
10
0
1963
1965
1967
1969
1971
1973
1975
1977


Awdegle
% Available Daily StreamFlow
100
90
80
70
60
50
40
30
20
10
0
1963
1966
1969
1972
1975
1978
1981
1984
1987