Analysis of the General Climatic Conditions of Somalia in Support of Drought Monitoring

$$PDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R^{(P)}_{m,(i-k)}}{R^{(P)}_{m,i}}\right)} * \frac{\sum_{j=1}^{5} P_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} P_{(i-k),(m-j)}\right]}$$

$$VDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R^{(NDVI)}_{m,(i-k)}}{R^{(NDVI)}_{m,i}}\right)} * \frac{\sum_{m=1}^{5} NDVI_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} NDVI_{(i-k),(m-j)}\right]}$$

$$TDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R^{(T)}_{m,(i-k)}}{R^{(T)}_{m,i}}\right)} * \frac{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} T_{(i-k),(m-j)}\right]}{\sum_{j=1}^{5} T_{i,(m-j)}}$$

$$CDI_{i,m} = (PDI_{i,m-2} + TDI_{i,m} + VDI_{i,m}) * \frac{1}{3}$$

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Disclaimer

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List of Abbreviations

AEZ	Agro-ecological zones
AMC	Antecedent moisture content
AVHR	Advanced very High Resolution
CDI	Combined Drought Index
CV	Coefficient of variation
DEM	Digital Elevation Model
EV1	Extreme value type 1 distribution
FAO	Food and Agriculture Organisation of United Nations
FSAU	Food Security Analysis Unit
FSAU	Food Security Analysis Unit- Somalia
GEV	General Extreme value distribution
GHA	Great Horn of Africa
ICPAC	IGAD Climate Prediction and Applications Center
IGAD	Inter-Governmental Authority for Development
IDWA	Inverse Distance Weighted Average
ITCZ	Inter tropical Convergence Zone
IWRM	Integrated Water Resources Management
NOAA	National Oceanographic and Atmospheric Administration
KMD	Kenya Meteorological Department
PET	Potential Evapotranspiration
PDI	Precipitation Drought Index
RC	Runoff coefficient
RFE	daily rainfall estimates
RH	Relative Humidity
SWALIM	Somalia Water and Land Information Management
SWIMS	Somalia Water Source Information Management System
TDI	Temperature Drought Index
UNCEF	United Nations Children’s Fund
UNDP	United Nations Development Programme
UNESCO	United Nations Education, Science and Cultural Organization
VDI	Vegetation Drought Index
WMO	World Meteorological Organization

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Acknowledgement

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1. Introduction

Africa is characterised by extremes of climate both spatially and temporally. Unlike in the temperate zones where growing seasons primarily reflect changes in temperature, Africa's rhythms of life reflect rainfall as the "limiting" factor. Generally, Africa has a wide variety of bimodal climates based around a summer wet season and a winter dry season. In fact, Africa's swings between dry and wet seasons are the most pronounced of any of the continents. Not surprisingly therefore, floods and droughts are a common feature all over the continent. Due to the high drought vulnerability in most countries in Africa, it is not surprising that the drought hazards easily develop into disasters with serious consequences. The situation seems to be more serious in the Great Horn of Africa (GHA). The table below shows the extent, to which, some of the worst droughts, in the GHA region, have affected the populations.

Table 1: Drought Disasters over Eastern Africa

Country	Year	No's affected
Ethiopia	1973	3 million
Rwanda	1976	1 million
Sudan	1984	8.4 million
Ethiopia	1984	7.8 million
Uganda	1988	600,000
Sudan	1991	8.6 million
Ethiopia	1991	6.2 million
Kenya	1992	2.7 million
Tanzania	1992	800,000

The table below shows some of the worst drought in Somalia and the affected population.

Table 2: Drought Disasters in Somalia

Date	Affected
Dec-1964	700,000
1969	30,000
Dec-1974	230,000
Apr-1987	500,000
1988	53,500
Jan-2000	1,200,000
June 2001	1,100,000
Dec 2001	500,000
Jan-2004	200,000
2008	On-going

2. Somalia - Country Profile

2.1 *Geography*

Somalia is situated in the Horn of Africa and covers an area of 637 660 km^2. It extends from approximately 1°40’ south of the Equator to 11° 58’° north and from 40°59’ to 51° 24’ east. The country is bordered by Djibouti to the north-west, the Gulf of Aden to the north, the Indian Ocean to the east, Kenya to the south and south-west and Ethiopia to the west. It has the longest coastline of all African countries, with nearly 3,300km. Figure 1 shows the map of Somalia

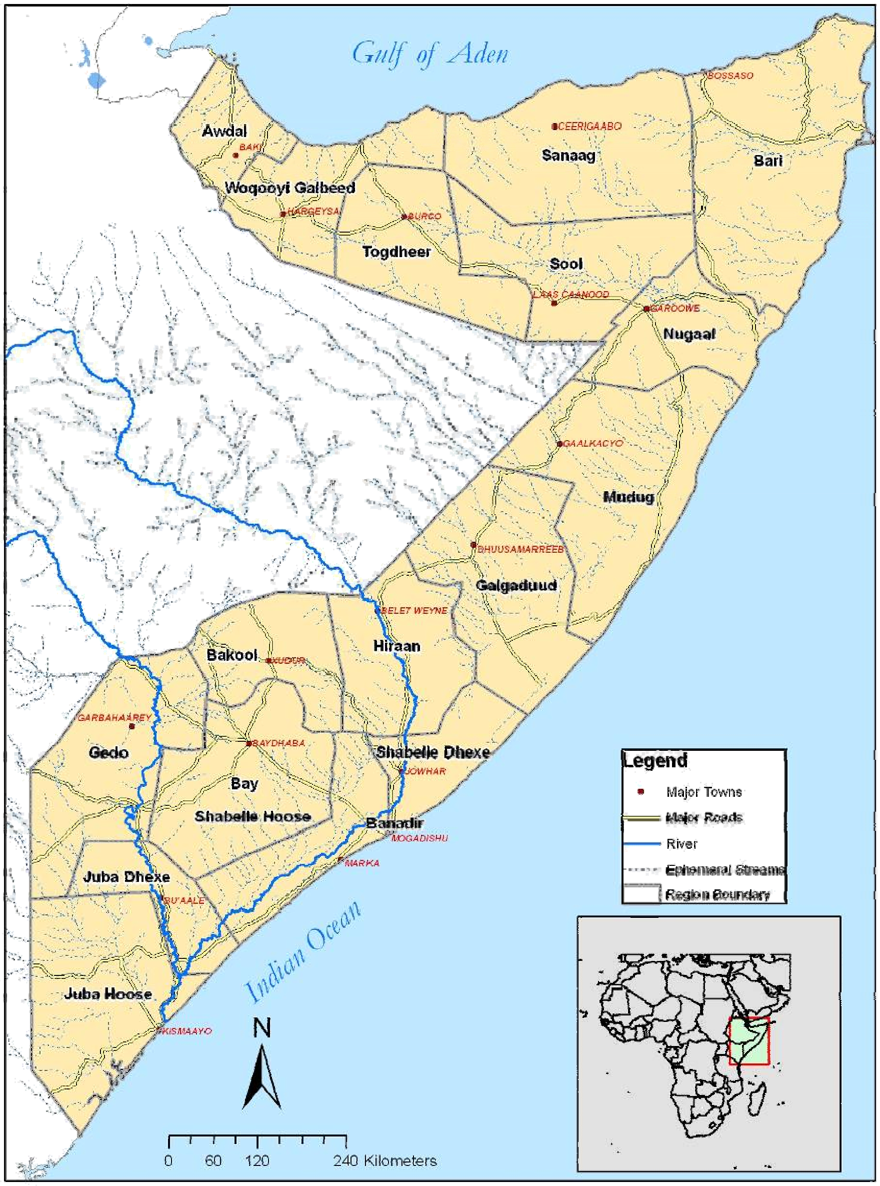


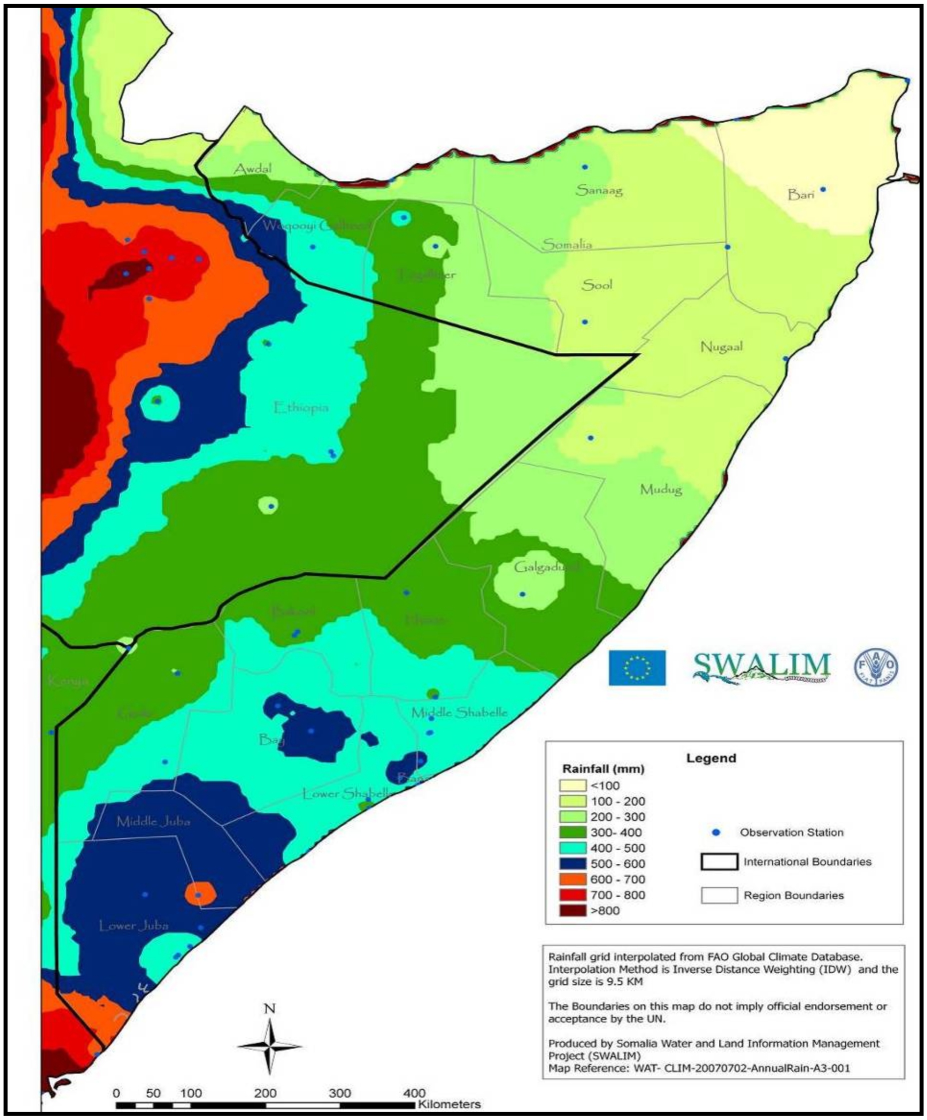
Figure 1: Position of Somalia in Africa

Most of Somalia is desert or semi-desert. Approximately 60 percent of Somalia is savannah woodlands, which is used as rangeland and as the primary local source of fuel. Only about 13 % of the land can be cultivated, and much of that is not farmed on a regular basis. Cultivation of arable land occurs primarily in southern Somalia.

2.2 Climate of Somalia

The climate varies from desert in the northern coastal areas of the Gulf of Aden Basin and some areas in the Darror in the north-east; arid and semi arid in most of the areas within the Gulf of Aden, Nugal and Ogaden Basin in the central and northern regions; and moist semi-arid in most of the Juba-Shabelle River Basins in the south and in the mountainous areas of the Gulf of Aden in the north-west.

The distribution of the annual rainfall over Somalia is presented in Figure 2 shown below.



Rainfall grid interpolated from FAO Global Climate Database. Interpolation Method is Inverse Distance Weighting (IDW) and the grid size is 9.5 KM

The Boundaries on this map do not imply official endorsement or acceptance by the UN.

Produced by Somalia Water and Land Information Management Project (SWALIM)
Map Reference: WAT- CLIM-20070702-AnnualRain-A3-001

Figure 2: Mean annual rainfall distribution in Somalia

It varies from 93 mm in the Darror Basin to 549 mm in the Lag Badana Basins. While the maximum annual rainfall in the Ethiopian and Kenyan parts of the catchment reaches 1100 – 1350 mm, the maximum annual rainfall within Somalia reaches a height of 704 mm in some areas of Juba and Lag Badana Basins. The minimum annual rainfall is around 20 mm in some parts of the northern coastal locations in Gulf of Aden while the minimum in some parts of Darror and Nugal is as low as 66 and 80 mm, respectively. Table 3 gives s summary of the distribution of the rainfall over the major river basins in Somalia.

Table 3: Areal Annual Rainfall

Basin	**Mean Annual (mm)**	**Maximum (mm)**	**Minimum (mm)**
Shabelle Basin within Somalia	**460**	**651**	**279**
Juba Basin within Somalia	**427**	**704**	**279**
Lag Dera within Somalia	**478**	**571**	**332**
Lag Badana	**549**	**704**	**452**
Gulf of Aden	**228**	**531**	**27**
Darror	**93**	**159**	**66**
Tug Der/ Nugal	**164**	**465**	**80**
Ogaden within Somalia	**257**	**558**	**133**
Central Coastal	**358**	**545**	**186**
National (Somalia)	**307**	**704**	**27**

The annual Potential Evapo-transpiration (PET) is between 1500 to 2000 mm in the southern river basins but exceeds 2000 mm in the northern basins (and is as high as 3000 mm in the northern coastal regions of the Gulf of Aden). In most locations PET exceeds rainfall in all months of the year (see Figure 3 below). In the southern basin areas, the monthly rainfall exceeds 0.5PET in the *Gu* and *Deyr* seasons giving room for growing periods which allow rain-fed agriculture. However in the case of the northern basins, except for a few locations in Somaliland (e.g. Borama and Gebiley), even 0.5PET exceeds rainfall in all months giving zero values for the longest growing period (LGP) in most of the areas. This is one of the main reasons why most areas are not suitable for agriculture.

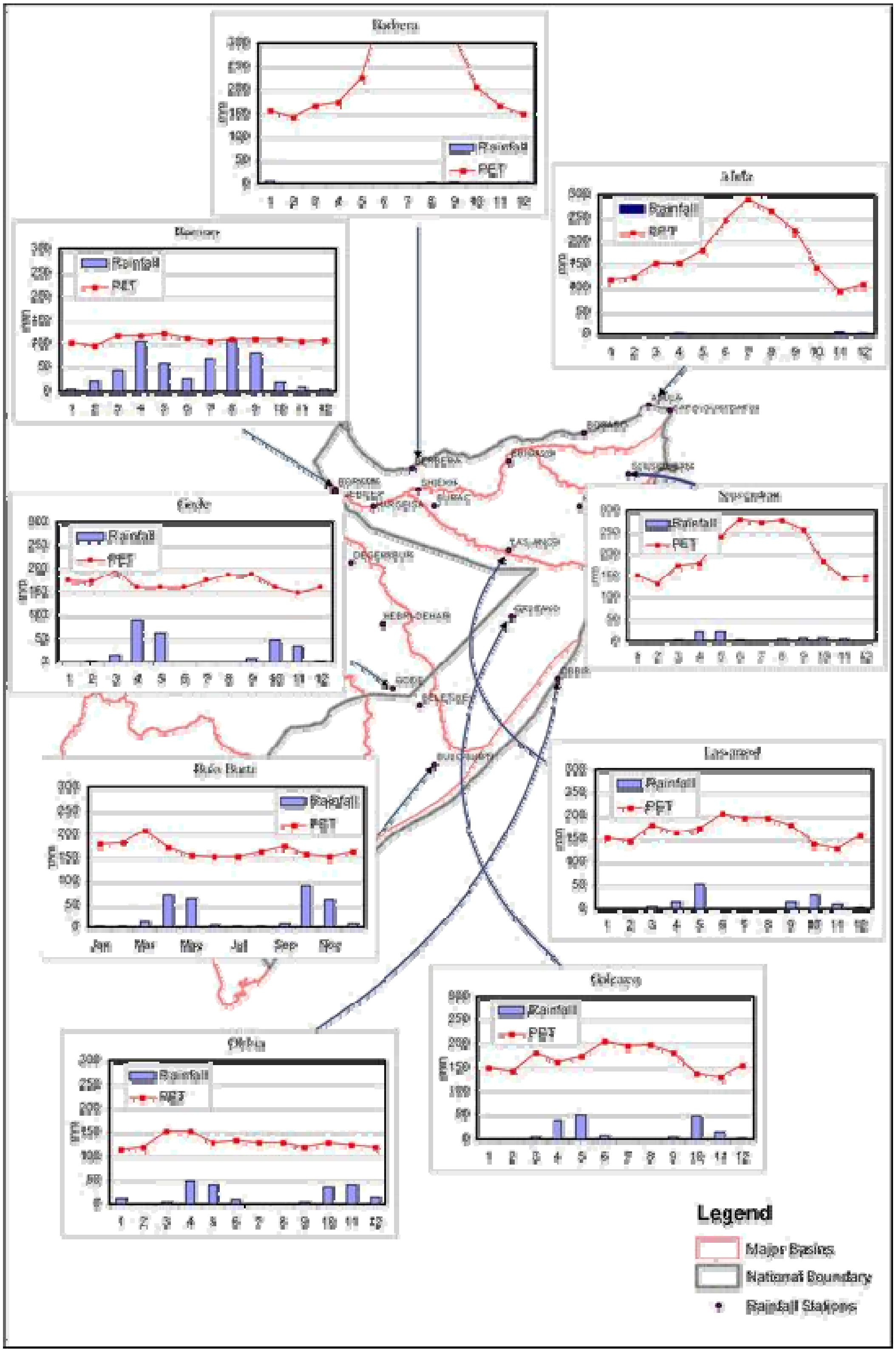


Figure 3: Distribution of the mean monthly rainfall and potential evapo-transpiration in some selected parts of Somalia

The principle synoptic systems controlling rainfall in Somalia are: Arabian High, ITCZ, Mascarene High, St. Helena High and other oceanic and atmospheric teleconnections. Teleconnections refers to the relationship between climate over a location of interest and the conditions of the atmosphere or the ocean for a place which is remotely located from the area of interest.

Rainfall characteristics over Somalia have been observed to be teleconnected with many anomalies in the general circulation outside the region. These teleconnections include the large-scale systems such as the El-Niño/Southern Oscillation (ENSO), Quasi-biennial Oscillation (QBO), and intra-seasonal waves, amongst many others.

The sea surface temperatures over the West Indian Ocean, ITCZ and atmospheric pressure gradients over the African and Asian continents drive the monsoons and the associated Somali Low-level Jet. The intensification and relaxation of these systems determines the moisture injection into the country and the conditions for the performance of either good or bad rainfall seasons. Figure 4 shows the normal oscillation of the ITCZ in Africa.

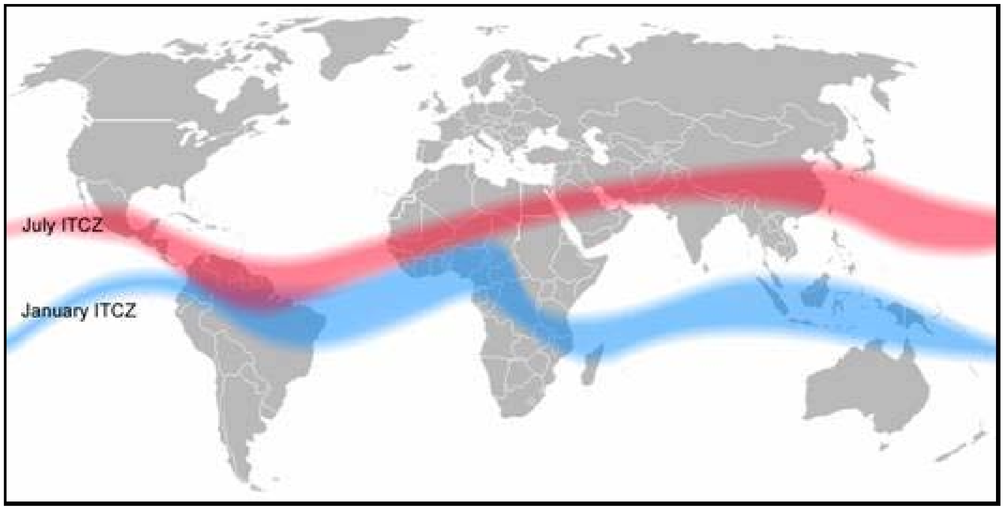


Figure 4: The extreme positions of the ITCZ

It can be observed from figure 4 that the spatial oscillation of the ITCZ is the largest over the East-African regions, forcing the ITCZ to criss-cross these regions much faster than elsewhere over the globe. This phenomenon introduces high variability and unreliability in the full dominance and establishment of clear convergence over these regions. As a consequence, these regions, which include Somalia, are characterised by high seasonal variability.

There is therefore a marked variability in the amount and reliability of precipitation throughout Somalia. Precipitation increases toward the south, with a large area in the south receiving in excess of 58 centimetres in most years. The north coast generally receives less than 10 centimetres per year. The interior plateau receives 250 to 480 millimetres per year. The southeast monsoon, beginning in April, is responsible for most of the precipitation over the country.

In general, the climate of Somalia is hot, ranging from dry desert to tropical semi-arid. The average daily high temperature ranges from 29°C in the winter months to more than 38°C during the summer months. Along the coasts, compounding the high temperatures is an average relative humidity in excess of 70% creating an exceedingly hot humid environment. Inland areas are generally dry with extended periods of no rainfall. The weather can be divided into two dry seasons (one characterised by the dominance of the

North-east Monsoon and the other by the South-west Monsoon) and two wet seasons (one during the spring transition of the monsoon system and the other during autumn transition of the monsoon system).

In Somalia the Monsoon seasons are windy but dry. The North-east Monsoon is from December through March and produces some precipitation in the highlands. During this season, which is locally called **Jilaal**, high temperatures range from 27°C in the highlands to 43°C in the southern interior. During this time, the ITCZ is in the southern hemisphere and the country is under the influence of the dry north-easterlies.

Conditions during the Spring Transition season, locally referred to as the **GU** season (April through June) are at their worst, with low clouds, showers and thunderstorms seen primarily in the south. Temperatures range from the upper 27°C in the south to near 38°C along the northern coast. During this time, most of the country gets rainfall. The ITCZ is over Somalia and the south-east trades are warm enough to bring in moisture from the Indian Ocean. If rains are heavy, flooding can occur in the low-lying areas along the perennial and seasonal rivers.

The Southwest Monsoon, (July through September) brings a return to infrequent showers over the southern part of the country with sustained strong winds, blowing sand, and dust. Locally this season is referred to as the **Hagaa** season Temperatures range from 27°C in the south to well over 38°C along the Gulf of Aden. During this time, the ITCZ is in the northern parts of Somalia where the Hagaa is most significant. During this time, the country is also under the influence of the Somali Jet (Also called the East African Low Level Jet stream, EALLJ) and it intensifies over the high grounds. The "Somali Jet" is a relatively narrow wind stream along the East African Coast and is part of the larger Southwest Monsoon circulation pattern. The Somali Jet is one of the strongest and most sustained low-level wind systems on earth. It is normally strongest in July and August when the core of the jet attains maximum speed up to 180 km/h. The core is usually centred at an elevation of about 1500 meters above mean sea level. The low-level wind speed maximum just east of Socotra Island usually appears as a nearly cloud free area bounded on the north and east by diverging cloud lines. The coastal areas realise what is known as coastal showers. During this period, the SE trade winds are very strong at the coast of Somalia but too cold to be able to bring in adequate moisture.

The Fall Transition period, locally referred to as the **Deyr** season (October through November) includes the second and shorter rainy season. At this time, the Arabian ridge intensifies and extends approximately south-west from Arabia towards the equator creating a (weak) zone of diverging winds. These winds on the eastern side of the ridge may converge with the weakening SE monsoons over the central parts of Somalia, bringing rainfall over these areas. The northern part of the country is under the influence of dry air from the Arabian peninsula and therefore receives less precipitation during this period. Figure 5 shows the patterns of pressure and monsoons which are normally observed on the western Indian Ocean, off the coast of Somalia.

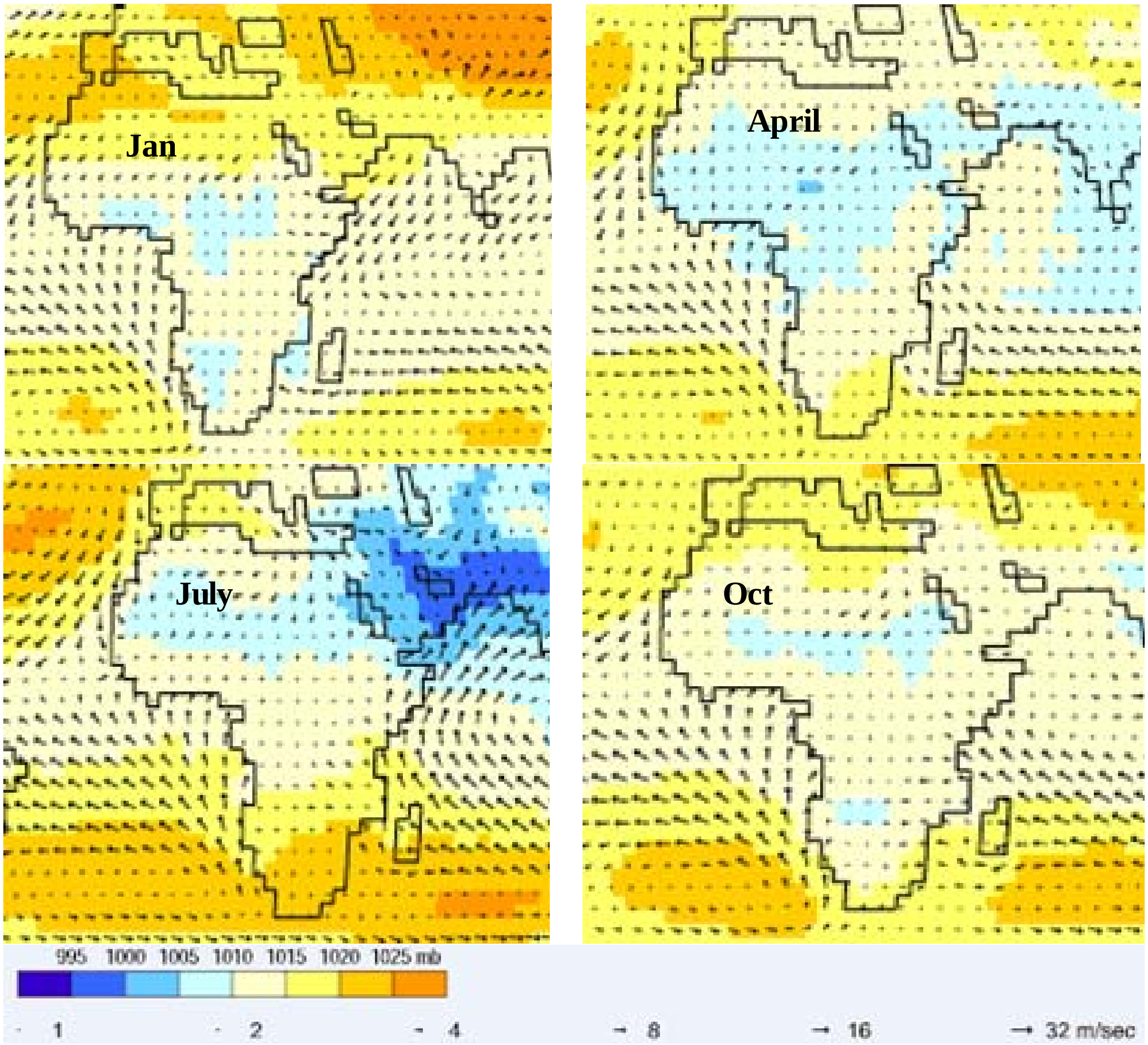


Figure 5: The monsoon wind systems over Africa

Figure 6 summarises both the temporal as well as the spatial rainfall distribution (rainfall calendar) over the country.

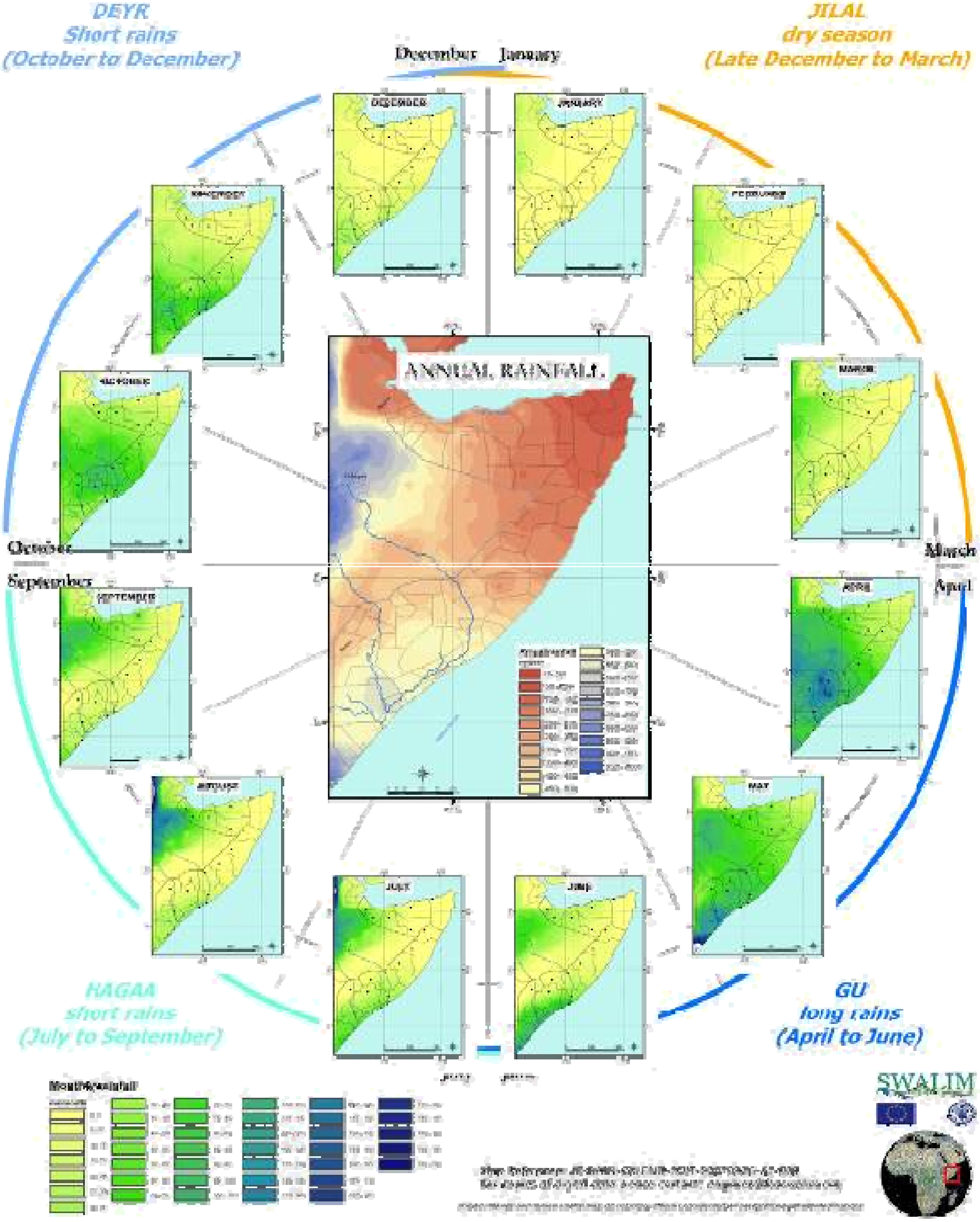


Figure 6: The Rainfall Calendar for Somalia

2.3 Physical Features

Somalia can be divided in five distinct physiographic zones differentiated by topography (FAO, 2005):

(i). The northern coastal plains, called Guban;
(ii). The Golis mountain range and plateaus in the north. The Golis mountain range parallel to the Gulf of Aden coast and the plateaus evidently form the great part of the country.
(iii). The central coastal plains, with a wide sand dune system;
(iv). The broad limestone-sandstone plateau covering all of central and southern Somalia;
(v). The flood plains of the Juba and Shabelle Rivers in the south, which provide the highest agricultural potential.

The lithology of Somalia mainly consists of marine sedimentary rocks ranging from Mesozoic to Recent in age. Only two isolated crystalline pre-Cambrian basement outcrops (one in the northern part and one in the southern) occur. The marine sedimentary cover is represented mainly by limestone and marly-limestone of the Karka and Auradu Formations in the north, and of the Mudug Succession in the central and southern parts. Several Quaternary deposits of aeolian, lacustrine, and alluvial origin outcrop along the coast and in the main alluvial valleys. A long coastal dune system runs almost parallel to the Indian Ocean coastline for nearly 1,300 kilometres. Isolated volcanic basaltic rocks, from Late Miocene to Pleistocene in age, are visible along the border with Djibouti, while Proterozoic and late Cambrian basement volcanic and metamorphic terrains outcrop in the north of Somalia in a very complex structural setting, while in the south they are present in a less complex arrangement (Abbate et al., 1994).

Slopes in the entire country are generally very low, reflecting the morphology of most of its territory. The northern mountain range registers the highest slope values, while a more undulated morphology in the Nuugal Valley also displays some sharper slopes.

The underwater morphology reflects the geological origin of the seas surrounding the country. On the north side, the coastline on the Gulf of Aden drops off quickly on a very steep slope to its sea bed, some 2,000 m below sea level. On the Indian Ocean side, the continental shelf extends several kilometres into the sea before it slopes gently down to the ocean bed, whose average depth is 4,500 meters below sea level. Figure 7 below shows some of these features mentioned above.

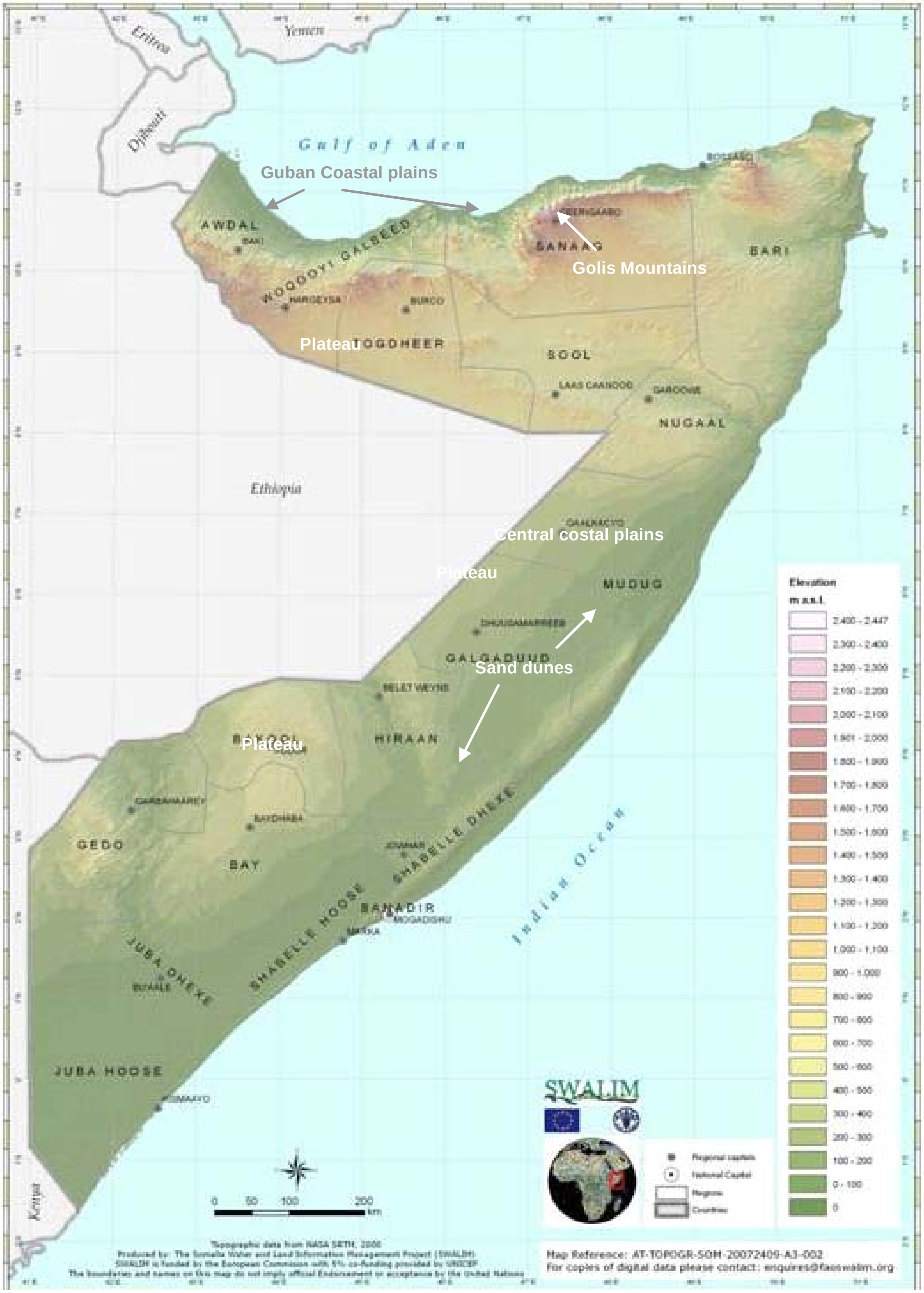


Figure 7: Topography of Somalia.

The surface waters of the country can be subdivided in the following drainage basins (Figure 8) that sum to a total area of about 1.3 million km^2, of which more than half is outside the country:

1) Gulf of Aden basin;
2) Daroor basin;
3) Tug Der/ Nugal basin;
4) Ogaden/Central basin;
5) Shabelle basin;
6) Juba basin;
7) Lag Dera basin;
8) Lag Badana basin;
9) Coastal basin.

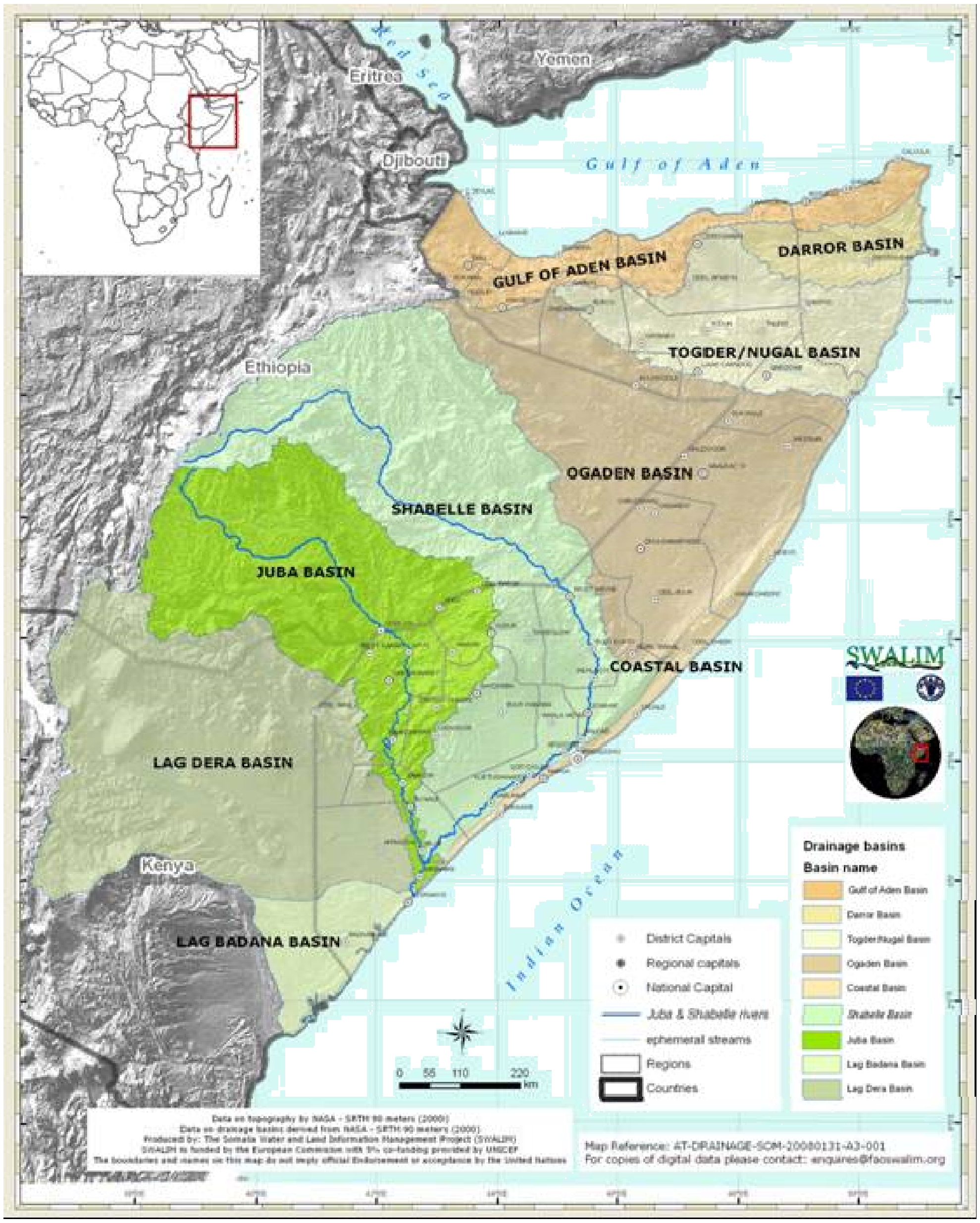


Figure 8: Main drainage basins of Somalia and their extension within the Horn of Africa Region

A significant portion of the water resources of Somalia is contributed by the catchment areas outside Somalia. The catchment areas of the major river basins are summarized in the table (Table 4) below. The elevations of the Juba, Shabelle and Lag Dera River basins reach higher than 3000 m in the upper catchment areas in Ethiopia and Kenya, but the elevations within Somalia for these basins are below 700 m. The highest elevations of the northern basins are above 2000 m.

Table 4: Catchment Areas of Major Drainage Basins

Major Drainage Basin	Catchment Area		
	Total	Within Somalia	
	Km^2	Km^2	% of total
Juba	220,872	64,744	29%
Shabelle	296,972	108,295	36%
Lag Dera	231,639	46,335	20%
Lag Badana	16,575	16,575	100%
Ogaden	234,943	159,500	63%
Tug Der/Nugal	112,231	112,231	100%
Darror	34,195	34,195	100%
Gulf of Aden	74,422	74,422	100%
Central Coastal	27,638	27,638	100%

Based on the agro-climatic conditions and water availability, irrigated agriculture is practiced in areas within the riverine areas of the Juba and Shabelle Rivers and some patches of land along the *toggas* in the mountainous areas of north-western Somalia (e.g. Durdur watershed) and the northern coastal areas. The areas in the Juba, Shabelle, Lag Dera and Lag Badana basins are either moderately or marginally suited for rain-fed agriculture. In the case of the northern basins (Gulf of Aden, Darror, Nugal and Ogaden), most of the land areas are not suitable for rain-fed or irrigated agriculture. There are however some areas in Somaliland, in Borama, Hergeisa, Gebiley, Burco, Owdweyne and Sheikh districts where rain-fed cultivation is carried out. Most of the areas in these basins are marginally and moderately suitable for extensive grazing and forestry plantation.

Of the nine river basins, the predominant hydrographical features of Somalia are the downstream stretches of the two main permanent rivers, the Juba and Shabelle, both of which flow from the highlands of Ethiopia towards the Indian Ocean. The Juba, which flows in Somalia for more than 1,000 km out of its 1,800 km of total length, and the Shabelle, which extends for more than 1,200 km from the Somali-Ethiopian border to its confluence with the Juba. Both these rivers, as well as other main Somali drainage networks, have their headwaters in the neighbouring countries of Ethiopia and Kenya, and are most affected by the rainfall from these territories. In the Ethiopian highlands, the high amount of rainfall – more than 1,000 mm per year contributes about 90% of discharge to the Juba and Shabelle. The contribution of other drainage basins to surface water is generally insignificant. This normally consists of occasional runoff in seasonal watercourses.

The Shabelle River joins the Juba before this flows into the Indian Ocean (just north of Kismayo), but it is only at the time of large floods, which are rare, that the Shabelle waters reach the Juba River. Similarly, waters from seasonal rivers like Lag Dera occur only during extreme rains and it is very rarely that they join the Juba River. Hence, technically, both Shabelle and Lag Dera Rivers are tributaries of Juba. The Shabelle is an aggraded river, meaning that its waters normally flow for most part of its reach at a higher elevation than the surrounding floodplain. The river flow of the Shabelle River normally flows at a lower level than the floodplain. The Jubba River is more than 150 meters wide during high water levels that occur from May through June and from September through November.

2.4 Vegetation

Climate, elevation, population, and soil characteristics affect the vegetation in Somalia. Climate has the most pronounced effect, with annual rainfall being the dominant climatic factor. More specifically, due to the importance of precipitation, this dictates the types of vegetation capable of surviving the harsh dry environment common throughout the country. Elevation is also a controlling factor in determining the type of vegetation found in an area due to the various temperature ranges, particularly lower temperatures, which are common to mountainous regions. Cold temperatures, coupled with a paucity of water, create the harshest conditions for vegetation. Besides climate and elevation, human activity also contributes to controlling or modifying the vegetation regimen in the region.

Many salt flats are present along the coastal areas, due to seawater intrusion into the groundwater table. These areas are usually entirely void of vegetation.

Irrigation projects have also modified vegetation in Somalia. There are large irrigation projects along the Rivers Juba and Shabelle. Agricultural produce, such as bananas and papayas, are grown in the region. Rice is also cultivated in the vicinity of the River Shabelle.

The Guban area (northern coastal region facing the Gulf of Aden) has broadleaf evergreen vegetation. This region is characterized by dry climatic conditions. The vegetation includes acacia trees, about three meters high, scattered throughout the region, with thorny acacia bushes and other shrubs. Grasses grow sporadically in the region. Tall tamarisk trees grow along dry river courses as well as in large tug beds. The smaller tug beds only support grasses and bush along their banks. The sand dunes in the Guban area support bunch grasses. Low sand dunes support grasses or salt bushes, but not both.

The northern mountain vegetation is mainly controlled by elevation and secondarily by precipitation and soil. The northern mountain region has three distinct regimes depending on altitude: open woodland, shrub evergreen, and juniper. The open woodland consists of acacia trees that range in height up to eight meters. Interspersed with these trees are low shrubs. The acacia trees are found up to 1,500 meters in elevation. Above 1,500 meters, vegetation changes to needle leaf evergreen shrubs ranging from one meter to four meters in height. The shrub evergreen vegetation gives way to juniper at the highest elevations of the mountain areas. The juniper trees grow close together. The shrubs form locally dense thickets in scattered pockets throughout the area. Trees are generally more than eight meters tall, but local inhabitants cut the forest for poles. This area has also been heavily over-grazed.

The Northern Plateau is characterized by open spaced bush-type vegetation. Its mixed deciduous vegetation consists of *Acacia sp*. And *Commiphora sp*. In the northern plateau area, there are small depressions where rainwater accumulates after rain: the larger ones are called ‘ballehy’ and can have a diameter from a few meters to several hundred. These pools generally last for a day or two. The soil in there is usually grey, sandy clay that cracks when dried. Ballehy support grass clumps from one to two meters in height. These may retain water throughout the year, although the water level drops. The dry ballehy floor does not support any vegetation. Along the edges, however, bunch grasses and scattered acacia trees grow.

The vegetation of the Southern Somali Plateau is predominantly bunch grasses with scattered acacia trees in areas that have a moisture source, such as watercourses. Very little agriculture is practiced in the area due to sparse precipitation.

The Coastal Plains are divided into two separate zones. Short grasses interspersed with isolated trees and brush vegetation characterizes the northern section, located north of the Shabelle River. Along the tugs some tree growth occurs. The grassland in this area is used for grazing. In the areas along the Rivers Shabelle and Juba, dense vegetation is found along the river channel. South of the river, typical savannah vegetation takes over, characterized by grass-covered areas with trees growing along the river banks and near sources of water.

Cultivated cropland is confined to two areas: the hills and high plains north and west of Hargeisa and the land along and between the Rivers Shabelle and Juba. Agriculture along the two rivers is based on controlled irrigation or field inundation during high water periods. Primary crops are bananas, sorghum, and millet. Bananas are a major source of export income for Somalia. Other crops consist of corn, wetland rice, beans, and sesame. Near Hargeisa and on the land between the two rivers (Bay and Bakool regions), agriculture consists of small plots of crops sustained by natural rainfall. Other crops grown include groundnuts, cowpeas, mung beans, and corn.

2.5 Agro-ecological zones

Agro-ecologic zones for Somalia have been defined and mapped through a combination of information on soil, landform and climate (Venema, 2007). Information on soil and landform was mainly derived from the Soil and Terrain (SOTER) Database for north-eastern Africa (FAO, 1998), updated by recent information from the SWALIM study areas. Available data on rainfall and potential evapotranspiration (FAOCLIM, 2001) has been used to define Length of Growing Period Zones (LGP Zones), as described in the following Sections. The resulting AEZ map (Figure 9) shows 29 Zones defined by a combination of LGP and soil, and an additional three "inter-zonal" mapping units defined by landform (i.e. Dunes, Floodplains and Mountains).

The Length of Growing Period (LGP) is the period (in days) that moisture supply exceeds half potential evapotranspiration1 (P > 0.5PET). The LGP is calculated over a whole year and may consist of one or more "normal" or "intermediate" Growing Periods (GP), whereby a normal GP is a period in which P exceeds full PET (P>PET) and an intermediate GP a period in which P exceeds half PET, but is less than PET (0.5PET<P<PET).

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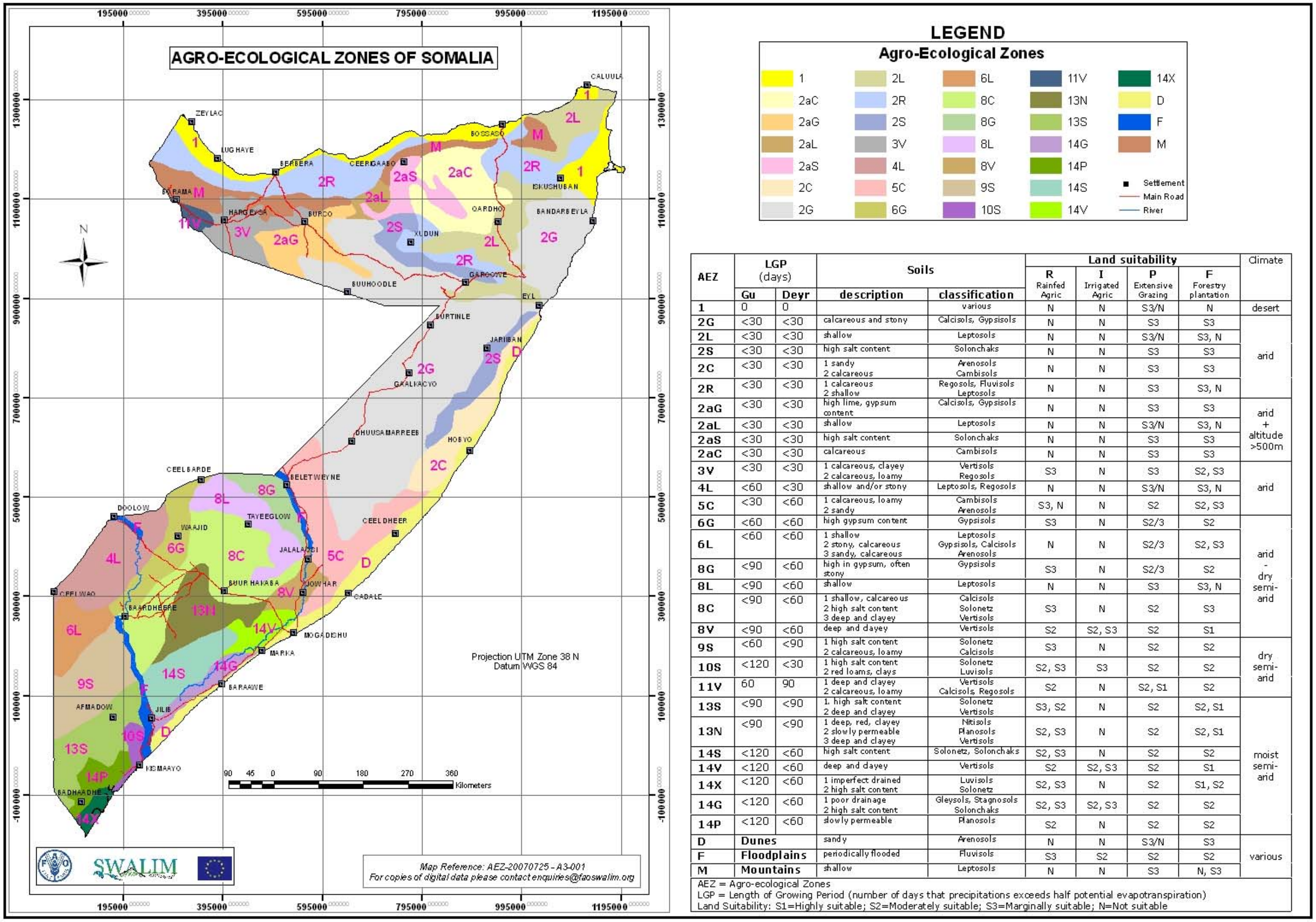
[1] It also includes the time required to evapotranspire up to 100 mm of stored soil moisture. This soil moisture storage has not been included in the present assessment, as all growing periods in Somalia are of an "intermediate" nature in which full water requirements are rarely met and little moisture is stored in the soil.



AEZ	LGP (days)		Soils		Land suitability				Climate
	Gu	Deyr	description	classification	R Rainfed Agric	I Irrigated Agric	P Extensive Grazing	F Forestry plantation	
1	0	0		various	N	N	S3/N	N	desert
2G	<30	<30	calcareous and stony	Calcisols, Gypsisols	N	N	S3	S3	arid
2L	<30	<30	shallow	Leptosols	N	N	S3/N	S3, N	
2S	<30	<30	high salt content	Solonchaks	N	N	S3	S3	
2C	<30	<30	1 sandy 2 calcareous	Arenosols Cambisols	N	N	S3	S3	
2R	<30	<30	1 calcareous 2 shallow	Regosols, Fluvisols Leptosols	N	N	S3	S3, N	
2aG	<30	<30	high lime, gypsum content	Calcisols, Gypsisols	N	N	S3	S3	arid + altitude >500m
2aL	<30	<30	shallow	Leptosols	N	N	S3/N	S3, N	
2aS	<30	<30	high salt content	Solonchaks	N	N	S3	S3	
2aC	<30	<30	calcareous	Cambisols	N	N	S3	S3	
3V	<30	<30	1 calcareous, clayey 2 calcareous, loamy	Vertisols Regosols	S3	N	S3	S2, S3	arid
4L	<60	<30	shallow and/or stony	Leptosols, Regosols	N	N	S3/N	S3, N	
5C	<30	<60	1 calcareous, loamy 2 sandy	Cambisols Arenosols	S3, N	N	S2	S2, S3	
6G	<60	<60	high gypsum content	Gypsisols	S3	N	S2/3	S2	arid - dry semi-arid
6L	<60	<60	1 shallow 2 stony, calcareous 3 sandy, calcareous	Leptosols Gypsisols, Calcisols Arenosols	N	N	S2/3	S2, S3	
8G	<90	<60	high in gypsum, often stony	Gypsisols	S3	N	S2/3	S2	
8L	<90	<60	shallow	Leptosols	N	N	S3	S3, N	
8C	<90	<60	1 shallow, calcareous 2 high salt content 3 deep and clayey	Calcisols Solonetz Vertisols	S3	N	S2	S3	
8V	<90	<60	deep and clayey	Vertisols	S2	S2, S3	S2	S1	
9S	<60	<90	1 high salt content 2 calcareous, loamy	Solonetz Calcisols	S3	N	S2	S2	dry semi-arid
10S	<120	<30	1 high salt content 2 red loams, clays	Solonetz Luvisols	S2, S3	S3	S2	S2	
11V	60	90	1 deep and clayey 2 calcareous, loamy	Vertisols Calcisols, Regosols	S2	N	S2, S1	S2	
13S	<90	<90	1. high salt content 2 deep and clayey	Solonetz Vertisols	S3, S2	N	S2	S2, S1	moist semi-arid
13N	<90	<90	1 deep, red, clayey 2 slowly permeable 3 deep and clayey	Nitisols Planosols Vertisols	S2, S3	N	S2	S2, S1	
14S	<120	<60	high salt content	Solonetz, Solonchaks	S2, S3	N	S2	S2	
14V	<120	<60	deep and clayey	Vertisols	S2	S2, S3	S2	S1	
14X	<120	<60	1 imperfect drained 2 high salt content	Luvisols Solonetz	S2, S3	N	S2	S1, S2	
14G	<120	<60	1 poor drainage 2 high salt content	Gleysols, Stagnosols Solonchaks	S2, S3	S2, S3	S2	S2	
14P	<120	<60	slowly permeable	Planosols	S2	N	S2	S2	
D	Dunes		sandy	Arenosols	N	N	S3/N	S3	various
F	Floodplains		periodically flooded	Fluvisols	S3	S2	S2	S2	
M	Mountains		shallow	Leptosols	N	N	S3	N, S3	

AEZ = Agro-ecological Zones
LGP = Length of Growing Period (number of days that precipitations exceeds half potential evapotranspiration)
Land Suitability: S1=Highly suitable; S2=Moderately suitable; S3=Marginally suitable; N=Not suitable

Figure 9: FAO Agro-Ecological Zones in Somalia

3. Droughts in the Horn of Africa

3.1 Effects of Droughts

In the Horn of Africa, drought is a common occurrence. It is so common that in many African societies, the drought season marks an important part of the annual calendar. If conflict and drought are the scourge of our modern world, it would therefore be appropriate to question their symbiotic relationship. If they are related, how do they influence each other? Is drought a cause of conflict or is conflict a catalyst of drought? Will drought always trigger conflict? Will conflict exacerbate drought? Conflict cannot change weather patterns, but it can affect agricultural practices, land use, and other social factors that intensify the effects of diminished rainfall, particularly by causing famine.

Drought is one of the causes of conflict. Many areas affected by drought are arid and semi-arid areas. Under normal circumstances, these areas are low in resources and under substantial ecological pressure. When drought occurs in such arid areas, the living conditions of local people become very difficult. In these conditions, the land yields no crops and water is insufficient for human consumption as well. People compete for the meagre available resources. Pastoral communities are an example of this. Pastoralists depend on their livestock (camels, cattle, sheep, and goats) and move from place to place with their livestock to look for usable pasture land and water. During drought, their movement increases. Sometimes, different pastoral groups move to the same place and want to use the same scarce resources, which cause conflicts between the two communities. There is a history of pastoral communities fighting for scarce resources in the southern parts of Ethiopia, northern Kenya, parts of Somalia and the Sudan. Most of the conflicts in those areas were manageable, and tend to be resolved by elderly leaders through traditional conflict resolution mechanisms on an ad hoc basis. However, these conflicts are exacerbated and more difficult to resolve when serious droughts occur.

When the State of Somalia collapsed in early 1990s, the country was also suffering from drought and human-induced famine. Rival pastoral clans who had been deprived of development investment invaded the fertile Juba River farming area. Many farmers were caught unprepared and they bore the brunt of the fighting. The availability of small arms and light weapons along border areas where pastoral communities reside also contributes greatly to conflict. Arms ownership is regarded as necessary for the protection of one's community and livelihood in such areas, as they are situated in remote regions, far from the protection of regular state security. But the prevalence of arms also means the prevalence of armed conflicts.

The response of the central government to the drought-affected region determines, to some extent, when and where a conflict breaks out. Delays of aid often create a feeling of alienation and marginalization among the affected groups. These communities may form different factions and rebel groups to address their frustration with the central government. In such contexts, conflict erupts among the rebel groups and between the rebels and the government in power. Running away from conflict and persecution, leaving their home and land, many people become refugees in neighbouring countries. According to a 2004 UNHCR report the total number of refugees reached to 9.2 million in the world. Food aid, health care and human rights protection are the basic needs of refugees. Often it is beyond the capacity of host countries to provide such assistance. It even becomes challenging to humanitarian organizations and UNHCR. Hence, people at refugee settlement areas are exceptionally susceptible to famine. Relief aid is sometimes looted by rival groups which make humanitarian assistance additionally difficult. For instance, in the early 1990s in Somalia, fighting and looting made providing humanitarian assistance very difficult. As a result, many people died from famine, unable to obtain aid.

3.2 Problems of defining drought

Drought is a complex interaction of the physical and social processes. Despite all of the problems that droughts have caused, drought has proven to be difficult to define and there is no universally accepted definition because:

- Drought, unlike flood, is not a distinct event;
- Drought is often the result of many complex factors such that drought often has no well-defined start nor end; and
- The impacts of drought vary by affected sector, thus often making definitions of drought specific to particular affected groups.

Notwithstanding, drought is often misunderstood vis-à-vis aridity. The next section describes the main characteristics of drought and aridity

3.2.1 Droughts and Aridity

Two terms: *drought* and *aridity* should be explicitly separated. This could help to eliminate perceptions like "we are living in a permanent drought" or that "we have had the drought for the past almost 60 years". Drought is a recurrent natural climatic event, which stems from the lack of precipitation over an extended period of time (e.g. a season or several years). It occurs in all the geographical zones, but its characteristics vary significantly from one region to another.

Drought is a temporary anomaly and as such it differs from aridity, which is a permanent feature of climate, associated with low rainfall regions. The aridity measures suggested to date normally represent a ratio of precipitation to temperature characteristics during a warm season of the year. Aridity is also indexed by the ratio of a region's mean annual potential evaporation (MAE) to its mean annual precipitation (MAP). Aridity is usually taken as a situation in which MAP is less than half the value of potential evaporation. Many attempts have been made to classify climate using different sets of climate data. The FAO Eco climate classification method defines an arid zone as one whose mean annual precipitation (MAP) ranges from 100 to 400mm. The method classifies a higher percentage of Somalia as arid. Figure10 illustrates the different classes of climate in Somalia as extracted using new_LocClim software for interpolation.

Defining what drought is – is the fascinating arena of speculation. Drought has many facets in any single region: it always starts with the lack of precipitation, but may (or may not, depending on how long and severe it is) affect soil moisture, streams and groundwater. Definitions vary from region to region and may depend upon the dominating perception, and the task for which it is defined (academic study or a drought relief plan).

Generally, there are two important aspects which are associated with drought studies, namely, the causes of drought and the impacts of drought. While the impacts of drought are tangible and measurable, the causative factors are many and their combinatorial nature is very complicated and often not well understood.

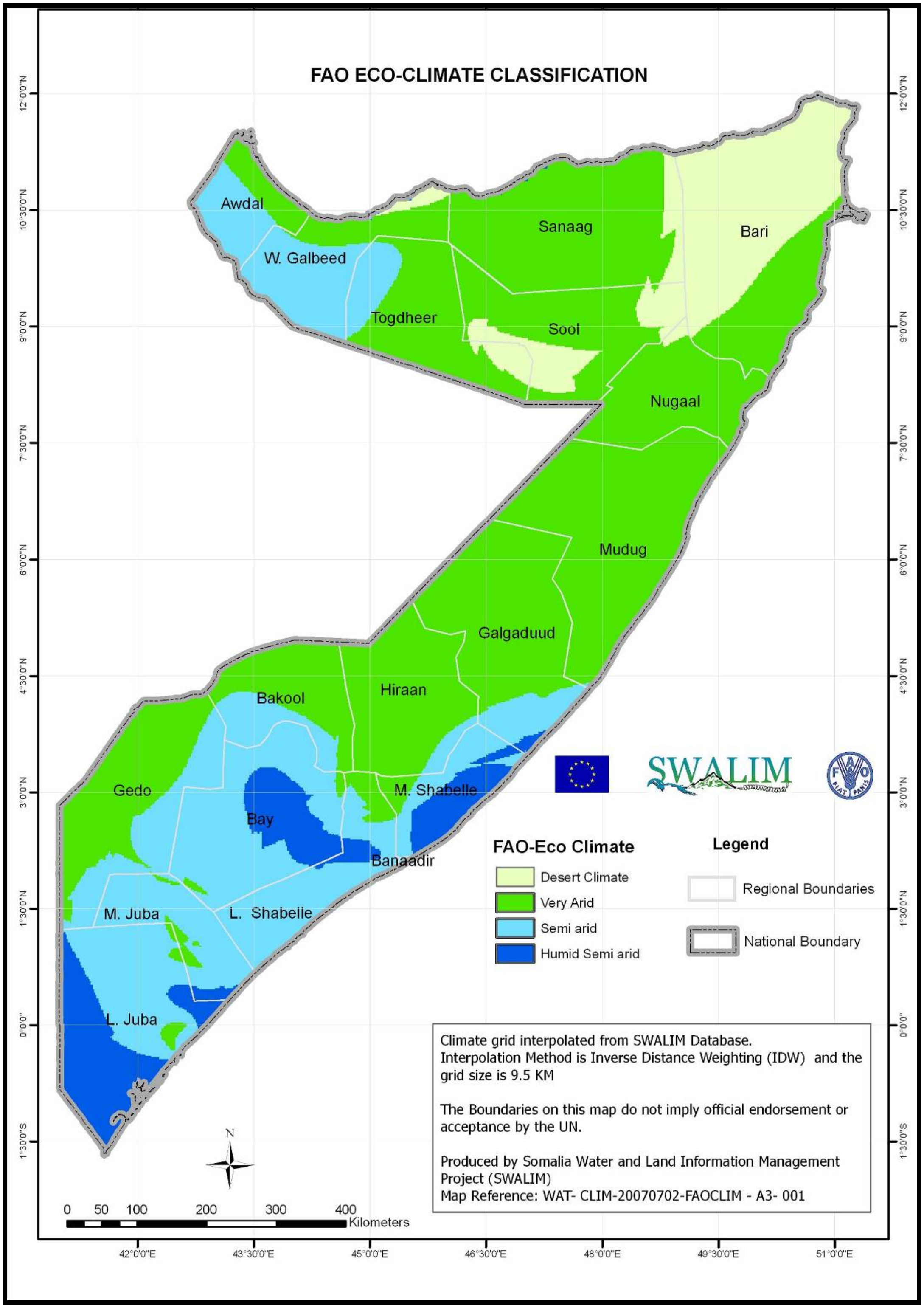


Figure 10: FAO Eco climate classification map

Generally, the main cause of drought, as a hazard, is the persistence of unfavourable weather conditions which lead to scarcity of fresh water resources, high temperatures and strong winds - phenomena which are intricately imbedded in the climate variability. Although many erroneously consider drought a rare and random event, it is actually a normal, recurrent feature of climate. It occurs in virtually all climatic zones, although its characteristics vary significantly from one region to another. Drought is a temporary aberration and differs from aridity since the latter is restricted to low rainfall regions and is a permanent feature of climate. Thus, while drought as a natural phenomenon is caused by natural factors, drought disasters are caused by a unique combination of natural drivers and the socio-economic and socio-political vulnerabilities over the affected area. Thus, the impact of the drought hazard varies regionally and over time. Thus, we observe that drought disasters triggered by prolonged drought in Africa can affect millions of people and contribute to malnutrition, famine and loss of lives, whereas droughts in the United States primarily result in economic losses.

Drought should generally be defined relative to some long-term average conditions (e.g. precipitation, balance between precipitation and evapotranspiration etc.). This is normally reflected in most of the general drought definitions. Below are a few examples of such definitions:

(i). Drought is a decrease of water availability in a particular period and over a particular area.
(ii). Drought is an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply.
(iii). Drought is a severe shortage in the appearance of natural waters with respect to normal.
(iv). Drought is a condition whenever the amount of water which has been expected and relied upon for use in any of man's activities cannot be met for some reason.
(v). Drought is a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency with respect to man's usage of water.

These definitions are normally vague and do not provide quantitative answers to "when", "how long" or "how severe" a drought is and are often used as a start-up in scientific papers and reports. Some sources refer to them as "conceptual definitions" and differentiate between conceptual and operational definitions of drought. Operational definitions identify the beginning, end, spatial extent and severity of a drought. They are often region specific and are based on scientific reasoning, which follows the analysis of certain amounts of hydro-meteorological information. They are beneficial in developing drought policies, monitoring systems, mitigation strategies and preparedness plans. Operational definitions are formulated in terms of drought indices.

3.2.2 Drought Types

A deficit of precipitation has different impacts on different components of hydrological cycle (river flow, groundwater) and components of biosphere (ecosystems, humans). For example, soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, river flow and reservoir storage reflect the longer-term precipitation anomalies. These anomalies allow different drought types to be defined conceptually and to be described in terms of various drought indices. The distinction between these types are, however, rather arbitrary as different types of drought may happen simultaneously.

The drought type terminology is effectively an academic exercise. One thing, however, is worth stressing. Different drought "types" are effectively different stages of the same natural and recurring process. The deficiency of rainfall effectively triggers a drought. The longer and the more spatially extensive this deficiency is - the more likely that, other impacts (types) of the droughts will occur as the result.

Thus, Meteorological droughts attempt to explain the primary causes, while agricultural and hydrological droughts attempt to explain the secondary impacts of the meteorological droughts. The economical, social and environmental droughts, although, not droughts in the strict sense, but are actually as a consequence of the secondary drought impacts and are therefore attempts to explain the tertiary impacts of meteorological droughts. This is illustrated on the figure below (Figure 11).

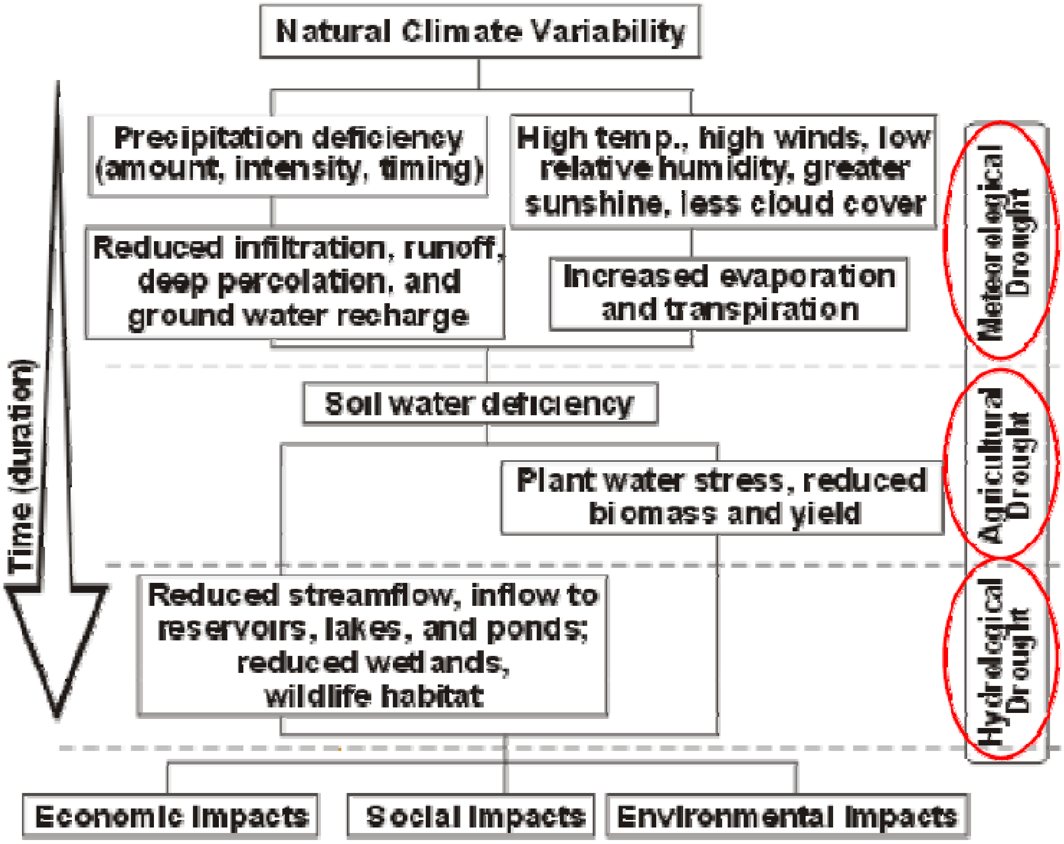


Figure 11: Concept of the drought Definitions

4. Reviews of the common Drought Assessment Methodologies

4.1 General

Drought indices are commonly used to assess and monitor the severity of droughts. Drought indices assimilate thousands of bits of data on rainfall, snow pack, stream flow, and other water supply indicators into a comprehensible big picture. A drought index is typically a single number, far more useful than raw data for decision making.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for specific country/regional uses.

Many indices have been developed to measure drought magnitudes, in different parts of the world. To date, the most commonly used drought indices include:

1) meteorology-based drought indices, (often based on station or point data) include:
    (i). Percent Normal Drought Index (PNDI)
    (ii). Standardized Precipitation Index (SPI)
    (iii). Pamer's Drought Severity Index (PDSI)
    (iv). Crop Moisture Index (CMI)
    (v). Surface Water Supply Index (SWSI)
    (vi). Precipitation Decile Index
    (vii). Reclamation Drought Index (RDI)
    (viii). Weighted Anomaly Standardized Precipitation (WASP)
2) satellite-derived drought indices such as
    (i). Modified perpendicular drought index (MPDI).
    (ii). Keetch-Byram Drought Index (KBDI)
    (iii). NDVI

Annex 1 gives a brief description of the characteristics of these drought indices. From the point of view of the present study, however, the following conclusions can be drawn about the use of the indices for the purpose of the study.

The above mentioned drought indices have been adopted for drought monitoring/assessment, separately or in conjunction, in different parts of the world. However, these indices have the following disadvantages:

(i). They are not consistent with the fundamental requirements of the definition of drought, namely, "*... a prolonged dry period (deficit rainfall and soil moisture) accompanied by excessively high air temperatures...*" Thus, besides the rainfall and moistures deficits or the temperature excesses, which are either explicitly or implicitly considered in most of these indices, there is the important element of run-lengths which is generally lacking these indices.
(ii). Except for the Palmer index, most of the other indices do not show clearly the dynamics of the drought process.
(iii). Most of the indices focus on one causative parameter, usually rainfall, while the drought process is more complex.
(iv). All the indices are based on continuous data observations (no data gaps).

(v). Most of the indices are designed to operate on a fixed computational period (e.g. month) that cannot be changed easily by the user without compromising on the underlying assumptions/principles of the index.

4.2 National and Regional Drought Assessment Approaches in Use in Eastern Africa

Eastern Africa, like many other parts of the tropics, is prone to extreme climate events such as droughts and floods. These extreme events have severe negative impacts on key socio-economic sectors of all the countries in the region. In efforts to minimise the negative impacts of these extreme events many organisations in the region have developed ways and means of drought assessment. The FAO Global Information and Early Warning System on Food and Agriculture (GIEWS) is the most globally complete system, but other systems, including the USAID sponsored Famine Early Warning System (FEWS NET), the ICPAC and FSAU are also key players in drought monitoring in Somalia.

4.2.1 Famine Early Warning Systems Network (FEWS NET)

FEWSNET is an information system designed to identify problems in the food supply system that potentially lead to famine or other food-insecure conditions in Sub-Saharan Africa, Afghanistan, Central America, and Haiti. It is a multi-disciplinary project that collects, analyzes, and distributes regional, national, and sub-national information to decision makers about potential or current famine or other climate hazard, or socio-economic-related situations, allowing them to authorize timely measures to prevent food-insecure conditions in these nations.
The USGS/EROS Data Center (EDC) works with USAID, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and Chemonics International (Chemonics) to provide the data, information, and analyses needed for the FEWS NET project. NASA and NOAA collect and process satellite data that are used to monitor the vegetation condition (Normalized Difference Vegetation Index, or NDVI) and rainfall (RainFall Estimate, or RFE) across the entire African continent. The NDVI and RFE data are but two tools used by FEWS NET to monitor agricultural conditions in Africa.

By comparing current NDVI and RFE values and that of long term average it becomes possible to tell cases of existing or prevailing droughts. Agro-meteorological Product Development, such as rainfall estimate algorithm enhancement, and crop-specific water requirement satisfaction index (WRSI) modelling and yield reduction assessment are used widely by FEWSNET in the region. The "crop-specific water requirement satisfaction index (WRSI)" is a methodology developed and currently used by FAO and by several countries around the world through FAO's projects.

4.2.2 IGAD Climate Prediction and Applications Centre (ICPAC)

ICPAC has a mission of fostering sub-regional and national capacity for climate information, prediction products and services, early warning, and related applications for sustainable development in the IGAD Sub-Region”. ICPAC monitors droughts and floods indirectly through seasonal forecast/outlook forums. The forecasts are developed using statistical regressions between seasonal rainfall and Sea Surface Temperatures (SSTs) and other climate indices that affect rainfall characteristics in the region.

ICPAC products are as below.

- Monitoring of past climate

- Current State of Climate.
- Prediction products
- Impacts
- Seasonal forecasts

The ICPAC drought monitoring and assessment methodology is much more directed towards the primary causative factors. While this approach is generally acceptable, it is important to point out that the SST correlations with local seasonal rainfall are not time invariant, that is, the correlations and dominant regions seen to vary from year to year for a given season and for different baselines over a given rainfall location. This unfortunately lowers the level of confidence in the whole approach. Further, the MAM analysis has a very low reliability.

4.2.3 Arid Lands Resource Management Project (ALRMP)

ALRMP is a community-based drought management project of the Government of Kenya (GoK) committed to enhancing food security social services delivery and reducing livelihood vulnerability in drought prone arid and semi-arid areas in Kenya through sustainable people driven development. ALRMP produces early warning bulletins to 28 districts in Kenya. The bulletins indicate the rainfall performance in each region and the effects of the rainfall to agricultural related activities and food security. In this case impending cases of droughts or floods can be identified in advance. The main disadvantage with this method is that the drought here is generally of the secondary nature (agricultural droughts) and is unable to identify droughts from the primary causes. Since the agricultural impacts are strongly dependent on the baseline societal attributes, the method renders itself to misuse and exaggerations for personal and political gains.

4.2.4 Food Security Analysis Unit (FSAU) Somalia

FSAU monitors agricultural droughts indirectly through a complex food security analysis system. FSAU has field monitors all over Somalia who monitor agriculture, rainfall, and market prices of food commodities etc. After every rainy season the field monitors come together with experts in food security and nutrition to analyse the previous season and its impacts on the community. The analysis is summarised in one map representing Integrated Food Security Phase Classification (IPC). The country is then categorised according to the prevailing situation in terms of food security/insecurity. The causes of food insecurity are also highlighted on the map which could be floods, insecurity, drought, population influx etc. However, it is important to note that the process of the drought monitoring and assessment in FSAU is partly an attempt to circumvent the unavailability of real-time climate and soil water information. Therefore it has a subjective element that can be influenced for personal or political gains.

5. The SWALIM Drought Monitoring Methodology

5.1 Need for a composite drought assessment and monitoring methodology in Somalia

Drought is one of the most frequently used terms in African humanitarian actions, at the same time it is one of the most confused terms. Although originally it was quite well identified as a natural phenomenon, nowadays it is used for all kinds of food shortages. It is clear that malnutrition and food shortage can be caused by various factors. They can be caused by

- droughts
- floods
- diseases
- human conflicts or
- Unsatisfactory use of resources, among others.

Unfortunately the term "drought" is often used for food shortages, which are not caused by "drought" in its original sense. Drought is a natural phenomenon causing failure in producing essential crops and other products needed for the food supply of humans and livestock. In order to find the proper remedy, it is important to find the proper diagnosis first. In case of a real drought, appropriate measures are needed to be taken, which must be different from measures for situations when food shortage is caused e.g. by armed conflicts or market problems. In countries where weather monitoring networks are regularly maintained and upgraded, meteorological droughts are monitored and assessed by methods based on physical or statistical models. Elsewhere, where climate monitoring is poor, such as the case in Somalia, meteorological droughts are often misinterpreted. As a consequence, the drought management strategies are not based on observed data and information. Although several studies have been prepared recently as a response to recurrent severe droughts in Somalia, the studies focused more on the impacts of droughts in the agriculture/livestock sectors than on the primary causes. There is therefore a definite need for a system that is able to measure the severity of the drought or the very existence of the drought on a pre-defined scale with objectively verifiable indicators.

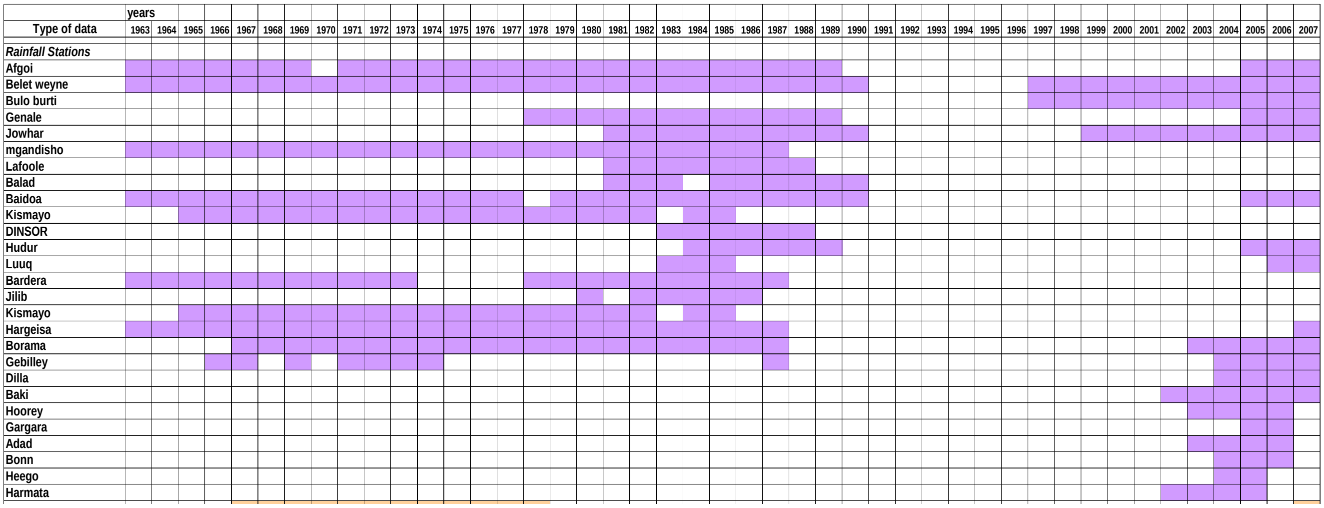
The main aim of the present study is to elaborate a drought monitoring methodology that is able to measure the natural components of the drought by comparing the prevailing situation to the multi-year average situation at the given time of the year. As drought is a composite natural phenomenon, the methodology should be able to take into account at least three factors at the same time, which are (i) rainfall, (ii) soil moisture or its proxy, the NDVI and (iii) temperature. (It is known that wind is also an important factor in Somalia contributing to drought conditions, however, at present it cannot be included because of lack of data.)

This study therefore focuses on developing a simple and operational CDI that:

(i). Clearly shows the dynamics of the drought development process
(ii). That utilises rainfall, temperature and NDVI as a soil moisture proxy with the corresponding run-lengths
(iii). Has a flexible computational period which can easily be changed by the user
(iv). Is applicable in situation of data gaps

5.2 Climate data availability

In Somalia most of the direct data needed for drought monitoring are discontinuous, or missing or very difficult to collect on site, neither is there an institution that can claim ownership of comprehensive data resource for planning and management of natural resources in Somalia. There is a general gap in climate observations for the period 1989-2003. Figure 12 is a bar chart that summarises the rainfall data availability in Somalia



	years																																												
Type of data	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
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Figure 12: Rainfall data availability in Somalia

As a result of SWALIM's efforts, the pre-war manual rainfall observation network with 68 rainfall stations has been rehabilitated and slightly extended, and a system of automatic weather stations is currently built in partnership with local authorities and international development organisations. The new system will provide data with adequate reliability and frequency to form a basis of continuous monitoring of drought tendencies in the future.

For the past years, however, Somali rainfall data series are discontinuous, practically no temperature time series were available and NDVI data series could only be established with limited reliability and continuity. The level of reliability and the discontinuity of historical data in Somalia gave reason for using data with higher reliability and better continuity for testing the methodology. It was therefore decided that Kenyan stations, some with similar climatologic characteristics to those in Somalia would serve as test data series, and once proven good, the methodology would be used in Somalia in real life.

The Kenyan stations which were utilized in this study were, Lodwar, Wajir, Kakamega, Dagoretti Corner, Narok, Embu and Meru. These stations represent a wide range of climates ranging from arid/semi-arid to humid. Kakamega is humid, Meru and Embu range between humid and semi-humid, Dagoretti Corner and Narok are semi-arid and Lodwar and Wajir range between arid and semi-arid. The map below shows the location of these stations on the map of Kenya. Although 8 Kenyan stations were analysed for testing purposes, the results of only three are presented in this report, because the others provided similar results, and the three demonstrate adequately the applicability of the method for monitoring the natural parameters of the drought.

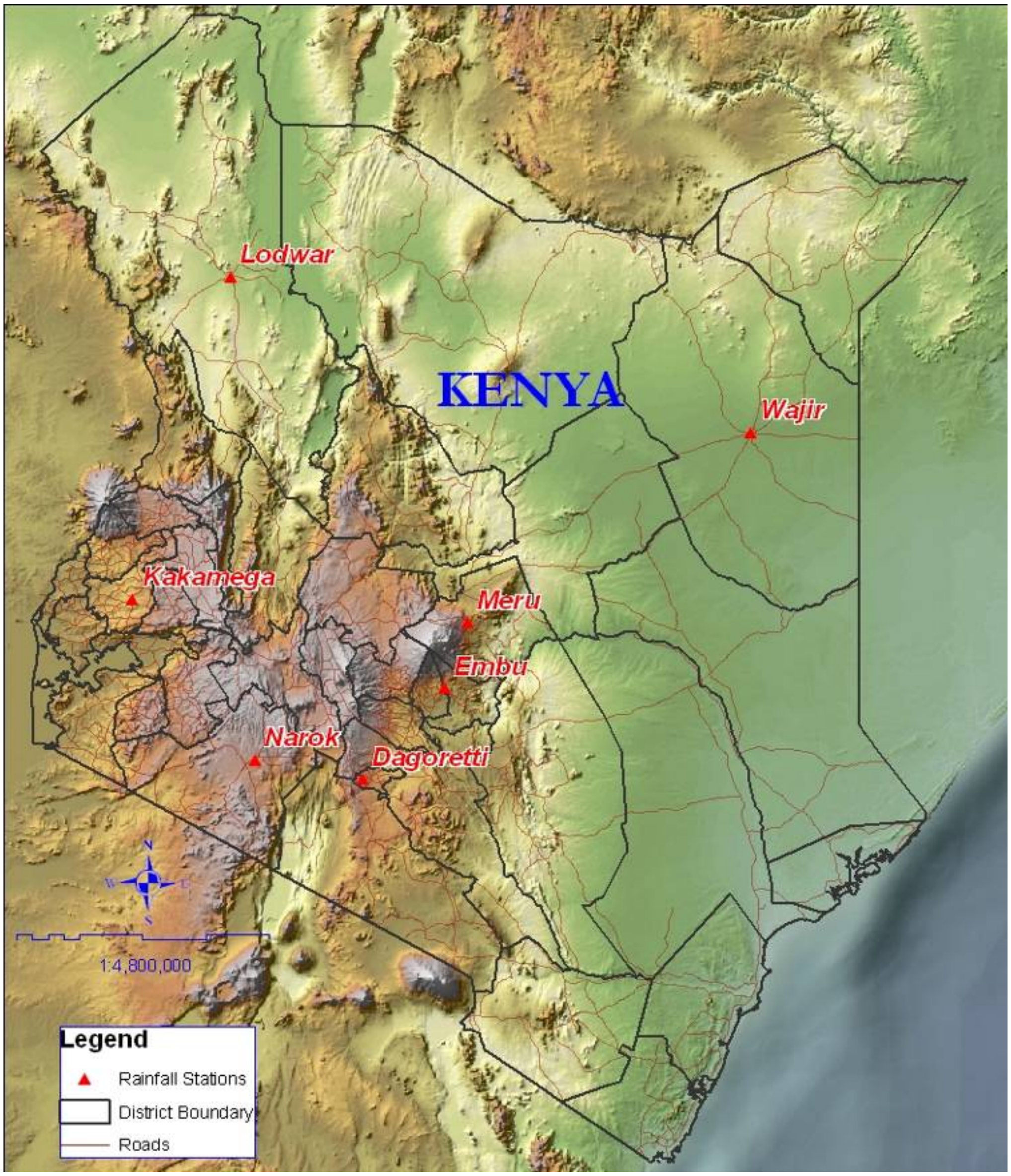

Figure 13: Location of the selected rainfall stations in Kenya

The dekadal and the monthly rainfall data for the Kenyan stations were obtained from KMD. While the monthly data were available from the 1950s to June 2008 in all the selected stations, the dekadal data were available for the period 1993 to June 2008. The temperature data for these stations was made available for the period 1993-2003. The dekadal AVHRR NDVI (8x8 km) data was used in this study. Extraction of NDVI values for the areas of interest was downloaded from the NOAA website and converted to ASCII format using Windisp© software for the period June 1981 to July 2008. All statistical analysis was performed in MSExcel©.

In this study the analysis of three Kenyan test stations is presented, which are

- Dagoretti
- Narok and
- Lodwar

Four stations were analysed in Somalia, for which the data series were satisfactorily reconstructed

- Belet-Weyne
- Jowhar
- Afgoi and
- Boroma

These 4 stations represent various climatic regions in Somalia. The location of the stations is shown in Figure 14

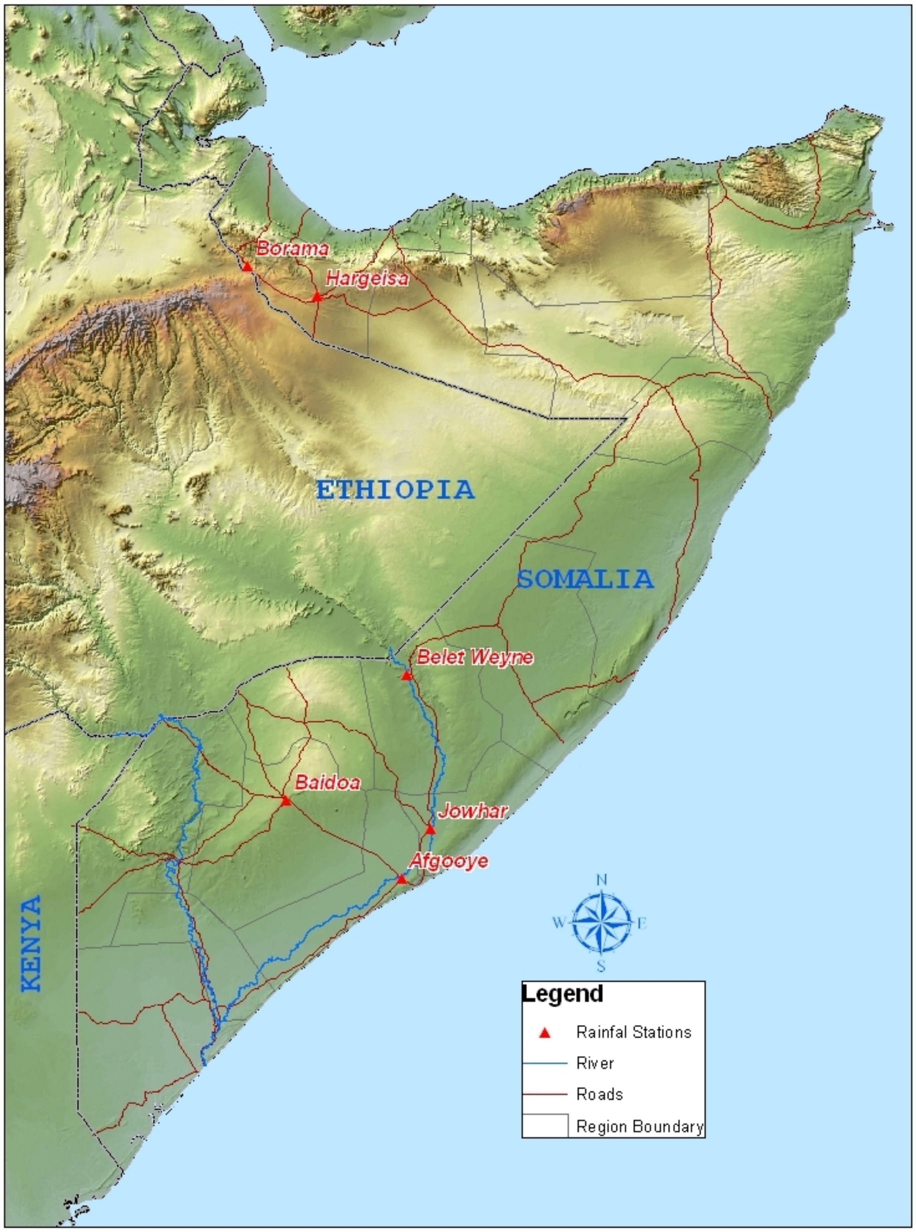

Figure 14: Location of selected rainfall stations in Somalia

5.3 The SWALIM Combined Drought Index

On the basis of the primary definition of drought as "an extended period during which fresh water availability (particularly rainfall and soil moisture) is below normal and temperatures (and or winds) are high…" the SWALIM Combined Drought Index includes:

(i). Rainfall amounts and the run-length of the rainfall deficits,
(ii). NDVI and the run-length of the below average NDVI values,
(iii). Temperature and the run-length of the above average temperatures.
Note: Run-length is the number of dekads continuously under or above the average.

The three components of the combined drought index CDI are by themselves single parameter drought indices. The rainfall index is herein referred to as the PDI, the NDVI drought proxy as the VDI and the temperature drought proxy as the TDI. In all these separate indices, the concepts of deficit and excess are used exhaustively.

It is important to note that the SWALIM CDI does not measure physical parameters of vegetation or soil, neither does it attempt to simulate the physical phenomena. It is a statistical comparison, it measures how much the present conditions deviate from the reference level, which is the multi-year long-term average, characteristic for the given dekad.

The reference level for calculating the deficit and excess in all cases of rainfall, temperature, NDVI and the run-length of all is the long term average.

The drought index for any of the above parameters in a given dekad (*m*) of a given year (*i*) measures the actual value of the parameter as compared to the multi-year average of the same parameter for the same dekad. If the ratio between the two

- equals 1.00, then the actual dekad can be considered "normal"
- greater than 1.00 then it is better than the "normal"
- small than 1.00, then it is worse than the "normal"

Better means more rainfall or lower temperatures and worse means drier or hotter weather.

The severity of the drought can be easily measured by the values of the above parameters. A value of 0.8 for example means close to normal, a value of 0.3, however indicates a very severe drought. A classification system for the above values can be elaborated in the future.

The PDI, VDI and TDI drought indices for dekad *m* of year *i*, have basically the same formulation and are given in the equations below:

$$PDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,(i-k)}^{(P)}}{R_{m,i}^{(P)}} \right)} * \frac{\sum_{j=1}^{5} P_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} P_{(i-k),(m-j)}\right]}$$

$$VDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,(i-k)}^{(NDVI)}}{R_{m,i}^{(NDVI)}} \right)} * \frac{\sum_{m=1}^{5} NDVI_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} NDVI_{(i-k),(m-j)}\right]}$$

$$TDI_{i,m} = \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,(i-k)}^{(T)}}{R_{m,i}^{(T)}} \right)} * \frac{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=1}^{5} T_{(i-k),(m-j)}\right]}{\sum_{j=1}^{5} T_{i,(m-j)}}$$

Where:

PDI	Precipitation Drought Index
VDI	Vegetation Drought Index
TDI	Temperature Drought Index
CDI	SWALIM Combined Drought Index
P	precipitation
NDVI	Normalized Difference Vegetation Index
T	temperature
$R^{(P)}$	maximum number of successive dekads with below long term average rainfall in the previous 5 dekads.
$R^{(NDVI)}$	maximum number of successive dekads with below long term average NDVI in the previous 5 dekads.
$R^{(T)}$	maximum number of successive dekads with above long term average temperature in the previous 5 dekads.
n	number of years where relevant data are available
j	summation running parameter covering a period of 5 dekads
k	summation parameter covering the years where relevant data are available

The above mathematical expressions in words can be written as below, where LTM stands for long-term mean or long-term average.

Precipitation Drought Index =
Square root of ((LTM of max rainfall deficit runs in the past 5 dekads) / (Actual max rainfall deficit run in the past 5 dekads)) * (Actual rainfall amount in the past 5 dekads) / (LTM of rainfall amount for the past 5 dekads)

Vegetation Drought Index =
Square root of ((LTM of max NDVI deficit runs in the past 5 dekads) / (Actual max NDVI deficit run in the past 5 dekads)) * (Actual average NDVI in the past 5 dekads) / (LTM of NDVI for the past 5 dekads)

Temperature Drought Index =
Square root of ((LTM of max temperature excess runs in the past 5 dekads) / (Actual max temperature run in the past 5 dekads)) * (Actual average NDVI in the past 5 dekads) / (LTM of NDVI for the past 5 dekads)

Note that the temperature has inverse values compared to the other parameters. While with precipitation and NDVI small values signal drought conditions, with temperature it is the high values that contribute to drought. That is why in the first term temperature excess is used instead of deficit, and in the second term is the inverse of the above two.

Analysis of several time series showed that the multi-year average run-length never came even close to zero. However, in exceptional cases the actual run-length was zero. In order to avoid dividing by zero, in these cases it was assumed that half a dekad fell below the average value, which meant that the few zero values were substituted by 0.5.

It is important to note that the PDI, VDI and TDI are drought indices by themselves. There are no other existing simple indices to compare the VDI or the TDI with.

In the present study the length of the period used for the analysis is 5 dekads, which in Somali environment is approximately half of the season. However, depending on the purpose of the analysis the period can be extended to a whole season or decreased to a single dekad. In the first case the graph of the three indexes will be smoother, in the second case more fluctuating. The equations also can be adapted to yearly analysis, in which case however, attention must be paid to how to use the run-length, because of the recurrent dry seasons.

Analysing the Kenya decadal time series we can conclude that NDVI tended to peak approximately 2 dekads after the peak of the rainfall. This is completely in line with the results of several other studies. Temperature does not closely follow either of them, although the tendency is very clear. Due to the limitations of data availability, it was not possible to determine the lag between rainfall and NDVI with a high confidence, and other factors also play an important role in the development of the NDVI graph as it will be seen further down.

Thus the combined drought index was computed as an equal-weighted average of the current TDI and VDI and the 2-dekad lagged PDI, as shown on the equation below:

$$CDI_{i,m} = (PDI_{i,m-2} + TDI_{i,m} + VDI_{i,m}) * \frac{1}{3}$$

5.4 *Applications in Kenya and Somalia*

The following figures 15.1, 15.2 and 15.3 show the distribution of the PDI, TDI, VDI and the CDI for three stations in Kenya.

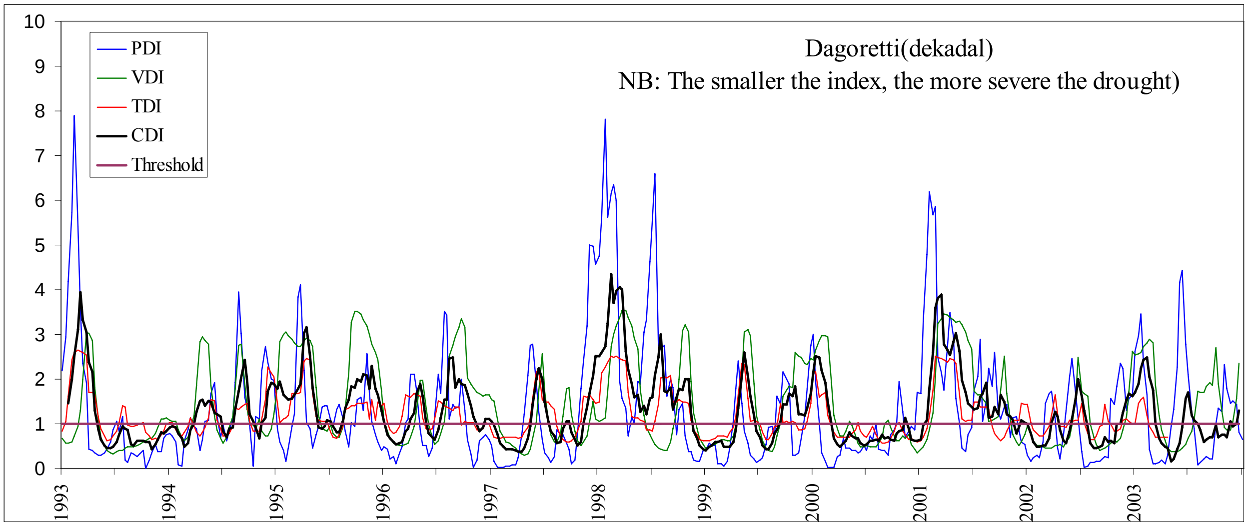

Figure 15.1

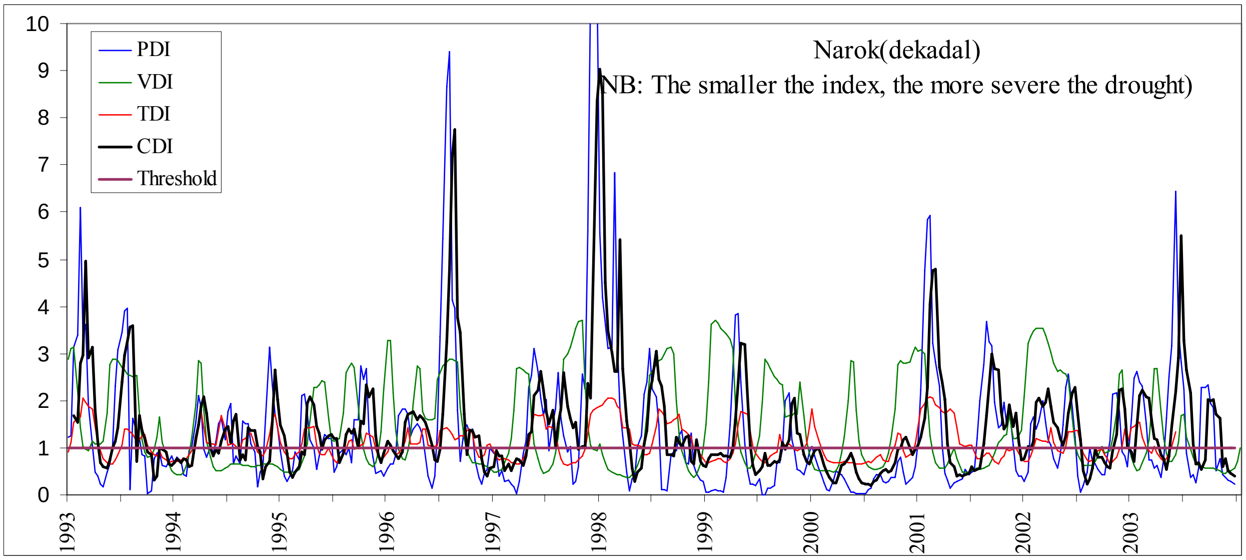

Figure 15.2

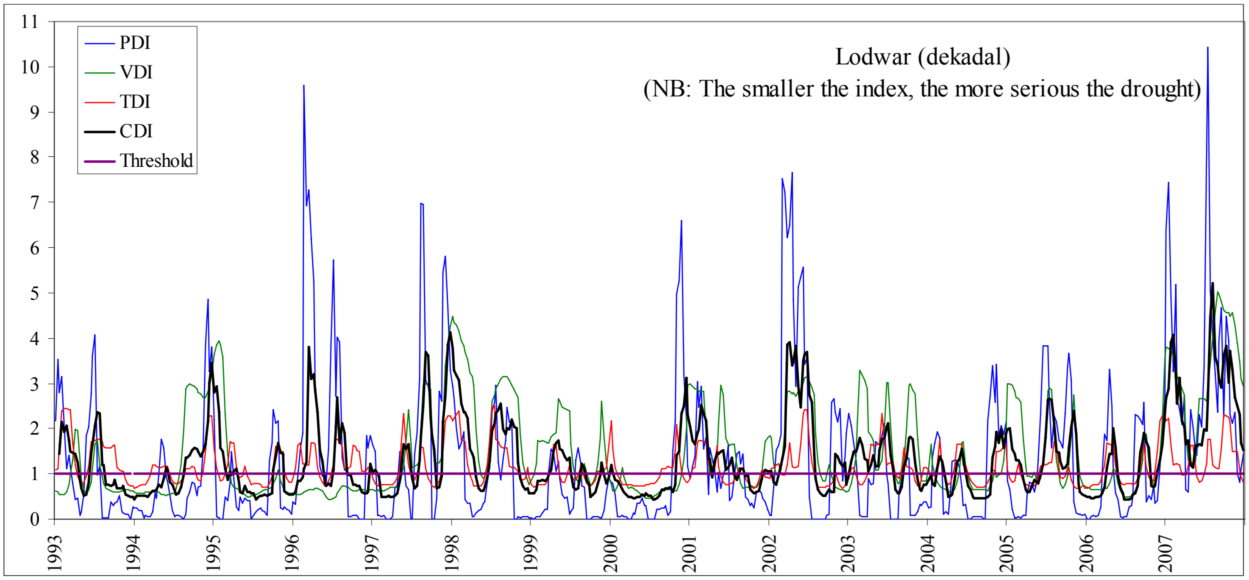

Figure 15.3

Figure 15: Distribution of the PDI, VDI, TDI and the CDI for stations in Kenya.

Four stations were selected in Somalia and the results are shown in Figure 16 as below

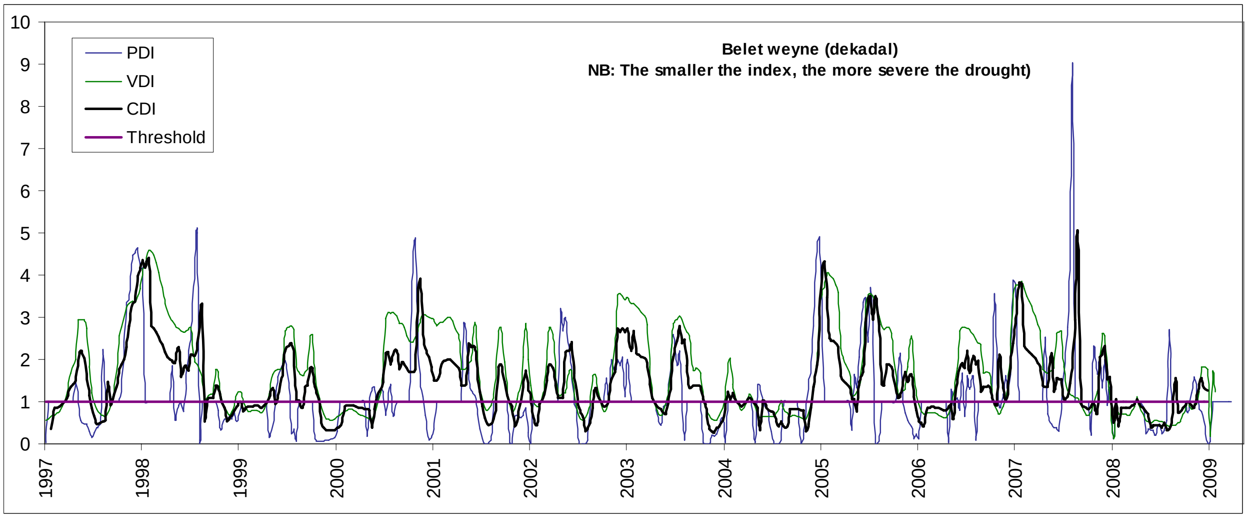

Figure 16.1

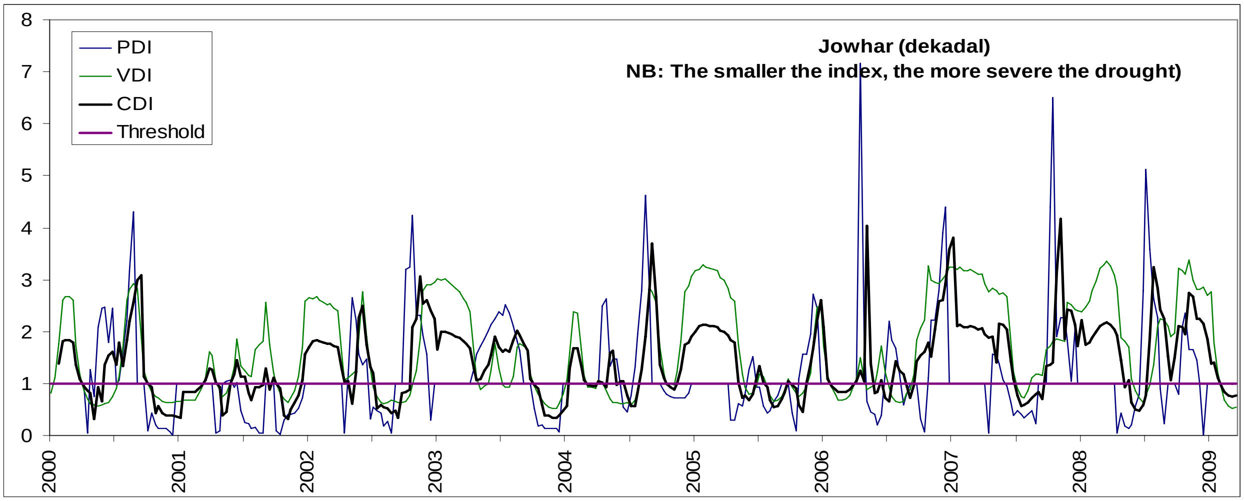

Figure 16.2

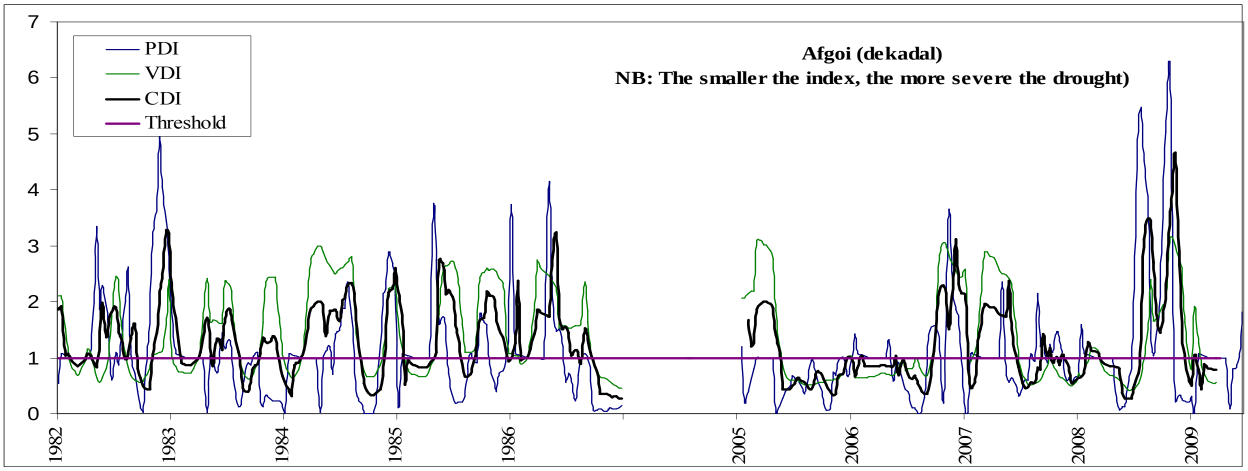

Figure 16.3

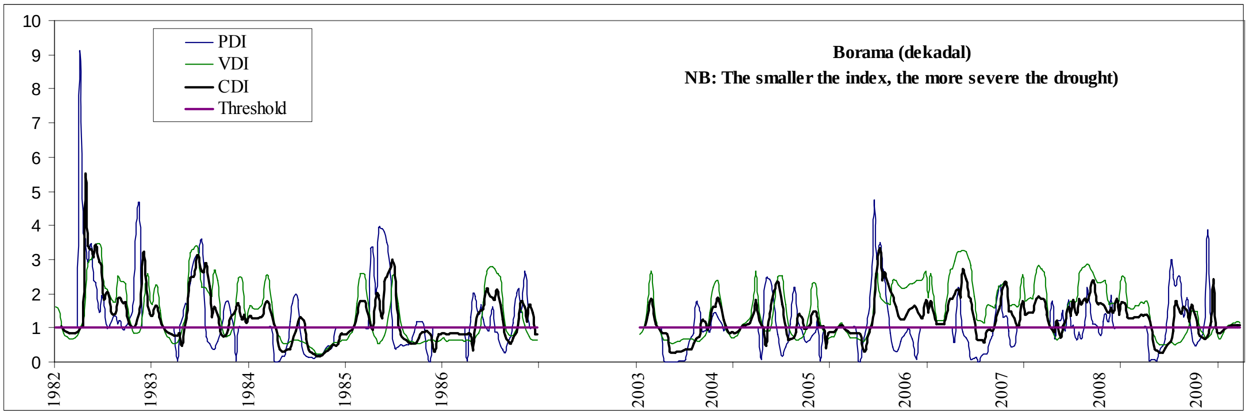

Figure16.4

Figure 16: Distribution of the PDI, VDI, TDI and the CDI for stations in Somalia

5.5 *Discussion of the results*

The PDI, TDI and VDI are new one-parameter drought indexes, which are applicable at any summation time scale. The CDI is a combination of the above three indexes. For large values of the indexes wet conditions prevail and vice versa. The selection of the summation time period depends on the purpose of the research. Short summation periods (3-5 dekads) reveal drought conditions within the season. A 9-dekad summation period will give more information about the behaviour of the whole season; and a yearly summation period will reflect multi-year tendencies without marking short drought conditions within the year.

At the one-month summation time scale, the results from the PDI can be compared to those of other drought indices. A comparison of the PDI and the SPI[2](3) for monthly rainfall data in Kenya and Somalia yields the relationship which is illustrated on the figure shown below.

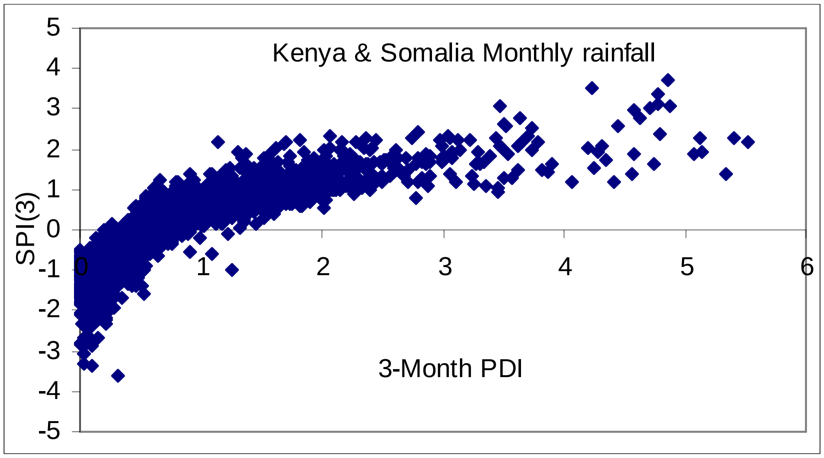

Figure 17: Comparison of PDI with SPI(3)

It is interesting to note that although the PDI is not designed to measure the severity of floods, the PDI relates very well with the SPI in the flood values of rainfall (PDI>2.0). By extension therefore, this tends to point out that; the SPI method may not be an appropriate measure of flood intensities. The PDI- SPI relationship within the drought range is approximately a cubic polynomial. Notwithstanding, the computation and data requirements of the PDI is less demanding that that of the SPI.

Similarly to the PDI, the TDI is also a new one-parameter drought index. The TDI is structured in such a way that it also gives high values when low temperatures persist and low values when high temperatures persist. During drought conditions, temperatures generally remain persistently high and therefore the TDI is low; while during the rains, the temperatures generally persist at lower levels, and therefore the TDI values remain high. Interestingly, the TDI is fairly and consistently in-phase with the PDI in all the studied cases. Consequently, it is justified to conclude that the TDI is a good index for drought assessment.

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[2] Standardized Precipitation Index

On the other hand, the VDI here is intended to be a measure of the health of the vegetation vis-à-vis the soil moisture availability. Persistently low soil moisture periods would give low values of VDI and vice versa. Thus, the VDI would behave more or less the same patterns as the PDI and the TDI. Nevertheless, we would expect there to be a lag between the PDI and the VDI since in most cases, there is a time lag between the time of a rainfall commencement and its translation into healthy vegetation. Similarly, once good soil moisture content has been established, the state of the vegetation may stay healthy up to much later after the rains have ended. Thus, the VDI tends to build-up from the end of the rains to a maximum which is dependent on the temporal-rainfall-distribution and which occurs approximately 2 dekads after the rainfall maximum and then drops quickly to a minimum about 3 months after the end of the rains. These lags require more intensive analyses to confirm authentically. Further, while NDVI could be a good proxy for the soil moisture content over locations where there are minimal human interferences, it is important to note that in human habited locations, vegetation could be seriously interfered with as a consequence of human activities, particularly livestock keeping. Nevertheless, for the study cases, the analyses show that the VDI is generally consistent with the PDI and the TDI during the drought situations.

Vegetation growth depends on a number of factors besides the main factors which are the amount and run-length of deficiency of the rainfall and temperature. For instance it is known that small amounts of regular rainfall through an extended period are more favourable for vegetation growth than larger amounts falling in shorter periods. It is worth noting that this phenomenon is very well reflected in the above figures.

On the other hand, the PDI depicts higher frequency oscillations than the VDI or the TDI. The VDI and the TDI have a higher spatial representativeness (and therefore smoother) than the PDI. As expected also, the VDI seems to be smoother than either the PDI or the TDI. Further, in most cases, the PDI, TDI and the VDI are in-phase during the known major droughts in Kenya and Somalia. During other times when there are rainfall and NDVI excesses, these indices are not necessarily in phase although the patterns generally show wet conditions. When the three indices, PDI, TDI and VDI, are combined, the CDI comes out as a smooth index that seems to highlight the major droughts better than the PDI, VDI or the TDI in isolation.

6. Conclusions and Recommendations

The CDI is a simple multiple-parameter index which attempts to fulfil the basic requirements of the primary definition of drought. The CDI incorporates rainfall and temperature as the primary drivers of drought and NDVI as a secondary proxy of soil water availability. The rainfall and NDVI deficits and the temperature excess (all of which measure the degree of departure from the average) as well as the run lengths (which estimate the persistence of the drought) of the deficit-periods for rainfall and NDVI and temperature excesses are well represented in the formulation of the CDI. The index shows great potential in monitoring and perhaps assessing droughts on dekadal, monthly, and seasonal scales. However, at the moment it is possible to monitor droughts in Somalia on monthly or dekadal time scale for a few stations only, where temperature data are concurrently available. It is on this basis that we strongly recommend intensification / strengthening of the initiatives for monitoring climate at different scales over Somalia. It is also important to do more analyses to establish the time lag between rainfall and NDVI maxima so that the correct CDI is computed. The CDI in principle is capable of capturing multi-season or multi-year droughts. Within the limitations of the present study, however, we were able to analyse only dekadal and monthly time series covering seasonal time-spans. Further analysis, based on reliable data series is needed to answer longer term drought related questions.

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Annex 1

Review of common Drought Assessment Methodologies

1. Percent of Normal Index (PNI)

The PNI is computed as follows:

$$PNI_i = \frac{X_i}{\overline{X}} * 100\%$$

Where X_i representation the rainfall observation at time *i,* and $\overline{X}$ represents the mean of the observations.

Overview: The percent of normal is a simple calculation well suited to the needs of TV weathercasters and general audiences.

Pros: Quite effective for comparing a single region or season.

Cons: Easily misunderstood, as normal is a mathematical construct that does not necessarily correspond with what we expect the weather to be.

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. The percent of normal is easily misunderstood and gives different indications of conditions, depending on the location and season. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departures from normal and form a plan of response (Willeke et al., 1994).

2. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed for the detection and monitoring of drought (McKee et al.. 1993). The SPI estimation for any location is based on the long-term precipitation record during a period of time. This long-term record is fitted to a probability distribution which is then transformed into a normal distribution so that the mean SPI for the location and the desired period of time is zero. Positive SPI values indicate precipitation greater than the median precipitation and negative values indicate precipitation less than the median precipitation. The SPI is normalized: therefore wet and dry climates can be represented in the same way. Wet periods can also be monitored using the SPI.

Generally, that the gamma distribution fits well precipitation time series, particularly, at the monthly time scale. The gamma distribution is defined by its probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad x > 0$$

Where α and β the shape and scale parameters respectively, x is the precipitation amount and Γ(α) is the gamma function. Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station. The α and β parameters of the gamma probability density function are estimated for each station, for each time scale of interest.

Maximum likelihood solutions are used to optimally estimate α and β as follows:

$$\alpha = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right), \quad \beta = \bar{x} \quad where \quad A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad and \quad n = number \quad of \quad observations$$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x)$$

Where *q* is the probability of a zero and *G(x)* is the cumulative probability of the incomplete gamma function. If *m* is the number of zeros in a precipitation lime series, then q can be estimated by *m/n*. The cumulative probability *H(x)* is then transformed to the standard normal random variable *z* with mean zero and variance of one, which is the value of the SPI. Once standardised the strength of the anomaly is classified as it is shown in the table (Table A1) below.

SPI Value	**Category**	**Probability**
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
0.00 to 0.99	Mildly wet	34.1
0.00 to -0.99	Mild drought	34.1
-1.00 to -1.49	Moderate Drought	9.2
-1.50 to -1.99	Severe Drought	4.4
-2.00 or less	Extreme drought	2.3

Table A1: Drought classification by SPI value and corresponding event probabilities

Table 1 also contains the corresponding probabilities of occurrence for each level of severity arising naturally from the normal probability density function. '[bus, at a given location for an individual month, moderate droughts (SPI —I) have a probability of occurrence 15.9%. whereas extreme droughts (SPI —2) have a probability of 2.3%. The SPI will have extreme values, by definition, with the same frequency at all locations

The procedure for estimating the SPI is as follows:

First, a time series of the precipitation value of interest is generated. Then, a frequency distribution is selected and a statistical fit to the data is determined. The cumulative distribution is formed from the fitted frequency distribution. The percentile for the particular time series element of interest, usually the latest one, is selected from the cumulative distribution. For "ties" (multiple instances of the same value), the upper value is used (probability of non-exceedance). For any other theoretical probability distribution, the analogous point on its associated cumulative frequency distribution can be determined. Here, the normal distribution is used, with mean zero and standard deviation of one, and value in standardized units of a given percentile is found can be readily determined. For the normal distribution, these are exactly the same as units of standard deviations. The Standardized Precipitation Index can be thought of as the number of standard deviations that the precipitation value of interest would be away from the mean, for an equivalent normal distribution and adequate choice of fitted theoretical distribution for the actual data. In effect, the method consists of a transformation of one frequency distribution to another frequency distribution, in this case the widely used normal, or Gaussian, distribution.

- ***Overview:*** The SPI is an index based on the probability of precipitation for any time scale.
- ***Who uses it:*** Many drought planners appreciate the SPI's versatility.
- ***Pros:*** The SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Palmer.
- ***Cons:***
    - Rainfall data may change over time from the baseline data which was used for calibration.
    - Long-term precipitation record (30 years at least)is required
    - Misleading high values (positive or negative) in areas with low amount of seasonal rainfall for short time scales (1, 3 months)
    - Monthly (or shorter period) data may not be necessarily gamma distributed. More so, the serial dependence in the data may contradict the use of probability distributions in this form of modelling.

3. Palmer Drought Severity Index (PDSI)

The computation of the PDSI begins with a climatic water balance using historic records of monthly precipitation and temperature. Soil moisture storage is considered by dividing the soil into two layers. The upper layer is assumed to contain 1 inch (25.4 mm) of available moisture at field capacity. The underlying layer has an available capacity that depends on the soil characteristics of the site. Palmer used an available water capacity (AWC) of 9 inches for central Iowa and 5 inches for western Kansas. The AWC value should be representative of the area soils in general. Moisture cannot be removed from the lower layer until the top layer is dry. Runoff (RO) is assumed to occur when both layers reach their combined moisture capacity (AWC).

Four potential values are computed:

- Potential evapotranspiration (PE) e.g. by Hargreaves equation or other
- Potential recharge (PR) - the amount of moisture required to bring the soil to field capacity.
- Potential loss (PL) - the amount of moisture that could be lost from the soil to evapotranspiration provided precipitation during the period was zero.
- Potential runoff (PRO) - the difference between the potential precipitation and the PR

The climate coefficients are computed as a proportion between averages of actual versus potential values for each of 12 months. These climate coefficients are used to compute the amount of precipitation required for the Climatically Appropriate for Existing Conditions (CAFEC). The difference, *d*, between the actual (*P*) and CAFEC precipitation ($\hat{p}$) is an indicator of water deficiency for each month.

$$d = P - \hat{P} = P - (\alpha PE + \beta PR + yPRO + \delta PL)$$

Where $a = \overline{ET} / \overline{PE}, \beta = \overline{R} / \overline{PR}, \gamma = \overline{RO} / \overline{PRO}$, and $\delta = L / \overline{PL}$ for 12 months. The value of *d* is regarded as a moisture departure from normal, because the CAFEC precipitation is an adjusted normal precipitation.

A Palmer Moisture Anomaly Index (PMAI), Z, is then defined as

$Z = Kd$

Where K is a weighting factor. The value of K is determined from the climate record before the actual model calculation. Palmer suggested empirical relationships for K such that

$$K_i = \left(\frac{17.6}{\sum_{i=1}^{12} \overline{D}_i K_i^{'}} \right) K_i^{'} \tag{3}$$

Where $\overline{D_i}$ is the average of the absolute values of d, and K'_i is dependent on the average water supply and demand, given by

$$K'_i = 1.5 \log_{10} \left[\left(\frac{\overline{PE} + \overline{R} + \overline{RO}}{\overline{P} + \overline{L}} + 2.8 \right) \overline{D}^{-1} \right] + 0.5$$

Where PE is the potential evapotranspiration, R is the recharge, RO is the runoff, P is the precipitation, and L is the loss. The PDSI is now given by

$$PDSI_i = 0.897 PDSI_{i-1} + \frac{1}{3} Z_i$$

Where the PDSI of the initial month in a dry or wet spell is equal to $\frac{1}{3} z_i$.

The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts. The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance, such as irrigation, are not considered.

The Palmer Index varies roughly between -6.0 and +6.0. Palmer arbitrarily selected the classification scale of moisture conditions based on his original study areas. The PDSI classifications are summarised on the table (Table A2) below.

4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought

-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extreme drought

Table A2: PDSI Classifications

- ***Cons:***
  - Palmer values may lag emerging droughts by several months; less well suited for mountainous land or areas of frequent climatic extremes; complex—has an unspecified, built-in time scale that can be misleading.
  - Often values of AWC are not always available;
  - Palmer values may lag emerging droughts by several months;
  - Sensitive to the AWC of a soil type;
  - It is calibrated for regions relatively homogeneous and is less well-suited for mountainous land or areas with frequent climatic extremes;
  - Palmer index is not particularly suitable for droughts associated with water management systems, because they exclude water storage, snowfall, and other supplies. Human impacts on the water balance, such as irrigation, are also not considered.

4. Crop Moisture Index (CMI)

The CMI is a derivative of the PDSI. The CMI reflects moisture supply in the short term across major crop-producing regions and is not intended to assess long-term droughts.

The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions. It was developed by Palmer (1968) from procedures within the calculation of the PDSI. Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture conditions across major crop-producing regions. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week. The CMI responds rapidly to changing conditions, and it is weighted by location and time so that maps, which commonly display the weekly CMI across the United States, can be used to compare moisture conditions at different locations.

Because it is designed to monitor short-term moisture conditions affecting a developing crop, the CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. For example, a beneficial rainfall during a drought may allow the CMI value to indicate adequate moisture conditions, while the long-term drought at that location persists. Another characteristic of the CMI that limits its use as a long-term drought monitoring tool is that the CMI typically begins and ends each growing season near zero. This limitation prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extend over several years. The CMI also may not be applicable during seed germination at the beginning of a specific crop's growing season.

5. Surface Water Supply Index (SWSI)

The SWSI is designed to complement the Palmer in the state of Colorado, where mountain snowpack is a key element of water supply; calculated by river basin, based on snowpack, streamflow, precipitation, and reservoir storage.

SWSI is expressed as

$$SWSI = \frac{aP_{snow} + bP_{prec} + cP_{strm} + dP_{resv} - 50}{12}$$

Where a, b, c, and d = weights for snow, rain, streamflow and reservoir storage respectively, (a + b + c + d = 1) and P_i = the probability (%) of non-exceedence for each of these four water balance components. Calculations are performed with a monthly time step. In winter months, SWSI is computed using snowpack, precipitation and reservoir storage. In summer - streamflow, precipitation and reservoir storage data are used. For each month, the values of each component measured at all stations (or reservoirs) across the region/basis are summed. Each sum is normalized and its non-exceedence probability is determined. Weights are assigned to each water balance component depending on its typical contribution to surface water within a basin. Subtracting 50 and dividing by 12 are the normalization procedures designed to make SWSI values to have a similar range as PDSI (-4.2 to +4.2).

The procedure to determine the SWSI for a particular basin is as follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snowpack/streamflow measuring stations over the basin. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence—the probability that subsequent sums of that component will not be greater than the current sum—is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer Index, the SWSI is centered on zero and has a range between -4.2 and +4.2.

The Surface Water Supply Index (SWSI) was developed by Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions. The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI to be an indicator of surface water conditions and described the index as "mountain water dependent", in which mountain snowpack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snowpack, streamflow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, streamflow replaces snowpack as a component within the SWSI equation.

The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state.

Several characteristics of the SWSI limit its application. Because the SWSI calculation is unique to each basin or region, it is difficult to compare SWSI values between basins or regions (Doesken et al., 1991). Within a particular basin or region, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Additional changes in the water management within a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin needs to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the index (Heddinghaus and Sabol, 1991). Extreme events also cause a problem if the events are beyond the historical time series, and the index will need to be re-evaluated to include these events within the frequency distribution of a basin component.

Cons:

- Changing a data collection station or water management requires that new algorithms be calculated, and the index is unique to each basin, which limits interbasin comparisons.

6. Reclamation Drought Index

The Reclamation Drought Index (RDI) was recently developed as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought. The impetus to devise the RDI came from the Reclamation States Drought Assistance Act of 1988, which allows states to seek assistance from the Bureau of Reclamation to mitigate the effects of drought.

Like the SWSI, the RDI is calculated at a river basin level, and it incorporates the supply components of precipitation, snowpack, stream flow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature-based demand component and duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors.

Cons:

- Because the index is unique to each river basin, interbasin comparisons are limited.

4.0 or more	extremely wet
1.5 to 4.0	moderately wet
1 to 1.5	normal to mild wetness
0 to -1.5	normal to mild drought
-1.5 to -4.0	moderate drought
-4.0 or less	extreme drought

Table A3: RDI Classification

7. Deciles

Description:

Groups monthly precipitation occurrences into deciles so that, by definition, “much lower than normal” weather cannot occur more often than 20% of the time. In this approach suggested by Gibbs and Maher (1967) monthly precipitation totals from a long-term record are first ranked from highest to lowest to construct a cumulative frequency distribution. The distribution is then split into ten parts (tenths of distribution or deciles). The first decile is the precipitation value not exceeded by the lowest 10% of all precipitation values in a record, the second is between lowest 10 and 20% etc. Any precipitation value (e.g. from current or past month) can be compared with and interpreted in terms of these deciles. A reasonably long precipitation record (30-50 years) is required for this approach. This is not a shortcoming of a method, but rather a requirement of a statistical analysis. Decile Indices (DI) are grouped into five classes, two deciles per class. If precipitation falls into the lowest 20% (deciles 1 and 2), it is classified as "much below normal". Deciles 3 and 4 (20 to 40%) indicate "below normal" precipitation, deciles 5 and 6 (40 to 60%) give "near normal" precipitation, 7 and 8 (60 to 80%) - "above normal" and deciles 9 and 10 (80 to 100%) are "much above normal". DI is relatively simple to calculate, requires only precipitation data and fewer assumptions than more comprehensive indices (like PDSI or SWSI).

The deciles are then grouped as on the following table:

deciles 1-2	Much below normal (lowest 20%)
deciles 3-4	Below normal (next lowest 20%)
deciles 5-6	Near normal (middle 20%)
deciles 7-8	Above normal (next highest 20%)
deciles 9-10	Much above normal (highest 20%)

Table A4: Deciles classification

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the “percent of normal” approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a *decile*. The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications.

Cons:

Accurate calculations require a long climatic data record.

8. Weighted Anomaly Standardized Precipitation (WASP)

WASP is an acronym for the "Weighted Anomaly Standardized Precipitation" index and is based solely on monthly precipitation data. This index gives an estimate of the relative deficit or surplus of precipitation for different time intervals ranging from 1 to 12 months.

To compute the index, monthly precipitation departures from the long-term average are obtained and then standardized by dividing by the standard deviation of monthly precipitation. The standardized monthly anomalies are then weighted by multiplying by the fraction of the average annual precipitation for the given month. These weighted anomalies are then summed over varying time periods - here, 3, 6, 9 and 12 months. On the plots, the value of the given WASP index has itself been standardized.

This index was developed as a simple univariable index to measure the relative surplus or deficit of precipitation on different time scales The Index is based solely on monthly precipitation but requires historical data (at least 25-year period) as well.

$$WASP_N = \frac{12}{\sigma_N} \sum_{j=1}^{N} \left(\frac{P_j - \overline{P}_j}{\sigma_j} * \frac{\overline{P}_j}{P_A} \right)$$

Where,

$WASP_N$	is the N-month WASP, where N is the number of months (here N=12), over which the standardized weighted anomalies have been integrated.
σ_N	is the standard deviation of the N-month WASP over the historical record for the last month in the integration.
P_j	is the observed precipitation for month j
$\overline{P}_j$	is the long-term mean for the precipitation for month-j
σ_j	is the standard deviation of the precipitation for month-j
P_A	is the overall mean precipitation over the location of interest.

9. Normalized Difference Vegetation Index (NDVI)

It is a remotely (satellite) sensed proxy of the health of vegetation. But by adding in additional radiation information from the near infrared portion of the spectrum, the type and health of vegetation may be quantified owing to both botanical properties of the leaves and to the amount of available moisture in the soil. Scientists have invented a data processing algorithm for these two radiation "channels" called the *Normalized Difference Vegetation Index* (NDVI). This image, therefore, is really an image of a mathematical quantity calculated from the raw radiation data measured by the AVHRR. It is formally incorrect to say that a satellite "senses vegetation". The satellite senses up-welling radiation from which vegetation health is inferred using an NDVI *algorithm*. The NDVI can be linked to climate variability and hence drought. A number of derivatives and alternatives to NDVI have been proposed in the scientific literature to address these limitations, including the Perpendicular Vegetation Index (PVI), the Soil-Adjusted Vegetation Index (SAVI), the Atmospherically Resistant Vegetation Index (ARVI), the Corrected Vegetation Index (CVI), and the Global Environment Monitoring Index (GEMI). Each of these attempted to include intrinsic correction(s) for one or more perturbing factors. It is not until the mid 1990's, however, that new generations of algorithms were proposed to estimate directly the bio-geophysical variables of interest such as the Fraction of Absorbed Photosynthetically Active Radiation or FAPAR, taking advantage of the enhanced performance and characteristics of modern sensors to take all the perturbing factors into account. In spite of many possible perturbing factors upon the NDVI, it remains a valuable quantitative vegetation monitoring tool when the photosynthetic capacity of the land surface needs to be studied at the appropriate spatial scale for various phenomena. The earliest formal reporting of the NDVI was in 1973 by Dr. John Rouse who was then the Director of the Remote Sensing Center of Texas A&M University where the Great Plains study was conducted. The person responsible for a series of early scientific journal articles describing uses of the NDVI was Compton Tucker of NASA's Goddard Space Flight Center. (Tucker 1979, Rouse et al (1973a,b)

Assessment of vegetation condition by means of multispectral Remote Sensing has seen a strong spin in the early 80s due to the launch of NOAA satellite Advanced Very High Resolution Radiometer - AVHRR. This global daily dataset has started a routinely investigation of vegetation from space and has put the foundation for long term observation and comparison of vegetation through several indexes, first of all the Normalized Difference Vegetation Index - NDVI.

Since the launch in June 1981 of the first 5-channel polar orbiting AVHRR/2 satellite and its subsequent family onboard the NOAA satellite series 7, 9, 11, 14, 16 and 17 it has been possible to have a daily global test of the efficacy of environmental change detection.
Although the primary focus of the design of AVHHR family (http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html) was to monitor clouds and thermal emission from the Earth it has been proved to be very suitable also for other applications among which the most used is the Normalized Difference Vegetation Index (NDVI) and its derivatives for vegetation monitoring with daily frequency.
The two generations of AVHRR (AVHRR/2 and -/3) though had slight difference in the bandwidth have proved to maintain a consistent continuum of data that can be compared from the second half of 1981 up to date. As shown on the following table:

Sensor	**Ch1**	**Ch2**	**Ch3 Ch3A for AVHHR/3**	**Ch 3B for AVHRR/3**	**Ch4**	**Ch5**
AVHRR/2	0.58 – 0.68	0.725 – 1.10	3.55 – 3.93	---	10.3 – 11.3	11.4 – 12.4
AVHRR/3	0.58 – 0.68	0.725- 1 .10	1.58 – 1.64	3.55 – 3.93	10.3 – 11.3	11.4 – 12.4

Table A5: Differences in wavelength of the channels on board of AVHRR/2 and AVHRR/3.

The coarse resolution (ground resolution of almost 8 km) of the freely available AVHRR data is not the best option for detailed analysis of environmental change but it has proved to be a useful monitoring tools for regional analysis also due to its long term series (almost 27 years).

Live green plants **absorb** incoming solar radiation in the so-called Photosynthetically Active Radiation (**PAR**) region of the electromagnetic spectrum, that is in the range of 0.400 and 0.700 µm, almost overlapping with the range of light visible to the human eye. Leaf cells have also the characteristic of **reflecting** (and transmitting) in the near-infrared (**NIR**) portion of the electromagnetic spectrum, which correspond to wavelength between 0.700 µm and 1.100 µm. For these reasons, green plants appear darker in the PAR region of the spectrum and brighter in the NIR region of it. Figure A1 explains these different reflection characteristics using a diagram with Wavelengths on the X axis and percentage of reflection on the Y axis.

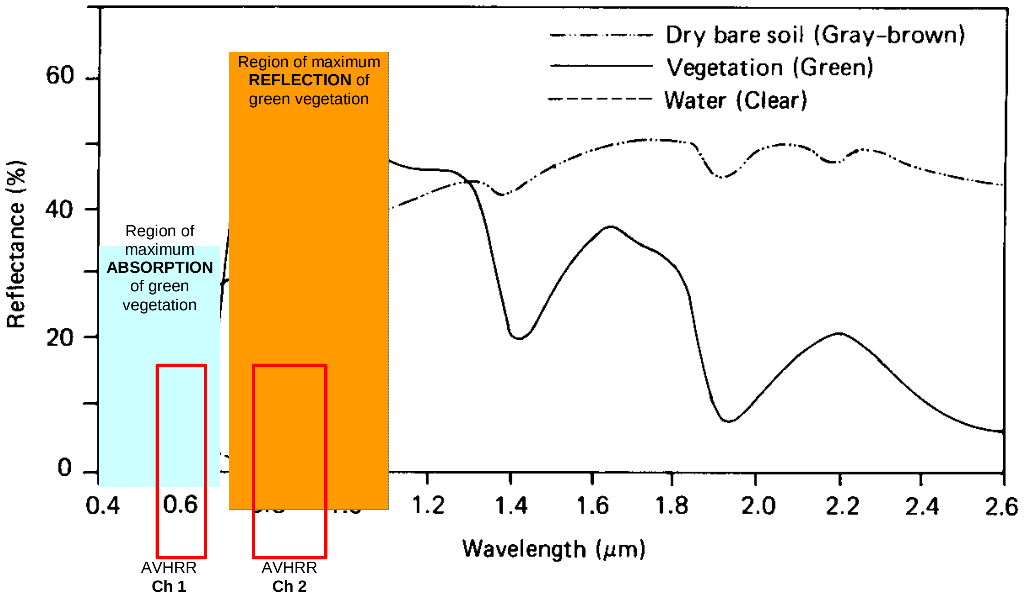


Figure A1: Typical reflectance curve for vegetation (continuous line), soil (hatched line) and water (dashed line) (modified from Lillesand and Kiefer, 1994)

By combining channels 1 and 2 of AVHRR in a ratio or difference, allows the response to vegetation growth to be distinguished from the background signal. The method, developed by NASA is known as the Normalised Difference Vegetation Index (NDVI) and is given by the equation:

$$NDVI = \frac{NIR - \mathrm{Re}d}{NIR + \mathrm{Re}d} = \frac{Ch2 - Ch1}{Ch2 + Ch1}$$

By normalising the difference in this way, the values can be scaled between a range of values from -1 to +1. This also reduces the influence of atmospheric absorption.

AVHHR NDVI

Water, snow and ice typically has an NDVI value less than 0, bare soils between 0 and 0.1 and vegetation over 0.1 (see table A6)

COVER TYPE	RED (Ch1)	NIR (Ch2)	NDVI (ch2-ch1/ch2+ch1)
Dense vegetation	0.1	0.5	0.7
Dry Bare soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

Table A6: Typical NDVI values for various cover types (modified from Holben, 1986)

The NDVI is a type of product known as a transformation, which is created by transforming raw image data into an entirely new image using mathematical formulas (or algorithms) to calculate the colour value of each pixel. This type of product is especially useful in multi-spectral remote sensing since transformations can be created that highlight relationships and differences in spectral intensity across multiple bands of the electromagnetic spectrum.

In addition to the simplicity of the algorithm and its capacity to broadly distinguish vegetated areas from other surface types, the NDVI also has the advantage of compressing the size of the data to be manipulated by a factor 2 (or more), since it replaces the two spectral bands by a single new field (eventually coded on 8 bits instead of the 10 or more bits of the original data).

NDVI derives from passive satellite sensors and as such it is subject to all problems related to this family of sensors. The main problems are due to atmospheric interference and to sensor calibration and degradation. The British Meteorological Office in Reading offers in its web page (http://www.met.rdg.ac.uk/~swsgrime/artemis/ch3/ndvi/ndvi.html) a detailed description of NDVI use limitation that are here reported in the following order: Temporal resolution; Atmospheric interference; Land Cover types; Sparse vegetation and soil types; Sensor degradation; Off-nadir effects

Temporal resolution

It is important to get the right balance between the temporal resolution of data and the timescale of variation in the quantity measured. For example, maximum value composites of NDVI data are rarely less than dekadal. Consequently, NDVI Mean Values Composites (MVC's) should not be used to investigate short-term events like forest fires. It is more appropriate to use NDVI data to monitor longer-term events like the growth of vegetation through a season, or annual rates of deforestation.

Atmospheric Interference

Light is scattered in all directions by particles in the atmosphere. Scattering tends to increase the amount of red radiation received by the satellite as red is more readily scattered in the atmosphere than near infrared. This has the effect of reducing NDVI values. For short periods, this problem is minimised by taking the maximum value composite because each pixel's maximum value is likely to have occurred when scattering was at a minimum. However, in extreme cases of long-term, large-scale aerosol events, such as ash clouds from the Mt. Pinatubo eruption in June 1991, maximum value compositing will not work. For the Mt. Pinatubo explosion a correction procedure was developed by NASA, but not all the corrected images were of high quality.

Land cover types

With the exception of very large irrigation schemes and commercial agriculture, an NDVI pixel very rarely covers a single homogeneous agricultural region. Instead it may cover roads, buildings, bare soil, small water bodies, natural vegetation and agriculture, all within one pixel. An NDVI pixel is the sum of the radiation reflected from all the land cover types within the area covered by the pixel. NDVI is an indicator of the condition of the overall vegetation in an area, including natural vegetation and agriculture. In rain-fed agriculture, natural vegetation may follow similar patterns to the agriculture. More often however, agriculture is more susceptible to adverse conditions and follows different growth cycles. When looking at NDVI, always remember that you are looking at general conditions and not necessarily the condition of a specific crop.

Sparse vegetation and soil-type

Light reflected from the soil can have a significant effect on NDVI values (changing the values by up to 20%). Generally, the greater the radiance reflected from the soil, the lower the NDVI values. The soil-type therefore is an important factor. Given two soil types, one with a greater reflectivity but with similar vegetative conditions, the soil with the greater reflectivity will on average produce lower NDVI values. Huete and Jackson (1988) found that the soil-type had the greatest effect on NDVI values between 40 and 75% vegetative cover.

Sensor degradation

Satellite radiometers degrade over time. Consequently, the calibration coefficients are not constant. The thermal channels of the AVHRR have internal systems of calibration, but the visible channel (Ch1) does not. The simplest technique for calibration of channel 1 is to use stable targets on the Earth's surface such as desert sands and oceans. Corrections are applied directly to the NDVI using the deviation from the expected values found in the Sahara desert. The use of an offset to the NDVI is simplistic because the correction factor may vary over the range of NDVI values, but it is better than no correction at all. The corrections for the offsets to the NDVI for NOAA-7, -9, and -11 (up to 1989) are shown in the table below (table A7). When using NDVI imagery, care must be taken to ensure the data has been corrected, and if not, then to make the corrections yourself.

YEAR	1981	1982	1983	1984	1985	1986	1987	1988	1989
NDVI	0.022	0.037	0.043	0.038	0.027	0.027	0.006	0.002	0.060

Table A7: corrections to be made to NDVI data from NOAA 7, 9 and 11 satellites, up to 1989.

Off-nadir effects

As the radiometer scans across the Earth, there is only one point, in the centre of the scan that is directly underneath the radiometer (called the sub-point or nadir). The distance from the radiometer to the ground increases away from the sub-point. This results in increased atmospheric interference as the light must pass through more atmosphere before reaching the radiometer, and therefore reduced NDVI values. These 'off-nadir' effects are limited by simply dropping the pixels too far from the nadir. For quantitative work, only 40^0, on either side of the sub-point, can be used.

In addition, the viewing angle at which the radiometer surveys vegetation has an influence on the NDVI value. For example, directly above a region of crops the crops *and* the soil will be visible to the radiometer. However, viewed at an angle, the region may seem to have continuous vegetative cover. In this case, the NDVI values will be lower directly beneath the radiometer.

Furthermore some technical details, including limitations in the AVHRR derived NDVI (that is the main data source used in this study) are also described by the FEWSNET Early Warning system web page (http://earlywarning.usgs.gov/adds/readme.php?symbol=nd, last visit 23rd Sep 2008) where the following description is provided:

> **Normalized Difference Vegetation Index** February 15, 2005
> Since the late 1980's, the Famine Early Warning System (FEWS) has used AVHRR data to produce dekadal (10-day) composite NDVI images of Africa, and has built a valuable archive of these data from mid 1981 to present.
>
> **NDVI-g data background:**
> EROS processes and archives a dekadal (i.e. ~10 days, 36/year) Africa NDVI product from the NASA GIMMS group called NDVI-g. The dataset is inter-calibrated with SPOT Vegetation NDVI, and uses NOAA-17 data since January 2004. The NOAA-17 NDVI data have also been inter-calibrated with NOAA-16 and previous NDVI products. These data are available from the ADDS server in WinDisp and generic BIL formats. The data from January dekad 1, 2008 to present are NDVI-rg. NASA has stated that the NDVI-rg data will be updated to the archival NDVI-g product approximately every 6-12 months.

For more information about AVHRR data and NDVI processing, please see the references at the end of this document or see the GIMMS documentation. The FEWS-NET NDVI data originates from the NASA GIMMS group. For proper acknowledgement of these data in any report or publication, please cite documents 1 and 2 of the references listed at the end of this document. Copies of these papers can be made available upon request.

NDVI-g data characteristics:
Source: NASA - GIMMS group
Time step: 10-day (dekadal)
Resolution: 8km
Projection: Albers equal area conic
File Format: byte (8 bit); WinDisp image or generic BIL

The satellite that acquired the data is noted below:
NOAA 7 periods (Jul 81 - Feb 85)
NOAA 9 periods (Feb 85 - Nov 88)
NOAA 11 periods (Nov 88 - Sep 94)
NOAA 9(descend) periods (Sep 94 - Jan 95)
NOAA 14 periods (Jan 95 - Oct 00)
NOAA 16 periods (Nov 00 - Dec 03)
NOAA 17 periods (Jan 04 - present)

Processing Details:
No correction has been applied to correct for atmospheric effects due to water vapor, Rayleigh scattering or stratospheric ozone. Maximum value compositing has been used, with a forward binning procedure method implemented. A stratospheric aerosol correction has been applied during April 82-Dec 84 and June 91-Dec 93 to correct for stratospheric aerosols due to volcanic eruptions (Tanre, Holben and Kaufman 91). The corrections use a hybrid of retrieved optical thicknesses (Vermott et al. 95) and modeled thicknesses from GISS.
Artifacts in NDVI due to satellite drift have been corrected using the empirical mode decomposition (EMD). The correction is especially important in tropical regions. For details see paper Pinzon et al 2004, reference below. The VIg correction has been applied to the GIMMS VId data, that has had the desert calibration applied for NOAA 7-14 (Los 1998).

Scaling info:
NDVI is archived as byte data files. In the formulas below, the data, once imported, is referred to as the 'raw' data. To recover the -1 to 1 range of NDVI, use the following formula: NDVI = raw/250. After conversion, Water pixels have a value of 1.0200, and 1.0160 are masked pixels, and missing are 1.0120.

Africa Continental Details:
coordinates for corners:
Lower left lat : -42.243 deg
Lower left lon : -23.490 deg
Upper left lat : 43.711 deg
Upper left lon : -24.600 deg
Lower right lat : -42.242 deg
Lower right lon : 63.414 deg

Upper right lat : 43.712 deg
Upper right lon : 64.523 deg

Image size : 1152 rows x 1152 cols
Center lat,lon : 1.000000, 20.000000
Pixel size h x w : 8.000000 km x 8.000000 km
Origin of latitudes : 1.000000 deg
Central meridian : 20.000000 deg
First std parallel : -19.000000 deg
Second std parallel : 21.000000 deg
projection = ALBERS Conical Equal-area projection uses the clarke ellipsoid
Applied Temperature Threshold for cloud screening = 285 K

Regardless of the many limitations subsequent work has shown that the NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Sellers 1985 and Myneni et al. 1995).

NDVI has proved to have an extremely wide (and growing) range of applications. It is used to monitor vegetation conditions and therefore provide early warning on droughts and famines. It has been deployed to estimate evapotranspiration, to identify regions suitable for locust development and to identify particular ecological zones with important implications for disease prevention (like Rift Valley Fever, for Eastern Africa) among other applications.

The relationship between NDVI and rainfall has been described by Kassa (1999), among the others, analysing the use of NDVI to detect Drought in Sudan “The relationship of NDVI to rainfall is used as a basis for employing NDVI as an indicator of drought. The onset of suitable conditions for vegetation causes the emergence and growth of plants. The resulting increase in the amount of vegetation and photosynthetic activity leads to consistent increase in the NDVI values. When these conditions cease, the resulting moisture stress will reduce biophysical rates (photosynthetic rate and transpiration) which will result in a substantial fall in NDVI values (Bonifacio et al., 1993).”

To this regards particular attention should be paid to the lag time between rainfall onset and vegetation response –that varies according to the different land cover type- and also to the possible shifting onset of rainfall seasons.

For all the potentialities of remote sensed NDVI described before, combined with the existence of wide observed meteorological data gaps or data inconsistency in Somalia, AVHRR has been chosen as the reference dataset for analysing NDVI trends in the drought monitoring.

In doing this we have followed the major practices in use in many different regions of the world like the ones, for instance, from the USA (Kogan, 1997, 2001; NOAA – Climate Prediction Centre; University of Nebraska at Linocln), India (Bhuiyan et al., 2006), Australia, and Africa.

Beside the AVHRR sensor two other instruments are generally used for detecting NDVI: SPOT Vegetation and MODIS. A comparison between the three sensors is provided in table A8.

N	**Data Source**	**Sensor**	Date	**Wavelength**	**Bands**	**Spatial resolution**	**Frequency delivery**
1	NOAA	AVHRR/2 and AVHRR/3	June 1981 – to date	Red=0.585-0.680 µm NIR=0.739-0.980µm			
2	Spot10	VEGETATION, VEGETATION 2 (SPOT 4 and SPOT5)	March 1998 - to date	R=0.610-0.680 µm, IR=0.790-0.890 µm MR=1.580-1.750 µm BO=0.430-0.470 µm	4 bands (R, IR, MR, BO)	1km^2	10 day composites (revisit is daily)
3	MODIS	Moderate resolution Imaging Spectro-radiometer	Dec 1999 – to date	Red=0.620-0.670 µm NIR=0.841-0.876 µm	36 bands (B1, B2)	250 m	16 day NDVI composite

Table A9: comparison between AVHHR, Modis and SPOT VEG sensors used to detect drought by means of NDVI

Other remotely sensed indexes

The NDVI is not the only vegetation index to have been developed. Other indices are used, with a range of complexities. Indices are chosen depending on their application.

The simplest vegetation index is the Ratio Vegetation Index (RVI). A more complex index is the Perpendicular Vegetation Index (PVI; Richardson et al., 1977) that takes into account the soil emissivity (one of the major limitations of NDVI). Other widely used indexes are the Vegetation Condition Index (VCI; Kogan, 1995) the Thermal Condition Index (TCI; Kogan, 1995) the Soil-Adjusted Vegetation Index (SAVI: Huete 1988), the Atmospherically Resistant Vegetation Index (ARVI: Kaufman and Tanre 1992) and the Global Environment Monitoring Index (GEMI: Pinty and Verstraete 1992). Each of these attempted to include intrinsic correction(s) for one or more perturbing factors. Four indexes are here discussed more in details, while for the others the reader can find useful information in the available specific literature.

The Ratio Vegetation Index (RVI)

The simplest vegetation index is the RVI, which takes the ratio of the near infrared (NIR) and red (R) radiances.

$$RVI=NIR/R.$$

The Perpendicular Vegetation Index (PVI)

It has been found that there is a more or less linear relationship between Red and NIR reflectances from bare soils. This was tested for several different soil types, including sand, pebbles and clay. It was even true when the roughness and moisture of the soil varied. This relationship is called the soil line and is given by:

$$NIR_{soil}=a\ R_{soil} + b;$$

In calculating the PVI of a surface with vegetation, the reflectance in the red and NIR ranges are measured and plotted on a graph. The PVI is the perpendicular distance of the measured point from the soil line, defined as follows:

$$PVI=1/\mathrm{sqrt}(a^2+1)\ \mathrm{x}\ (NIR - aR + b)$$

where a and b are the slope and gradient of the soil line respectively. In this way, the PVI measures the changes from the bare soil reflectances caused by the vegetation. In this way it gives an indication of vegetative cover independent of the effects of the soil.

Vegetation Condition Index & **Temperature Condition Index** (VCI; Kogan, 1990, 1995)
VCI separates the short-term weather-related NDVI fluctuations from the long-term ecosystem changes (Kogan, 1990, 1995). Therefore, while NDVI shows seasonal vegetation dynamics, VCI rescales vegetation dynamics in between 0 and 100 to reflect relative changes in the vegetation condition from extremely bad to optimal (Kogan, 1995, 2003).

$$VCI = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} 100$$

Where NDVI is smoothed weekly NDVI, $NDVI_{max}$, and $NDVI_{min}$ are multiyear absolute maximum and minimum respectively. BT, BT_{max}, and BT_{min} are similar values for Brightness temperature. In the case of Somalia freely available BT data have not been found and thus the TCI has not been applied.

$$TCI = \frac{BT_{\max} - BT}{BT_{\max} - BT_{\min}} 100$$

VCI and TCI characterises respectively the moisture condition and thermal condition of vegetation (Kogan, 2001). Since favourable weather provides optimal moisture condition, high values of VCI correspond to healthy and unstressed vegetation.
On the other hand, low TCI values correspond to vegetation stress due to dryness by high temperature. TCI provides opportunity to identify subtle changes in vegetation health due to thermal effect as drought proliferates if moisture shortage is accompanied by high temperature (Kogan, 2002).

In the mid 90's, however, a new generation of algorithms were proposed to estimate directly the biogeophysical variables of interest (e.g., the Fraction of Absorbed Photosynthetically Active Radiation or FAPAR), taking advantage of the enhanced performance and characteristics of modern sensors (in particular their multispectral and multiangular capabilities) to take all the perturbing factors into account.

In spite of many possible perturbing factors upon the NDVI, it remains a valuable quantitative vegetation monitoring tool when the photosynthetic capacity of the land surface needs to be studied at the appropriate spatial scale for various phenomena.

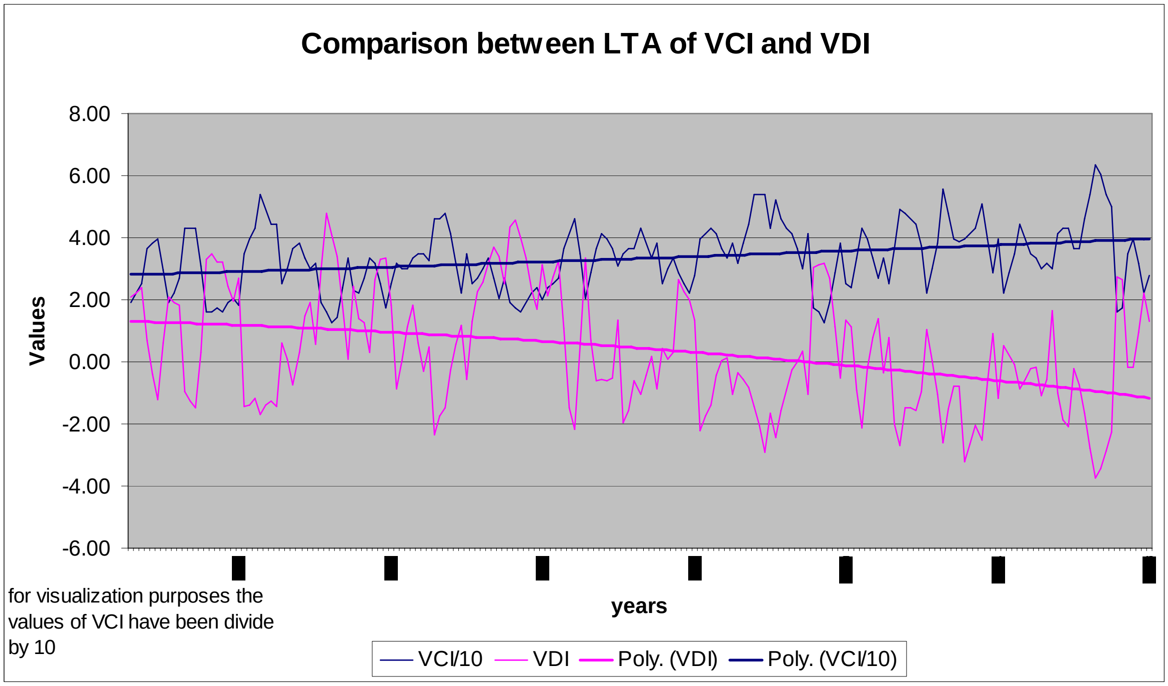
It is interesting to note that all the indices respond almost similarly to situations of drought (low values) as well as during situation of excess wetness (high values). While it may be difficult to combine the three indices on account of the lack of a basic calibration platform and therefore the fact the TI and the VDI have not been standardized to conform to a specific categorization, the plots reveal that it is possible to identify some of the worst droughts which must have been experienced over the selected stations, as the years/periods when the three indices persist for that duration at negative values. For example, 2001 and 1994 stand out clearly as the most serious drought years over Dagoretti Corner during the period 1992-2003.

NDVI Drought Mapping of Somalia

Extraction of NDVI values for each of the Agro-ecological zones described in chapter 2.5 has been performed using Windisp© software and the AVHRR derived decadal NDVI for the period June 1981 to July 2008 (downloaded from the site). The statistical analysis performed in MSExcel© was then elaborated in order to be plotted on maps created using ESRI ArcgGIS© 9.2 software

A preliminary analysis of the NDVI trends by season –using the two rainy season only (Gu and Deyr)- highlighted that for the Gu season the contribution of the month of June was negligible compared with the NDVI values of April and May, and for the Deyr season the contribution of the month of October was negligible too, when compared with the values of November and December.

Figure A2



This fact is better understood if we consider that the Gu season starts after a prolonged dry and very hot period (Jilal season) and then the first rains have a strong impact on the greenness of the foliage of the vegetation. On the other hand the Deyr season onset starts after a period of cold and relatively cloudy, allowing for the vegetation to keep part of the greenes in their foliage. In this case the onset of the rain and the improved greenes of vegetation shows a longer lag time than in the Gu.
For all these evidences we decided to consider for the NDVI analysis only the months of April and May as representative of the GU season and the months of November and December for the Deyr season

10. Keetch-Byram Drought Index (KBDI)

The KBDI is a continuous reference scale for estimating the dryness of the soil and duff layers. The index increases for each day without rain and decreases when it rains. The scale ranges from 0 to 800. Elements of ENSO and climate change have now been factored into the index (Keetch, J.J and Byram, G.M. 1988)

Drought, as defined by the KBDI, is a condition of dryness in the litter, duff, and upper soil layers that progresses from saturation to an absence of available moisture. The KBDI is based on an arbitrary 8 inches of water in the litter/duff/soil column. When the full 8" of water are available, KBDI = 0. As water is removed from the column by evapotranspiration, the KBDI increases in value. When KBDI = 800, all the water has been removed. As a drought proceeds, the upper soil layers dry and the amount of dead fuel available for consumption increases. During combustion some of this fuel contributes directly to fire line intensity (BI), but most increases total heat release (ERC) and contributes to burn severity through smouldering combustion with its resulting smoke. The interpretations below are based on experience within forested areas in the south-eastern United States.

KBDI Value	Interpretations
0 - 200	Nearly all soil organic matter, duff, and litter are left intact after a burn. Once the fire passes, remaining embers extinguish quickly and, within a few minutes, the area is completely extinguished and smokes free.
200 - 400	At these levels, litter and duff layers begin to contribute to fire intensity. Heavier fuel classes can become involved in the burn. Soil exposure is minimal. Smoke management can become a real hazard, especially if there are larger fuel classes available. Smouldering with resulting smoke can carry into the night.
400 - 600	These levels represent the upper range at which most understory type burning should be conducted. Most of the duff and organic layers will ignite and actively burn. The intensity can be expected to increase almost exponentially from the lower to upper ends of this range. Considerable soil exposure occurs. Complete consumption of all but the largest dead fuels can be expected, and larger fuels not consumed may smoulder for several days, leading to smoke and possible fire control problems.
600 - 800	These levels represent the most severe drought conditions, and many states issue burning bans at these levels. Prescribed fires should not even be attempted at levels over 700. Fires that do occur will be intense and deep-burning. Live understory vegetation (2-3" range) should be considered part of the fuel complex due to its low fuel moisture. Most subsurface soil organic material will be consumed; great soil exposure will occur with great future erosion potential. Smouldering may occur for many days, with smoke and fire control problems.

11. Modified Perpendicular Drought index (MPDI)

Soil moisture and vegetation growth are the most direct and important indicators of drought events and, therefore, an understanding of vegetation and soil spectral behaviour is critical to the drought estimation. The Perpendicular Drought Index (PDI) that is based on an extensive analysis of spatial distribution features of soil moisture in NIR-Red spectral space. The MPDI is developed introducing vegetation fraction, which takes into account both soil moisture and vegetation growth. The PDI and the MPDI provide quite similar results for bare soil surfaces, especially in the early stages of vegetation growth. However, the MPDI demonstrates a much better performance in measuring vegetated surfaces since it takes into account both soil moisture and vegetation growth in the modelling process. Both the PDI and MPDI utilize the Enhanced Thematic Mapper Plus (ETM+) and MODerate Resolution Imaging Spectrometer (MODIS) data (Ghulam, A., Qin, Q. and Zhan, Z., 2006).