The 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 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 successive time units (dekads, months, years) with values under the multi-year average. A dekad is a ten-day period.

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 (Precipitation Drought Index), the NDVI drought proxy as the VDI (Vegetation Drought Index) and the temperature drought proxy as the TDI (Temperature Drought Index). 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. As for actual drought monitoring the 10-day time intervals, dekads, seem to be the most useful units, in this description we use only this unit for analysis. For different analytical purposes, however, different time intervals (TI), like months, seasons or years can also be used.

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:

$$PDI_{i,m} = \frac{\sum_{j=0}^{IP} P_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP} P_{(m-j),k}\right]} * \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,k}^{(P)}}{R_{m,i}^{(P)}}\right)} \qquad (1)$$

$$VDI_{i,m} = \frac{\sum_{j=0}^{IP} NDVI_{i,(m-j)}}{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP} NDVI_{(m-j),k}\right]} * \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,k)}^{(NDVI)}}{R_{m,i}^{(NDVI)}}\right)} \qquad (2)$$

$$TDI_{i,m} = \frac{\frac{1}{n}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP} T_{(m-j),k}\right]}{\sum_{j=0}^{IP} T_{i,(m-j)}} * \sqrt{\left(\frac{\frac{1}{n}\sum_{k=1}^{n} R_{m,k}^{(T)}}{R_{m,i}^{(T)}}\right)} \qquad (3)$$

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
TU	time unit
IP	Interest Period (e.g. 3, 4, 5 … dekads or 2, 3, 4…..months, etc.)
$R^{(P)}$	maximum number of successive dekads with below long term average rainfall in the previous Interest Period.
$R^{(NDVI)}$	maximum number of successive dekads with below long term average NDVI in the previous Interest Period.
$R^{(T)}$	maximum number of successive dekads with above long term average temperature in the previous Interest Period.
n	number of years where relevant data are available
j	summation running parameter covering the Interest Period
k	summation parameter covering the years where relevant data are available

For further information on the CDI please contact swalim@fao.org

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 =
(actual rainfall / LTM rainfall) * Square root of (LTM of the longest rainfall deficit runs / actual longest rainfall deficit run):- all calculated for the given interest period.

Vegetation Drought Index =
(actual NDVI / LTM NDVI) * Square root of (LTM of the longest NDVI deficit runs / actual longest NDVI deficit run):- all calculated for the given interest period.

Temperature Drought Index =
(LTM temperature / actual temperature) * Square root of (LTM of the longest excess temperature runs / actual longest excess temperature run):- all calculated for the given interest period.

Note that the temperature has inverse values compared to the other parameters. While low values of precipitation and NDVI contribute to drought conditions, with temperature it is the high values that contribute to drought. That is why in the second term of temperature excess is used instead of deficit, and the first 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 the weighted average of the current TDI and VDI and the 2-dekad lagged PDI, as shown on the equation below:

$$CDI_{i,m} = 0.5 * PDI_{i,m-2} + 0.25 * TDI_{i,m} + 0.25 * VDI_{i,m} \quad (4)$$

The above weights reflect the experience that rainfall is more important in the process of the drought than the other two factors. (Note that in our previous calculations we used equal weights which we are going to change.)

In the calculation process attention should be given to avoiding dividing by zero. This could happen in case the actual longest run in any of the above three index equations is zero. The CDI calculation method in these cases replaces the 0 run-length by 0.5, assuming that at least a few days in the interest period were below average in case of rainfall and NDVI and above average in temperature. This is an approximation; however it affects only one actual value in the whole time series and this value in not on the "drought" side of the average situation.