Index-based approaches for drought monitoring

Index-based approaches used thus far by the insurance sector are related to meteorological data collected by ground stations. Examples of meteorological observations are rainfall, temperature, relative humidity and sunshine hours.

Indices based on satellite images, acquired by various Earth Observation (EO) systems, offer a cost-effective solution that accurately reflects crop status, current crop acreage, pasture conditions and its effects on the livestock and much more, in a synoptic view over vast areas and on a regular basis. Examples already published are given in FAO/GIEWS (Global Information and Early Warning System), FEWSNET (Famine early Warning System Network), Drought Monitor and the linked NOAA Climate Prediction Center. In Appendix 1 an overview of the current public services on drought monitoring available in the Web is given.

1.1 Drought Indices

After a review of the published scientific literature on drought indices (see Figure 2) Airbus DS shortlisted a number of possible candidates, plus others in more recent publications. Evidence from the published experimental usage in different geographic and climatic contexts will indicate their robustness for potential operational use.

Figure 1 *Corn affected by drought in a family led farm in Kenya.*

NMDC – Normalized Multi-Band Drought Index
VCADI – Vegetation Condition Albedo Drought Index
PDI – Perpendicular Drought Index
MPDI – Modified Perpendicular Drought Index
RDRI – Remote Sensing Drought Risk Index
VegDRI – Vegetation Drought Response Index
ADI – Aggregate Drought Index
SMDI – Soil Moisture Deficit Index
ETDI – Evapotranspiration Deficit Index
RDI – Reconnaissance Drought Index
RSDI – Regional Streamflow Deficiency Index
SDI – Sperling Drought Index
NDVI – Normalized Difference Vegetation Index
VCI – Vegetation Condition Index
NDVIA – Anomaly of Normalized Difference Vegetation Index
SVI – Standardized Vegetation Index
NDWI – Normalized Difference Water Index
NDII – Normalized Difference Infrared Index
LWCI – Leaf Water Content Index
DTx – agricultural drought index
DFI – Drought Frequency Index
TCI – Temperature Condition Index
VHI – Vegetation Health Index
SRWI – Simple Ratio Water Index
GVWI – Global Vegetation Water moisture Index
WI – Water Index
%N – percentage of normal
DECILES – deciles
RAI – Rainfall Anomaly Index
BMDI – Bhalme and Mooly Drought Index
SAI – Standardized Anomaly Index
DSI – Drought Severity Index
PAI – Palfai Aridity Index
EDI – Effective Drought Index
Q90 – low flow index
BFI – Base Flow Index
SWSI – Surface Water Supply Index
PHDI – Palmer Hydrological Drought Index
RDI – Reclamation Drought Index
CMI – Crop Moisture Index
SMDI – Soil Moisture Drought Index
CSDI – Crop Specific Drought Index
CDI – Corn Drought Index
SCI – Soybean Drought Index
KBDI – Keetch-Byram Drought Index
NBR – Normalized Burn Ratio
PDSI – Palmer Drought Severity Index
PMDI – Palmer Modified Drought Index
Z-Index – Palmer Z-Index

Figure 2 *Summary of candidate drought indices.*
Source: S. Nyemeyer, IES, JRC, 1st international Conference on Drought Management, Zaragoza, June 2008

1.2. Shortlisting the drought indices

Airbus DS shortlisted some of the indices reported in Figure 2 and tested them with the purpose of identifying potential candidates for drought mapping. They are described as follows:

- VCI: The Vegetation Condition Index is an indicator of the vigour of the vegetation cover as a function of NDVI minima and maxima in a certain period. This index has been already tried experimentally for insurance purposes in South African environments (Makaudze and Miranda, 2008). This experiment showed that a VCI shows appreciably high correlation with yield losses. The VCI was able to satisfactorily detect extreme drought events but tended to miss on events of lesser intensity. In as far as protecting against extreme drought events, a VCI-based contract could be sufficient but for drought events of bad-moderate intensity the index tends to fail.

- NMDI: Normalised Multi-Band Drought Index (Wang and Qu, 2007): this is another index exhibiting good sensitivity to drought severity. It is well suited to monitor both soil and vegetation moisture conditions through the combination of information from three spectral bands in the NIR and SWIR spectral regions. In the case of the MODIS sensor, bands 2, 6 and 7 (859nm, 1640nm and 2130nm, respectively) provide the spectral information, achievable from the 500m reflectance product (the so-called MOD09) which is available for free and ready for use. However, further testing for calibration / validation must be considered. Airbus DS already tried to test this index with MODIS images and compare them with rainfall data. An outlook of these findings is given in Appendix 2.

- VHI: Vegetation Health Index (Kogan, 1995, 1997). Successfully applied in numerous case studies, VHI is a composite index joining the Vegetation Condition Index and the Temperature Condition Index. A detailed description and examples of application are given in Appendix 3 of this document where a drought probability product is derived from this index.

- NDWI: Normalized Difference Water Index (Gao, 1996) is a widely used water monitoring index of the land surface. It is easily calculated using MODIS reflectance data bands 2 (859 nm) and 5 (1240 nm) or, alternatively, bands 2 and 6 (1640 nm). Contrary to NDVI, NDWI has a good capability for retrieving vegetation water content information (Zhang, Lu et al. 2008).

- NDWDI: Normalized Difference Water Deviation Index (Zhang, Lu et al. 2008): this index is derived from the previously mentioned NDWI and is more sensitive to regional drought than other absolute soil moisture-based indices. The inputs are the 8-day MODIS products of surface reflectance (MOD09A1, 500 m) bands 2 and 5.

- PDI: Perpendicular Drought Index (Ghulam et al. 2006): originally tested on Landsat ETM+ images, it can be profitably used with MODIS images (Quin, Ghulam et al. 2007). It is a practical method for monitoring soil moisture status, which correlates better than the TVX index below. The additional merit of this index is its simplicity, being derived just from Red and NIR reflectance however some algorithm development effort must be considered.

- TVX: Temperature Vegetation Index (Prihodco and Goward 1997): the ratio of NDVI and LST (Land Surface Temperature, derived from the thermal bands of some EO sensors). This index has been proven to be significantly correlated with crop moisture and soil moisture. Moreover the well-known LST vs NDVI scatter plot displays the pixel values in a typical triangle distribution which reveals more meaningful information on drought (Price, 1990). TVX does, however, require thermal observations which are not available from most EO sensors. Furthermore, when thermal data are available, the pixel size is typically not consistent with the Red/NIR spectral bands (e.g. the MODIS resolution for Red/NIR is 250m while for thermal bands it is 1000 m). This causes a degradation of the drought index product resolution.

- MAT: Method of the Area of the Triangle (Sobrino and Raissouni, 2000): this is an approach similar to the TVX and considers the slope of the LSTmin/NDVImax segment in the bi-dimensional LST/NDVI space. Some algorithm development effort must also be considered.

- VTCI: Vegetation and Temperature Conditions Index (Wang et al. 2001; Wang et al. 2004): derived from VCI and TCI (Vegetation Condition Index and Temperature Condition Index, respectively). With the assumption that the shape of the scatter plot between LST and NDVI is triangular, the index seems to correlate well with meteorological data in drought conditions. Some algorithm development would be needed to determine 'warm' and 'cold' edges of the LST/NDVI scatter plot.

- Ts-VI triangle: this method, similarly to the previous method, considers vegetation and thermal information. A recent review of this method uses the Fraction of Vegetation instead of the NDVI for the construction of the triangular shape (Tang et al. 2010).

1.3. Indices and spectral bands

Generally the indices for drought detections can be grouped, on the basis of required spectral information, in two kinds of methods (Zhang et al. 2008):

- near infrared - thermal infrared (NIR-TIR) indices. These are based on the negative relationship between Land Surface Temperature (LST) and Vegetation Index (VI), as the slope of their scatter plot (LST/VI) is used to indicate crop water stress, which has ever been considered by MODIS evapotranspiration product. However, the LST-VI relationship is not linear, which raises theoretical doubts upon the LST/VI slope.

- near infrared – short wave infrared (NIR-SWIR) indices. They use the characteristic of strong water absorption in SWIR spectrum to construct surface water index.

The choice of a given index is strongly dependant on the availability of imagery in the required spectral bands. Table 1 summarizes the suitability of many sensors against the most interesting drought indices.

indices	needed spectral information		low resolution				medium resolution				high and very high resolution							
	centre bands, (nm)	regions	MSG	MTG	AVHRR	SPOT-Vegetation	MODIS 3)	VIIRS 4)	MERIS	sentinel-3 3)4)	AWiFS	sentinel-2 3)4)	L7	DMCii	ASTER 5)	SPOT-4/5	RE	K2
VCI, PDI	645, 860	R, NIR	√1)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
NDWI	860 1240 or 1640	NIR SWIR	√	√	X	√	√	√	X	√	√	√	√	X	√	√	X	X
NDWDI	860 1240	NIR SWIR	X	X	X	X	√	√	X	X	X	X	X	X	X	X	X	X
NMDI	860 1640 2130	NIR SWIR SWIR	X	X	X	X	√	√	X	X	X	√	√	X	√2)	X	X	X
TVX, MAT, VTCI, Ts-VI	645, 860 11030, 12020	R, NIR thermal	√	√	√	X	√	√	X	√	X	X	√	X	√	X	X	X

1) the red window of SEVIRI-MSG is extremely wide, covering also some green.

2) one of the ASTER SWIR bands is similar but not exactly the same required for the index: centre band is 2165 nm instead of 2130 nm.

3) different resolution arrangements.

4) future mission.

5) too low acquisition frequency for regular drought monitoring.

Table 1 *Mapping of sensor capabilities to drought index inputs*

Sentinel-2 (resolution of 10, 20 and 60m) started delivering the first operational products to users at the end of 2015. Unlike other optical commercial missions it exhibits 13 bands distributed across the visible, VNIR and SWIR spectrum. Especially interesting are the two bands centred around 1600 nm and 2200 nm as they are suitable inputs for the NDWI and NMDI index respectively. Sentinel-3 (different resolution arrangements between 300m and 1.2km), conceived as a follow-up and in synergy with MERIS, MODIS, METOP series and other satellites of the same class, will have two sensors, OLCI and SLST, with 21 and 9 spectral channels respectively, covering the broad spectrum from visible to thermal windows. Both Sentinel-2 and -3 are promising candidates to ensure a long lasting monitoring of the land use and the vegetation conditions.

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