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.
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 LST/NDVImax segment in the bi-dimensional LST/NDVI space. Some algorithm development effort must also be considered.

• VT-CI: 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 dependent on the availability of imagery in the required spectral bands. Table 1 summarizes the suitability of many sensors against the most interesting drought indices.
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.

### Bibliography

Anke Poelstra, Jan Friesen, Frank Annor, William Horner, Jens Liebe, Nick van de Giesen. SMOS validation in West Africa Comparison to other satellite datasets. SMOS Validation and Retrieval Team workshop, ESRIN, 29-30 Nov 2010.


<table>
<thead>
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<th>indices</th>
<th>needed spectral information</th>
<th>low resolution</th>
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<th>high and very high resolution</th>
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</tbody>
</table>

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


J. Munoz Sabater and Fernando Martin Porqueras, URL: http://www.cesbio.ups-tlse.fr/SMOS_blog/


