



Food and Agriculture
Organization of the
United Nations

Protocol for Country-Level ASIS

*calibration and
national adaptation process*



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Protocol for Country-Level ASIS

*calibration and national
adaptation*

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1. Background

The Food and Agriculture Organization of the United Nations (FAO) has developed a tool to help countries monitor agricultural drought and manage its risks, using satellite data to detect cropped land that could be affected by drought. The country-specific version of the tool is based on the general methodological principles of the global Agricultural Stress Index System (ASIS), which is used at FAO headquarters to support the Global Information and Early Warning System (GIEWS) (see <http://www.fao.org/giews/earthobservation>). The task of the GIEWS team is to continuously monitor the world's food supply and demand situation, using geo-spatial data as an auxiliary variable to detect weather-related problems that could have an impact on food security in member countries.

The global ASIS simulates the analysis that previously a remote sensing expert would have undertaken manually, and presents results in a simplified form i.e. as maps to final users. Every ten days, ASIS generates a map showing hot spots around the world, where crops are affected by water stress during the growing period. To avoid generating false alarms, the hot spots identified have to be confirmed by data from public institutions. Where possible, checks are conducted on the ground, and socio-economic variables such as variations in agricultural product prices are analysed. Hot spots may also be verified using agrometeorological models based on data obtained from national meteorological networks, which ultimately show indicator convergence.

2. Drought detection – the global ASIS

ASIS uses the Vegetation Health Index (VHI) derived from the Normalized Difference Vegetation Index (NDVI), which indirectly measures primary production through its relationship with photosynthetically active radiation. VHI was developed at the United States National Environmental Satellite, Data and Information Service (NESDIS), and has been successfully applied in many different environmental conditions around the globe, including in Asia, Africa, Europe and the Americas.

A first step in ASIS is to calculate the average VHI as crop development proceeds (time-scale), which makes it possible to assess the intensity and duration of dry periods during the crop cycle at pixel level. ASIS is based on data on climatic conditions necessary for crop development (temperature of vegetation coverage and biomass production) from the METOP-AVHRR sensor at 1 km resolution.

The second step is the calculation of the percentage of agricultural area affected by drought (pixels with $VHI < 35$ – a value identified as critical in previous studies) to assess the spatial extent of the drought. Finally, the whole administrative area is classified according to the percentage of affected area. For agriculture, it is important to focus on the periods most sensitive to water stress, such as the flowering and grain filling phases.

ASIS evaluates the severity (intensity, duration and spatial extent) of the agricultural drought and presents the final results by administrative unit, thereby allowing for comparison with the country's agricultural statistics. The ASIS database contains 30 hot spots, starting in 1984 when the Sahel was severely affected by drought. Since METOP imagery is only available from 2007 onwards, the Flemish Institute for Technological Research (known by its Dutch acronym of VITO) – a partner of FAO for scientific and technical development – simulated METOP data in the NOAA-AVHRR time series through an "inter-calibration" study to obtain a time series spanning the period from 1984 to 2015. This simulation between the two satellites makes it possible to recover long-term pixel memory, thereby guaranteeing that the pixel has suffered

at least one extreme event over the 30 years on record. In the absence of long term data series, there is a risk of underestimating the drought phenomenon. Thanks to this simulation between the two satellites, FAO has a single historical series with geospatial data at 1 km resolution.

3. Country-level ASIS

3.1. Introduction

Based on the general methodological principles of ASIS at the global level, FAO has developed a tool to help countries monitor agricultural drought more accurately, by allowing the analysis parameters to be adapted to each country's specific agricultural conditions. The development of the tool is financed with funds from the European Union, channelled through the "Improved Global Governance for Hunger Reduction" programme. This tool differs from the global ASIS in the following ways:

- The country-level ASIS uses crop coefficients (kc) to better model water sensitivity for each phenological stage of cultivation; in other words, it recognizes the differing sensitivity of the various phenological stages, and attaches greater importance to the flowering and grain filling phases.
- The VHI<35 threshold used in the global ASIS (identified as representing extreme drought, whereby most of the crops are expected to be totally lost) is adjusted and modified in the country-level version, with thresholds being identified for each crop based on production statistics. The country-level ASIS may also include different user-defined thresholds, depending on the user's interest in defining extreme, severe or moderate drought events.
- The agricultural crop mask, which in the global version encompasses ten cereal crops, may be replaced by crop-specific masks derived from land use maps available in each country. This flexibility enables greater correlation between the vegetation indices and the final crop yield.
- The country-level version allows the user to define the basic unit of analysis (administrative or agro-ecological).
- The tool enables the user to calculate, midway through the crop cycle, the probability that a specific pixel will be classified as drought-affected at the end of the cycle. The probability at the start of the cycle is based on the pixel's historical probability of being drought-affected, obtained from the 30-year historical series. As the agricultural season proceeds, every ten days new information on the evolution of the vegetation at pixel level becomes available, making it possible to adjust the historical probability on the basis of recent data. Once at least half the crop cycle has elapsed, the omission error is reduced and the probability of correctly classifying the pixel as drought-affected or not increases.
- Lastly, the values of the Agricultural Stress Index (ASI) can be used as independent variables to predict agricultural crop yields by multiple regression. The resulting equation is incorporated into the tool and a map of the estimated yields is automatically generated.

This document describes the steps involved in implementing ASIS at country level, as well as the calibration needed to obtain a closer correlation between vegetation indices and agricultural crop yields. The tool can also be calibrated for perennial crops, where grasslands can be monitored with very high precision.

3.2. Satellite hardware and data

The country must have a computer with a hard disk capacity of at least 10 TB, dedicated exclusively to the agricultural drought monitoring system. Historical data obtained through 30 years of record keeping will be downloaded from FAO headquarters via file transfer protocol

(FTP) and will be updated every ten days via FTP. To ensure rapid data download, an excellent Internet connection is needed. The basic vegetation indices to be downloaded are the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). These indices will be used to calculate the Vegetation Health Index (VHI). Further information on the indices can be found in Annex 1.

3.3 Calibration

The country must have an (ideally interagency) team, drawn from national institutions working on the agricultural drought problem. This group will select the agricultural crops to be calibrated. In view of the FAO mandate, it is suggested that priority be given to the most important crops in terms of food security (i.e. provision of calories and nutrients); for example, in Central America, the staple diet crops are maize, beans and rice. Once the crops have been selected, agricultural statistics must be obtained at the lowest possible subnational level (province, district, municipality, borough, etc.). The data required concern production, yields and planted areas, with historical series spanning ten years of reliable records. Recognition of the quality of the data will ensure that institutions and final users trust the agricultural drought monitoring system to be accurate. Subsequently, a regression analysis will be performed between crop yields and the vegetation and temperature indices VCI and TCI. The results of this regression analysis produce the values “a” and “b” of Equation 1:

(1)

$$Y = a \text{ VCI} + b \text{ TCI}$$

Y: Crop yield expressed in tonnes per hectare or another agricultural yield unit used in the country.

VCI: Vegetation Condition Index, with values varying between 0 and 1.

TCI: Temperature Condition Index, with values varying between 0 and 1.

The regression analysis can be performed using a spreadsheet. The values obtained will be applied as the first calibration for calculating the VHI through Equation 2:

(2)

$$\text{VHI} = a \text{ VCI} + b \text{ TCI}$$

VHI: Vegetation Health Index, with values varying between 0 and 1.

VCI: Vegetation Condition Index, with values varying between 0 and 1.

TCI: Temperature Condition Index, with values varying between 0 and 1.

This calibration makes it possible to give a different weighting to the biomass production component represented by VCI and to the temperature index TCI. For crops whose yield crucially depends on temperature, the calibration will give a greater weight to this component ($a < b$) and vice versa.

For each selected crop, recent land use maps will be used as available. For example, country-level ASIS will analyse agricultural areas devoted to maize separately from areas cultivated with rice. This will ensure a greater correlation between crop yield and the agricultural stress index (ASI), which represents the drought-affected area in the administrative unit selected for analysis.

If the country has crop coefficient (kc) data obtained from studies using lysimeters for the selected crops, these data will be used to assign a different weight to each phenological phase. For example, in the case of cereal crops, the flowering and grain filling are the phases most sensitive to water stress. The value of kc is therefore higher during these phases and is as-

signed a preponderant weight when producing the temporally integrated VHI. If no lysimeter studies are available, general kc values published in literature will be used¹.

3.4. Estimation of yields

To obtain an equation to estimate yields, historical yield and production data (minimum ten years of records) are used at the administrative unit level. For each administrative unit, the ASI value is extracted, and a regression is performed between yield values (dependent variable) and ASI values (independent variable). This analysis is performed using a spreadsheet or a statistical analysis package. A multiple regression is performed (the linear model is included), and the equation with the highest coefficient of determination (r^2) is chosen. Statistical tests, such as the jackknife resampling technique, are conducted to verify the model's stability. Once the model's stability has been verified, the equation parameters are introduced into the country-level ASIS, which relates crop yields to ASI. The tool uses the equation to generate maps estimating the yield for each administrative unit.

3.5. Predictive power of the model

The following step is recommended to obtain an early estimation of yields per administrative unit. At the start of the growing period, insufficient information is available to perform an estimation using the mathematical equation; the best estimation therefore is the average of historical yields for the administrative unit. To use an equation that has an acceptable statistical level, a partial regression analysis must be performed for every 10-day period. The path of the r^2 values is plotted during the crop cycle, and equation parameters with r^2 above 50 percent are chosen. Starting from the 10-day period where r^2 is above 50 percent, the average historical yield is replaced by the values estimated by the model.

3.5.1. Predictive probability of agricultural drought

Country-level ASIS will enable the user to calculate, midway through the crop cycle, the probability that a specific pixel will be classified as drought-affected at the end of the cycle. The tool will have this predictive application with statistical significance. The probability at the start of the cycle is based on the pixel's historical probability of being drought-affected, obtained from the 30-year historical series. As the agricultural season proceeds, every ten days new information on the evolution of the vegetation at pixel level becomes available, making it possible to adjust the historical probability on the basis of recent data. Once at least half the crop cycle has elapsed, the omission error is reduced and the probability of correctly classifying the pixel as drought-affected or not increases. This probability is calculated at pixel level, making it possible to produce maps with information at 1 km resolution. Statistics relating to the calculated probability are also expressed in the form of maps to help the user to visually check the statistical validity of the probability.

3.5.2. Definition of agricultural drought severity thresholds

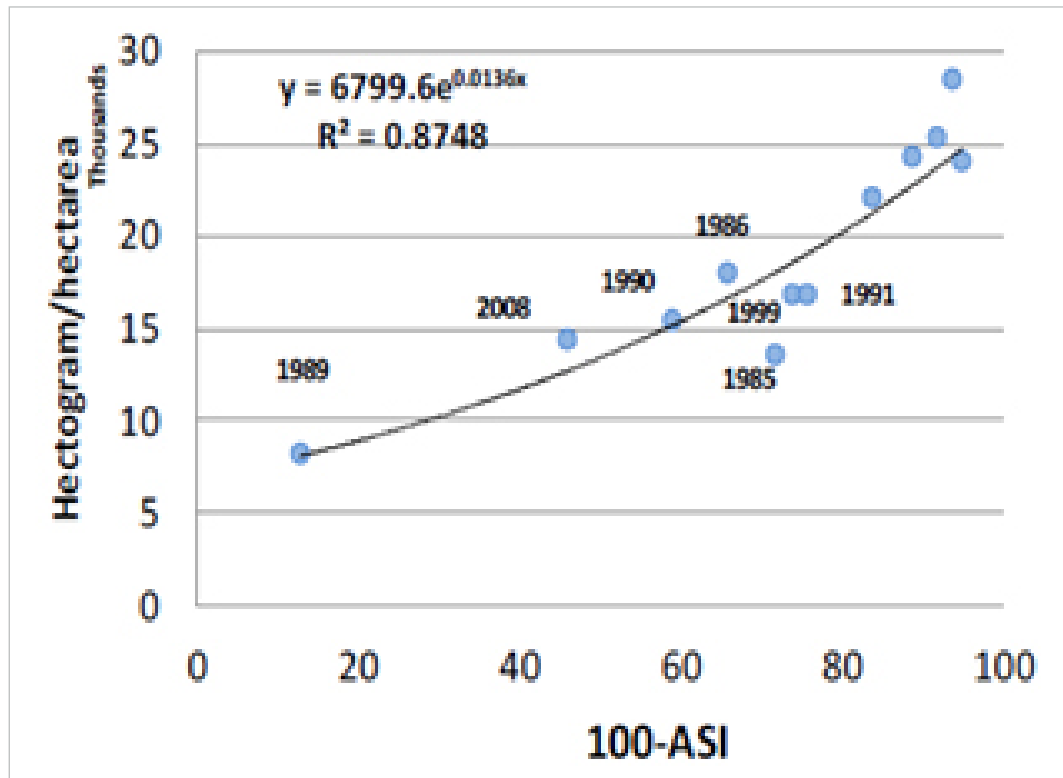
Agricultural drought severity thresholds can be defined for each crop on the basis of yield and production statistics for each administrative unit available in the country. Considering the maize crop for a specific administrative unit, it is possible to identify years with low yields as affected by extreme drought (if these coincide with years that also have low ASI values). On this basis, years with higher yield levels can be classified as severe droughts or moderate

(¹) FAO, 1979. *Yield response to water*. By Doorenbos, J. and Kassam, A. FAO Irrigation and Drainage Paper No. 33. Rome.

FAO, 2012. *Crop yield response to water*. By Steduto, P., Hsiao, T.C., Fereres, E. and Raes, D. FAO Irrigation and Drainage Paper No. 66. Rome.

droughts. Figure 1 shows the results of a regression between the yields for wheat crops and ASI values for Syria. ASI explained 87 percent of the variation in yields. ASI values below 35 can be defined as representing extreme drought; values between 35 and 60 as severe drought; values between 60 and 70 as moderate drought; values between 70 and 90 as a dry period; and values above 90 as periods without water stress problems.

Figure 1. Wheat yield prediction model for Syria.



3.5.3. Index-based harvest insurance

ASI values can be used as a trigger for geospatial index-based insurance policies. For this purpose, the ASI historical values series is extracted from the 30-year series, and the empirical probability that it exceeds a certain value “x” is calculated, as the threshold for defining a catastrophic event which it is to insure against. The premium of the insurance contract is calculated for the number of catastrophic events to be insured. Insurance based on geospatial data is preferable to contracts indexed to data from the meteorological network. Indeed, geospatial data have a higher resolution and are more reliable for insurance companies, since they eliminate the risk of data manipulation (moral hazard). On the other hand, they are harder to explain to farmers, and insurance policies must therefore be targeted to agricultural associations or cooperatives, which may better understand data from remote sensors. Figure 2 presents the fluxogram of the process of calibration and adaptation of the Country-Level ASIS tool.

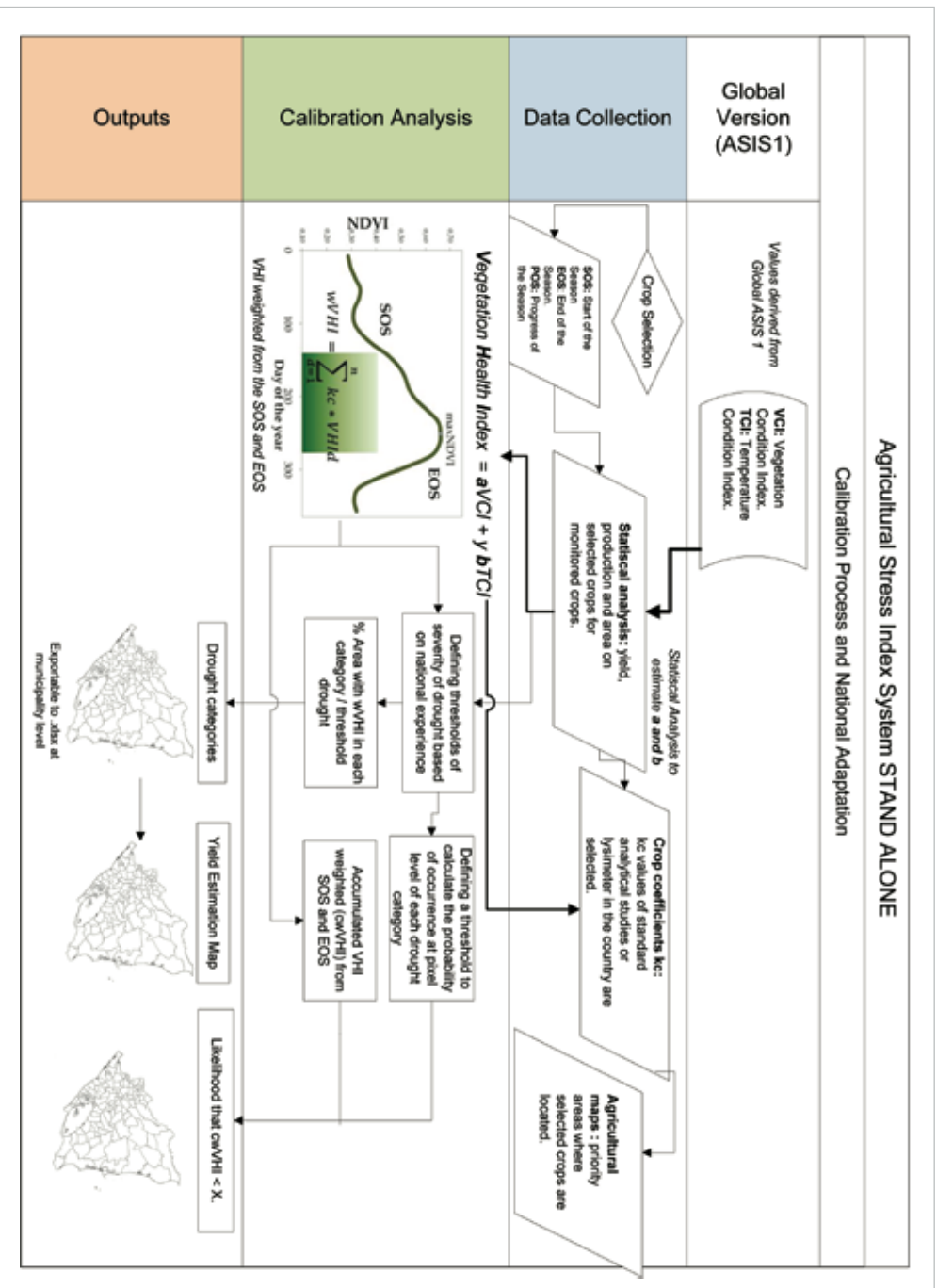


Figure 2. Flowchart of the country-level ASIS calibration and adaptation process

4. Annex

4.1. Technical description of vegetation indices

The Vegetation Condition Index (VCI) is derived from the Normalized Difference Vegetation Index (NDVI), which is an indirect measure of primary production through its relationship with photosynthetically active radiation. The VCI places the NDVI between the maximum and minimum of historical series of satellite data and is expressed as follows:

(1)

$$VCI_i = 100 * (NDVI_i - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$$

VCI_i: Vegetation Condition Index of 10-day period *i*.

NDVI_i: Normalized Difference Vegetation Index of 10-day period *i*.

NDVI_{max}: Maximum value of the vegetation indices series.

NDVI_{min}: Minimum value of the vegetation indices series.

The VCI has been designed to separate the climate component from the ecological component which affects the NDVI value. In general the VCI is better than the NDVI at capturing the precipitation dynamic in heterogeneous geographic areas. The VCI not only reflects the spatial and temporal variability, but also makes it possible to quantify the impact of the climate on vegetation.

The TCI algorithm is similar to the VCI, but relates to the temperature estimated by the infrared band of the AVHRR sensor (channel 4). Kogan (1995) proposes this temperature index to remove the distorting effect of clouds on satellite assessment of vegetation, since channel 4 is less sensitive to water vapour content in the atmosphere than the visible light channels. High temperatures in the middle of the crop cycle indicate drought conditions, whereas low temperatures indicate favourable conditions. The mathematical formulation of the TCI is:

(2)

$$TCI_i = 100 * (T_{max} - T_i) / (T_{max} - T_{min})$$

TCI_i: Temperature Condition Index of 10-day period *i*.

T_i: Temperature of 10-day period *i*.

T_{max}: Maximum temperature value of the series.

T_{min}: Minimum temperature value of the series.

Lastly, these two indices are used to calculate the VHI, whose mathematical expression is:

(3)

$$VHI_i = a * VCI_i + b * TCI_i$$

VHI is the additive combination of VCI and TCI for each 10-day period. The parameters “a” and “b” have different weights depending on the crop being analysed. Under near normal conditions, vegetation is more sensitive to humidity during canopy formation and to temperature during flowering.

5. Related literature

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